Chapter 12
Pest Dynamics and Suppression Strategies

A. Josephrajkumar, Chandrika Mohan, P. S. Prathibha, Rajkumar, T. Nalinakumari, and C. P. R. Nair

Abstract Dynamism of pests attacking coconut is ever increasing realizing action threshold many a times diminishing palm productivity and threatening livelihood security. Living with pests is, thus, gaining momentum for sustaining coconut yield and safeguarding environment considering the perennial and homestead nature of palms. Bionomics, geo-maps and bio-intensive area-wide management of key pests of coconut, viz. rhinoceros beetle, red palm weevil, black-headed caterpillar, eriophyid mite, white grubs and rodents, as well as emerging pests such as coreid bug, slug caterpillars, whiteflies including the invasive rugose spiralling whitefly, mealybugs, scale insects, ash weevils and nut borers are lucidly presented with all cutting-edge eco-friendly technologies to counter their menace. Storage pests of copra and techniques to unhinge are drawn around. Palm nematodes and potential invasive pests such as *Brontispa longissima*, *Aspidiotus rigidus* and *Wallacea jarawa* are underscored with strategies on emergency preparedness and incursion management. Biorational approaches and health management of palms are greatly emphasized to suppress pests in the most economical and convincing manner. Good agricultural practices, agroecosystem-based stimulo-deterrent strategies, semiochemical tools and nanoporous delivery mechanism of pheromones, diversity farming methods and farmer-participatory community approaches including farmer field school mode to empower farmers with all innovative pest management actions towards harnessing sustainable palm yield in all coconut-growing countries are accentuated.

A. Josephrajkumar (✉) · Chandrika Mohan · C. P. R. Nair
ICAR-CPCRI, Regional Station, Kayamkulam, Kerala, India
e-mail: joecpcri@gmail.com; cmcpcri@gmail.com; Cprnair_47@yahoo.com

P. S. Prathibha · Rajkumar
ICAR-CPCRI, Kasaragod, Kerala, India
e-mail: prathibhaspillai007@gmail.com

T. Nalinakumari
Kerala Agricultural University, Thiruvananthapuram, Kerala, India
e-mail: achutnk@yahoo.co.uk

K. U. K. Nampoothiri et al. (eds.), *The Coconut Palm (*Cocos nucifera *L.) - Research and Development Perspectives*,
https://doi.org/10.1007/978-981-13-2754-4_12

12.1 Introduction

Coconut is depredated by at least 830 insect and mite species, 173 fungi and 78 species of nematodes drastically affecting the productivity (CPCRI 1979). In the monograph of coconut pests, Lever (1969) listed 110 pests including 2 species of mite. Damage by insect, mite and vertebrate pests induces a crop loss as high as 30% in palms (Gitau et al. 2009). The annual crop loss due to pest complex was estimated as 618.50 million nuts in Kerala, a predominant coconut-growing state in India (Abraham 1994). It is practically impossible to eliminate insect pests from palms and, therefore, must be 'lived with' so as to incur minimum economic damage as far as possible (Howard et al. 2001). The major pests infesting coconut would be classified as (1) borers, (2) defoliators, (3) sap feeders, (4) subterranean pests, (5) mammalian pests, (6) emerging pests, (7) nematodes, (8) potential invasive pests and (9) storage pests.

12.2 Borers

12.2.1 Asiatic Rhinoceros Beetle, Oryctes rhinoceros *Linn. (Coleoptera: Scarabaeidae)*

12.2.1.1 Distribution

O. rhinoceros is a cosmopolitan pest endemic to all coconut-growing countries. It was first reported to be damaging coconut palms in 1889 from Malaysia (Ridley 1919) and subsequently described in India by Pillai (1919).

12.2.1.2 Crop Loss

A loss in yield of 5.5–9.1% due to beetle attack was estimated in Kerala, India (Ramachandran et al. 1963). Nair (1986) reported damage to spathe causing reduction in coconut yield up to 10% in India. During 1969, the crop loss in South Pacific countries alone was estimated as at least $US 1,100,000 due to *O. rhinoceros* damage (Catley 1969). Stride (1977) found leaf and central crown damage levels of 40–60%, 60–80% and 80–100% resulting in nut losses to the tune of 12, 17 and 23%, respectively. Of late, incidence of rhinoceros beetle is very alarming in Samoa and Solomon Islands causing crop loss of about $US 10 million.

12.2.1.3 Host Plants

Besides coconut, the pest attacks palmyrah palm (*Borassus flabellifer*), toddy palm (*Phoenix sylvestris*), oil palm (*Elaeis guineensis*), date palm (*Phoenix dactylifera*), areca palm (*Areca catechu*) and other palms. Occasionally, it was also found feeding on agave, sugarcane, pineapple, tree fern, banana and taro (Menon and Pandalai 1960).

12.2.1.4 Taxonomy

The genus *Oryctes* has about 42 species, out of which 15 species are pests of coconut palm (Gressitt 1953). The predominant species in East Africa are *Oryctes monoceros* Oliv., *Oryctes gigas* Cast., *Oryctes boas*, Fa. and *Oryctes owariensis* P.de B. In Mauritius and Reunion, *Oryctes chevrolati* Geu. and *Oryctes tarandus* Ol. are the pests of coconut. *Oryctes latecavatus* Fair., *Oryctes pyrrhus* Burm., *Oryctes ranavalo* Coq. and *Oryctes simiar* are reported from Madagascar, and *Oryctes trituberculatus* Lamb. causes damage to coconut palm in Malaya. *Oryctes australis* was reported as a pest on juvenile palms in Papua New Guinea (Menon and Pandalai 1960; Lever 1969).

12.2.1.5 Symptoms

The robust adult beetles cause damage to palms of all age groups by boring into the unopened spear leaves and spathes and chewing off the soft internal tissues after imbibing the juice. As the pest bores deeper into the host, it pushes out the chewed up tissues as fibres, which are seen extruding from the entry points. Once these injured spindles open up, the green leaves present a geometric 'V'-shaped cut pattern (Fig. 12.1). The damage to inflorescence is seen as round to oblong holes on the spathes which soon dry up resulting in complete loss of nuts in the affected bunch. Attack on juvenile palms results in stunted growth and delayed flowering (Ghosh 1911; Pillai 1919; Nirula 1955b; Bedford 1980; Howard et al. 2001; Rajan et al. 2009).

Of late, entry of rhinoceros beetle through collar region of the freshly transplanted coconut seedlings and eating away the growing spear leaf resulting in wilting as well as improper establishment of seedlings was observed. In certain cases, the spear leaf gets twisted resulting in elephant tusk-like symptom, and farmers uproot such deformed seedlings/juvenile palms as the growing point remains stunted. Recurrent attack on the same seedling is often noticed due to the emanation of odour in the healing process of the injured portions (Josephrajkumar et al. 2015).

O. rhinoceros infestation causes another serious damage by providing egg-laying sites for the lethal pest, viz. red palm weevil (*Rhynchophorus ferrugineus*), and for

Fig. 12.1 Symptom of rhinoceros beetle attack. (Photo: Josephrajkumar)

entry of fungal pathogens like *Phytophthora* sp. (Nirula 1955b; Menon and Pandalai 1960; Bedford 1980; Rajan et al. 2009).

12.2.1.6 Bioecology

Detailed investigations on bioecology and distribution were conducted by Nirula (1955a, b). The adult is a stout black beetle 35–50 mm in length and 14–21 mm in breadth. It has an erect, slightly tapering cephalic horn, which is longer in males. The pygidium has reddish brown hairs in the female. Antennae are lamellate possessing short and strongly toothed mandible. The beetle breeds in the decaying organic matter like cattle dung, farmyard manure, compost heaps, coconut stumps, dead and decaying coconut logs, etc., where the adults lay eggs and complete the larval and pupal stages. Antony and Kurian (1975) observed that in cattle dung pits, the pest breeds in a temperature range of 10–50 °C and 30–60% moisture. The range of breeding sites utilized by *O. rhinoceros* underlies the versatility in breeding and survival dynamics (Menon and Pandalai 1960; Bedford 2013).

Eggs are white and globular in shape with fairly hard shell. Incubation period prolongs for 10 days in west coast of India (Nirula 1955b). Larvae are creamy white in colour with dorsally arched body (C-shaped) with well-developed head capsule, mandibles and thoracic legs. Fully grown grubs are stout and fleshy and may grow up to 60–100 mm length (Wood 1968; Ooi 1988). Nine pairs of spiracles are present on lateral side of the body. Larval period is about 130 days with three instars. The pupal period varies from 20 to 29 days and uniformly brown in colour measuring 50–70 mm lengthwise and 20–25 mm breadthwise (Menon and Pandalai 1960). Life stages of rhinoceros beetle are given in Fig. 12.2.

Adult longevity is 3–6 months. Adults are active during night and remain hidden during daytime in the feeding sites or breeding sites where mating occurs. Multiple mating may occur, but are not essential as spermatozoa remain viable for about

Fig. 12.2 Life stages of rhinoceros beetle. (Photo: Josephrajkumar)

6 months in the spermatheca (Hurpin and Fresneau 1973). Average fecundity per female is 108 eggs. It has been estimated that a single pair of beetle under optimum condition can reproduce 15 million beetles in a span of 3 years (Nirula 1955b). Pest occurs throughout the year with peak adult emergence during June to September. Population of the beetle was observed to be high in young plantations with multiple breeding sites and high rainfall and humidity.

12.2.1.7 Integrated Pest Management

Since the pest is an active flyer, integrated pest management (IPM) strategies adopted on a community basis are essential to bring an effective control (Nair et al. 1998). The major components of IPM package consist of sanitation, ecological engineering, mechanical, chemical, biological and semiochemical methods.

Sanitation Method The dead and decaying coconut logs and other organic debris in the vicinity of coconut plantations are to be properly disposed off, since this act as prolific breeding grounds of the beetle. Never mulch the seedlings with coconut leaves during initial phase of establishment, and planting two turmeric rhizomes on either side of the seedlings was found to reduce pest attack. Planting at correct spacing (Tall and hybrids at 7.5 m × 7.5 m; Dwarfs 7 m × 7 m) with adequate light is very essential to reduce pest attack (Rajan et al. 2009; Josephrajkumar et al. 2015).

Ecological Engineering Intercropping of palms with nutmeg, rambutan, curry leaf and banana along the interspaces disorients the pest away from the source due to crop-habitat diversification induced pest-repulsion cues. Crop heterogeneity is, therefore, preferred for pest regression, income generation as well as continuous employment of farmers. Installation of bird perch and flowering plants like coral vines (*Antigonon leptopus*) maintains pest defenders and executes ecosystem services. Damage by rhinoceros beetle was reduced in coconut-based cropping garden than in monocropped garden. A greater environmental heterogeneity, high species diversity and less host density favour less rhinoceros beetle attack on palms (Josephrajkumar et al. 2014b; Josephrajkumar and Krishnakumar 2016).

Mechanical Method This method involves periodic and systematic examination of the palm crown and removing the adult beetle by means of a metal hook during peak periods of pest abundance (June to September). In order to suppress *O. rhinoceros*, all breeding places should be rendered innocuous, or the grubs should be collected regularly (Menon and Pandalai 1960; Rajan et al. 2009).

Prophylactic Method Application of powdered oil cakes of neem (*Azadirachta indica* A. Juss.), or marotti (*Hydnocarpus wightiana* Bl.) or pongamia cake (*Pongamia pinnata* Linn.) at 250 g mixed with equal volume of sand, into the topmost three leaf axils around the spindle leaf thrice a year during May, September and December is recommended as a prophylactic measure against rhinoceros beetle and red palm weevil (Chandrika Mohan et al. 2000; Josephrajkumar et al. 2014b). Placing three or four naphthalene balls in the leaf axil at the base of spindle leaf at 12g $palm^{-1}$ and covering them with sand to prevent quick evaporation provide good protection against the pest for 45–60 days (Gurmit Singh 1987; Sadakathulla and Ramachandran 1990).

Placement of two perforated sachets containing chlorantraniliprole (3 g) or fipronil (3 g) was found effective in monsoon phase for successful seedling establishment and warding off rhinoceros beetle attack. During dry period, 100 ml of water may be poured over the sachet after placement to release the molecule. Placement of two botanical cakes made out of extracts from *Clerodendron infortunatum* Linn. and *Chromolaena odorata* Linn. (each tablet weighing 1.9 g, 2.5 cm diameter and 4.0 mm thickness) on the topmost leaf axils reduced 54% leaf damage and was found superior than chlorantraniliprole sachets (34%). A paste based on botanical extracts/oil was developed and swiped over the spindle and adjoining petioles at 10 g to safeguard juvenile palms for about 3 months from rhinoceros beetle attack (CPCRI 2016).

Biological Control This method accomplishes long-term and sustainable rhinoceros management. Pigs, rodents, fowls, frogs and toads are generalist predators.

Nirula (1955b) reported carabid, hysterid and elaterid beetles and their larvae in the breeding sites of *O. rhinoceros*, but none of these have any appreciable effect on the population of the grub. Insect predators are observed in the natural breeding grounds of the beetle, which feed on the eggs and early-instar grubs of the beetle. Most important predators are *Santalus parallelus* Payk., *Pheropsophus occipitalis* Macleay, *Pheropsophus lissoderus*, *Chelisoches morio* (Fab.) and species of *Scarites*, *Harpalus* and *Agrypnus* (Kurian et al. 1983). As these predators bio-suppress the pest population, their conservation is essential.

Two potential microbial agents, viz. green muscardine fungus (*Metarhizium anisopliae*) and *Oryctes rhinoceros* nudivirus (*Or*NV), cause diseases to the immature and adult stages. Their use is advantageous as these are relatively host specific, eco-friendly and compatible with other management tactics.

Green Muscardine Fungus M. anisopliae (Metchnikoff) Sorokin is an entomopathogenic fungus which kills the pest in conditions of low temperature and high humidity (Antony and Kurian 1975). The susceptibility of *O. rhinoceros* to the fungus was first reported in Western Samoa in 1913 and in India by Nirula et al. (1955a, b). *M. anisopliae* var. *major* (spore size 10–14 mm) is a highly virulent strain widely used for the control of the pest. The fungus could be mass multiplied using cheaper substrates in both solid and liquid media, and the spores could be harvested and treated in the breeding site at 5×10^{11} spores m^{-3} (Mohan and Pillai 1982; Danger et al. 1991). The infective potential of a strain may become reduced by culturing on media but is restored considerably following infection of a host. In vermicomposting sites, treatments with *M. anisopliae* spores killed all third-instar larvae, with the highest dose giving the fastest kill, taking 8 days when favoured by high humidity (Gopal et al. 2006). It was observed in Malaysia that without spore applications, 2-year-old shredded rotting coconut trunk debris, with 0–2% *M. anisopliae* infections and cover crop over growth, could contain substantial numbers of larvae (Tey and Ho 1995).

Currently, *M. anisopliae* is multiplied on semi-cooked rice medium for field application in organic manure as well as vermicompost pits at 100 g m^{-3}. This technology through farmer-participatory and women group approach has created a great impact on the long-term bio-suppression of the pest in community mode. Mass production technology of *M. anisopliae* was standardized in semi-cooked rice grains yielding a spore count of 3×10^{7} cfu g^{-1} of the culture. For liquid broth culture of *M. anisopliae*, carbon source dextrose could be replaced with less expensive jaggery. Tapioca jaggery broth and coconut water jaggery broth were found highly suitable for the liquid broth culture of *M. anisopliae*.

Oryctes rhinoceros Nudivirus (OrNV) *Or*NV was first reported from Malaysia by Huger (1966) and named as rhabdion virus of *O. rhinoceros*. The virus multiplies in the midgut and fat body of grubs and in the midgut of adults and becomes ‘flying virus factories’ aiding dispersal while defecating. Grubs die from the infection, and their cadavers release emerging virus into the breeding sites, where adults are infected by ingesting it there or during mating. The adult life span is shortened, and females cease oviposition (Bedford 2013). *Or*NV is very effective and kills the grub in 15–20 days time significantly suppressing the longevity and fecundity of adult beetles. Previously known as baculovirus, *Or*NV is presently grouped under nudivirus category with a rod-shaped virion as infective agent (Burand 1998). *Or*NV prepared from the infected *O. rhinoceros* adults and stored in sterile vials remain infective for 2 weeks to 3 months at 28 °C or for 20 weeks to 1 year at 4 °C (Zelazny et al. 1987). In India, *Or*NV-infected grubs after developing the symptoms could be stored in the deep freezer at −40 °C indefinitely retaining its virulence (Rajan et al. 2009).

During 1967, the Malaysian isolate of *Or*NV was introduced into *O. rhinoceros* population in many South Pacific Islands. Due to the natural spread and establishment of the disease, the pest population got reduced tremendously. Pest suppression continued for several years in these regions (Bedford 1980). *Or*NV was used to control *O. monoceros* in the Islands of Seychelles (Lomer 1986) and Tanzania (Purrini 1989). Similarly, release of *Or*NV-infected beetle led to the bio-suppression of *O. rhinoceros* in Papua New Guinea and Mauritius (Monty 1978; Gorick 1980).

Diagnosis of OrNV Giemsa stain smear technique was found very simple and convenient to detect hypertrophied nuclei of infected adult midgut cells in India (Mohan et al. 1983) and Papua New Guinea (Gorick 1980). The Giemsa method was supplemented by ELISA (Enzyme-Linked ImmunoSorbent Assay) techniques (Longworth and Carey 1980) and then followed by PCR techniques for detecting *Or*NV DNA in midgut tissues from adults or larvae (Ramle et al. 2001).

Zelazny (1981) reported the occurrence of *Or*NV in India and elaborate work was undertaken by Mohan et al. (1983). Studies conducted at ICAR-CPCRI indicated that *Or*NV-infected grubs become less active and stop active feeding. As a result of virus multiplication in the midgut epithelium, fat body disintegrates and haemolymph content increases. This causes translucency in the abdominal region which is an important exopathological symptom of the *Or*NV infection and mortality in grubs. The infected beetles disseminate the virus through faecal matter into the surroundings after 3–9 days of inoculation at 0.3 mg virus adult^{-1} day^{-1} (Mohan et al. 1983; Rajan et al. 2009).

Field Dissemination The simplest and best practical method of dissemination of *Or*NV is by releasing the infected adult beetles in the field. Healthy adult beetles are allowed to crawl on the viral inoculums at 1g infected midgut 100 ml^{-1} of buffer, for half an hour. The beetles are then kept under starvation for 12–24 h. The beetles are released preferably at dusk in the infested coconut gardens at 12–15 beetles ha^{-1} (Mohan et al. 1985; Rajan et al. 2009). Horizontal spread of *Or*NV was reported as 1 km month^{-1} (Jacob 1996). Introduction of *Or*NV in Minicoy and Androth Islands of Lakshadweep (Mohan et al. 1989; Mohan and Pillai 1993), Chittilappily, Thrissur, Kerala (Biju et al. 1995) and Sipighat, Andaman Island (Jacob 1996) successfully reduced the population of *O. rhinoceros* and its damage on coconut.

Insect Growth Regulatory Effect Restricting and managing the breeding sites could check the proliferation of the pest. The weed plant, *Clerodendron infortunatum* Linn. (Verbenaceae), is very effective in controlling the pest buildup in the breeding sites. Alkaloids of *C. infortunatum* have got a juvenile hormone analogous activity on *O. rhinoceros*. Formation of larval-pupal mosaic, pupal-adult intermediates or adultoids (adults with malformed wings) is some of the common abnormalities elicited. These abnormal adults were unable to fly and survived for only 6–8 days against the longevity of 2–3 months for healthy adults (Chandrika Mohan and Nair 2000a).

Attractants An effective trapping method with rotting castor cake slurry kept in mud pots has been developed to attract rhinoceros beetle (Rajamanickam et al. 1992). Hallett et al. (1995) reported the potential of using ethyl 4-methyl octanoate (E4MO), a male-produced aggregation pheromone, to attract and control rhinoceros beetle. Trapping of adult beetles in a PVC trap using the pheromone 'Oryctalure (E4MO)' is a recent innovative method in the IPM for rhinoceros beetle. The traps are set up in the gardens, and beetles trapped inside are collected periodically. These beetles can be used for field release after inoculation with *Or*NV (Rajan et al. 2009). The effectiveness of traps as management tools may well change with population size and only a portion of the population in the correct physiological condition at that time may go to traps, as reported in trap catches for *O. monoceros* (Allou et al. 2008).

12.2.1.8 Area-Wide Demonstration

In a large-scale demonstration of rhinoceros beetle control by *M. anisopliae* as well as *Or*NV conducted at Kerala, India, in 2400 ha, it was found that *O. rhinoceros* damage on spear leaf and spathe could be reduced by 95.8% and 62.5%, respectively (Nair et al. 2008). Area-wide technology adoption facilitated by ICAR-CPCRI covering 1500 ha in Alappuzha district indicated 76–85% reduction in leaf damage by rhinoceros beetle over the pretreatment period. Palm infestation by rhinoceros beetle was reduced to 54.14% from the initial level of 82.35% in a period of 3 years. Coconut yield increased to 13.1% nuts palm^{-1} year^{-1} due to these interventions. The Farmer Field School (FFS) was found to be an ideal method for technology transfer in coconut health management system (CPCRI 2016), and the average knowledge score on pest management of those farmers attending FFS was 51.69 compared to 32.80 in case of non-FFS farmers.

12.2.2 *Red Palm Weevil,* Rhynchophorus ferrugineus *Olivier (Coleoptera: Curculionidae)*

12.2.2.1 Distribution

Red palm weevil (RPW), *Rhynchophorus ferrugineus* Oliv, is a concealed and lethal pest of coconut palm. First information about the pest in India was published in 1891 in the *Indian Museum Notes*. Lefroy (1906) reported RPW as a local sporadic major pest of coconut and other palms throughout India. RPW was reported as a pest of coconut from Sri Lanka (Green 1906), Indonesia (Leefmans 1920), Burma (Ghosh 1923) and the Philippines (Copeland 1931). Although Buxton (1920) reported this pest on date palm from Mesopotamia, it was during the mid-1980s in the Middle East that the pest attained a major pest status (Abraham et al. 1998). Subsequently, RPW moved from North Africa into Europe, and it was reported in the South of Spain for the first time (Cox 1993). In Malaya, red stripe weevil, *Rhynchophorus schach* Olivier, was reported, and its biology worked out (Corbett 1932). *Rhynchophorus palmarum* is reported from coconut palms in the western tropics.

12.2.2.2 Crop Loss

It is estimated that 0.5% of the palms was attacked by the pest every year in erstwhile Travancore-Cochin, India, alone (Menon and Pandalai 1960). Due to the lethal nature of the pest and high value of the crops involved, the assumed action threshold for RPW in coconut and date palm is very low. In big plantations, 1% infested palm is the assumed action threshold.

12.2.2.3 Host Plants

Besides coconut, RPW attacks 26 species of palms (Menon and Pandalai 1960; Esteban-Duran et al. 1998; Malumphy and Moran 2009).

12.2.2.4 Taxonomy

The genus *Rhynchophorus* contains ten species, of which seven, including *R. ferrugineus* and *R. vulneratus*, are known to attack palms (Booth et al. 1990). A key to related genera and the revision of this species was provided by Wattanapongsiri (1966). Reginald (1973) suggested that *R. ferrugineus* is the typical *Rhynchophorus* species occurring worldwide. The species attacking palms are *Rhynchophorus ferrugineus*, *R. bilineatus*, *R. quadrangulus*, *R. palmarum*, *R. lobatus*, *R. distinctus* and *R. ritcheri*. Through molecular-genetic data, *R. vulneratus* was found synonymous to *R. ferrugineus* (Hallett et al. 2004).

12.2.2.5 Symptoms

RPW is reported to attack juvenile palms mostly aged below 20 years (Nirula 1956a; Abraham et al. 1998). Being an internal feeder, it is difficult to diagnose the pest infestation during early stages. It is mostly noticed when the palm has been fatally infested and is irrecoverable (Ghosh 1911; Menon and Pandalai 1960). Mechanical injury on palms; damage by rhinoceros beetle, as well as infection by leaf rot; and bud rot diseases, inappropriate crop geometry, etc. predispose RPW females for egg laying (Abraham and Kurian 1975; Abraham et al. 1998; Josephrajkumar et al. 2014a). According to Abraham et al. (1998) and Rajan et al. (2009), damaged palms exhibit one of the following symptoms depending on the stage of attack, yellowing and later wilting of the inner and middle whorl of leaves, small circular holes as well as tunnels on the palm trunk with oozing out of a brown viscous fluid, emanation of fermented odour around the infested tunnel, longitudinal splitting of leaf base with solidified gums, gnawing sound of grubs and presence of cocoon or chewed up fibres at leaf axil or palm base, ultimately resulting in the toppling of the crown (Fig. 12.3).

Entry of the pest through the crown is the most common and most fatal type of infestation. The grubs in such cases stay very close to the cabbage portion (growing point) of the palm, and this results in drying of the young heart leaf. In seedlings and younger palms, entry of the pest through the bole region is generally noticed. Shallow planting and injuries to the soft stem due to mechanized cultivation practices are the major reasons for this type of pest entry. In Dwarfs, entry is noticed through leaf axil also, if injured usually due to heavy bearing bunches.

Fig. 12.3 Toppling of crown of coconut palm due to attack of red palm weevil. (Photo: Josephrajkumar)

12.2.2.6 Bioecology

Life history of RPW has been well studied and documented in many countries including India, Indonesia, Myanmar, the Philippines, Iran and Spain (Ghosh 1911; Menon and Pandalai 1960; Esteban-Duran et al. 1998; Murphy and Briscoe 1999). Several overlapping generations comprising of different stages of the insect could be seen in the infested palm. The adult weevils measure 35 mm long and 12 mm wide and is ferruginous brown in colour. The snout is elongated in both sexes, and the dorsal apical half of the rostrum in males is covered with a patch of short tuft of brown hairs. The snout of female is bare, relatively slender and a little longer than the males. Oviposition by female weevils is confined to the softer tissues of the palms in holes made with its rostrum (Nirula 1956a). The weevils are crepuscular and, according to Leefmans (1920), are capable of long flights and can locate their hosts in widely separated areas. The weevils after emergence from the pupal case will remain inside the cocoon for about a week making them sexually mature during the period of inactivity (Hutson 1933). A single female lays 58–131 eggs (creamish white, oval and broader at one end) and emerges out as whitish-yellow grubs that could sustain for a period of 25–105 days (Faleiro 2006). Computer-aided flight mill studies to analyse the flying ability of *R. ferrugineus* revealed that 54% adult weevils are short-distance flyers (covering <100 m), 36% are medium-distance flyers (covering 100–5000 m) and 10% are categorized as long-distance (>5000 m) flyers (Ávalos et al. 2014).

The fully grown apodous grubs are conical shaped, bulged in the middle and pointed towards both the ends. The body is 13 segmented with the brownish head pointed downwards. Mouth parts are well chitinized enabling the grubs to burrow the hard woody portions. Grubs chew the palm tissue and move interior leaving behind the chewed up frass emanating foul odour (Menon and Pandalai 1960; Faleiro 2006). Viado and Bigornia (1949) reported nine larval instars for RPW, while El-Shafie et al. (2013) reported eight larval instars sustaining for a period of 25–105 days. The life stage of RPW is depicted in Fig. 12.4.

The grubs construct an oval fibrous cocoon strong wound and are arranged spirally. Interior of the cocoon is smooth and plastered to house the exarate pupa with prominent antenna and eyes. The pupal period ranges from 11 to 45 days (Menon and Pandalai 1960; Faleiro 2006).

Rahalker et al. (1978) developed an artificial diet for rearing RPW based on sugarcane bagasse, while El-Sebay et al. (2003) developed a diet based on potato and carrot. Recently, a meridic diet consisting of agar, distilled water, commercial yeast as well as laboratory produced amino and fatty acid rich brewer's yeast (*Saccharomyces cerevisiae*), wheat meal, corn flour, benzoic acid, ascorbic acid, sorbic acid, vitamin mix and tetracycline hydrochloride was developed for the successful rearing of red palm weevil (El-Shafie et al. 2013).

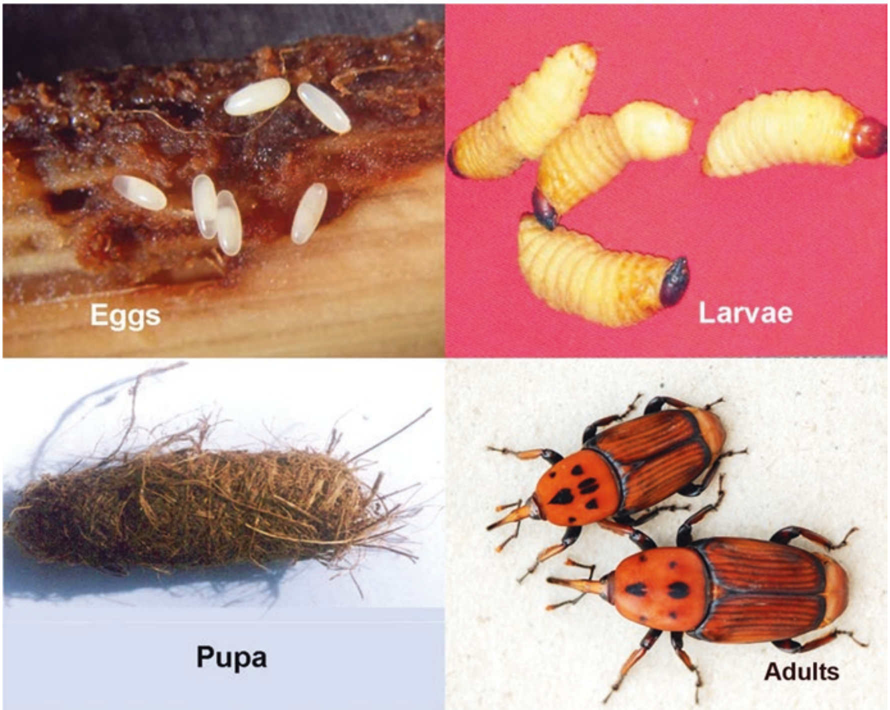

Fig. 12.4 Life stages of red palm weevil. (Photo: Josephrajkumar)

12.2.2.7 Integrated Pest Management

Prevention of pest entry into the palm is the major step to be adopted in the IPM package. Maintenance of field sanitation by removal, splitting and burning of dead palms, which harbour various stages of the pest, helps a lot in reducing fresh incidence and hence should be considered as an important step in IPM. A systematic intervention of farm and palm hygiene is very critical for pest avoidance.

Early Detection Davis (1964) first developed an electronic detector which consisted of an amplifier, a probe and an earphone which was subsequently modified as built-in speaker for the detection of RPW. Power is supplied by a 3 volt dry battery cells to the amplifier. The probe lead has to be plugged into the amplifier and the needle pressed on the palm trunk to detect the gnawing sound of the grub. Abraham et al. (1966) studied methods of entry of the weevil into the palm, the important symptoms and the detection of the pest infestation by an electronic amplifier. Ramachandran and team developed a prototype detector which could not specifically pinpoint the presence of grubs due to extraneous noise factor. A prototype acoustic detection was developed with the technical support of CDAC, Thiruvananthapuram for early detection of the pest, which is to be refined (CPCRI 2014).

Cultural Control Maintaining optimum palm density is very important not only for harnessing the highest benefits of light energy but also for reducing the release of volatiles orienting the pest towards the host. Intercrops admix and diminish the volatile cues disorienting RPW away from host (Josephrajkumar et al. 2014a). Shallow planting incites more damage (Rajan et al. 2009). Systematic diagnosis through close monitoring and vigilant scouting is the key for early diagnosis. Avoiding physical injury to palms is very critical to reduce pest incidence. Cutting fronds leaving at least 1.2 m from trunk, evading knife injury on crown region and avoiding injury to bole and frond need to be overemphasized (Abraham et al. 1989; Rajan et al. 2009; Josephrajkumar et al. 2014a).

Sterile Male Release Technique Control of *R. ferrugineus* using radiosterilized males (1.5 Krad for 1–2 days) was undertaken by Rahalkar et al. (1973). A total of over 5000 radiosterilized males were released in a 320 ha young coconut plantation in Kerala, India, with limited success due to the fact that the floating female weevils were already mated inside the infested palm. Ramachandran (1998) studied biotypical variability among four populations of red palm weevil from different parts of India and found populations are genetically different and strainal variability exists between them. The weevil has a very high fitness due to high production potential and the absence of effective parasites, predators and pathogens. In addition, gamma radiation also did not have significant effect on the F_2 generation (Ramachandran 1991).

Biological Suppression Murphy and Briscoe (1999) outlined the prospects for biological suppression as a component of RPW-IPM programme. More than 50 natural enemies have been reported to attack *Rhynchophorus* species (Mazza et al. 2014). The highly potent cytoplasmic polyhedrosis virus (CPV), recorded first in India, infected all stages of RPW and could reduce insect population (Gopinadhan et al. 1990). Dangar and Banerjee (1993) discovered bacterial isolates belonging to *Bacillus* sp., *Serratia* sp. and the coryneform group in larvae and adults in India. Alfazariy (2004) reported successful control of RPW in laboratory conditions by infection with *B. thuringiensis* subspecies *kurstaki* isolated from larvae in Egypt. *Pseudomonas aeruginosa* (Schroeter) isolated from infected larvae collected in Kerala, India, induced mortality in early-instar grubs (Banerjee and Dangar 1995). Salama et al. (2004) isolated three potent spore-forming bacilli, as variants of *B. sphaericus*, *Bacillus megaterium* de Bary and *Bacillus laterosporus* Laubach, which caused larval mortality ranging between 40% and 60%. *B. sphaericus* which produced spherical endospores and crystalline endotoxins was the most virulent pathogen responsible for the larval mortality.

Besides phoretic mites, some ectoparasitic podapolid mites associated with *Rhynchophorus* species, such as *Rhynchopolipus rhynchophori* (Ewing), were used as a successful biocontrol agent against RPW (Abdullah 2009). Natural insect enemies of *Rhynchophorus* include several species belonging to the orders Dermaptera, Heteroptera, Coleoptera, Diptera and Hymenoptera (Murphy and Briscoe 1999). Among earwigs, *Chelisoches morio* (Fabricius) was reported as a common predator of RPW eggs and larvae in the canopy of coconut plantations in India (Abraham and Kurian 1973), and *Euborellia annulipes* (Lucas) was found in RPW-infested palms in Sicily (Massa and Lo Verde 2008). Among Hymenoptera, *Scolia erratica* Smith was found in Malaysia as a parasitoid of RPW (Burkill 1917). Krishnakumar and Sudha (2002) observed Indian tree pie bird, *Dendrocitta vagabunda parvula* as an effective predator on RPW adults.

Beauveria bassiana (Balsamo) Vuillemin and *M. anisopliae* (Metchnikoff) Sorokin are two of the most commonly studied species of entomopathogenic fungi. *B. bassiana* isolated from the United Arab Emirates, Italy and Spain, though found effective against RPW grubs and weevils, a commercial formulation of *B. bassiana*, had little effect on RPW (Abdel-Samad et al. 2011). Francardi et al. (2012) showed that *M. anisopliae* isolated from RPW in Italy had the highest efficacy against RPW larvae and adults with high efficacy on dry spores. Cito et al. (2014) reported the first recovery of *Metarhizium pingshaense* associated to RPW in Vietnam killed RPW mainly due to efficient protease activity and toxin production.

Banu et al. (2003) reported the infectivity of red palm weevil grubs and adults to entomopathogenic nematodes (*Heterorhabditis indica*, *Steinernema glaseri* and a local isolate *Steinernenam* sp.). Encouraging results were obtained using *Steinernema* sp. isolated from RPW pupae and adults in Egypt, when tested against field population (Shamseldean and Atwa 2004). The use of chitosan as adjuvant could protect *S. carpocapsae* from environmental conditions increasing the length of efficacy period (Llacer et al. 2009). Josephrajkumar et al. (2014c) reported higher virulence of local entomopathogenic nematode (EPN) strain of *H. indica* (LC_{50} 355.5 IJ) in the suppression of *R. ferrugineus* grubs as well as greater susceptibility (82.5%) of prepupal stage than that of grubs. Synergistic interaction of *H. indica* (1500 IJ) with imidacloprid (0.002%) against red palm weevil grubs indicated combined application of *H. indica*-infected *Galleria mellonella* cadavers and imidacloprid (0.002%) would be an effective strategy in the field-level management of RPW in coconut.

Attractants Henry (1917) suggested, for the first time, that fermenting kitul palm *Caryota urens* wood could be effective in trapping RPW adults. However, it was found that split coconut logs smeared with fresh toddy were more effective in trapping RPW in India (Abraham and Kurian 1975). Kurian et al. (1984) investigated several attractants for red palm weevil management. Log traps consisting of tender coconut stems, 50 cm long and spilt longitudinally, were treated with macerated fruits, molasses (jaggery from sugarcane), acetic acid, yeast and toddy, singly or in combination, and it was found that logs treated with coconut toddy + yeast + acetic acid attracted more weevils which could therefore be used in the management of RPW.

Hallett et al. (1993) identified and synthesized the ferrugineol (4-methyl-5-nonanol) from male-produced aggregation pheromone, and subsequent experiments confirmed that the addition of a second component (4-methyl-5-nonanone) in small amounts enhanced the capture rate of weevils by 65% (Abozuhairah et al. 1996). For operational ease in servicing food bait as well as trapping efficiency, bucket traps were used for trapping RPW (Oehlschlager et al. 1993). Nair et al. (2000a) found that the plantains and sugarcane were equally effective as food baits in enhancing the catch of weevils in pheromone trap and good bait relies on the high sugar content. Effective trapping of the weevils could be accomplished in the field when traps were set up with pheromone and food bait together (Nair and Nair 2003). Mayilvaganan et al. (2003) had assayed locally synthesized ferrugineol dispensed through capillary vials for trapping *R. ferrugineus* and found enhanced catches of female weevils. RPW was successfully brought down within 2 years in Israel by mass trapping the pest at 10 traps ha^{-1} in infested plantations; however, monitoring its activity could be accomplished at one trap in 3 ha (Soroker et al. 2005). Thomas et al. (2014) reported refinement in aggregation pheromone (4-methyl-5-nonanol and 4-methyl-5-nonanone 9:1) in tandem with food baits to attract RPW. Though effective, lures need to be replaced once in 3- to 4-month interval. Use of nanoporous materials as a novel carrier for loading the pheromone and kairomone of RPW trapped higher number of weevils than the commercial lure and sustained for more than 6 months. Mostly the trapped female weevils in pheromone traps are young, fertile and gravid; however, the infestation rate of palms around the trap is higher in certain agroecosystem which further requires fine-tuning in field delivery of pheromones and the field placement of traps. A pull-push strategy of moving weevils away from the field and orienting towards the trap is the need of the hour.

Trypsin Inhibitor Josephrajkumar et al. (2016a) highlighted suppression of growth and endopeptidases of red palm weevil using proteinase inhibitors. Serine protease inhibitors, viz. aprotinin (50 μg), soybean trypsin inhibitor (50 μg) and phenyl methyl sulphonyl fluoride (1700 μg), inhibited the gut proteinases of *R. ferrugineus* such as trypsin, elastase-like chymotrypsin and leucine aminopeptidase. Digestion and nutrient uptake of the insect are affected leading to impaired growth and development.

Chemical Control Several phased-out chlorinated hydrocarbons have been found effective in the control of RPW which are not described here. Mathen and Kurian (1967) recommended carbaryl 1% for the effective management of the pest. The molecule is relatively cheap and non-phytotoxic. Injection of Procyon E suspension after plugging all holes in the stem suppressed existing infestation. Abraham et al. (1975) reported the effectiveness of trichlorphon (1%) in recovering 92% of infested palms. It was found that 10% cashew apple extract was as effective as 1% carbaryl in killing RPW grubs in the laboratory (Krishnakumar and Maheshwari 2003). Laboratory evaluation showed that carbosulfan (0.05%) was superior against adult weevils and fifth-instar larvae (Beevi et al. 2004). Curative treatment of imidacloprid (0.02%) or spinosad (0.013%) was found effective in the management. As the pest has prolonged larval period including nine moultings, use of insect growth regulator would be an appropriate management strategy. Application of lufenuron (0.01%) leading to defective morphogenetic moults and malformed adults spurs long-term strategy in biorational approach to RPW management (Josephrajkumar et al. 2014c). At a global level, chemical groups, phenylpyrazole- and neonicotinoid-based insecticides, are used as preventive and curative applications to control RPW (Kaakeh 2006; Llácer et al. 2012; Al-Shawaf et al. 2013). Injected imidacloprid was capable to cause more than 90% mortality in young grubs for more than 2 months after treatment (Dembilio et al. 2015). With the limitation of insecticides causing environmental and health hazards, the focus has been currently oriented towards the use of eco-friendly strategies in the management of RPW.

Abraham et al. (1989) tested the IPM strategy for management of RPW in farmer's field in Kerala, India, and found the systematic adoption of IPM practices could bring down the pest population to nil and prevent fresh incidences. Josephrajkumar et al. (2014c) suggested refinement in the schedule for integrated management of red palm weevil. Closeness of farmer and systematic scouting would enhance better understanding about regular physical changes in palm for early diagnosis. Maintaining optimal palm density supplemented with intercrops for diminishing volatile cues through crop-habitat diversification strategy diminished pest attack. Prophylactic leaf axil filling with botanical cakes developed by ICAR-CPCRI and new-generation molecule, chlorantraniliprole at 3 g in perforated polythene sachet, safeguarded palms from invasion by rhinoceros beetle for 4–5 months as palm injury incites RPW attack. Influence of insect growth regulator, lufenuron (0.01%), leading to defective morphogenetic moults and malformed adults spurs long-term strategy in biorational approach to RPW management. Integrated management technologies involving complete destruction of infested palms, close monitoring and sustained surveillance for early diagnosis, leaf axil filling of chlorantraniliprole sachet, curative management with imidacloprid (0.02%) and pheromone trap at 1 trap ha^{-1} were found effective in pest suppression. Community-level technology convergence and large-area adoption of IPM technologies conducted in 2150 ha in Kerala (Bharanikavu, Cheppad), Tamil Nadu (Palladam), Andhra Pradesh (Ambajipet) and Karnataka (Bidramamandi) could reduce the pest incidence to 56.8%. Saving approximately 1% of palms from the pest damage all over the country with complete recovery brings a huge monetary gain to the country.

12.2.3 Nut Borer **Cyclodes omma** *Van der Hoev (Noctuidae: Lepidoptera)*

Cyclodes omma is an occasional pest that feeds on immature nuts inducing button shedding. Different stages of hairy caterpillars bore into the meristematic tissues surrounding the tepel and make prominent and typical bore holes. Caterpillars construct fibrous cocoons around the crown region. Adult moths are ochre green tinged with bilayered ring spots towards apical margin (Menon and Pandalai 1960).

12.3 Defoliators

12.3.1 Coconut Black-Headed Caterpillar Opisina arenosella *Walker (Lepidoptera: Oecophoridae)*

12.3.1.1 Distribution

Coconut black-headed caterpillar, *O. arenosella* Walker (synonym *Nephantis serinopa* Meyr.) (Oecophoridae: Lepidoptera), is a serious defoliator of coconut palm. The oldest record of the pest is by Green (1898) from Batticaloa of Ceylon (Sri Lanka). *O. arenosella* was first described by Meyrick in 1905. In India, *O. arenosella* was noted for the first time during 1907 on palmyrah palms in Tamil Nadu and first record of its presence on coconut leaves was from Andhra Pradesh in 1909 (Rao et al. 1948). During 1917 and 1920, severe outbreaks of *O. arenosella* were observed in Kerala and Karnataka, India (Pillai 1919; Rao 1924; Venkatasubban 1932). Since then, it has been reported causing serious damage periodically in major coconut-growing tracts in coastal and backwater areas and in the vicinity of water bodies in the inlands of peninsular India. Pest appears in several locations in a discontinuous manner; but under favourable conditions, it multiplies very rapidly resulting in sporadic outbreaks. This pest was reported to be a serious menace to coconut cultivation in other countries, viz. Sri Lanka (Jayaratnam 1941; Dharmaraju 1963), Myanmar (Ghosh 1923) and Bangladesh (Alam 1962).

12.3.1.2 Symptoms

The caterpillars construct galleries of silken webs reinforced with excreta and scrapes of leaf bits on the abaxial side of leaflets. By hiding in these galleries, they feed on the chlorophyll-containing parenchymatous tissue leaving the thin upper epidermis (Nirula 1956b). The affected portions get dried and form conspicuous grey patches on the upper surface of the leaflets which is the first noticeable symptom of infestation. Usually the feeding and drying start from the outer whorl of fronds and proceed inwards. Close examination of leaflets shows the presence of larval galleries on the lower side with live or dead stages of the pest. Severe pest damage results in complete drying of middle to inner whorl of fronds also. From a distance, the crown of such palms gives a burned appearance (Fig. 12.5). Since drying of fronds occurs due to many reasons, dried fronds should be cut and examined for the presence of larval galleries to identify the pest problem correctly. The pest infests coconut palms of all age groups round the year to varying intensities.

Fig. 12.5 Symptom of attack of leaf-eating caterpillar. (Photo: Josephrajkumar)

12.3.1.3 Crop Loss

Damage results in drying of the outer and middle whorl of leaves, reduction in the rate of production of spikelets, retardation of growth, reduction in photosynthetic efficiency and decline in yield. In addition, the damage renders the leaves unsuitable for thatching. Young palms often die due to the pest attack. The occurrence of the pest causing over 40% damage is considered to be an outbreak (Perera 1993). Joy and Joseph (1972) reported 63% reduction in yield due to *O. arenosella* attack. Annual loss in the pest-infested fields is estimated as INR 7280 ha^{-1} (Rajagopal and Arulraj 2003). Chandrika Mohan et al. (2010b) highlighted a 45% nut yield loss in the succeeding year of severe pest infestation.

12.3.1.4 Host Plants

Although *O. arenosella* is best known as a pest of coconut palm, palmyrah (*Borassus flabellifer* Linn.) is presumed to be the original host. Several palm species including ornamental palms and other crops such as banana, cashew and jack were reported as potential hosts (Rao et al. 1948; Lever 1969; Baburayanayak 1970; Butani 1975;

Kapadia 1982; Talati and Kapadia 1984; Talati and Butani 1988; Murthy et al. 1995a; Manjunath 1985; AICRP 1997; Chandrika Mohan and Shameer 2002; Sujatha and Singh 2002).

12.3.1.5 Bioecology

Rao (1924) studied the occurrence of the pest along the East and West coasts of India. Detailed account of bionomics, life history and morphology of *O. arenosella* was given by Nirula et al. (1951), Nirula (1956b) and Antony (1962). The moth is small, ash grey in colour, measuring 10–15 mm in length with a wing spread of 20–25 mm. The male moth is smaller than female with a slender abdomen ending in a short brush of scales, while in the female, the abdomen is stouter and pointed at the tip. The moths are nocturnal in habit and during daytime are found resting on the undersurface of the leaves. They are poor fliers, a fact that might have contributed to their relatively slow rate of spread and the localized nature of infestations. The moths are not found attracted to light, and strong wind and rain have little effect upon the resting moths. In the laboratory with honey as food, the male moth lives for 7 days on an average and the female for 5 days. Female moths lay eggs in irregular groups in webbed galleries on the underside of the previously attacked leaves of coconut palm. Nirula (1956b) noted that fecundity varied from 59 to 252 eggs, the capacity being influenced by climatic and other factors. The egg is oval in outline, 0.6–0.8 mm long and 0.3–0.4 mm broad, creamy white in colour when freshly laid and turn pinkish before hatching. The surface of the egg is shiny and is covered with irregular faint reticulations. Incubation period varies from 3 to 8 days. Newly hatched caterpillar is about 1.5 mm long and pink coloured with black head and dark thoracic plates. The abdomen is smooth and shining with long setae on the sides. The caterpillar spins a silken gallery on the abaxial frond surface, remaining in it while feeding. Fully developed caterpillar measures 13–18 mm in length and is greenish in colour with reddish brown stripes on the dorsal side (Nirula 1956b; Menon and Pandalai 1960) (Fig. 12.6).

There is difference of opinion among the workers regarding the number of instars. Nirula et al. (1951), Lever (1969) and Mohamed et al. (1982) observed five instars, whereas Antony (1962), Santhosh Babu and Prabhu (1987) reported six and eight instars, respectively. The caterpillars, after feeding voraciously on coconut leaflets, enter the prepupal stage and spin cocoons with white silken fibre. Prepupa is 12–15 mm long and is light pink in colour. The pupa is reddish brown in colour and measures 9–14 mm in length.

Population buildup in field varies with respect to climate and locations, and pest dynamics vis-à-vis abiotic factors are well documented (Nirula 1956b; Joy and Joseph 1972; Narendran et al. 1979; Mohamed et al. 1982; Sathiamma et al. 1973; Puttarudriah and Shastry 1964; Nadarajan and ChannaBasavanna 1980; Pushpalatha and Veeresh 1995; Sujatha 2001). In Sri Lanka, Perera et al. (1989) correlated the population outbreaks with climatic and biotic factors. Analysis of records of population outbreaks from 1965 to 1985 revealed cycles in the populations of approximately

Fig. 12.6 Life stages of leaf-eating caterpillar. (Photo: Josephrajkumar)

one generation period. Parasitism remained high throughout the outbreaks, and there was some evidence that pupal parasitism increased towards the end of the outbreak.

12.3.1.6 Integrated Pest Management

Low to moderate pest infestations in the field can be effectively managed by the biological control methods. However, an IPM strategy is recommended for management for *O. arenosella* in severe outbreak conditions. In IPM, biological control with releases of stage-specific parasitoids is supplemented with mechanical and chemical control approaches.

Mechanical Method Early to mild stages of infestation can be reduced by cutting and burning the badly affected fronds/leaflets. In case of very severe infestation also, removal and burning of fully dried two to three outer whorl of fronds helps in removing the pupae and other pest stages. Careless disposal of the pest-affected leaves in the vicinity of healthy palms can lead to newer infestations. This aspect has to be well taken care of while transporting pest-infested fronds or leaflets to pest-free areas as such or using pest-infested fronds for wrapping other commodities for transporting to newer areas.

Chemical Method Since a very rich natural enemy fauna is associated with *O. arenosella* in the field, chemicals are generally not being encouraged for the management of this pest. In case of very severe outbreaks, one spray of malathion (0.05%) (which is comparatively safe to natural enemies) is recommended to bring down the active pest stages. Spray solution has to reach underneath of the leaves to drench the larval galleries of the pest. If any chemical spraying is undertaken, a waiting period of 3 weeks is to be observed before the release of parasitoids. Due to the difficulty experienced in recent years in getting skilled labourers for palm climbing, chemical spraying recommendation is at a low profile in IPM.

Biological Method The black-headed caterpillar is attacked by several species of parasitoids, predators and microorganisms in the natural environment, and hence biological control provides the best solution for the management of *O. arenosella* on a perennial crop like coconut (Rao et al. 1948; Nirula 1956b; Nagarkatti 1973; Perera 1984, 1987; Cock and Perera 1987; Pillai and Nair 1993; Singh 1999; Chandrika Mohan and Sujatha 2006).

Natural Enemies of O. arenosella Dharmaraju (1962) provided a checklist and distribution of natural enemies of the pest in India and Sri Lanka. The list was updated by Cock and Perera (1987) and Pillai and Nair (1993). The coconut caterpillar supported about 60 species of natural enemies belonging to Class Insecta (Pillai and Nair 1993).

Parasitoids Among the parasitoids recorded from the pest, the larval parasitoids *Goniozus nephantidis* (Bethylidae) and *Bracon brevicornis* (Braconidae), the prepupal parasitoid *Elasmus nephantidis* (Elasmidae) and the pupal parasitoid *Brachymeria nosatoi* (Chalcididae) are the most promising ones which are used for augmentative releases for pest suppression. The major desirable attributes of these parasitoids are their greater host-searching ability, production of higher proportion of females, occurrence throughout the year and distribution in all pest-infested areas. Techniques have been developed for mass production of the promising parasitoids. Close monitoring of the endemic areas is essential to detect pest buildup at the initial stage itself for release of parasitoids at the appropriate period. Usually initial pest buildup was observed after post-monsoon (October to November) in Kerala and coastal Karnataka, India. The most important aspect in field release of parasitoids is that the release should synchronize with the stage of pest in the field. Presence of larvae in the leaflets should be confirmed before release of parasitoids to avoid wastage of parasitoids. George et al. (1982) developed a technique to estimate population of *O. arenosella* in the field. Sathiamma et al. (1987) worked out the norms for release of larval, prepupal and pupal parasitoids based on the estimated population of the larvae, prepupae and pupae of *O. arenosella* in the field. Releases are to be done at fortnightly intervals. The parasitoid *G. nephantidis* is released if the pest is at third-instar larval stage or above at 20 parasitoids palm^{-1} and *B. brevicornis* at 30 parasitoids palm^{-1}. The prepupal parasitoid *E. nephantidis* and pupal parasitoid *B. nosatoi* are released at 49% and 32%, respectively, for every

100 prepupae and pupae estimated to be present on the palm. In a multistage condition of the pest, a combined release of all the parasitoids at 40% of each of the target pest stage is required.

Before releasing the parasitoids in field, they should be fed with honey, and newly emerged parasitoid can be released in the field after 3 days of emergence. *G. nephantidis* and *B. Brevicornis* could easily be mass multiplied on larvae of the rice moth *Corcyra cephalonica*. The prepupal parasitoid *E. nephantidis* is a highly host- and stage-specific parasitoid and always requires a steady supply of prepupa of *O. arenosella* for mass multiplication. This is the major constraint for mass production of *E. nephantidis* in the parasite breeding laboratories. Other major parasitoids associated with *O. arenosella* in the field include early larval parasitoid *Apanteles taragamae*, larval-pupal parasitoid *Meteroidea hutsoni* and pupal parasitoids *Xanthopimpla* spp. and *Trichospilus pupivora* (Ghosh and Abdurahiman 1984, 1985; Chandrika Mohan 2005; Sujatha and Singh 1999; Pillai and Nair 1982, 1983, 1989; Joy and Joseph 1977). Perera (1993) opined that the performance of different parasitoids of *O. arenosella* was highly variable and is perhaps the reason for the periodic occurrence of pest outbreaks. Superiority of the solitary parasitoids over gregarious species in the biological suppression of the pest is well documented in Kerala, India (Pillai and Nair 1995). There are indications that the relative distribution as well as levels of parasitism of the natural enemies varies considerably in different climatic conditions and localities.

Exotic Parasitoids In many biocontrol successes, the introduction of an exotic parasitoid or predator is involved, and in most cases, a single exotic species has eventually been able to reduce the population to a non-pest status. Systematic efforts to breed the exotic natural enemies of *O. arenosella* and release in pest-infested coconut gardens were not successful. Exotic tachinid parasitoids, such as *Stomatomyia* (*Spoggosia*) *bessiana* Baranov from Sri Lanka and *Bessa remota* Aldrich introduced from Malaysia, released in India were not successful (Rao et al. 1971; Jayanth and Nagarkatti 1984; Cock and Perera 1987).

Predators The efficiency of the predators is neither fully assessed nor widely used in the biological control programme of *O. arenosella* (Pillai and Nair 1993). Insect and spider predators are abundant in the coconut ecosystem. The dominant insect predators are the carabid *Parena nigrolineata* Chaudoir and *Calleida splendidula* Fabricius, anthocorid *Cardiastethus* spp., chrysopid *Ankylopteryx octopunctata candida* Fabricius and coccinellid beetles (Pillai and Nair 1986, 1993). Rao et al. (1979) reported four species of spiders (*Cheiracanthium melanostoma* (Thorell), *Olios lamarcki* (Licrielle), *Heteropoda leprosa* Simon, *Marpissa calcuttaensis* (Tikader)) in association with *O. arenosella* in East Godavari district of Andhra Pradesh. A total of 26 species of spiders are recorded on the pest of which *Rhena*, *Sparassus* and *Cheiracanthium* are the major predators (Sathiamma et al. 1987). Surveillance in Karnataka, India, revealed the occurrence of efficient insect predators, viz. *C. exiguus*, *Buchananiella sodalis* Buchanan-White, *Mallada astur* (Banks), *Jauravia* sp. and *Phytoseiulus* sp., and ants, namely, *Tapinoma* sp., *Monomorium pharaonis* (Linnaeus), *M. latinode* Mayr, *Crematogaster* sp. and *Tetraponera rufonigra* (Jerdon) (Sujatha and Singh 1999). In Sri Lanka, Way et al. (1989) observed that 11 species of ants nested in coconut palm spathes and some of them are predators of eggs of *O. arenosella*.

Mites *Pyemotes ventricosus* Newport belonging to Pymotidae family was a gregarious ectoparasitic mite collected from the field. It parasitizes mostly the larval and pupal stages and occurs during rainy season (Mathen et al. 1968). A predatory mite, *Phytoseiulus* spp., was recorded in both coastal and interior zones of Karnataka, India (Sujatha 2001). Studies on seasonal variation revealed their numerical abundance during summer and post-monsoon in coastal area. Population of the mite ranged from 86.25 to 261.25 per 20% sample leaflets palm^{-1}. *Phytoseiulus* sp. and *C. exiguus* in the ratio 2:1 were associated with low population of *O. arenosella* during summer in interior Karnataka.

Pathogens *Bacillus thuringiensis* Berliner, *Serratia marcescens* Bizio and *Aspergillus flavus* Link are observed to be pathogenic to the pest in the field (Antony and Kurian 1961; Muthukrishnan and Rangarajan 1974; Oblisami et al. 1969; Kanagaratnam et al. 1983; Gopal et al. 2000). Philip et al. (1982) and Narayanan and Veenakumari (2003) reported a nuclear polyhedrosis virus affecting the caterpillars in Kerala and Karnataka, India, respectively. Sujatha (2001) observed 15% larval mortality due to bacterial and fungal pathogens soon after the monsoon rains (October) in coastal Kerala, India.

Attractants Kairomones could be used to enhance the efficiency of potential parasitoids (Bakthavatsalam and Singh 1996). Hexane wash of gallery and body of *O. arenosella* elicited positive response from the efficient parasitoids, namely, *G. nephantidis*, *E. nephantidis* and *B. brevicornis*. Analysis of infochemicals using GCMS revealed the presence of dodecane, pentadecane, hexadecane, heptadecane, eicosane and tricosane in the gallery of *O. arenosella*, and larval wash showed terpenoids (Bakthavatsalam et al. 1999). Subaharan et al. (2005) reported improvement in host-searching efficiency of *G. nephantidis* by exposing the newly emerged parasitoids to the host odours (smell of the volatiles of the injured *O. arenosella* larvae and gallery volatiles). The attraction of males of *O. arenosella* to conspecific virgin females was studied on coconuts at three locations in Sri Lanka during November to December 1996. The number of males caught in traps baited with virgin females was significantly greater than the number caught in unbaited traps (Fernando and Chandrasiri 1997). A female sex pheromone was reported by Murthy et al. (1995b). Four components of the pheromone of *O. arenosella* were identified by the Natural Resources Institute, UK (NRI), using insects from Sri Lanka (Cork and Hall 1998).

12.3.1.7 Field Performance of the Bioagents and Demonstration of IPM

Field performance on biological suppression of coconut leaf-eating caterpillar through release of stage-specific parasitoids was established as early as the 1920s. In 1929, a boat laboratory was functioning to breed and transport parasitoids in the Travancore and Cochin (erstwhile Kerala State, India), belt with very successful results (Nirula 1956b). Using IPM technologies or exclusive release of promising biocontrol agents, many demonstrations were laid out from 2000 by ICAR-CPCRI in coastal Kerala and Karnataka, India.

Studies conducted in an endemic area during 1990–1993 at Kollam District, Kerala, India, with the field release of the three stage-specific parasitoids, viz. *G. nephantidis*, *E. nephantidis* and *B. nosatoi*, at fixed norms and intervals in *O. arenosella*-infested coconut garden (2.8 ha) resulted in highly significant reduction (94%) in *Opisina* population (Sathiamma et al. 1996). Regular monitoring and release of stage-specific parasitoids induced 52.6% and 94.7% reduction in pest population after 1 year and 2 years, respectively, of parasite release in a heavily infested tract in Kollam Dist., Kerala (Chandrika Mohan and Sujatha 2006). A large-area field validation of the bio-suppression technology of coconut black-headed caterpillar with regular monitoring and release of stage-specific parasitoids, viz. *G. nephantidis*, *B. brevicornis*, *E. nephantidis* and *B. nosatoi*, was taken up during 1999–2002 in different geographic locations in coastal Karnataka and coastal Kerala (India) comprising of a total of 1,400 ha which could achieve 93–100% reduction in *O. arenosella* population in a period of 2 years (Chandrika Mohan et al. 2010a). Ghode et al. (1987) and Mohanty et al. (2000) had reported biological pest suppression of *O. arenosella* in coastal districts of Odisha, India, by the release of parasitoids. Successful biocontrol of *O. arenosella* was reported in Andhra Pradesh, India (Sujatha and Chalam 2009), and timely augmentation of *G. nephantidis* at 10 adults palm^{-1} at 15-day interval suppressed the pest population in Karnataka, India, at a cost of Rs. 2100 ha^{-1} (Venkatesan et al. 2006).

The higher frequency of occurrence of G. *nephantidis* in all the locations during post release period indicated the suitability of this larval parasitoid to adapt in various locations in the coastal belts of Kerala and Karnataka, India. Nutritional management of the palm with balanced dose of recommended fertilizers and proper irrigation to rejuvenate the pest-affected palms are essentially required to regain the yield potential of pest-infested palms.

The IPM package should be adopted in a larger area as a community programme with active involvement of farmers and development agencies for achieving the desired goal. It is of utmost importance that the parasitic fauna of a locality is to be studied before initiating the biological control programme. Role of solitary parasitoids in pest suppression is well documented. Clipping off the pest at the very initial stage and releasing appropriate dose of parasitoids synchronizing with the stages of the pest during lean periods in the field could check the pest from attaining a severe infestation level. Monitoring the infested field during successive years is the most important step for regulating further releases and for reducing the cost of parasitoid release. Conservation of promising predators (anthocorids, chrysopids, coccinellids and ants) helps a long way in natural suppression of the pest, and hence, spraying of palms with chemical pesticides has always been harmful to the natural enemies. Palmyrah can serve as an alternate host for the conservation of promising natural enemies of *O. arenosella*.

12.4 Sap Feeders

12.4.1 Coconut Eriophyid Mite **Aceria guerreronis** *Keifer (Acarina: Eriophyidae)*

12.4.1.1 Distribution

Coconut eriophyid mite, *Aceria guerreronis* Keifer (Eriophyidae: Acarina), is the most destructive pest among the various species of eriophyid mites affecting coconut palm in 30 countries of Tropical America, Africa and Asia (Mariau 1969). In India, coconut eriophyid mite was first reported from Amballur Panchayat in Ernakulam district of Kerala during 1998 (Sathiamma et al. 1998). Within a short span of time, the mite had spread rapidly to all major coconut-growing regions of the country, and currently its incidence is seen in the entire coconut-growing states of west and east coasts of India and north-east part of India (Nair et al. 2000a; Ramaraju et al. 2000; Mallik et al. 2003; Khan et al. 2003). The occurrence of the pest was also reported from Lakshadweep Islands (Mullakoya 2003). The history of the occurrence of *A. guerreronis* on coconut starts with the first report from the Guerrero State, Mexico by Keifer in 1965. In the same year, it was reported from Rio de Janeiro, Brazil (Ortega et al. 1967). It was widely noticed in several countries from South America and neighbouring Caribbean Islands by 1968. During the 1970s and early 1980s, severe damage of the pest was reported from Central America and West African countries. Tanzania witnessed an outbreak of the pest during 1980. In Sri Lanka, the pest occurrence almost coincided with that of India when the pest was recorded in the later part of 1997 at Kalpitiya Peninsula in the north-west province (Fernando et al. 2000). The mite has never been reported in the presumed region of coconut origin, namely, between the remaining of Southeast Asia and Papua New Guinea (Chan and Elevitch 2006). The mite might have moved from its original host to coconut after it became extensively cultivated in the Americas or Africa, continents where the mite was first found (Moore and Howard 1996).

12.4.1.2 Hosts

A. guerreronis was primarily recorded on coconut. It was also reported from cocosoid palm, *Lytocaryum weddellianum* (H. Wendl.), in Brazil (Flechtmann 1989); queen palm, *Syagrus romanzoffiana* (Cham.) Glassm., in southern California, USA (Ansaloni and Perring 2002); and palmyrah palm (*Borassus flabellifer*) in India (Ramaraju and Rabindra 2002). In cocosoid and queen palm, it was observed on nursery seedlings.

12.4.1.3 Bionomics and Nature of Damage

Coconut mite is a microscopic creamy white, vermiform organism measuring 200–250 microns in length and 36–52 microns in breadth. The body is elongated, cylindrical and finely ringed and bears two pairs of legs at the anterior end (Keifer 1965). Mites attain sexual maturity within a week's time and start laying eggs. An adult mite lays about 100–150 eggs. The eggs hatch into protonymphs and deutronymphs and finally to adults. The total life cycle is completed in 7–10 days.

In coconut, mites infest the developing young buttons after pollination and are seen in the floral bracts (tepals) and the soft meristematic portions beneath the perianth. Entry of the mite into the developing nuts takes place during the early phase of the development immediately after fertilization. Very young fruits are almost entirely covered by the perianth (Fig. 12.7), which is tightly adherent to the fruit surface, giving maximal protection against mite. However, as the fruits grow, the space underneath the bracts increases, in many cases allowing the mite to first have access to the protected tissues when fruits are about a month old (Moore and Howard 1996). The mites, thus gaining entry into the nuts, multiply and form active colonies containing various stages of development, viz. eggs, nymphs and adults. Usually in a developing nut, the coconut mite colonies are seen as two or three congregations on the meristematic regions of the buttons below the perianth.

Fig. 12.7 Symptom of coconut eriophyid mite infestation. (Photo: Josephrajkumar)

Mite could be found on a small proportion of nuts indicative of its egg laying a few days earlier, and that the level of infestation increased progressively afterwards. Thus, it seems that infested young buttons could also be aborted, reducing the number of infested buttons on the palms to low levels, possibly turning their detection difficult. Mite density was found to be higher in 3- to 7-month-old nuts after fertilization which thereafter gets reduced due to buildup of natural enemies (Moore and Alexander 1987; Varadarajan and David 2002).

Under favourable conditions, the high reproductive potential and shorter life cycle of mite result in the enormous multiplication of the colonies. When colony size becomes substantially increased, mite comes out of the interspaces between the tepals of the developing nut for dispersal. The dispersal of the pest takes place mainly through wind. Honeybees and other insects visiting inflorescence of coconut also act as agents for dispersal. The mite infestation symptoms are observed approximately 1 month after the initial colonization of the mite inside the fertilized buttons. Appearance of elongated white streaks below the perianth is the first external visual symptom on young buttons. In many cases, a yellow halo develops around the perianth. Within a few days, this halo develops into yellow triangular patch pointing towards the distal end of the button. This can be clearly seen in 2- to 3-month-old buttons. In a short time, the yellow patch turns into brown and shows necrotic patches on the periphery of the perianth (Moore and Howard 1996; Haq 2001; Nair 2002). As the nut grows, the injuries form warts and longitudinal fissures on the nut surface. In severe infestation, the husk develops cracks, cuts and gummosis. Shedding of buttons and young nuts and malformation of nuts as a result of retarded growth are the other indications associated with severe attack of the pest (Rajan et al. 2009).

12.4.1.4 Population Dynamics

High mite population is related to high temperature, low humidity and diminished level of precipitation (Mariau 1969; Moore et al. 1989; Nair 2002; Fernando and Aratchige 2010). In India, the pest activity has been observed throughout the year with the population peak during the summer months. Studies undertaken in Kerala coast (India) revealed that a period of high temperature with intermittent rains causing high humidity favoured higher multiplication and rapid spread of the mite (Nair et al. 2003). Investigations on population dynamics in Tamil Nadu, India, revealed that maximum population existed during November and May. Mathew et al. (2000) observed monthly variations in total population of mite with a peak in February to March and a sharp decline in subsequent rainy months indicating a negative relationship between rainfall and mite population. Perhaps the cryptic habitat of mite under the perianth may protect them from direct external abiotic stresses.

12.4.1.5 Crop Loss

Mite infestations cause extensive premature fruit drop (Nair 2002; Wickramananda et al. 2007), significant reduction in coconut fibre length and tensile strength (Naseema Beevi et al. 2003), as well as a reduction in husk availability for the coir industry (Wickramananda et al. 2007). Yield loss at various levels has been reported worldwide as a result of infestation by the pest. In general, pest incidence and extent of loss are comparatively high during the initial few years of pest occurrence in a particular locality. Yield loss depends on the cultivar, health and general maintenance of the crop as well as intensity of infestation. Feeding by a few mites causes only cosmetic damage to the husk without affecting the quality and quantity of copra and coconut water. In India during 1998, the pest outbreak was reported where 70% of nuts were affected with malformation and reduction in nut size (Nair 2002). But observations recorded during subsequent years revealed overall reduction in incidence and intensity of pest in areas of its initial occurrence (Nair et al. 2004). In Kerala, though pest damage has been reported initially ranging from 50% to 70%, later surveys carried out during 2000 have shown significant reduction in crop loss indicating an average loss of 30.94% in terms of copra and 41.74% in husk production mainly due to buildup of natural enemies (Muralidharan et al. 2001).

Similar studies undertaken in Tamil Nadu, India, during 2000 revealed an average loss of copra yield to the tune of 27.5% (Ramaraju et al. 2000). A reduction in copra yield ranging from 18% to 42% was observed in Karnataka, India, when severe infestation symptoms were seen on more than 50% of surface area of infested nuts (Mallik et al. 2003). Mite damage caused significant reduction in quality of fibres in terms of fibre length and tensile strength. Studies undertaken at Kerala Agricultural University during 2003 revealed that fibres from moderately to severely infested nuts suffered 26% to 53% reduction in length (Naseema Beevi et al. 2003). Surveys carried out by ICAR-CPCRI in Kerala, India, during 2004 registered lower levels of pest incidence with comparatively less intensity of infestation. The loss in terms of copra in southern districts of Kerala ranged from 8% to 12% compared to an average loss of 25% in initial years (Rajan et al. 2007).

12.4.1.6 Integrated Pest Management

Chemicals Over five dozen systemic and contact insecticides have been evaluated world over and recommended from time to time for management of coconut mite. In India also, a wide spectrum of pesticides have been tried by various research agencies including both central institutes and state agricultural universities (Nair et al. 2000b; Ramaraju et al. 2000; Saradamma et al. 2000; Mallik et al. 2003). Though these pesticides were effective in the field when given as spray or root feeding or stem injection, none of the chemicals has been recommended for larger adoption due to environmental reasons. The massive crown of the palm, large area to be covered in a short spell of time, need for repeated application, residual toxicity of pesticides, labour-intensive mode of application, etc. were other factors which were unfavourable for the wider use of chemical pesticides.

Currently, botanical pesticides, viz. neem-based biopesticides, are recommended for management of the pest in the field. Spraying of neem oil-garlic soap mixture at 2% or commercial botanical pesticides containing azadirachtin 10,000 ppm at 0.004% or root feeding with neem formulations containing azadirachtin 50,000 ppm (7.5 ml) or azadirachtin 10,000 ppm (10 ml) mixed with equal volume of water is recommended for mite management (Nair et al. 2000b, 2003; Saradamma et al. 2000; Mallik et al. 2003; Rajan et al. 2009).

Biological Control Use of predators and pathogens was not attempted in the initial phase of pest outbreak. More emphasis is being given to bioagents for long-term management of the pest. Among the biocontrol agents, predators and pathogens constitute the major groups of natural enemies. So far no parasitoid has been reported on *A. guerreronis*.

Predators Classical biological control is considered as an appropriate approach to provide a sustainable solution to the mite problem as the pest is invasive in nature. Careful import and introduction of natural enemies from the centre of origin of the pest into the new region is very crucial. In this context, efficient natural enemies of mite should be prospected in the tropical areas in the Americas, considered to be its possible area of origin (Navia et al. 2005).

In India, many predatory mites including *Amblyseius largoensis* (Muma), *Neoseiulus paspalivorus* De Leon and *Bdella distincta* Baker and Balogh were reported as potential predators of the mite (Ramaraju et al. 2000; Haq 2001; Nair et al. 2005). *N. paspalivorus* and *N. baraki* are the most abundant predators on nuts attached to the palms, melicharids and blattisociids are predominant on fallen coconuts, whereas *A. largoensis* is predominant on leaves (Lawson-Balagbo et al. 2008). In Sri Lanka, *N. baraki* was found predominant than *N. paspalivorus* (Fernando and Aratchige 2010). Though interpopulation crosses showed complete reproductive isolation between *N. paspalivorus* and *N. baraki*, molecular diagnosis indicated the existence of cryptic species (Negloh et al. 2008). Two successful methods, viz. tray-type arena and sachet-type method, have been developed in Sri Lanka to mass produce *N. baraki*, and the augmentative field release of which reduced mite incidence (Fernando et al. 2010). Occurrence of flattened idiosoma and short legs would allow *N. paspalivorus* and *N. baraki* enter into the microhabitat of eriophyid mite. It was also observed that *N. paspalivorus* usually enters the fruit about a month after mite entry, leading to highly diverging population curves of both species (Negloh et al. 2008).

The predatory mite population was registering an increasing trend of incidence and better establishment in nature over the years in India. From an initial occurrence recorded in 37.1% samples, predator population increased to 62.3% and 80% in 2001 and 2011, respectively. The activity of the predators was high during June to December and frequently noticed in 4- to 6-month-old nuts. The predatory mites are larger in size compared to the coconut mite, and hence they gain entry only later into the nuts. This is one of the limiting factors for the wider use of the predators. However, conservation of the predatory fauna in the ecosystem is beneficial to regulate the coconut mite in nature (Nair et al. 2005; Rajan et al. 2009).

Pathogens Beevi et al. (1999) reported *Hirsutella thompsonii* var. *synnematosa* Samson, McCoy and OoDonnell, infecting eriophyid mite in India. Cabrera (2002) reported two fungi, *H. thompsonii* Fisher and *Hirsutella nodulosa* Petch, infecting mite. Painstaking efforts by a multidisciplinary team in search of potential entomopathogen infecting mite encountered seven isolates of actinomycetes, four yeast isolates, three fungal isolates and two bacterial isolates from mite-infested nuts during the initial years of mite invasion. Gopal et al. (2002) established moderate pathogenicity against mite in the following eight microbial isolates *Fusarium moniliforme* [*Gibberella fujikuroi*], *Aspergillus niger*, *Penicillium* sp., *Aspergillus flavus*, *Scopulariopsis brevicaulis*, *Cladophialophora* sp., *Pseudomonas* sp., *Bacillus* sp., *S. brevicaulis* and *Cladophialophora* sp. Notwithstanding the higher mite incidence during the initial years of emergence (1999–2000), the percentage incidence of mite diminished in subsequent years (2010–2012) with the population buildup of natural enemies especially the predatory mites (*Neoseiulus baraki*) as well as the acaropathogen, *Hirsutella thompsonii* Fisher, in the system.

Searching for natural enemies, ICAR-CPCRI could collect more than 40 isolates of the acaropathogenic fungus, *Hirsutella thompsonii*, from all over the country which are being maintained at the institute. Based on the bio-efficacy studies, one virulent isolate collected from Kayamkulam (Kerala) was molecularly characterized confirming species identity. Talc preparation of this *H. thompsonii* at 20 g l^{-1} of water palm^{-1} containing 1.6×10^8 cfu with a frequency of three sprayings each year resulted in 63–81% reduction in mite incidence. It was found effective in many locations, though seasonal variation in efficacy existed. Coconut water was found as an ideal medium for mass production of *H. thompsonii*, as evidenced by comparable growth rate (1.91 cm in 20 days), spore production (12.9×10^4 cm^{-3}) and yield of dry mycelium mat (1.017 g 100 ml^{-1}) to that of standard fungal growth media (Chandrika Mohan et al. 2016a). Variability of microclimatic conditions, particularly in relative humidity among sites, and virulence of isolates may be likely explanations, which need to be looked into carefully before considering the application of *H. thompsonii*.

Palm Health Management Damage by eriophyid mite generally increased with increasing levels of nitrogen in coconut leaves, and it was suggested that higher levels of potassium could result in less damage by the mite (Moore et al. 1991). The use of organic fertilizers and potassium was reported to result in reduced mite damage in India (Muthiah et al. 2001).

A decreasing trend in mite incidence and intensity was observed in gardens where balanced NPK application and recycling of organic matter were practised. A unified recommendation was therefore formulated with IPM and INM components for adoption in all coconut-growing tracts during 2003. IPM strategies involved phytosanitary measures in coconut garden including crown cleaning, burning of fallen mite-infested nuts and spraying azadirachtin 0.004% on affected younger bunches thrice a year during December to January, April to June and September to October. Wherever spraying is difficult for adoption, root feeding with azadirachtin 5% (7.5 ml + 7.5 ml) or azadirachtin 1% (10 ml + 10 ml) formulation thrice as in the case of spraying was recommended. In synergy with IPM package, adoption of recommended package of practices was also recommended for effective recovery from mite infestation.

Varietal Susceptibility The tepal traits, colour, shape and size of the nut influence the degree of damage. Among these, shape of the nut (round shape) and tepal traits (tight perianth) are important attributes for mite tolerance. A coconut variety exhibiting resistance to eriophyid mite is not reported from any country. However, varieties like Malayan Yellow Dwarf (MYD), Malayan Red Dwarf, Rennal Tall, Cameroon Red Dwarf, Equatorial Green Dwarf and Hybrid [MYD × West African Tall (WAT)] were reported to show varying degrees of tolerance to mite attack in different countries of the world (Rethinam 2003). In India, work done at ICAR-CPCRI revealed that Chowghat Orange Dwarf (COD) variety shows maximum tolerance to mite infestation in the field. Malayan Green Dwarf (MGD), Laccadive Micro and Spicata also recorded comparatively lower mite incidence. West Coast Tall (WCT) and Laccadive Tall (LCT) recorded maximum incidence in the field. WCT with green colour and oblong nuts recorded higher level of mite incidence as compared to WCT with reddish bronze colour and round nuts. Among the hybrids, DxT with COD as mother parent exhibited high level of tolerance compared to Hybrids with Chowghat Green Dwarf (CGD) as mother parent (Nair et al. 2000b). Ramaraju et al. (2000) reported Kenthali variety to have lower surface damage by mite, while Tiptur Tall is the most susceptible variety. In 2015, a high-yielding, tall selection recorded with lesser mite infestation at field level was selected at ICAR-CPCRI from Kulasekharam coconut population, christened as Kalpa Haritha and released for cultivation (Josephrajkumar et al. 2016b). For details, please refer Chap. 5.

Success Story IPM technologies developed by ICAR-CPCRI involving 2% neem oil-garlic emulsion spray, root feeding of azadirachtin 10000 ppm at 10 ml + 10 ml water and soil and palm health management practices reduced pest incidence to the tune of 71.4%. From an initial pest incidence of 58.6% observed in Kerala, Tamil Nadu, Andhra Pradesh and Karnataka (India), the pest incidence was reduced to 16.3% in a period of 2 years indicating the success of the technology at national level. Natural buildup of predatory mites as well as acaropathogenic fungus, *H. thompsonii*, could sustain in the field.

12.5 Subterranean Pests

12.5.1 Coconut White Grub Leucopholis coneophora *Burm. (Coleoptera: Scarabaeidae)*

12.5.1.1 Nature of Damage and Species Complex

White grub, *Leucopholis coneophora* Burm, is a univoltine pest of coconut and intercrops grown in pockets of sandy loam soils in southern parts of peninsular India. It was first reported as a pest of coconut by Nirula et al. (1952). It damages seedlings and adult palms by feeding on roots, boring the bole and collar regions, and severe infestation leads to death of the seedlings. In adult palms, they feed on roots impairing the conduction of water and nutrients and thus lead to yellowing of fronds, gradual shedding and complete yield loss. Survey conducted in Kerala and parts of Karnataka, India, indicated the predominance of *L. coneophora* along the coastal belt, where coconut-based cropping system is practised. It has an annual life cycle and prefers loose sandy soil as noticed by Nirula et al. (1952). Kumar (1997) described it as *L. coneophora* – coastal strain that is occurring at an altitude up to 200 m above MSL. Another species of *Leucopholis* which is morphologically very much similar to *L. coneophora* dominating in coconut gardens of Dakshina Kannada district in Karnataka, India, was described and identified as *Leucopholis burmeisteri* Brenske (Nair and Daniel 1982; Veeresh et al. 1982). According to Kumar (1997), the identified morphological characters by Veeresh et al. (1982) between *L. coneophora* and *L. burmeisteri* were not strong enough to permit the delineation of the two populations up to specific status. Though they exhibited distinct differences in biology, the two populations may be two different etho-species which are difficult to delineate morphologically and can be considered to be two geographical clines. Kumar (1997) designated these two species as *L. coneophora* – coastal strain which occurs at altitude up to 200 m above MSL – and *L. coneophora*, hill strain which occurs at altitude >200 m above MSL. Another species of palm white grub, *L. lepidophora*, is observed to be infesting palms in Western Ghats. *L. lepidophora* larvae and adults are morphologically and biologically distinct from *L. coneophora*. These grubs prefer clayey loam soil (Veeresh et al. 1982; Kumar 1997). Study of phylogenic relation by partial amplification of 16s rRNA and *COI* gene of *L. burmeisteri*, *L. coneophora* and *L. lepidophora* (collected from Dharmasthala, Kasaragod and Sringeri, India, respectively) revealed 98, 83 and 89% similarity, respectively, with *L. burmeisteri sulyareca* isolate, and high resolution melt (HRM) analysis revealed the existence of single nucleotide polymorphism among the three species.

12.5.1.2 Host Range

Leucopholis coneophora is highly polyphagous in nature. Apart from coconut, it feeds on root of arecanut as well as rhizomatous and tuberous intercrops raised in palm garden, viz. banana, colocasia, cassava, elephant foot yam, greater and lesser yams, sweet potato, fodder grasses, etc. It is reported to be feeding on roots of rubber and cocoa also.

12.5.1.3 Bionomics

L. coneophora has annual life cycle and adult emergence coinciding with the setting of south-west monsoon. Emergence occurs daily in the evening hours when luminance fall below 124.37 ± 75.5 lx (around 6.35 pm IST in June) and 1.2 ± 0.4 lx (around 7.10 pm IST), and active swarming is sustained for 3 weeks. On emergence, beetles feed on leaves of weeds, mango, cashew, ficus, etc. Females lay the eggs in interspaces in soil. The eggs have an incubation period of 23 days. Larva is pestiferous and passes through three instars which is prolonged for 260–270 days. First-instar larvae feed on organic matter and roots of grass and are seen at depths of 15–20 cm. They are observed during second half of May to beginning of October. Second-instar grubs are largely distributed at depths of 15–45 cm which could be observed from the first half of July to the first half of November. Late second- and third-instar larvae move towards the root zone and start feeding on palm roots. Third-instar grubs were seen from the first half of the October to the end of July of the succeeding year. With the movement of moisture in soil, larvae move deeper and deeper and subsequently pupate during summer (Abraham 1983). During the next monsoon season aestivating pupae emerge out. During 1976–1978, prolonged adult activity period of 60 days was recorded. Adult emergence initiated during first half of March continued at low level up to second half of May or till early part of June. Scanty emergence continued up to August and September (Abraham 1993). But, more recently a narrow window of adult activity that extended for a maximum period of 3 weeks was noticed in ethological study of *L. coneophora* during 2011–2013 (Prathibha et al. 2013). There has been a huge shift in the emergence pattern of *L. coneophora*. Climate change pertaining to rainfall pattern, distribution and soil temperature could be the major reason for this. A hike in soil temperature (an average increase of 0.22 °C in daily soil temperature from March to September) was noticed during 2011–2013 than those temperature regimes noticed in 1977 and 1978.

12.5.1.4 Integrated Pest Management

An IPM strategy comprising of mechanical, chemical and biological methods is recommended to effectively manage white grubs.

Mechanical: Handpicking and Destruction of Beetle Mechanical capture and destruction of cockchafers between 6.35 pm and 7.15 pm for 2–3 weeks commencing from the first day of monsoon is advisable as a mechanical tool in IPM (Abraham 1983; Prathibha et al. 2013; Prathibha 2015). As the peak swarming period is short and beetle congregate during swarming, this method can be well practised. It is found that capture of beetles by handpicking is significantly higher than light trapping.

Biological An array of natural enemies was reported on *L. coneophora*. A solitary ecto-larval parasitoid, *Campsomeriella collaris* Fab. (Hymenoptera: Scoliidae), and parasitism by *Prosena* spp. nr *siberita* (Tachinidae: Diptera) as well as a solitary endo-larval parasitoid were reported on *L. coneophora* grub for the first time from organically managed coconut garden. Entomopathogenic bacterium *Serratia entomophila* caused 'amber disease' to *L. coneophora* grubs. White muscardine fungus *Beauveria brongniartii* and green muscardine fungus *Metarhizium* spp. were obtained from infected *L. coneophora*. Epizootic due to caterpillar fungus *Cordyceps* spp. was noticed on third-instar *L. coneophora*. Two species of entomopathogenic nematodes *Steinernema carpocapsae* and *Heterorhabditis indica* are being used in the management of palms against root grubs. In coconut ecosystem, drenching aqua suspension of EPNs *Steinernema carpocapsae* in the interspaces (5–10 cm depth) at 1.5 billion IJ ha^{-1} was found effective. Soil application of EPN should be continued based on the white grub population.

Chemical Control Use of chemical insecticide is a vital component in IPM of root grub, and it is successful when applied in the right stage and season. During the early 1950s, organo chlorine compounds as dust formulations were commonly used for the management of root grubs. Application of 5% chlordane at 28 lb acre^{-1} gave good control of *L. coneophora* grubs in coconut garden (Nirula and Menon 1957; Valsala 1958). Similarly, application of 10% HCH at 56 lb acre^{-1} once a year after south-west monsoon was recommended against white grubs in coconut which was superior to DDT dusting (Nirula 1958). During the 1970s chlorinated hydrocarbons were replaced with organophosphates (OP) and carbamates for use in management of root grubs. Granules such as carbaryl, carbofuran, phorate, quinalphos and thiodemeton at 4, 6 and 8 kg a.i. ha^{-1} evinced 36% reduction in *L. coneophora* grub population (Abraham 1979). In the 1980s, use of emulsifiable concentrate (EC) formulations of chlorinated hydrocarbons, (chlordane, aldrin, dieldrin, heptachlor, etc.) and OP compounds like chlorpyrifos and quinalphos became popular. Drenching the root zone with chlorpyrifos (0.04%) is recommended for the management. In the early 2000s, soil application of neonicotinoid insecticide imidacloprid at 120 g a.i. ha^{-1} or fourth-generation synthetic pyrethroid bifenthrin at 2 kg a.i. ha^{-1} was found effective in the management of the palm white grubs.

A refined IPM strategy was formulated for the effective management of the pest. The various strategies include:

- Handpicking and destruction of adult beetles during peak emergence
- Blanket application of bifenthrin at 2 kg a.i. ha^{-1} (Talstar 10 EC at 20 l ha^{-1} in 500 l of water) when first-instar stage of grubs dominate in the field

- Drenching aqua suspension of EPNs *Steinernema carpocapsae* in the interspaces (5–10 cm depth) at 1.5 billion IJ ha^{-1} during September to October as well as during November to December
- Second round need-based root zone application of chlorpyrifos 20 EC at 7 ml palm^{-1} after 45 days of first round insecticide application
- Repeated ploughing to expose the grubs to predators/digging and removal of grubs during October to December.

12.6 Mammalian Pests

*12.6.1 Rat (*Rattus rattus*)*

12.6.1.1 Distribution

In coconut plantations, eight different species of rodents were observed to coexist (Advani 1984; Advani 1985). Among them, *Rattus rattus wroughtoni* was the most predominant one (45%) followed by the field mouse *Mus booduga* (31%). Other rodents found in association with these mammals were the tree mouse, *Vandeleuria oleracea* (12%); the Western Ghats squirrel, *Funambulus tristriatus* (7%); *R.r. rufescens* (4%); and the Indian gerbil, *Tatera indica* (1%). The burrows of the lesser bandicoot *Bandicota bengalensis* and the larger bandicoot *Bandicota indica* were also found in certain gardens. *R.r. wroughtoni* lived mostly on the tree canopy, whereas *M. booduga* remained on the ground, thus minimizing competition for food and shelter.

Rat (*Rattus rattus*) is the major and threatening mammalian pest of coconut in the island ecosystem both in Lakshadweep and Bay Islands. The damage intensity varied from 14.3% during 1988 to 20.4% during 1990 in the mainland. Advani (1984) has reported that the damage intensity to coconut was more in coconut-cocoa mixed cropping systems (28.5%) than in coconut monocrop system (21%). In Lakshadweep Islands, nut loss as high as 50% was recorded. Detailed studies on population structure; movement pattern; breeding behaviour including breeding season, ovulation rate and litter size; post-natal development; juvenile emergence; and adult persistence were studied by Advani (1985).

Colonies of rats are found on the crowns of the coconut palm feeding on nut. In closely planted coconut gardens, rats jump from tree to tree. All palms are not invaded by the rats perhaps selected palms that yield sweet nut water and pulp are highly preferred. All stages of the nuts were found to be fed by the rats in Minicoy Island making a typical circular hole by gnawing and feed on the inner contents. Gnawing sound of rats is quite audible during dusk, and all islanders are well familiarized to the sound. Under severe conditions, even the emerging spathes are very badly eaten by the rats in the island. Rats are also habituated to make breeding nests using leaflets on the crown of the palms.

Some of the major reasons attributed for the increased rat damage in the island are higher density of coconut palms; inadequate crown cleaning and delayed harvest of nuts; heaping fallen fronds and husks in the farm; absence of predators like snakes, owls, etc. in the island; and improper care provided by the farmers.

The bandicoot rat, popularly known as Malabar rat or pig rat, causes serious damage to juvenile coconut palms (1–2 years old). It eats the growing stem resulting in the complete collapse of the young palm. Krishnakumar et al. (2014) reported that Gangabondam was highly preferred by *R. rattus* followed by Laccadive Orange Dwarf, Laccadive Green Dwarf and Laccadive Yellow Dwarf. Varieties/hybrids that are highly preferred by *R. rattus* are, therefore, likely to possess sweet nut water and pulp. Flying fox, robber crabs and pigs (Andaman Islands) were also reported as mammalian pests on coconut (Menon and Pandalai 1960).

12.6.1.2 Management

Nirula (1954) suggested the use of poisonous bait, fumigation of rat burrows, trapping, erection of physical barriers, application of chemical repellents and encouragement of natural enemies for the management of rats.

Timely removal of weeds as part of orchard sanitation and regular crown cleaning operation would expose the rats to predators. Banding of coconut trees with GI sheet 25–30 cm wide at a height of 2 m above-ground level is effective in controlling arboreal rats if coconut palms are raised at recommended spacing. Trapping using live or death traps is the safest but labour-intensive method for controlling rodents (Bhat and Sujatha 1987). Bamboo traps are used for the control of burrowing rodents damaging seedlings.

Control methods by poison baiting with multiple- and single-dose anticoagulants were investigated by Bhat and Sujatha (1987). The damage of *R.r. wroughtoni* could be completely controlled by applying warfarin/fumarin wax blocks on the crown of coconut palms three times at an interval of 3 days at 105 g, 70 g and 35 g baits palm^{-1} on 30 palms ha^{-1}. Among the three promising single-dose anticoagulants, viz. brodifacoum, bromadiolone and flocoumafen, the first one was found to be more toxic than the other two. However, since only bromadiolone is registered in India, more detailed studies were conducted with that poison to control *R.r. wroughtoni* in coconut gardens. The rats did not exhibit any bait shyness when exposed to bromadiolone baits. In the field trial, one-time application of bromadiolone (0.005%) wax blocks on the crown of rat-infested coconut palm (30 palms ha^{-1}) reduced the damage by 79.6%. Application of poison baits twice at an interval of 12 days has completely controlled the damage.

Placement of bromadiolone cake (0.005%) (Roban®, two pieces of one cake palm^{-1}) on the crown of those rat-preferred palms was found to reduce the rat damage to a greater extent. ICAR-CPCRI has developed a rod device for easy placement of Bromadiolone cake on the palm top blockading the route map of rats and forcing for consumption (Krishnakumar et al. 2014). Placement of protection barriers such as tin sheets to prevent climbing of rats had limited success in the island condition. Traditional practices such as hanging a fertilizer bag on the petiole and banding the palms with polythene sheets could reduce rat damage in isolated palms in the main land.

12.7 Emerging Pests

Emerging pests are those pests that have newly appeared in the system or those that have existed but are rapidly increasing in incidence on a geographic range. In the climate change scenario, emerging pests need to be closely monitored to avoid gradient outbreaks. Reports on the incidence of a few insects on coconut plantations in different parts of India attaining the status of emerging pests are presented.

12.7.1 Coreid Bug **Paradasynus rostratus** *Dist. (Coreidae: Hemiptera)*

Paradasynus rostratus was reported as a serious emerging pest on coconut from Southern districts of Kerala, India, incidence ranging from 23.4% to 40.6%. The bug causes heavy crop loss by shedding of developing buttons and immature nuts ranging from 18.2% to 66.4% in endemic gardens. The characteristic symptoms include deep furrows, crinkles and gummosis on nut surface. A prominent spindle-like necrotic lesion could be observed inside the fallen buttons (Kurian et al. 1972). In combination with eriophyid mite, there is tremendous reduction in copra content (Mohan and Faizal 2004). *P. rostratus* was first reported from Kerala on coconut by Kurian et al. (1972).

In addition to coconut, the bugs attack other crops like cashew (tender nuts), guava (tender fruits), custard apple (tender fruits), cocoa (tender pods) and neem (young flushes). The pest is active in coconut gardens from June to February with peak population during October to December (Rajan and Nair 2005). An egg parasitoid, *Chrysochalcisea indica*, parasitizing egg mass; a reduviid predator, *Endochus inornatus*, predating on nymphal stages; and weaver ant, *Oecophylla smaragdina*, predating all stages of pest were recorded as natural enemies.

Nut infestation symptoms by coreid bug as well as eriophyid mite were characteristically distinguished by Chandrika Mohan and Nair (2000b). Physiological modulation of qualitative chemical parameters of coconut oil from coreid infested nuts was well documented (Mayilvaganan and Nair 2002). Visalakshy et al. (1987) reported carbaryl (0.1%) as an effective insecticide against coreid bug. Spraying of neem seed oil-garlic emulsion (2%) and profenophos (0.05%) was found effective for the management of coreid bug (Ambily et al. 2009).

12.7.2 *Slug Caterpillars*

12.7.2.1 *Conthyla rotunda* Hamp. (Limacodidae: Lepidoptera)

C. rotunda is a sporadic pest causing considerable damage to coconut palms. During severe outbreaks, caterpillars devour leaves and at times feed on spathe and nuts also. Defoliation causes extensive yield loss (Menon and Pandalai 1960). Though reported in 1916, Ayyar (1917) described its damage potential from Kochi, India. Occurrence of *C. rotunda* was confined to west coast of India, and its biology and management including natural enemies were studied by Nirula et al. (1954). On an average, the life cycle is completed in 52 days. *C. rotunda* was also reported on banana, wild arrowroot and tea bushes. During February 2010, outbreak of *C. rotunda* was reported from Kerala causing complete defoliation of the leaves resulting in drastic reduction in nut yield (Rajan et al. 2010a, b). Outbreak of a particular species corresponded to the geography-induced weather factors as well as the intrinsic biotic factors.

12.7.2.2 *Darna (Macroplectra) nararia* Moore (Limacodidae: Lepidoptera)

D. nararia was reported from South India and Sri Lanka (Fletcher 1914) and also from East and West Godavari districts of Andhra Pradesh, India (Nirula 1955a). It is also a pest on tea in Sri Lanka and *Pithecellobium dulce* in Tamil Nadu, India. In Eastern and Western Godavari districts of Andhra Pradesh, the outbreak of *D. nararia* was recorded during March to May, 2009 and the level of infestation ranged from 5% to 85%. Temperature and moisture are critical factors in the growth of herbivorous insects and their invertebrate predators, parasitoids and pathogens. Outbreaks can be of eruptive in nature driven by intrinsic population processes and trophic-level factors. It can also be gradient in nature as a consequence of changing environmental factors favouring population growth. High temperature (>39 °C) coupled with high relative humidity favoured emergence of *M. nararia* in higher population (Rajan et al. 2010a, b). Infested gardens showed a scorched/burnt appearance of the middle and outer whorl of leaves and the crop loss reached as high as 90–95% in severely affected gardens. Feeding damage was exacerbated by grey leaf blight fungus, *Pestalotiopsis palmarum*, which infect leaf tissue breached and damaged by early larval instars. This association has been reported from slug caterpillar species such as *Chalcocelis albiguttatus*, *Darna catenatus*, *D. trima*, *Parasa balitkae*, *Setora nitens* and *Thosea lutea* (Holloway et al. 1987; Howard et al. 2001). In the field, some caterpillars were found infected by entomopathogens. Light trapping is suggested as an effective monitoring tool and a feasible mechanical control strategy of the pest.

12.7.2.3 *Parasa lepida* (Cramer)

P. lepida is one of the slug caterpillar species, found in India, Southeast Asia including the Sunda Islands and the Philippines, China and Okinawa, Kyushu, Shikoku and Honshu of Japan (Hirashima 1989). It is widely prevalent in coconut gardens on the west coast of India, but severe infestation occurs sporadically. The biology of the pest was described by Menon and Pandalai (1960). Juvenile palms are invaded, and caterpillars with poisonous scoli (stinging spines) devour coconut leaflets leaving only the midrib. Besides coconut, this pest attacks castor, mango, banana, rose, pomegranate, palmyrah, camellia, poplar and willow. There is a risk of irritation and inflammation of the skin from inadvertent contact with the insect. Most insecticides evaluated were found effective. However, delivery of chemicals in tall palms poses environmental risk. A predatory caterpillar, *Phycita dentilinella* H., was recorded inside the cocoon of the pest destroying pupae (Ayyar 1940). Early stages of the caterpillars that are gregarious could be mechanically clipped along with the portion of leaf and destroyed. During 2007, a sex pheromone ((Z)-7,9-decadien-1-ol (Z7, 9-10:OH)) has been isolated from virgin females and attracting conspecific males in the field (Wakamura et al. 2007).

12.7.3 Whiteflies

Two species of whiteflies, viz. Arecanut whitefly *Aleurocanthus arecae* David (Aleyrodidae: Hemiptera) and spiralling whitefly *Aleurodicus dispersus* Russell (Aleyrodidae: Hemiptera), were recorded in mild to medium intensities in various tracts of Kerala, Tamil Nadu and Lakshadweep Islands of India. These soft-bodied insects were found in congregation on the undersurface of matured coconut leaflets. These whiteflies were suppressed in nature by the natural enemies preventing a pest outbreak.

12.7.3.1 Arecanut Whitefly *Aleurocanthus arecae* David (Aleyrodidae: Hemiptera)

A. arecae is noticed on young coconut palms of both tall and dwarf cultivars generally during April to May. Black envelope of sooty mould fungus is seen on upper surface of infested leaflets. Adult whiteflies have smoky grey wings, and ants are not commonly associated with the pest congregation. Pupae have blackish setae on the body (Chandrika Mohan et al. 2007).

12.7.3.2 Spiralling Whitefly *Aleurodicus dispersus* Russell (Aleyrodidae: Hemiptera)

As the name suggests, adults of *A. dispersus* have a typical spiralling fashion of egg laying and found in mild to moderate levels during March to May. It is a highly polyphagous pest infesting coconut leaflets and a wide array of crops in coconut plantations. In Minicoy (Lakshadweep Island, India), the spiralling whitefly nymphs were reported more on papaya, banana, cassava and castor and were found parasitized by the aphelinid parasitoids. Adults measure about 2 mm length with white wings (Ramani 2000; Josephrajkumar et al. 2010a).

12.7.3.3 Rugose Spiralling Whitefly *Aleurodicus rugioperculatus* (Aleyrodidae: Hemiptera)

Rugose spiralling whitefly, *Aleurodicus rugioperculatus* Martin (Fig. 12.8), is an invasive pest of coconut reported from Pollachi, Tamil Nadu and Palakkad, Kerala (India) during July to August 2016. The pest was initially presumed as *A. dispersus*, which, however, could not incite to the present level of damage on coconut when first appeared in 1995 (Prathapan 1996; Mani 2010). The extensive damage and specific confinement on coconut reinforced the occurrence of new *Aleurodicus* sp. (Chandrika Mohan et al. 2016b). The identity as *A. rugioperculatus* was subsequently confirmed by Shanas et al. (2016) and Selvaraj et al. (2017), based on puparial features. Occurrence of reticulated cuticle on dorsum, presence of compound pores in abdominal segments VII and VIII, presence of corrugation on the surface of operculum and acute shape of the apex of lingual were reported as unique features of *A. rugioperculatus*.

Distribution RSW adults can be distinguished by their large size and the presence of a pair of irregular light brown bands across the wings (Stocks and Hodges 2012). Rugose spiralling whitefly was first described by Martin in 2004 from samples collected in Belize on coconut palm leaves (Martin 2004) and subsequently in Florida from Miami-Dade County in 2009. The whitefly genus *Aleurodicus* Douglas encompasses 35 species, of which only the spiralling whitefly *Aleurodicus dispersus* Russel was so far known to occur in India (Martin 2008).

The pest, distributed in Central and North America, is limited to Belize, Mexico, Guatemala (Evans 2008) and the United States. In the continental United States, the first established population of RSW was reported from Florida in 2009, and since then, its distribution range has expanded considerably within the state. There have been reports of damage caused by this pest to ornamental plant hosts in at least 17 counties of Florida, with the maximum damage reported from Broward,

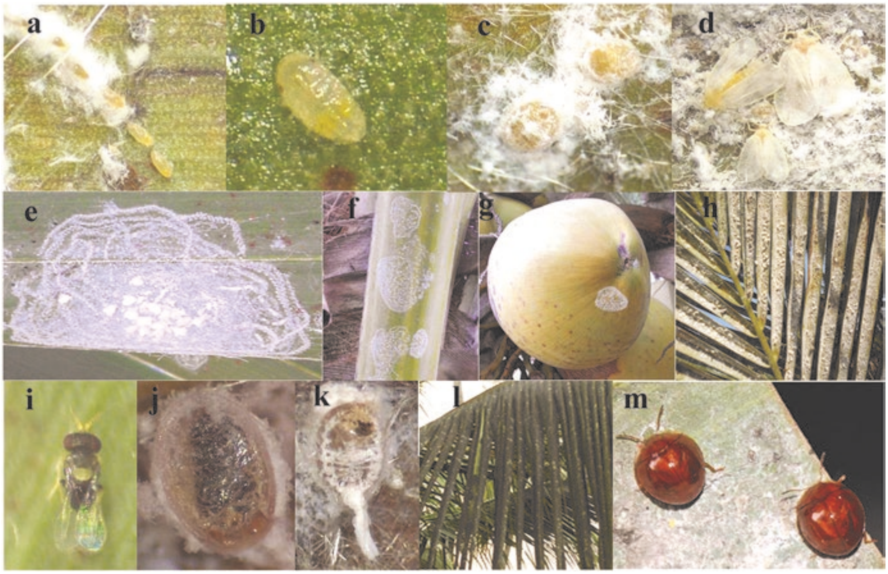

Fig. 12.8 Rugose spiralling whitefly. (**a**) Eggs of rugose spiralling whitefly (RSW). (**b**) Mobile crawler. (**c**) Nymphs. (**d**) Adult. (**e**) Damage on leaf. (**f**) Damage on petiole. (**g**) Damage on nut. (**h**) Leaf encrustation by RSW. (**i**) *Encarsia guadeloupae*. (**j**) Parasitized pupa, exit hole of the parasitoid. (**l**) Sooty mould laden leaf. (**m**) Sooty mould scavenger beetle, *Leiochrinus nilgirianus*. (Photo: Josephrajkumar)

Collier, Lee, Martin, Monroe, Miami-Dade, Palm Beach and St. Lucie counties. In India, in a period of 6 months, it could spread in limited pockets of Kerala (Palakkad, Malappuram, Thrissur, Kozhikode, Kannur, Ernakulam, Pathanamthitta, Alappuzha, Kollam and Thiruvananthapuram districts), Tamil Nadu (Pollachi) and isolated parts of Andhra Pradesh. Though the invasive pest, *A. rugioperculatus*, has been reported in different districts of Kerala, India, it has not caused any economic setback so far as it confined its feeding mostly on the older coconut leaves that has completed the bearing stage. Extensive desapping of whitefly would induce stress on the palms due to removal of water and nutrients, but neither colour change nor necrosis of leaves is reported. The economic loss is restricted mainly on the loss of photosynthetic efficiently due to the formation of sooty mould fungus (*Leptoxyphium* sp.).

Host Range Stocks and Hodges (2012) reported about 95 host plants of *A. rugioperculatus* in Florida, USA. Further, Francis et al. (2016) reported a broader host range of 118 species in 43 families. Shanas et al. (2016) reported a total of 17 plant species in 11 families from Kerala. In the recent survey, Chandrika Mohan et al. 2016b) observed at least ten alternate host plants (*Psidium guajava*, *Musa* sp., *Myristica fragrans*, *Colacasia* sp., *Garcinia* sp., *Annona muricata*, *Murraya koenigii*, *Spondias mombin*, *Mangifera indica* and *Artocarpus heterophyllus*) in coconut homesteads, but the pest is relatively more confined to coconut, and the reason for its selective preference indicates its host preference to coconut.

Natural Enemy Despite higher level of whitefly incidence in coconut, there is no absolute economic loss due to the pest, because *A. rugioperculatus* is confined mostly on the lower leaf whorls of coconut which had completed the nut production phase. During the observation made in November 2016 in Kerala, India, the pest population has come down quite significantly. Upon close examination, as high as 60% pupae of *A. rugioperculatus* was found parasitized by aphelind parasitoid, *Encarsia guadeloupae*, and many do have exit hole in situ in the field indicating the emergence of the parasitoid. *E. guadeloupae* is a tiny parasitoid of size <1.0 mm found effective in the bio-suppression of the whitefly under natural condition. On account of its miniature size, mass production strategies are not successful so far; however, reintroduction of parasitized pupae in the emerging zones of whitefly attack is feasible and quite practical.

Management

1. Application of 1% starch solution on leaflets to flake out the sooty moulds.
2. Installation of yellow sticky traps on the palm trunk to trap adult whiteflies.
3. Encourage buildup of parasitoids (*E. guadeloupae*) and reintroduce parasitized pupae to emerging zones of whitefly outbreak.
4. In severe case, spray neem oil 0.5%, and no insecticide is recommended.

12.7.4 Mealybugs

Fifty-seven species of pseudococcids have been recorded on palms. Half of the palmivorous species belong to the genera *Dysmicoccus*, *Planococcus*, *Pseudococcus* and *Rhizoecus*. Among the wide array of mealybug species, *Dysmicoccus* has the most palmivorous species (eight) including three species known only from palms. The most commonly reported mealybug pests of palms are highly polyphagous species, are distributed worldwide and are primarily known as pests of crops other than palms. Classical examples include *Dysmicoccus brevipes*, *Nipaecoccus nipae* and *Pseudococcus longispinus*. A few mealybug species, viz. *Dysmicoccus hambletoni*, *Dysmicoccus cocotis*, *Dysmicoccus finitimus*, *Neosimmondsia hirsuta*, *Palmicultor palmarum*, *Phenacoccus sakai*, *Planococcoides anaboranae*, *Pseudococcus portiludovici*, *Tylococcus malaccensis*, *Crinitococcus palmae* and *Cyperia angolica*, are almost restricted to palms (Nair 1983; Chandrika Mohan et al. 2016c).

In coconut, nine important species of mealybugs are reported from India, viz. *Palmicultor palmarum* Ehron., *Dysmicoccus cocotis* Maskell, *Pseudococcus longispinus* Targ., *Pseudococcus cryptus*, *Planococcus lilacinus*, *Pseudococcus microadonidam*, *Nipaecoccus nipae* Maskell, *Dysmicoccus finitimus* and *Rhizoecus* sp. In Guam, *Coccidohstrix insolita* was observed infesting coconut palm (Aubrey et al. 2014).

12.7.4.1 Species Diversity

P. palmarum infests young seedlings and juvenile palms on spear leaf. Red ants are normally associated with *P. palmarum*. *P. palmarum* was found mainly on coconut in Micronesia, Bangladesh, Hawaii and Bahamas (Williams 1981). In India, *Palmicultor* sp. took 22 days to complete its life cycle. Adult females and males survived for 18 and 3 days, respectively, and one female produced 37–89 offsprings (Jalaluddin and Mohanasundaram 1993). *Dysmicoccus finitimus* is found colonizing the spadix of coconut in southern India, Sri Lanka, Cocos Islands and peninsular Malaysia (Williams 1994). Infestation by *D. finitimus* was also recorded from the spathe of coconut palms from Kerala (CPCRI 2012). In India, *Dysmicoccus brevipes* was reported from the perianth of immature nuts in coconut (Radhakrishnan et al. 2003). *Rhizoecus* sp. infests roots of coconut palms in sandy areas. Infested seedlings turn yellowish and loose vigour (Nair et al. 1980). *P. microadonidam* and *P. lilacinus* are known to infest coconut in India (Mohandas and Remamony 1993). The occurrence of *N. nipae* was reported from West Bengal (Green, 1908). Re-emergence of the pest was reported in India after a time gap of 100 years. It was recorded on tender feeder roots of coconut seedling in Kayamkulam, Kerala, India. *N. nipae* was not located on any other arboreal parts of the palm (Josephrajkumar et al. 2012). The leaf mealybug, *Pseudococcus cryptus*, was found colonizing at moderate level on the leaves. Infested colonies were foraged by ants. *P. cryptus* was reported from Tamil Nadu, India (CPCRI 2012).

12.7.4.2 Management

Regular and systematic monitoring for early detection is very important for suppressing the pest. Collection and destruction of infested plant parts would reduce the pest load in the field. Conservation of natural enemies such as *Pullus* sp., *Scymnus* sp. (Coccinellidae), *Spalgis epius* (Lycaenidae), *Bergineus maindroni* (Mycetophazidae), *Dicrodiplosis* sp. (Cecidomyiidae) and *Homalotylus oculatus* (Encyrtidae) could exert natural pest reduction. Regular monitoring and spot application twice with dimethoate 0.05% at 20-day interval during summer were found effective in the management of the pest (Nair 1983).

12.7.5 Scale Insects

A total of seven species of scale insects were reported infesting coconut palms/ seedlings (Rajan et al. 2010a, b). These include four species of armoured scales and three species of soft scales. Armoured scales were recorded as emerging pests which include the coconut scale, *Aspidiotus destructor* Sign.; oriental scale, *Aonidiella orientalis* Newstead; mussel scale, *Lepidosaphes mcGregori* Banks; and needle scale, *Chionaspis* sp. The three species of soft scales recorded from coconut were wax scale, *Ceroplastes floridensis* Comstock; brown soft scale, *Coccus hesperidum* Linn.; and stellate scale, *Vinsonia stellifera* Westwood.

The coconut scale *A. destructor* was recorded from all states of South India, Lakshadweep Islands as well as Assam and West Bengal. Scale insects inhabit mainly on the undersurface of the leaves, and due to their infestations, the leaves turn yellow to brown. Vidyasagar (1989) elaborated symptomology of various scale insects infesting coconut. Kapadia (1984) reported five species of scale insects, viz. *Chrysomphalus aonidium* (Linn.), *Pseudaulacaspis cockerelli* (Cooley), *Aonidiella orientalis* (Newst.), *Hemiberlesia lataniae* (Sign.) and *Lepidosaphes* sp., infesting on nuts, leaf sheaths and leaflets of coconut. Jalaluddin and Mohanasundaram (1987) studied the biology of *A. destructor* and reported three sprays of 2.5% soap solution at weekly intervals induced complete mortality of *A. destructor* in the nursery. *A. orientalis* was also recorded from all major areas of South India and Lakshadweep Islands and are mostly confined to rachillae and nuts. The adult mussel scale feeds from undersurface of leaves and was mainly observed in Kerala and Minicoy Islands. White needle scale, *Chionaspis* sp., was mainly recorded from coconut seedlings in both Tamil Nadu and Kerala (India) (Josephrajkumar et al. 2010b).

Soft scales were seen as emerging pests in island conditions as well as in a few tracts of Kerala and Tamil Nadu, India. Wax scale has characteristic mound or projections on its body and usually seen singly on coconut leaflets. The brown soft scales are closely associated with black ants and infested leaves show sooty mould. Stellate scales are star-shaped and are seen in few numbers on coconut leaflets. Generally scales are bio-suppressed in nature by their natural enemies, and the main predators of this group include coccinellid beetles and cybocephalids. Aphelinid parasitoids also play a key role in suppression of scales along with predators (Josephrajkumar et al. 2010b).

12.7.6 Aphids

During 2010, the palm aphid, *Cerataphis brasiliensis* Hempel (Aphididae: Hemiptera), was noticed on unfurled spindle leaf of Malayan Green Dwarf variety of coconut seedlings at Kayamkulam, India. These aphids resemble whitefly pupae in many aspects especially the presence of fringe white waxy filaments circumscribing the body. Adult aphids have a mid-dorsal ridge and inconspicuous siphunculi. The aphid colony was found attended by two ant species, viz. *Solenopsis* sp. and *Oecophylla smaragdina* (Josephrajkumar et al. 2011b).

12.7.7 Ash Weevils

During 2010, a new species of Asian grey weevil, *Myllocerus undatus* (Curculionidae: Coleoptera), was recorded as an emerging pest of coconut seedlings at Kayamkulam and Karunagapally, Kerala, India. Mild to medium level of infestation damaging 5–10% leaf lamina of unsplit leaves with typical notching-like symptom along the leaf margins was noticed on majority of the coconut seedlings in these areas. The characteristic feature of this weevil is the presence of three-spined hind femur and is considered as an invasive pest from Sri Lanka (Josephrajkumar et al. 2011a). Coconut ash weevil, *Myllocerus curvicornis* Fab., was also noticed on coconut leaves of young palms especially on outer whorls in different tracts of Kerala (Ponnamma et al. 1982).

12.8 Palm Nematodes

Plant parasitic nematodes are obligate root parasites with well-developed protrusible stylet used for puncturing the plant tissues for food intake and release of the toxin. Among the plant parasitic nematodes reported, burrowing nematode (*Radopholus similis*), lesion nematode (*Pratylenchus coffeae*) and red ring nematode (*Rhadinaphelenchus cocophilus*) causing red ring disease and root-knot nematode (*Meloidogyne* spp.) infest intercrops grown in interspaces of coconut all over the world (Koshy 1986a, b). The characteristic symptoms of nematode infestation are formation of root galls, root rot, necrotic lesions, discolouration of roots, stubby root and root proliferation. Studies relating to the pathogenicity of nematode disease in coconut indicated that higher nematode population cause debilitation in growth and yield of adult palms. Palms with nematode infestation are more susceptible to other diseases caused by fungi and bacteria and further aggravate the disease condition. At seedling stage, higher nematode population causes severe root lesions and death of seedlings. In addition *Scuttellonem brachyurum*, *Rotylenchulus reniformis* and *Helichotylenchus elegans* were also recorded from coconut plantations in West Bengal (Rama and Dasgupta 2000). Soil examination from Kerala collected from coconut-growing locations yielded 29 genera of plant parasitic nematodes, viz. *Aphelenchus* (7%), *Aphelenchoides* (3%), *Atylenchus* (1%), *Caloosia* (6%), *Criconemoides* (11%), *Dolichodorus* (6%), *Ditylenchus* (9%), *Helicotylenchus* (50%), *Hemicriconemoides* (2%), *Hemicycilophora* (3%), *Hirshmanniella* (2%), *Hopololaimus* (25%), etc. (Koshy et al. 1980).

12.8.1 **Radopholus similis** ***(Cobb, 1893) Thorne, 1949***

12.8.1.1 Occurrence and Distribution

The burrowing nematode, *R. similis*, occurs in most tropical and subtropical areas of the world including Florida, Jamaica and Sri Lanka (Van Weerdt et al. 1959a, b; Ekanayake 1964; Latta 1966). In India, *R. similis* was reported from coconut palms in Kerala (Weischer 1967; Koshy et al. 1975). Surveys conducted in coconut plantations in South India recorded 24% incidence of *R. similis* in coconut which co-evolved with black pepper and certain cultivars of banana in the western hills of South India (Koshy 1986a).

12.8.1.2 Nature and Symptoms of Damage

Above-Ground Symptoms Burrowing nematode-infested coconut palms exhibit general decline symptoms which include stunting, yellowing, reduction in leaf number and size, delayed flowering, button shedding and reduced yield.

Below-Ground Symptoms Symptoms on roots are very specific. *R. similis* infestation produces small, elongated, orange-coloured lesions on tender creamy white roots. Consequent to nematode parasitization and multiplication, these lesions enlarge and coalesce to cause extensive rotting of roots. On merging of lesions, cracks develop on the epidermis of the semihard orange-coloured main roots. Lesions and rotting are confined to the tender portion of roots which are not conspicuous on the secondary and tertiary roots. Lesions are not usually seen on the old, hard, dark brown roots. Tender roots of heavily infested coconut seedlings become spongy in texture.

The nematode also attacks the plumule, leaf bases and haustoria of seedlings. The drastic reduction in the number and mass of tertiary feeder roots on parasitization by the nematode limits plant growth (Koshy and Sosamma 1987). Lesions are also not conspicuous on the secondary and tertiary roots since these are narrow and rot quickly upon infestation. In the early stage of infestation, roots develop separate cavities that later merge with each other consequent to feeding and multiplication of nematodes. Multiple cavities and their coalescence destroy the cortex to a great extent, but the stelar tube remains intact. Eggs and all immature stages of nematodes could be located in the cavities in longitudinal sections (Koshy and Sosamma 1982, 1987; Sosamma and Koshy 1991, 1998).

12.8.1.3 Diagnostic Features

Female Vermiform, migratory, endoparasitic, lip region rounded, strong well-developed stylet and oesophagus. Two outstretched ovaries, tail conoid to blunt, rounded terminus

Male Vermiform, migratory and not parasitic. Lip region sub-spheroid, offset, slender stylet, degenerated oesophagus, single testis, spicules paired with bursa extending two thirds length of the tail

Juveniles Vermiform, migratory and parasitic. Lip region rounded, well-developed stylet and oesophagus

12.8.1.4 Biotypes/Pathotypes

Two morphologically indistinguishable races of *R. similis* are known. One is the 'banana race' which parasitizes banana and not citrus and 'citrus race' which parasitizes both banana and citrus (Du Charme and Birchfield 1956). But, the citrus race has been elevated to species rank and named *Radopholus citrophilus* because of enhanced haploid chromosomes coupled with variation in protein profile and pheromone behaviour (Huettel et al. 1984). The coconut isolate of *R. similis* isolated from Kerala, India, has a haploid number of four chromosomes ($n = 4$) and does not infest any of the *Citrus* spp. and *Poncirus trifoliata* (Koshy and Sosamma 1977).

12.8.1.5 Alternate Hosts

Burrowing nematode has a wide host range, and among the 115 plant species tested, 48 are potential hosts which included several crops and weeds in coconut gardens (Koshy and Sosamma 1975; Sosamma and Koshy 1977, 1981). The common alternate hosts are arecanut, banana, black pepper, betel vine and ginger.

12.8.1.6 Survival and Dispersal

Burrowing nematode population survives under field conditions for 6 months in moist soil (27–36 °C) and 1 month in dry soil (29–39 °C), whereas it survives for 15 months in moist soil (25.5–28.5 °C) and 3 months in dry soil (27–31 °C) under greenhouse conditions. The nematode survives in root stumps of felled coconut palms up to 6 months (Sosamma and Koshy 1986). One-year-old coconut seedlings raised in such infested nurseries harbour large populations of the burrowing nematode within roots both internal and external to the husk. Transportation of infested seedlings disseminates nematodes to far-off places. Moreover, in the era of liberalized trade and tariff, plants such as *Anthurium* spp., *Calathea* spp., etc. could disseminate *R. similis* effectively (Koshy 1986a).

12.8.1.7 Nematode Management

Cultural The cultural practices existing in Kerala and Karnataka, India, such as application of oilcakes, farmyard manure and growing of sunhemp in the basins and interspaces and their incorporation as green manure may reduce nematode multiplication. In addition, growing of the crops such as cocoa that enrich the soil with sizeable quantum of shed foliage helps in the buildup of beneficial organisms and antagonistic microorganisms that may hinder nematode multiplication.

The root-knot- and burrowing nematode-susceptible crops such as ginger, turmeric, papaya, solanaceous vegetables and elephant foot yam may be avoided as intercrops, and if grown, planting sites may be changed every year. The practice of taking up vegetable cultivation at the same site for many years consecutively helps in the population buildup of root-knot nematodes. Preference may be given for growing nematode-resistant crops such as nutmeg, cinnamon, cloves, colocasia and tapioca. Maximum care should be taken to avoid crop combinations that are susceptible to the same nematode species. Sanitation methods such as opening pits when the weather is dry to expose the immature stages to sunshine and burning of trash in planting pits and avoiding water run-off from infested to uninfected pits are also advisable in managing nematode problem in coconut.

Mechanical Cut and remove all roots external to the husk of seedlings raised in the field before planting, and nematode-infested intercrops are to be destroyed.

Chemical Control Increased incidence of *R. similis* was noticed in coconut nurseries when banana was used as a shade crop. More than 50% of the seedlings raised in such nurseries failed to establish in the main field. Nematicide treatment was found very effective. With the phasing out of carbofuran and phorate, carbosulphan (0.05%) was found effective.

Biological Coconut seedlings raised in polybags filled with potting mixture enriched with bioagents such as *Paecilomyces lilacinus*, *Pasteuria penetrans* and mycorrhizae suppressed nematode population. A consortium of mycorrhizae consisting of multiple endophytes, i.e. *Acaulospora bireticulata*, *Glomus fasciculatum*, *G. macrocarpum*, *G. mosseae*, *G. versiforme*, *Sclerocystis rubiformis* and *Scutellospora nigra*, was found effective in improving the plant growth and reducing *R. similis* infestation on coconut seedlings (Sosamma 1994).

Host Plant Resistance Use tolerant or less susceptible cultivars or their hybrids in infested areas. Most of the coconut varieties were found susceptible to *R. similis* in India. The dwarf cultivars, viz. Kenthali and Klappawangi, recorded the least nematode multiplication and lesion indices. Similar reactions were noticed in hybrids such as Java Giant × Kulasekharan Dwarf Yellow, Kulasekharam Dwarf Yellow × Java Giant, Java Tall × Malayan Yellow Dwarf and San Ramon × Gangabondam (Sosamma et al. 1980, 1988; Sosamma 1984).

12.8.2 *Red Ring Disease:* Rhadinaphelenchus cocophilus *(Cobb 1919) Goodey 1960*

12.8.2.1 Occurrence and Distribution

Red ring disease of coconut caused by *R. cocophilus* and transmitted by the black palm weevil *R. palmarum* was reported from the West Indies (Trinidad, Tobago, Grenada and St Vincent) and Latin America (Venezuela, Guyana, Surinam, French Guyana, Colombia, Ecuador, Peru, Mexico, Brazil, Panama, Nicaragua, Costa Rica, Honduras, Belize and El Salvador) but is not known to occur in India as well as in Southeast Asia. The disease was first reported in Trinidad by Hart in 1905. Later, it was reported in Grenada (Nowell 1918). *R. cocophilus* was first described by Cobb (1919) as *Aphlenchus cocophilus*, and later Goodey (1960) designated it as *R. cocophilus*. This nematode is also associated with a little leaf disease of coconut and oil palm in Surinam (Van Hoff and Seinhorst 1962). In severely affected coconut gardens, up to 60% crop loss was recorded.

12.8.2.2 Nature and Symptoms of Damage

The most important characteristic symptom is the occurrence of internal lesions. In a cross section of the stem, lesions appear as orange- to brick red-coloured ring (2–4 cm wide). Young palms (2–10 years old) easily succumb to red ring disease. Chlorosis first appears at the tips of the oldest leaves and spreads towards their bases. The brown lower leaves may break across the petiole, or they become partly dislodged at the base and hang down. Nuts are shed prematurely. The crown often topples over in about 4–6 weeks after symptom development. However, the trunk remains standing in the field for several months until it decays.

12.8.2.3 Biology

Diagnostic Features

(a) Female – body very slender, offset head, prominent cephalic framework composed of strong sclerotized arches. Spear with strong basal knobs. Median bulb elongated. Vulva covered by flap of cuticle leading into curved vagina.
(b) Male – body slender. Offset head, prominent cephalic framework. Spear with strong basal knobs, elongated median bulb. The most important characteristic feature is the tail, which on death curves to about four-fifths of a circle. Spicules are slightly arcuate and have prominent rostrum. The tail bears a terminal bursal flap. Four pairs of ventrosubmedian papillae are present.
(c) Juveniles: Pre-adult juvenile has conical rounded head, not set off from the body. The tail is shorter than that of female with a short sharp terminal bearing mucron.

12.8.2.4 Alternate Hosts

Hosts of *R. cocophilus* are confined to the family Arecaceae where the nematode is known to infect over 17 species. Most palm species appear to be susceptible to inoculation by red ring nematode. The most economically important species with red ring disease susceptibility are coconut palm, the African oil palm and the date palm.

12.8.2.5 Nematode Management

There are no simple means of controlling red ring disease, and no effective measures are available as yet for control of the nematodes in living palms. Control is based on prevention rather than cure especially involving the destruction of infested palm material as well as trapping and killing of the weevil vectors before they spread the nematodes.

Cultural Since the nematode did not multiply in the insect nor survived for any appreciable time in the dead tree, the only known reservoir of inoculums was the diseased tree in which the vector palm weevils developed. Thus, the elimination of the diseased tree by burning or poisoning, as soon as red ring symptoms appeared, reduced significantly the available source of the pathogen and also controlled the population of the vectors.

Biological The vector weevil is found to be parasitized by several species of Rhabditidae or Heterorhabditidae throughout Latin America. Since the vector insects can be highly parasitized with the above nematodes, selective pressure can be introduced against the vectors. Such measures are being employed in Trinidad with a species of Rhabditidae (Griffith and Koshy 1989).

Chemical The leaf axils of diseased palms should be sprayed with 0.1% Lannate (Methomyl) for the suppression of weevil. Guard baskets made of 2 cm mesh wire are used to protect frequent outbreaks of the disease. These baskets are filled with fresh infected tissue and sprayed with 0.1% Lannate suspension. The palm weevils are attracted to the tissues in the basket. After 2 weeks, the tissues in the basket are burnt. One guard basket is used per 0.4 ha of palms.

12.8.3 Root-Knot Nematode: Meloidogyne incognita

Meloidogyne incognita infests intercrops in coconut system and not on the main crop. In ginger and turmeric, the root-knot nematode causes galling and rotting of roots and underground rhizomes. The nematode also causes severe injuries by way of gall formation in black pepper and vegetable crops.

12.8.3.1 Nematode Management

Control of root-knot nematode infestation in susceptible crops like black pepper, turmeric, ginger, various vegetables and fruit crops in coconut system could be managed by adopting integrated approaches such as crop rotation, selecting less susceptible crops, changing of planting site every year, fallowing and growing of antagonistic crops like marigold in alternate rows or in patches to reduce the nematode buildup in soil (Rajkumar et al. 2016). Regular application of biological agents such as *Trichoderma*, VAM and *Paecilomyces lilacinus* reduced the damaging effect of nematodes (Sosamma et al. 1990).

12.9 Potential Invasive Pests

Alien invasive species (AIS) is a non-native exotic pest which becomes established in natural or seminatural ecosystems or habitat and threatens native biological diversity. The spread of AIS is now recognized as one of the greatest threats to the ecological and economical well-being. Invasions by alien species imbalance native ecosystems and are likely to breed profusely in the absence of natural enemies in the new environment and cause upsets in biodiversity outcompeting native species.

The introduction of new pests into a locality is brought out in various ways such as (1) through a host as the carrier; (2) inert packing materials carrying the quiescent stages of the pest; (3) insect vectors, birds and air currents; and (4) deliberate, illegal introduction as bioweapons. Though the first two modes of distribution are curtailed by quarantine measures, the latter two are beyond the limitations of pest control by exclusion. This creates a need for biosecurity involving integrated approach that encompasses the policy and regulatory frameworks to analyse and manage the risks in the sectors of food safety and other environmental risks (Shetty et al. 2008).

Biosecurity covers the introduction of plant and animal pests and diseases, introduction of genetically modified organisms and their products and introduction and management of invasive alien species and genotypes. As such it is a holistic concept having a direct relevance to the sustainability of agriculture, food safety and protection of the environment including biodiversity. It is in this context that the likely advent of invasive insect pests like coconut leaf beetle (CLB), *Brontispa longissima* Gestro (Chrysomelidae: Coleoptera), and armoured scale insect, *Aspidiotus rigidus* Reyne (Diaspididae: Hemiptera), to India would be devastating and more likely an issue of biosecurity in our country.

12.9.1 Impending Biosecurity Risks

Coconut leaf beetle, *Brontispa longissima* Gestro, and the armoured scale insect, *Aspidiotus rigidus*, ravaging Maldives and the Philippines, respectively, have not been reported in India till 2016; however, there is an impending danger since it is in the doorsteps already (Rajan et al. 2012; Watson et al. 2014).

12.9.1.1 *Brontispa longissima*

The outbreak of the *B. longissima* in Myanmar and Maldives in recent years poses a great threat and concern to the nearby countries such as India, Sri Lanka and Bangladesh. It is feared that the pest will find its way from Maldives to Sri Lanka and southern parts of India to derail the economy of these important coconut-growing regions of the world. Since invasive pests fail to restrict along political/agroecological boundaries, these countries are ever in red alert zones (Rethinam and Singh 2004). Coconut leaf beetle (CLB) was originally described in 1885 from Aru Islands in Indonesia and from Papua New Guinea. Over a period of 124 years, it has widely spread in over 25 countries in Asia, Australia and Pacific Ocean Islands attacking a number of cultivated and wild ornamental palm species in addition to coconut palms. It is currently distributed in Australia, Pacific Ocean Islands, Malaysia, Singapore, Cambodia, Laos, Thailand, Vietnam, Maldives, the Philippines, Myanmar and China. In Solomon Islands, it is estimated that about 5% of CLB-infested palms die annually. In 1980, coconut palms grown in more than 10,000 ha area in seven provinces in Indonesia were attacked by this beetle. In Maldives, pest outbreaks occurred in several islands of South Attol causing extensive damage to coconut production both in inhabited and uninhabited islands. CLB had caused serious threat to the income generation from tourism industry as well as food security in countries like Maldives, Thailand and Vietnam (Rethinam and Singh 2004; Rajan et al. 2012).

Adult beetles (Fig. 12.9) measure 7.5–10.0 mm long and 1.5–2.0 mm wide, with a conspicuous orange to reddish pronotum. The anterior part of elytra is also orange to reddish in colour. Grubs and adult beetles inhabit the developing unopened still-folded heart leaves of coconut palm and feed on leaf tissues (Fig. 12.10).

The spread of *B. longissima* is mainly through the movement of infested seedlings. Since the flight range of the beetles is low, the natural spread is at a very slow pace. Shipments of ornamental palms from countries having the pest infestation have been the main source of spread within the Asia-Pacific region. Pest management is mainly effected by release of biocontrol agents. Two parasitoids of coconut leaf beetle, viz. *Tetrastichus brontispae* Ferriere (Hymenoptera: Eulophidae), a

Fig. 12.9 Adult beetle of *Brontispa longissima*

Fig. 12.10 Symptom of damage of *Brontispa longissima*

pupal parasitoid, and *Asecodes hisparum* Boucek (Hymenoptera: Eulophidae), a larval parasitoid, have been successfully used in several countries to control the beetle (Rethinam and Singh 2004; Rajan et al. 2012).

A close relative of *B. longissima*, viz. *Plesispa reichei* Chapuis, was reported from Sri Lanka. Belonging to the same family, *P. reichi* is reported only from the island nation feeding on coconut leaflets, and its pronotum is gradually narrowed than *B. longissima*. Presently, the incidence is very sporadic and does not cause any economic damage as per reports from Sri Lanka (Josephrajkumar et al. 2016b).

12.9.1.2 *Wallacea jarawa* (Chrysomelidae: Coleoptera)

A close relative of the chysomelid beetle, *B. longissima*, viz. *Wallacea jarawa*, feeding on the spindle region of coconut seedlings (Fig. 12.11) was recorded during 2014 from South and Little Andaman. The feeding niche of *Wallacea jarawa* confining on coconut spindle is a matter of concern. Though 80–90% of seedlings were infested by the pest damaging about 40% of leaf area, there was no seedling mortality; however, the pest was not observed from any adult palm during the snap survey conducted during October 2014. Invasive nature of *Wallacea jarawa* is under scrutiny, as a close relative, *Wallaceana* sp., was reported from Indonesia.

Adult beetles are brownish with six rows of constrictions on each elytron and measured 4.72 mm long and 0.9 mm wide. They are active fliers, may be for a short distance. Grubs possess short-lateral spines on each body segments and have prominent mandibles for active feeding. They measure 5.75 mm long and 0.8 mm wide. Grubs and adults remain within the folds of the spindle leaves and feed from within. Typical feeding damage can be seen within the leaf folds before unfurling along with faecal matters. In severe cases, the feeding streaks coalesce forming broader lesion with brown margin. Though a few feeding adult beetles were observed in between the leaf folds of emerged leaves, the grubs were mostly confined within the spindle region only. Pupae are located at the point of leaflet attachment to the main petiole. Pupae are exarate with exposed appendages and well-developed wing pads and are mostly located on the point of attachment of leaflet with the main petiole (Prathapan and Shameen 2015; Josephrajkumar et al. 2016b).

Fig. 12.11 Grubs of *Wallacea jarawa* on coconut seedling. (Photo: Josephrajkumar)

12.9.1.3 *Aspidiotus rigidus* (Diaspididae: Hemiptera)

Hard scale, *A. rigidus*, is a close relative of *Aspidiotus destructor*, a minor pest reported from Kerala, Tamil Nadu and other coconut-growing tracts of India. Gradient outbreak of coconut scale insect, *A. destructor*, was observed in Kerala during August to September 2012. Though the pest attack was confined in a limited pocket on coconut leaflets along a homestead farm pond, rise in maximum temperature and reduction in relative humidity and rainfall during June to July 2012 could be the major reasons for the immediate flare-up of the pest which was otherwise not reported as a major pest of the region. Population buildup of the pest was so high that caused severe yellowing as well as drying of coconut leaflets in the region. This could be one of the earlier reports on temperature-induced pest outbreak from India. Comparison of maximum temperature, relative humidity and rainfall data of June 2011 with that of June 2012 revealed increase in 0.8 °C of maximum temperature and reduction in relative humidity and rainfall to the tune of 4.1% and 91.8 mm, respectively. Though *A. destructor* is under check by natural enemies, *A. rigidus* is reported to be a ravaging pest in the Philippines incurring huge loss to coconut growers in that country (Watson et al. 2014). The mobile stage being the crawlers and males are easily drifted away by wind or passively carried through any inert packaging materials, nuts, leaflets, dried spathes, etc. (Josephrajkumar et al. 2016b).

A planned and holistic programme through awareness creation, capacity building on incursion management and strict quarantine are essentially warranted to combat invasions. Creation of an incursion management team comprising of experts from all disciplines as well as an emergency preparedness module would be the need of the hour to tackle accidental introduction of invasive pests.

12.10 Pests of Stored Copra

Copra, a most important commodity in international trade, is being infested by a number of pests, wherever it is stored for more than 5 months at a stretch in godowns and oil mills. The pests cause quantitative and qualitative losses to the commodity. Reports of pests infesting copra are given by various workers – Rutgers (1918) in Sumatra, De Fremery (1929) in Amsterdam, Corbett and Ponnaiah (1937) in Malaya, Peter (1974) in Gilbert and Ellice Islands, Rai and Singh (1977) in Guyana, Laborius et al. (1980) in West Samoa, Mathen (1961) and Nalinakumari (1989) in India and Zipagan and Pecumbaba (1974) in the Philippines. Lever (1969) and Nalinakumari et al. (1992) described the extent and damage caused by various insect pests of copra in detail and suggested management practices.

12.10.1 Ham Beetle: **Necrobia rufipes** *De Geer (Coleoptera: Cleridae)*

This pest occurs throughout the tropics and is virtually cosmopolitan. This beetle is common and becomes serious in wet season in copra stores in many countries in Asia and the Pacific. The occurrence of this insect is an indicator of the degree of uncleanliness of copra stores – their presence in large numbers indicating inferior management in both preparation of copra and unhygienic condition of stores (Lever 1969). The beetle is blue green, with reddish brown legs and antenna. The life cycle is about 66 days in tropical temperature. This beetle damages copra by extensive feeding by both adults and grubs. The larvae make ramifying tunnels inside the copra and feed within, and pupation also occurs inside the tunnels. The adults do not enter the tunnels. Instead they remain on the surface of copra pieces and eat inwards from the cut edges. The adults have the habit of feeding on their own young ones (Simmons and Ellington 1925). The feeding of young ones along with copra increases the longevity of the adult beetle sixfold when compared with feeding of copra alone (Nalinakumari 1989). In growth indices studies undertaken in nine varieties/cultivars, faster growth and multiplication of this pest were noticed in copra obtained from common cultivars, Laccadive micro and Laccadive ordinary (Nalinakumari and Mammen 1998). The development of immature stages of the beetle is faster, and the quantitative loss caused is up to 12% at the end of 6 months of storage of copra maintained at 8% moisture level (Nalinakumari et al. 1993a).

12.10.2 Sawtoothed Grain Beetle: **Oryzaephilus surinamensis** *Linn. (Coleoptera: Silvanidae)*

This beetle is slender, dark brown and flat and has a row of sharp teeth like projections on either side of the prothorax. Adults bore in through the cut end of the copra pieces and make extensive galleries between the kernel and testa. The eggs are laid in the galleries, and the emerging larvae feed within the galleries cause severe damage. The galleries within copra are not visible externally by holes or frass. This beetle prefers copra produced from the Dwarf × Tall and Tall × Dwarf hybrids. The damage was less in copra obtained from Chowghat Green Dwarf and WCT × CGD. The faster development and high population of the pest is observed in copra kept at 6% moisture level when compared with 4 or 8% moisture. The loss in weight of copra is 11.7% after 6 months of storage at the 6% moisture level (Nalinakumari et al. 1993a; Nalinakumari and Mammen 1996).

12.10.3 Almond Moth: **Ephestia cautella** *Walk. (Lepidoptera: Phycitidae)*

Almond moth has greyish wings with transverse stripes. It lays eggs on the inner surface of copra which are glued on to it. The egg is pearly white. It hatches in 3–4 days. The caterpillar is pinkish and is 12 mm long when fully grown. The duration of the caterpillar stage varies from 22 to 49 days according to the nature and condition of the food as well as temperature and humidity. The cycle from eggs to emergence of adult averages 45 days under tropical conditions. The emerging larvae make a silk woven mat on the inner surface of copra and remain within. The larvae feed by scraping from the surface and cause significant damage. The pupation occurs within the silken mat, and the emerging adults migrate to fresh copra.

12.10.4 Foreign Grain Beetle: **Ahasverus advena** *Walt. (Coleoptera: Silvanidae)*

This pest occurs in all tropical regions. This small reddish brown oval beetle with smooth elytra and clubbed antennae bores into the copra in between dried endosperm and testa. The damage is caused by the adults and larvae in the same manner as is done by *O. surinamensis*.

12.10.5 Cigarette Beetle: **Lasioderma serricorne** *Fab. (Coleoptera: Anobiidae)*

Cigarette beetle is light brown with the thorax and head bending downwards and presenting a humped appearance. Adults bore into dried slices of copra through the testa, and the entry holes could be seen prominently on the surface. The beetles feed by making galleries and lay eggs, and the emerging larvae feed from within and complete their life cycle inside the produce.

12.10.6 Coffee Berry Borer: **Araecerus fasciculatus** *De Geer (Coleoptera: Anthribidae)*

This greyish beetle has small dark patches on the elytra and prothorax. The adults bore into the copra through the inner side, and entry holes could be prominently seen. The beetles make galleries within the copra, lay their eggs and complete their life cycle inside. The adults and larvae also feed on copra remaining inside the galleries.

12.10.7 *Red Flour Beetle:* **Tribolium castaneum** *H. (Coleoptera: Tenebrioniidae)*

This beetle is distributed in all regions in India. This is a reddish brown, flat elongate beetle. Its life cycle at 30 °C is 26 days on an average. Adults of this beetle are found in small numbers in copra. They feed and breed on powdered copra and oil cakes.

12.10.8 *Short-Winged Beetle:* **Carpophilus dimidiatus** *F. (Coleoptera: Nitidulidae)*

This pest is also another cosmopolitan species. This dark brown, flat oval beetle has truncated elytra which does not cover the tip of the abdomen. It develops in about 5 weeks with a range of 26–44 days. The grubs are cream coloured, cylindrical and transparent with rudimentary legs. The adults and grubs are seen in large numbers in the godowns feeding only on decayed kernel but not on good quality copra.

12.10.9 *Black Larder Beetle:* **Dermestes ater** *De Geer (Coleoptera-Dermestidae)*

This is another widespread beetle that is likely to infect copra. The length of the adult is 8 mm; it is much larger than any other pests mentioned above. The life cycle covers about 6 weeks at 30 °C (Lever 1969).

12.10.10 *Management of Stored Pests*

Regular chemical treatment of the floor and walls of the storage sheds is to be undertaken to check the insect population and to keep it at a low and virtually harmless level. A malathion spray can be used at 450 g of 25% malathion dispersible powder, in 5 l water for 100 m^2 of floors and walls and applied monthly (Lloyd and Hewitt 1958).

For effective and long-term management of pests, well-dried copra preferably at 5% moisture content should be stored in polythene-/alkathene-lined gunny bags or netted polythene bags. As far as possible, avoid heap storage of copra stock (Nalinakumari 1989). Prophylactic application of malathion at 0.4% on gunny bags before storing copra protects the produce up to 6 months. The residue of the toxicant is below tolerance limit up to 15 days after treatment (Nalinakumari et al. 1993b).

For complete control of the major pests, 4.5 $g^{-1}m^3$ (2.5 g $ai^{-1}m^3$) of aluminium phosphide with 1-day exposure period has been found adequate. The residue of phosphine in copra fumigated as above was below tolerance limit after aeration for 24 h (Nalinakumari et al. 1993b).

To ensure that serious infestation does not develop in copra during storage, the following measures should be adopted (Lever 1969).

- Clean uninfested sacks should be employed. Sacks should be treated with steam to ensure disinfestation.
- The floors, corners and walls should be brushed regularly and thoroughly, and all dust and debris are to be removed.
- Bags should be piled neatly and systematically, with a space left between the piles and walls to increase ventilation and facilitate cleaning.
- The stocks must be removed from the stores for shipment in the order in which it was put, the oldest batch always being removed first.

12.11 Future Strategy

With the impact of climate change and modulation in pest dynamics, a holistic approach is very critical for effective implementation of IPM strategy. Farmer-participatory community mode should be given the topmost priority for successful translation of technologies and field reality. A systematic monitoring and overall palm health management are vital for successful coconut production. Good agricultural practices with emphasis on area-wide approach are very crucial for sustainable pest management. Pest management has now focused towards agroecosystem approach for accomplishing health management. Advancements in nanoporous delivery of pheromones, RNA interference, neuropeptide nanoformulations of entomopathogens and botanicals, enhancing the virulence of *Entomophaga* against biotic and abiotic stresses as well as smart upscaling technologies would go a long way in effective realization in palm health management. Early detection gadget for red palm weevil and effective forewarning strategies would foster IPM farmer-centric and eco-friendly.

Sensitization programmes under the Farmer Field School, information and communication technologies and mobile applications should be effectively clubbed and co-synergized. A planned and holistic programme through awareness creation, capacity building on incursion management and strict quarantine are essentially warranted to combat invasions due to biosecurity threats. Creation of an incursion management team would be the need of the hour to tackle accidental introduction of invasive pests. In an era of genomics, undeciphering signal transduction in pheromone chemistry and molecular identification in areas of taxonomic conflict would make pest management holistic and economically sound.

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Dr. A. Josephrajkumar is presently the Principal Scientist in the discipline of Agricultural Entomology at ICAR-CPCRI, Regional Station, Kayamkulam, India. He has refined IPM strategies for cardamom and black pepper and was instrumental in the release of three cardamom varieties. His current interest is in developing IPM of coconut pests and vector entomology of root (wilt) disease. He has published 50 research papers. He has received national awards including ICAR-Jawaharlal Nehru Award, ICAR-Lal Bahadur Shastri Young Scientist Award and AZRA-Young Scientist award. joecpcri@gmail.com

Dr. Chandrika Mohan is currently working as Principal Scientist (Agricultural Entomology) at the ICAR-CPCRI, Kerala, India. Her expertise is in coconut pest management. During her 32 years of research experience, she has contributed towards development and validation of biocontrol strategies for sustainable pest management of coconut palm. She has published 200 research papers and has contributed chapters for 10 books. Dr. Chandrika Mohan is a recipient of Fr. Gabriel Memorial Gold Medal. cmcpcri@gmail.com

Dr. P. S. Prathibha is a Scientist in entomology at the Central Plantation Crops Research Institute, Kasaragod, India. She has published five research papers. prathibhaspillai007@gmail.com

Dr. Rajkumar is a nematology Scientist at ICAR-CPCRI, Kasaragod, Kerala, India. He has also worked in ICAR-National Bureau of Agricultural Insect Resources (NBAIR), Bangalore. His specialization is phytoparasitic and entomopathogenic nematodes (EPN) and has over 10 years of research experience in bio-suppression of nematode disease associated with crops. He has published 25 research papers. rajkumarcpcri@gmail.com

Dr. T. Nalinakumari former Professor and Head, Entomology, Kerala Agricultural University, India, is currently serving as consultant to National Institute of Plant Health Management. She has specialized in storage entomology and integrated pest management. She has 28 years of teaching and research experience. She has published 75 research papers and contributed to 5 book chapters. achutnk@yahoo.co.uk

Dr. C. P. R. Nair former Principal Scientist and Head, ICAR-Central Plantation Crops Research Institute, Regional Station, Kayamkulam, Kerala, India, has more than 37 years of professional expertise in entomology of plantation crops. He had been the Principal Investigator of two International Projects on Integrated Pest Management in Coconut. He has more than 130 publications. cprnair_47@yahoo.com