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Chapter 1

Coconut

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1. Introduction

Coconut (*Cocos nucifera* L.) is one of the major plantation crops in India with an annual production of 20,439.60 million nuts. Coconut plays an important role in the environment, health, food and livelihood securities of millions of people. Even though the crop is cultivated in 93 countries globally, about 78.08 per cent of the world production is contributed by the four major nations, *viz.*, Indonesia, the Philippines, India and Sri Lanka. The current average productivity of coconut in India, being 10345 nuts/ha (CDB, 2016), could be doubled through optimum plant and soil health management. Consistent flowering and fruiting pattern of coconut palm throughout the seasons is the favourable abode for a wide array of insects, mites and rodents and Kurian *et al.* (1979) enlisted 547 insects and mite species infesting coconut worldwide. Among the insects, rhinoceros beetle, red palm weevil, black headed caterpillar, eriophyid mite and white grub are the major pests of concern, which are widely distributed in all coconut growing tracts of India adversely affecting coconut industry to a larger extent.

2. Rhinoceros Beetle (*Oryctes rhinoceros* Linn.) (Coleoptera : Scarabaeidae)

The Asiatic rhinoceros beetle or black beetle was reported damaging coconut palms in 1889 by Ridley. It is native to the southern Asiatic region, but has reached Africa, Australia and Pacific Islands. A number of workers have expanded the geographical distribution of *O. rhinoceros* (Gressitt, 1953; Nirula, 1955a, b; Swan 1974; Hill, 1983). There is an exhaustive literature on rhinoceros beetles, of which

comprehensive reviews have been published by Nirula *et al.* (1952), Gressitt (1953) and Bedford (1980, 2013).

Coconut palm is the primary host of rhinoceros beetle. It is a major pest in oil palm also leading to 'dead heart' symptoms. A broad list of food plants infested by *O. rhinoceros* was provided by Gressitt, (1953), which included 45 species of monocot plants, over 30 species of palms. Range of host plants invaded by black beetle are reported from India (Menon and Pandalai, 1960; Nirula *et al.*, 1952, Sivakumar and Chandrika, 2013), Indonesia (Kalshoven, 1951), the Philippines (Mackie, 1917) and Mauritius (Monty, 1978) including palmyrah, wild date, areca, date, sago palm, pandanus, pineapple, colocasia, banana, sugarcane *etc.* however, there is not much economic damage on host plants other than coconut and oilpalm.

2.1. Damage

The robust adult beetles cause damage to palms at all age groups by burrowing into the unopened spear leaf and feeds on juice from the host tissues. As the pest burrows deeper into the host (10-50 cm) it pushes out the chewed up tissues as fibres, which are seen extruding from the entry points. Once these injured leaves unfurl, they present a 'V' shaped cut pattern, reducing the functional leaf area

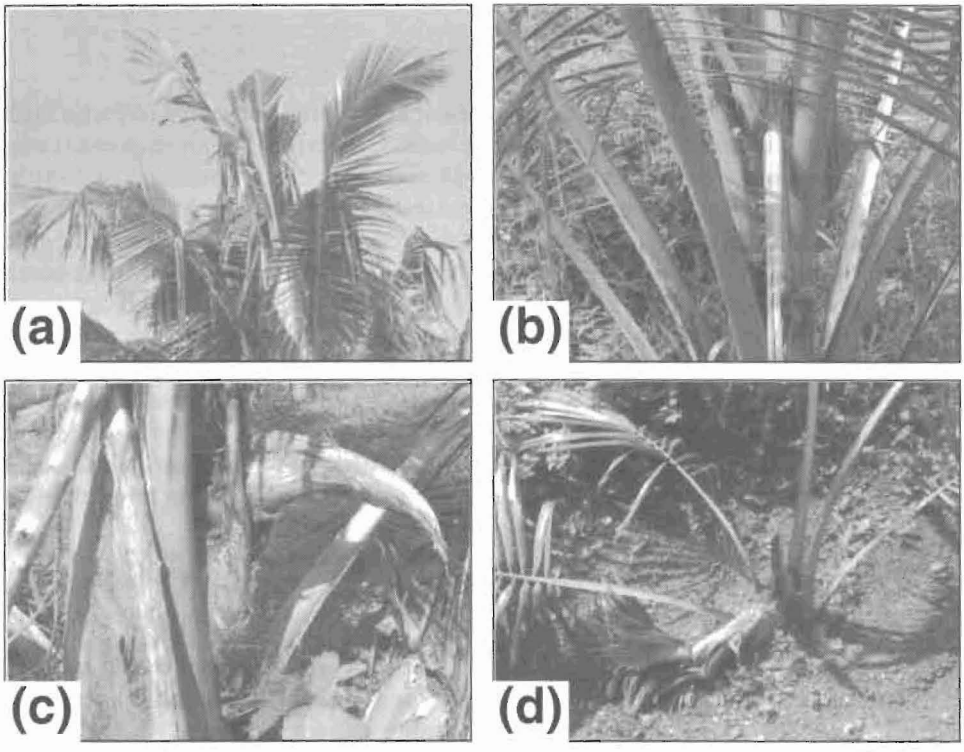


Figure 1.1: Rhinoceros Beetle Infestation.

a) Damage symptom on unfurled leaves, b) Spear leaf damage, c) Tusk like symptom due to beetle feeding, d) Twisted growth of juvenile palm due to beetle attack.

considerably (Figure 1.1). 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 (Figure 1.2).

Attack in juvenile palms results in stunted growth and delayed flowering and the repeated attack at the growing point may even lead to palm death. In the recent past, it was found invading coconut seedlings in the nursery as well as juvenile palms through collar entry and completely damaging the seedlings. Of late, the pest was found boring into the immature tender nuts (Figure 1.2b) causing yet another route of feeding when the spear leaf is protected.

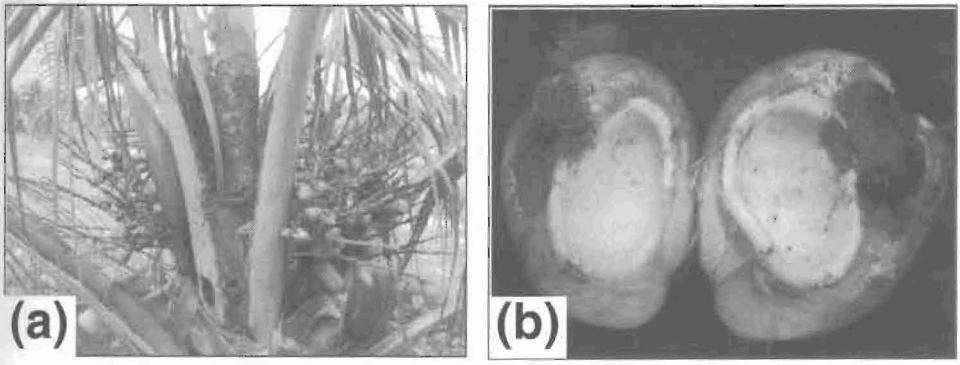


Figure 1.2
(a) Drying of spathe, (b) damage on the nut due to rhinoceros beetle.

Pest attack impedes palm growth and up to 10 per cent reduction in crop yield is reported. Black beetle infestation has to be considered serious as the damage done by this pest provides egg laying sites for another lethal pest *viz.*, red palm weevil or for entry of fungal pathogens. Attacks tend to be concentrated on the margins of palm groves and on taller, more prominent palms (Cumber, 1957; Young, 1975). One attack increases the likelihood of further attacks (Bedford, 1975; Young, 1975). Sison (1957) reported that palms with 50 per cent of all their fronds damaged had about one-fifth the number of developing nuts than on normal palms. Being a perennial crop, workers reported many difficulties in studying the effect of beetle attack on yield (Ramachandran, 1961: Ramachandran *et al.*, 1963; Young, 1975). In India damage of inflorescence is also reported in severely infested areas which cause reduction in yield up to 10 per cent (Nair, 1986) and of 5.5 to 9.1 per cent yield loss by Ramachandran *et al.* (1963). From artificially pruned leaf damage stimulation studies it was observed that damage to 50 per cent fronds corresponds to leaf area reduction of 13 per cent and decrease in nut yield by 23 per cent (Young, 1974). Pruning equivalent to1.5 attacks/month would have killed the palms if sustained long enough, even though the growing points were undamaged (Young, 1975). In south-eastern Luzon, Philippines, *O. rhinoceros* damage was significantly more common on old palms (which are predisposed to the disease), and more abundant on those infected with cadang-cadang than on neighbouring healthy palms (Zelazny and Pacumbaba, 1982). In Samoa, more attacks occur on higher than on lower palms, and that one attack is likely to be followed by others on the same palm. Attacks are

apparent to an observer on the ground after about 41 days and continue to be so for up to 150 days, as the damaged fronds open (Young, 1975).

2.2. Biology

Adults of *O. rhinoceros* are large beetles 30-50 mm long and 14-21mm breadth, black or reddish black in colour, stout and possesses a characteristic cephalic horn which is relatively larger in males (Figure 1.3d). Females can be identified by the densely clothed reddish brown hairs on pygidium on the ventral surface (Figure 1.3e). The females deposit yellowish-white eggs (Figure 1.3a) in dead and decaying vegetable matter such as cattle dung, compost, heaps of sawdust, felled logs and stumps particularly of the coconut palm and oil palm. Average fecundity per female is 108 eggs. The larval and pupal stages are completed in the breeding grounds. The grubs are creamy white in colour with the body strongly arched dorsally. Grub (Figure 1.3b) period is about 130 days with three instars. The pupa is uniformly brown, slightly convex (Figure 1.3c) dorsally and the pupal period varies from 20-29 days. Adult longevity is 3 - 4 months. Adults are active during night and remain hidden during daytime in the feeding or breeding sites. The life cycle from egg to adult stage takes about 5-6 months (Nirula *et al.*, 1952; Nirula 1955a, b). The three instars of grub period last 74 to 191 days with an average of 130 days (Nirula, 1955b) on the West Coast of India.

2.3. 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 of *O. rhinoceros* population. The major components of IPM package consist of sanitation, mechanical, chemical and biological methods.

2.3.1. Sanitation Method

In the IPM of *O. rhinoceros*, the best management decision to be implemented is elimination of pest multiplication sites from the coconut plantation itself that provide favourable niche for immature stages of the beetle. The dead and decaying coconut logs, heaps of fallen coconut leaves, shredded palm tissues and other organic debris in the vicinity of coconut plantations may be properly disposed off, since this act as prolific breeding grounds of the beetle (Figure 1.4a). The moisture content of the food material plays a very important role, the grub not being able to develop in absolutely dry or water soaked food materials. Farm yard manure should be properly dried and stored since low moisture content did not favour development of this pest. Composting tanks has to be iron netted to prevent beetle access.

Incorporation of the weed plant, *Clerodendron infortunatum* Linn. @ 10 per cent w/w in the farm yard manure/compost pit is suggested as a probable management strategy targeting grub stages (Chandrika and Nair, 2000) as this plant exerts insect growth regulatory properties on *O. rhinoceros*. Larval-pupal or pupal-adult intermediates, adults with malformed wings *etc.* are some of the common abnormalities elicited by the plant alkaloids on *O. rhinoceros* when the plant part is ingested by the grub along with food. These malformed adults were unable to fly and survived for only 6-8 days.

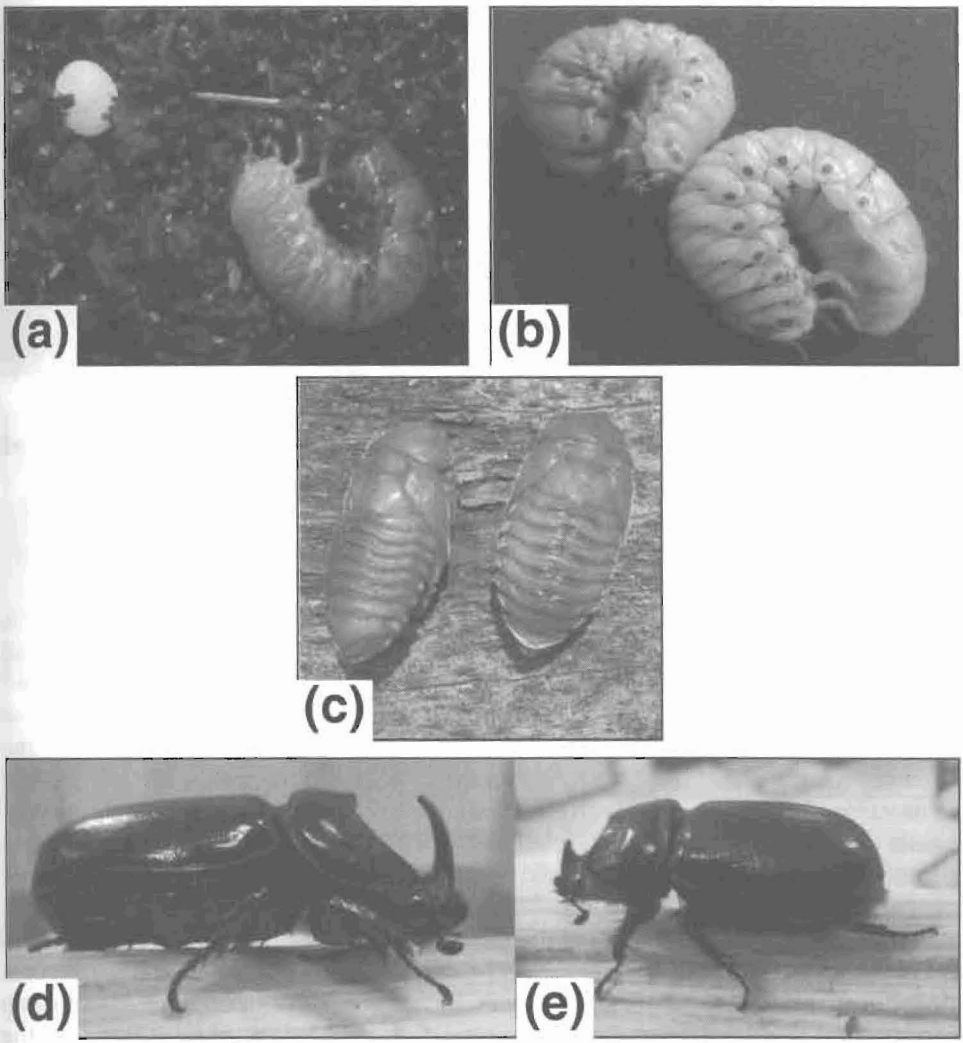


Figure 1.3a-e: (a) Egg and neonate grub, (b) Fully grown grubs, (c) Pupae, (d) Male beetle and (e) Female beetle.

2.3.2. Mechanical Control

This method involves periodic examination of the palm crown and removing the adult beetle by means of a metal hook (Figure 1.4c) during peak periods of pest abundance (June- September), but often only after damage has been done (Cherian and Anantanarayanan, 1939; Gressitt, 1953; McKenna and Shroff, 1911; Nair *et al.*, 1997). Care should be taken not to inflict any damage on the developing inner core palm tissues during this process and hole has to be filled with a mixture of neem cake and sand.

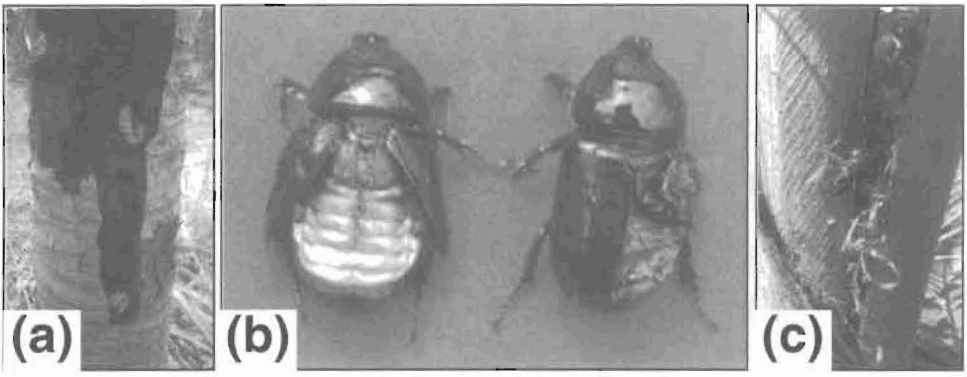


Figure 1.4

(a) Rhinoceros beetle breeding on decaying palm trunk, (b) *C. infortunatum* induced malformation in rhinoceros beetle, (c) Hooking out of beetle from infestested site.

2.3.3. Prophylactic Measures to Prevent Pest Entry

Placement of naphthalene balls @ 12g/palm (3-4 numbers) in the inner leaf axils with sand coverings to prevent quick evaporation of the compound is also found to be effective in preventing the pest incidence in young palms (Sadakathulla and Ramachandran, 1990). Application of oil cakes of neem (*Azadirachta indica* A.Juss.) or marotti (*Hydnocarpus wightiana* Bl.) in powder form @ 250g mixed with equal volume of sand, thrice a year during May, September and December to the base of three leaf axils surrounding spear leaf is an effective prophylactic method against rhinoceros beetle and red palm weevil (Chandrika *et al.*, 2001) (Figure 1.5a). Placement of two perforated sachets (Figure 1.5b) each containing 3 g chlorantraniliprole (0.4 per cent ai) or fipronil (80 per cent *ai*) or botanical cake (Figure 1.5c) (20g) developed by ICAR-CPCRI was found effective during monsoon phase. During dry period, 100 ml of water may be poured over the sachet after placement to release the molecule (Josephrajkumar *et al.*, 2015a). ICAR-CPCRI has also developed a botanical paste formulation (Figure 1.5d) for effective repulsion of the pest when swiped on the base of leaf or top most leaf axils of juvenile palms.

2.3.4. Biological Control

This method is the most important component in the IPM of *O. rhinoceros*. Insect predators are frequently observed in the breeding grounds of the beetle. They feed on the eggs and early instar larvae of the beetle. Two potential microbial agents *viz.*, *Metarhizium anisopliae* (Figure 1.7) and *Oryctes rhinoceros nudivirus* (OrNV) (Figure 1.6) cause disease to the immature and adult stages of the beetle. Use of these microbial control agents is advantageous because they are relatively host specific, does not cause environmental pollution, safe to humans and are compatible with other control methods.

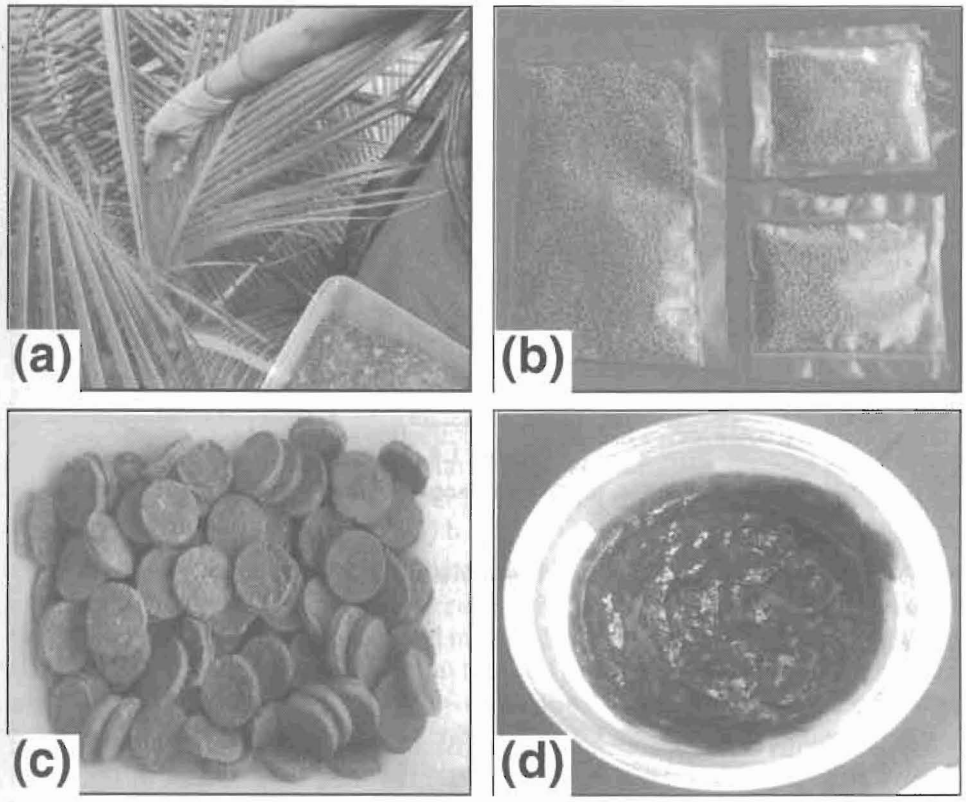


Figure 1.5

(a) Leaf axil filling with oilcake sand mixture, (b) Chlorantraniliprole sachet for leaf axil filling, (c) Botanical cake and (d) Paste developed by ICAR-CPCRI for prophylactic leaf axil filling.

2.3.5. Predators

The important predators are *Santalus parallelus* Payk., *Pheropsophus occipitalis* Macleay, *P. lissoderus* Chaudior, *Chelisoches morio* (Fab.) and species of *Scarites*, *Harpalus* and *Agrypnus*; (Antony and Kurien, 1966, Kurien *et al.*, 1983, Sathiamma *et al.*, 1982). *Platymeris laevicollis* Distant (Hemiptera: Reduviidae) is an exotic predator on rhinoceros beetle. *P. laevicollis* was imported from Zanzibar to India for the control of rhinoceros beetle. As compared to the indigenous predators, *P. laevicollis* feeds on adult beetles. Egg to adult period is completed in 131-161 days. The predator is long lived (170-240 days) and fecundity high (110-170 eggs/female). The predator mass multiplied on ground roaches was field released in coconut plantations in Kerala and Karnataka @ 6 bugs/palm and could achieve significant reduction in beetle population and the damage to the palm. Leaf damage was reduced to 13.1 per cent, nil spathe damage and 1 per cent spear leaf damage as compared to 59.2 per cent, 2.5 per cent and 37.0 per cent respectively, recorded during pre release

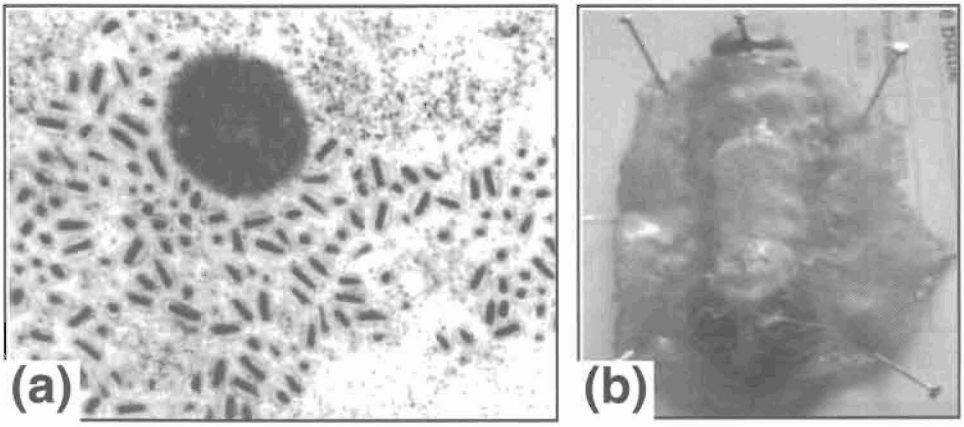


Figure 1.6
(a) OrNV particles under EM, (b) OrNV infected (fluid-filled) gut of *Oryctes* grub.

observations. But the predators failed to establish under field conditions (Antony *et al.*, 1979).

2.3.6. Pathogens

2.3.6.1. Oryctes rhinoceros Nudi Virus

The infection of *O.rhinoceros* by virus, Baculovirus of Oryctes (OBV) was first reported in Malaysia in 1966. Zelazny (1981) reported its presence in India and detailed work on it was done by Mohan *et al.* (1983), Mohan and Gopinathan (1989a,b) and Mohan and Gopinathan (1992). After detailed genomic characterization Mohan and Gopinathan (1992) proposed the taxonomic status of the variant for *OB*V K1, the Kerala isolate of *OB*V. After taxonomic revision of the genus Baculovirus of orcytes (OBV) was re-designated as Oryctes rhinoceros nudivirus (OrNV) through molecular characterization. *Or*NV gains entry in to the host orally through contaminated food material. It multiplies in the midgut epithelium and fat bodies of grubs and adults and also in the reproductive cells (Majumder and Jacob, 1993). Apart from *O.rhinoceros* it is pathogenic to *O.nasicornis* Linnaeus, *O.monoceros* (Olivier), *O.boas* Fabricius, *Scapanes australis grossepunctatus* Sternb., *Papuana uninodis* Prell and *Xylotrupes gideon* L. (Danger *et al.*, 1994).

All the three instars of grubs and adults of *Oryctes* are infected by the virus especially the 1st and 3rd instar grubs are more susceptible (Mohan *et al.*, 1985a), pupae are not susceptible to this disease. Infected grubs become lethargic, stop feeding and crawl to the surface of the feed. As the virus multiples, the haemolymph content increases, fat bodies disintegrate and the midgut filled with black solid food is replaced with white viscous mucoid fluid which makes the grub appear translucent, when observed against light (Figure 1.6b). Extroversion of the rectum due to increased turgor pressure is also noticed. Infected grubs die within 6 to 30 days. Diseased adults too become inactive, short-lived (by 60 per cent) and lay less number of eggs (1-2 eggs).

Diagnosis of *Or*NV: Lethargic condition, crawling to the surface of the feed, development of translucency in grubs and inactivity of adults are the key exopathological indications of this disease. Presence of this virus in the host can be detected by 3 per cent Giemsa staining of midgut fluid or midgut epithelium where in the pink colored hypertrophied nuclei with dark pink peripheral ring (Mohan *et al.*, 1983) is observed in the infected sample under microscope. Midgut slices fixed, stained and when observed under Electron Microscope shows the presence of rod-shaped viral particles (Figure 1.6a) Immunofluorescence, immuno-osmophoresis and ELSIA techniques (Mohan and Gopinathan, 1989a) can also be used to confirm the presence of this pathogen. Another sound diagnostic procedure is conducting bioassay test by inoculating healthy grubs\beetles orally with homogenized midgut of test sample and observing for typical OrNV symptoms (Mohan *et al.*, 1983). Presence of OrNV disease in the adult beetle can be diagnosed without sacrificing the host. This method involves collection of the beetles excreta in 0.01M phosphate buffer saline, centrifuging the fecal matter at 500 rpm for 10 min. and preparing 3 per cent Giemsa staining of the sediment for locating typically hypertrophied nuclei under microscope (Mohan *et al.*, 1985 b.)

Mass production, storage and Field application: Mass production and *in vivo* culturing of this bio-agent is done by rearing healthy grubs in viral contaminated food or forced- feeding using infected midgut homogenate, and maintaining them in sterilized cowdung or saw dust until the OrNV symptom develops. The infected cadavers can be stored indefinitely at –40°C. The simplest and the most economical method of dissemination of OrNV is by releasing laboratory-inoculated beetles (10-15 No./ha) preferably during dusk. The infected beetles transmit the pathogen in breeding/feeding sides by excreting viral contaminated faeces after 3rd and 9th day post OrNV inoculation (Mohan *et al.*, 1985b), where it is picked up by healthy susceptible *Oryctes*. Horizontal spread of this virus was reported to be 1 km/month (Jacob, 1996).

Dissemination of virus for pest management is effected by release of virus infected rhinoceros beetles @ 10-15 beetles/ha. The viral pathogen produces 100 per cent reduction in the egg laying capacity of female beetles and 40 per cent reduction in life span of affected population (Pillai, 1993). Introduction of virus in several islands of the South Pacific effectively suppressed the *O.rhinoceros* damage below economic threshold level. Extensive studies on the use of OrNV to suppress rhinoceros beetle population in Islands of Lakshadweep and Andaman-Nicobar had shown encouraging results during the last four decades (Mohan *et al.*, 1989; Pillai *et al.*, 1993; Jacob, 1996). The effectiveness of IPM package for management of rhinoceros beetle was well documented in mainland also (Nair *et al.*, 2010a). Thus, the success encountered by the use of this microbial pathogen has endorsed its claim as one of the landmark examples in the biological control of any insect pest.

2.3.6.2. Metarhizium anisopliae (Metschnikoff) Sorokin (Deuteromycotina: Hyphomycetes)

M. anisopliae commonly termed as the green muscardine fungus (GMF) is a well-known pathogen of rhinoceros beetle. The susceptibility of *O. rhinoceros* to

GMF was first reported in Western Samoa in1913 and in India by Nirula *et al.* (1955, 1956). *M. anisopliae* var. *major* (spore size 10-14 µm) is highly infective variety used widely for the control of this pest. It gains entry through membraneous joints of the cuticle of the host by mechanical and enzymatic action. The success of infection depends on an optimum temperature of 27-28°C and relative humidity of 70-90 per cent. All the stages of the host excepting the eggs are mycosed. The infected grubs become sluggish, and die within 10-15 days. Initially, the body gets hardened and a white fungal mycelial mat appears externally at all joints of the integument. After 4-7 days, green coloured spores are produced. Finally, the cadaver turns blackish green and mummified due to profuse spore growth.

Mass production: Autoclaved, filter sterile or aseptically drawn out coconut water is a good liquid substrate for the multiplication of this fungus (Danger *et al.*, 1991). It can also be mass-produced on cassava chips: rice bran mixture supplemented with urea or fishmeal extract as nitrogen source (Mohan and Pillai, 1982). Different substrates like broken rice/wheat grains, millets *etc.* were also found to be cheaper substrates for multiplication of the fungus. Area-wide farmer participatory mass production strategies using semi cooked rice media were standardized (Figure 1.7b) and validated for the biomanagement of rhinoceros beetle (Chandrika *et al.*, 2010c; Anithakumari *et al.*, 2016).

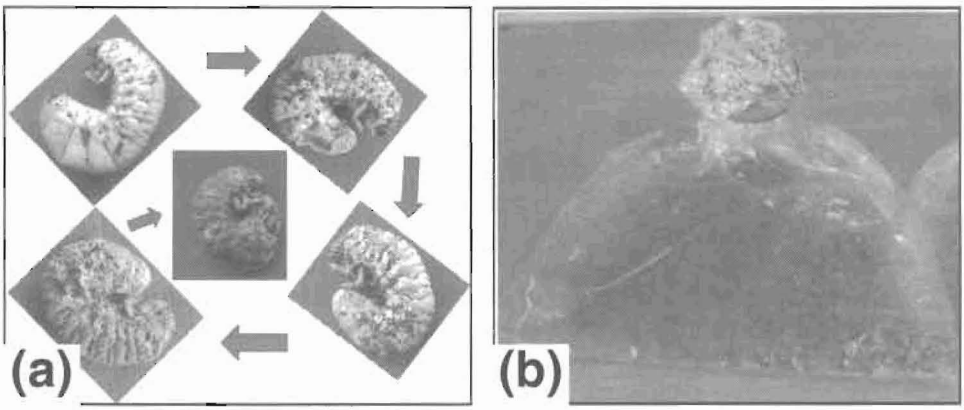


Figure 1.7

(a) Stages of GMF infection in *O.rhinoceros* grubs, (b) *M. anisopliae* culture in rice media.

For the field application of the fungus of GMF, the fungal spores are mixed with sterile water and used to drench or spread (cassava chips culture + powdered cow dung) over the breeding sites of the rhinoceros beetle @ of 5×10^{11} spores/m^3. The fungus survives in the breeding material for long periods. Use of this fungus for biocontrol of rhinoceros beetle has been popularized as a women friendly technology by ICAR-CPCRI.

2.3.7. Field Evaluation

Efficacy of these the two promising microbial pathogens *Metarhizium anisopliae* and *Oryctes rhinoceros* nudivirus in managing the pest in larger areas was

demonstrated by Nair *et al.* (2010a) in an area of 2400 ha homestead coconut garden in two districts Kerala during 1999-2002 and reported 66.6 per cent to 75.1 per cent reduction of leaf damage and 79.4 per cent to 95.8 per cent reduction in spear leaf damage in a period of 3 years.

2.3.8. Semiochemicals

Aggregation pheromones have been documented for the *O. rhinoceros* and *O. monoceros* as ethyl 4-methyloctanoate (Hallett *et al.*, 1995; Gries *et al.*, 1994) which are commercially available. Specially designed PVC tube trap employing synthetic pheromone ethyl 4-methyloctonate has been found to be quite feasible for trapping black beetles in reasonable numbers. The traps are set up in the gardens @ 1 trap/ha and beetles trapped inside are collected periodically and used in virus inoculation (APCC, 2007; Nair *et al.*, 2010b).

3. Red Palm Weevil (*Rhynchophorus ferrugineus*) (Coleoptera: Curculionidae)

Red palm weevil (RPW) is a lethal pest of coconut palm widely distributed in all coconut growing regions of India. This weevil is reported to attack 17 palm species worldwide, of which date palm *Phoenix dactylifera* is the host. Although the weevil was first reported on coconut, *Cocos nucifera* from South Asia, during the last three decades it has gained foothold on date palm, in several Middle Eastern countries from where it has migrated to Africa and Europe through movement of infested planting materials.

3.1. Biology

The adult weevils measure 35 mm long and 12 mm wide and ferruginous brown in colour with a long life span extending up to 76 to 133 days. The snout is elongated in both sexes and the dorsal apical half of the rostrum in males is covered with a tuft of brown hairs (Figures 1.8a,b and Figure 1.9) The mean fecundity is

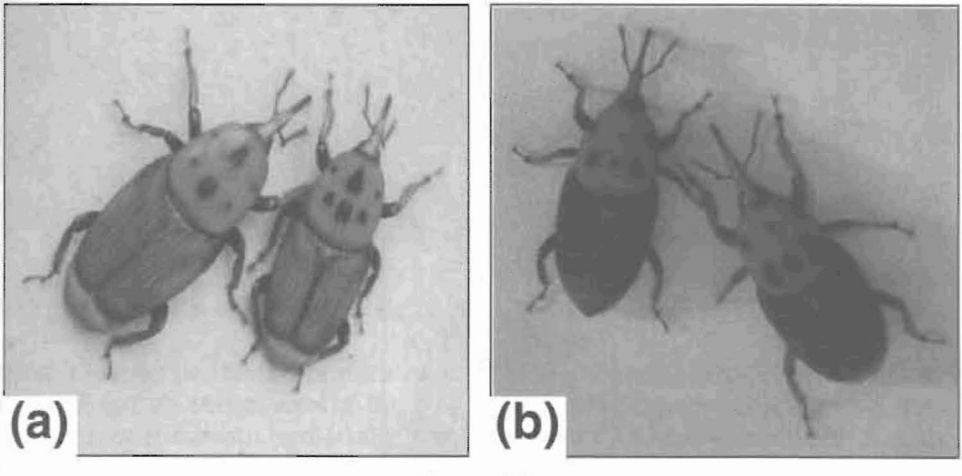


Figure 1.8
(a) Red palm weevil and (b) Colour variant from NEH region.

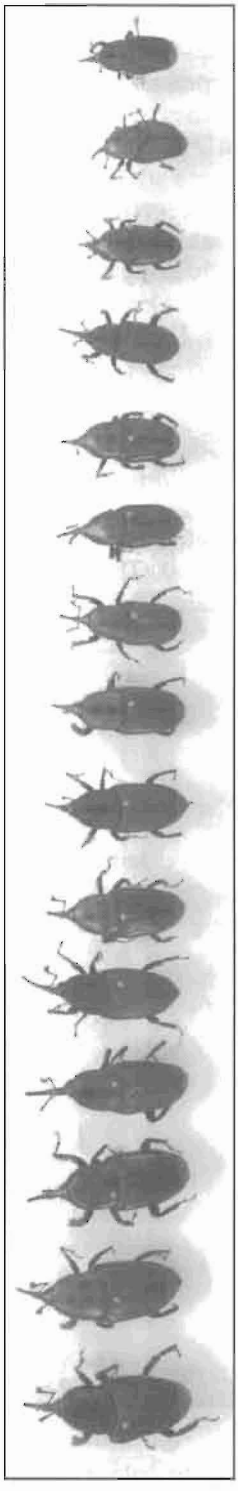


Figure 1.9: Size and Colour Morphs of Red Palm Weevil form different Coconut Growing Tracts of India.

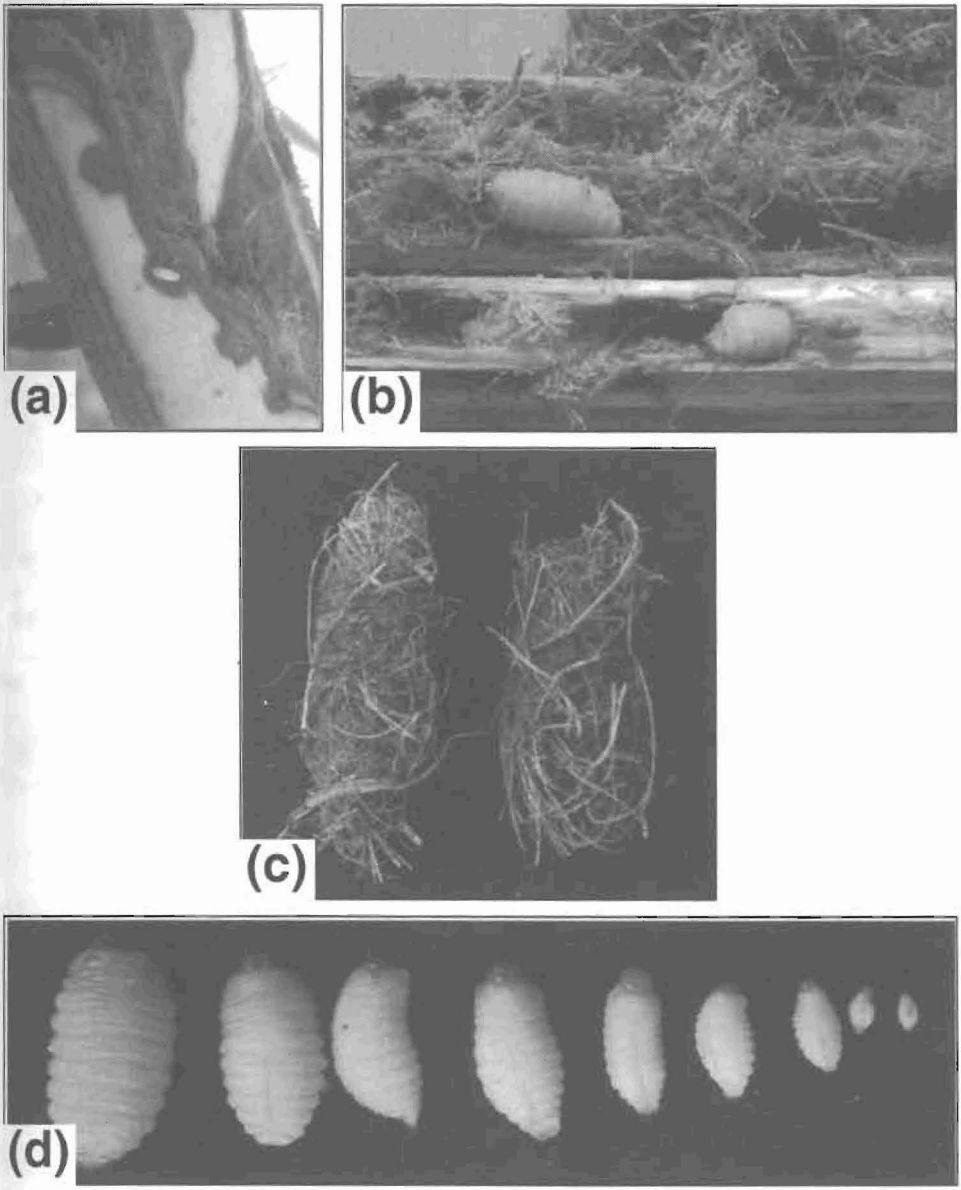


Figure 1.10: Life Stages of Red Palm Weevil.

(a) Egg of red palm weevil, (b) Grubs, (c) Pupal cocoons, (d) Various stages of grubs.

about 175 eggs per female and the creamy white oval eggs are laid in small holes scooped out on soft tissues of the palm. After hatching, the grubs tunnel their way into the trunk and feed on the internal contents. The full-grown grub is stout, fleshy and apodous measuring 50 mm long and 20 mm in width. The fully-grown grubs enter the pupal stage by winding around themselves the fibrous elongate oval cocoon(Figure. 1.10). The weevils on an average take 4 months to complete its

egg to adult stages depending up on weather conditions and type of food source (Nirula, 1956c, Abraham, 1994).

3.2. Damage and Symptoms

Juvenile and pre-bearing palms mostly below 20 years age are more susceptible to the pest infestation. Being an internal tissue feeder completing life stages inside the palm tissues, it is very difficult to detect the pest attack during early stages. However, on close examination of the palm, some symptoms can be detected at the early stages also. Yellowing and later wilting of the inner and middle whorl of leaves, small circular holes on the palm trunk with exudation of amber coloured viscous fluid, longitudinal splitting of leaf base, gnawing sound of grubs and presence of cocoon/chewed up fibers at palm base are the major symptoms of red palm weevil infestation. Unnoticed severe infestation results in toppling of the palm crown (Figure 11.1). In general dwarf and hybrid palms are more susceptible to red palm weevil attack than tall genotypes. The weevils orient themselves towards the palm to the fermenting odour emanated by mechanical injuries or fungal infections. Hence, the incidence of red palm weevil in coconut palm is comparatively more in areas having high incidence of rhinoceros beetle, bud rot disease and leaf rot disease. Shallow methods of planting also pave way for the pest attack (Nirula, 1956c; Abraham and Kurian, 1975; Abraham, 1994; Nair *et al.*, 1997; Rajan *et al.*, 2009, Faleiro, 2006). Pest entry through the leaf axil attachment at the trunk was observed if the bearing bunches are buckled from the point of contact due to overweight of developing nuts or succulence due to over nutrition. Access through the collar or bole region of the palm where injury is met out through tractor or tiller ploughing as well as swollen or cracked bole region through erratic nutrient uptake and improper translocation were commonly observed (Josephrajkumar *et al.*, 2014a).

3.3. Pest Management

3.3.1. Sanitation

Early detection of infestation in the field is important for any RPW-IPM programme. Being the internal tissue borer, it is very difficult to recognize pest infestation symptoms at an early stage. Hence, close palm surveillance has to be stressed for early pest detection and management. Coconut palms dead due to red palm weevil and retained in the field serve as ideal food source for a second generation or it acts as a source of inoculum for further build up of the pest in the field. Hence, field sanitation is very important to protect the palms (Abraham and Kurian, 1972; Rajan and Nair, 1997).

3.3.2. Scouting

Close and regular monitoring of the plantation, especially with previous pest history has to be practiced for early detection for saving the palm. Trained palm technicians such as Friends of Coconut Tree (FOCT) need to be effectively enriched on pest scouting and their skill upgraded through organizations such as ICAR-CPCRI, State Agricultural Universities, developmental agencies *etc.* for effective and timely monitoring, sensitization and diagnosis of this killer pest. Farmers

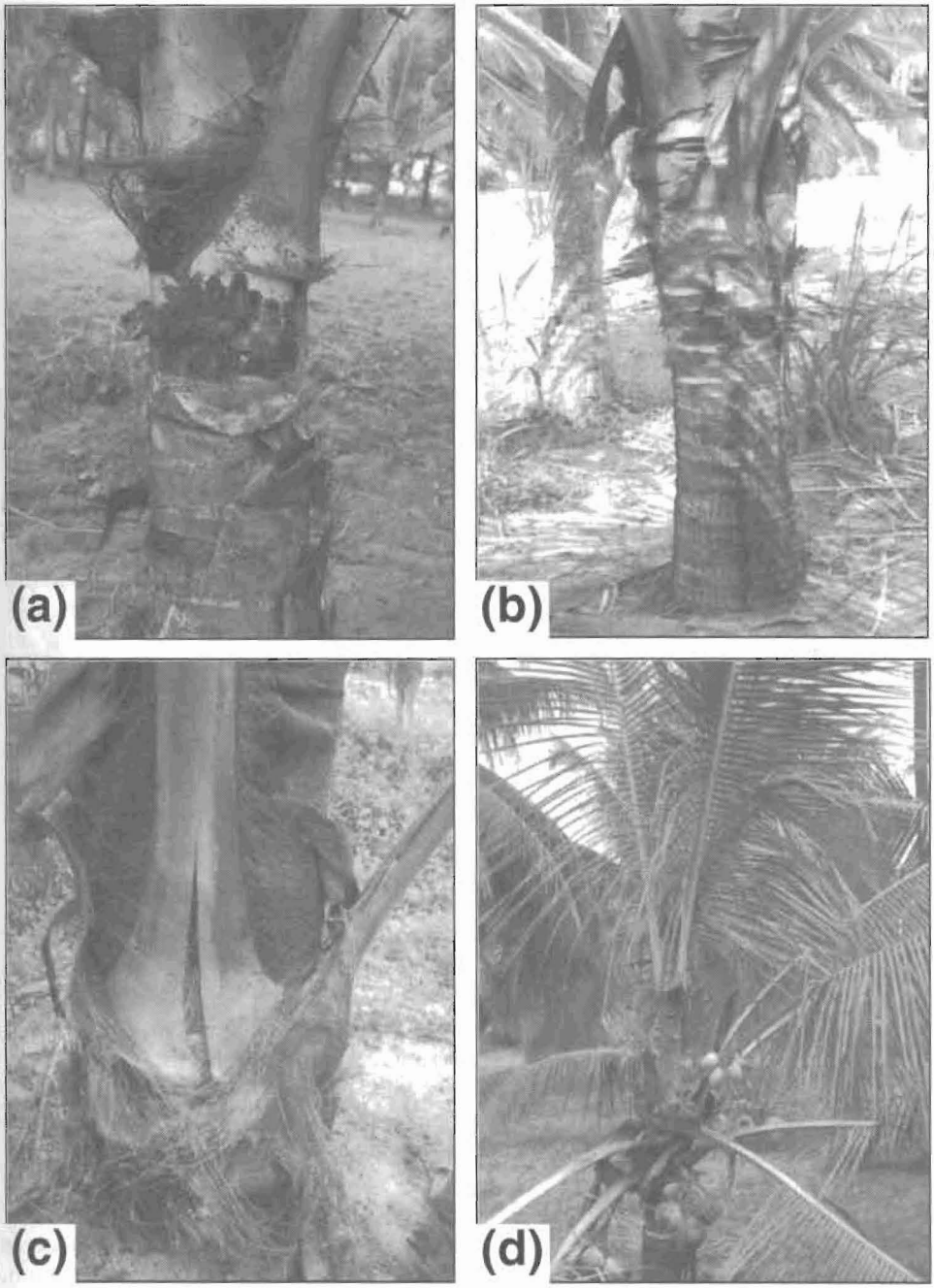


Figure 1.11a-d: Symptoms of Red Palm Weevil Infested Palms.

(a) Holes on palm trunk, (b) Oozing of brown viscous fluid, (c) Splitting of petiole (d) Wilting of spear leaf, (e) Crown toppled palm.

Figure 1.11e: Symptoms of Red Palm Weevil Infested Palms (Crown Toppling).

involvement in close checkup of palms for any detectable pest entry symptoms is need of the hour to detect the attack in early curable stage. Routine close examination would reveal any of the damage symptoms so that adequate curative strategies could be resorted to.

3.3.3. Crop Geometry

Maintaining optimum palm density during planting is very important for utilizing highest benefits of light energy as well as to reduce the release of volatiles orienting the pest away from the host. Spacing for tall varieties 8 x 8 m and dwarf varieties 7 x 7 m is found ideal. Interspaces can be effectively used for raising intercrops so as to admix and diminish the volatile cues disorienting RPW away from host (Josephrajkumar *et al.*, 2014b). Gardens planted with coconut seedlings with inadequate spacing was found heavily infested during the juvenile phase especially in root (wilt) disease tracts of Kerala.

3.3.4. Prophylactic Treatment

Prophylactic leaf axil filling techniques not only prevent attack by rhinoceros beetle and bud rot infection, but also protect the palm from RPW incursion. Prophylactic leaf axil filling with oil cakes such as neem, marroti, pongamia (250 g) admixed with equal volume of river sand/naphthalene balls (12 g)/6 g chlory dust/6 g chlorantraniliprole admixed with 250g sand/palm could effectively repel rhinoceros beetle and thus reduce chance of RPW attack also. Leaf axil placement

of two perforated polythene-sachet containing 3 g chlorantraniliprole safeguarded juvenile palms for about 4-6 months. In bud rot endemic zone, placement of *Trichoderma*-coir pith cake was found effective to reduce the disease and chance of RPW infestation.

The pest is attracted to kairomones emanating from fresh injuries inflicted on the palms for egg laying. Due to mechanical farm operations such as ploughing, cutting of steps for climbing the palms, tapping *etc.*, the injured palm becomes more susceptible to weevil infestation. Avoiding physical injury to palms is very critical to reduce pest incidence. While cutting fronds, leaving the basal portion at least 1 m from trunk, evading knife injury on crown region during crown clearing/tapping and careful tractor ploughing shunning away from bole and frond region to avoid injuries need to be overemphasized.

3.3.5. Curative Strategies

In cases of infestation by red palm weevil it becomes mandatory to apply chemical pesticides, either by crown application or through stem injection. After diagnosis, application of imidacloprid 18.5 SL 0.02 per cent (1 ml per litre of water) or spinosad 2.5 SC 0.013 per cent (5 ml per litre of water) or indoxacarb 14.5 EC 0.04 per cent (2.5 ml per litre of water) was found effective in the suppression of the pest (Josephrajkumar *et al.*, 2014b). Insecticide treatments are usually done after harvest of nuts and therefore a safe waiting period of 45 days is accomplished in this process before the next harvesting. In most cases young non-bearing palms are invaded by the pest. It was also found that there was no detectable residue of imidacloprid on leaves, nut and meat even after one-day after treatment up to 30 days period. Nearly one litre of the insecticidal suspension is required to treat an affected palm based on the serenity of the infestation.

3.3.6. Ecological Engineering

Judicious intercropping of palms with nutmeg, rambutan, curry leaf, 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 continuous employment of farmers, income generation as well as pest regression infusing stimulo-deterrant diversionary tactics (Figure 1.12). Installation of bird perch and flowering plants like coral vines maintains pest defenders and executes ecosystem services. Damage by rhinoceros beetle as well as red palm weevil was reduced in coconut based cropping system than in mono-cropped garden.

3.3.7. Entomopathogenic Nematodes

Entomopathogenic nematode (EPN) *Heterorhabditis indica* showed high virulence (LC_{50} 355.5 IJ) against *R. ferrugineus* grubs as well as greater susceptibility (82.5 per cent) of pre-pupal stage than that of grubs under laboratory trials (Figure 1.13). Synergistic interaction of *H. indica* (1500 IJ) with imidacloprid (0.002 per cent) against red palm weevil grubs was also reported. Investigations on combined application of *H. indica* and imidacloprid (0.002 per cent) for curative treatment in the field level management of red palm weevil in coconut were promising (Josephrajkumar *et al.*, 2013).

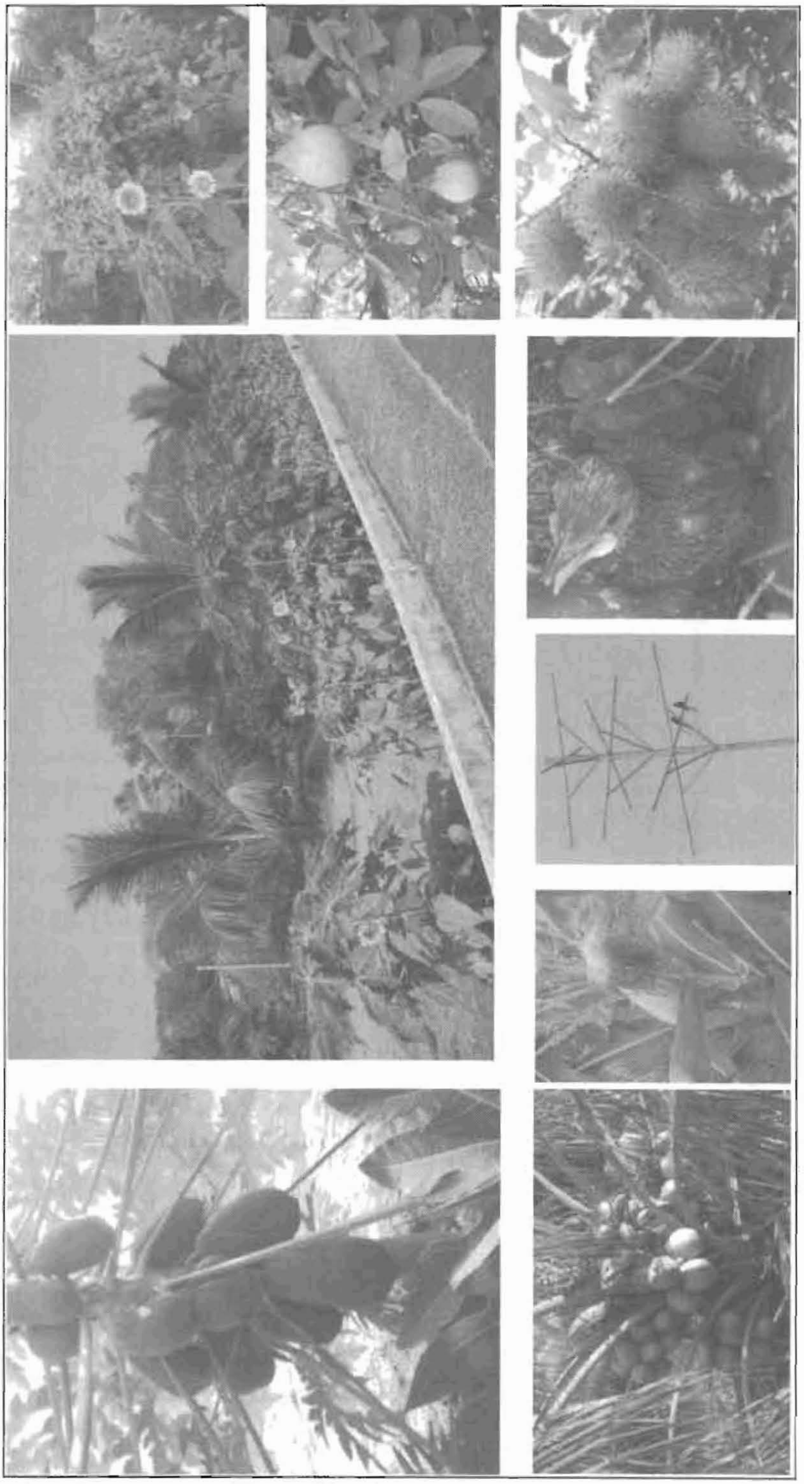


Figure 1.12: Crop Habitat Diversification for Pest Regression.

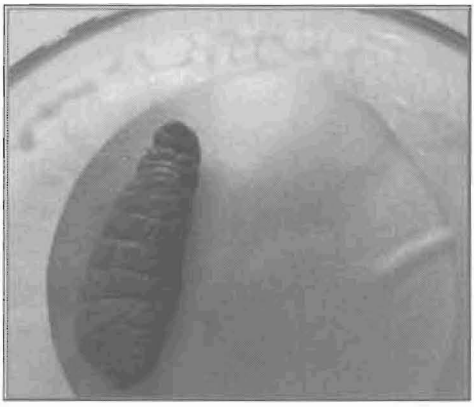


Figure 1.13: EPN Infected RPW.

3.3.8. Semiochemical

With the synthesis and availability of ferrugineol based pheromone lure (4-methyl 5-nonanone (Ferrugineone) and 4-methyl 5-nonanol (Ferrugineol) for RPW, the IPM programme was modified to incorporate pheromone traps and it was successfully utilized to combat the pest in coconut and date palm (Nair and Nair, 2002, Faleiro, 2006), provided all the precautionary steps involved in the use of pheromone traps are meticulously followed by the user. Installation of pheromone traps with ferrugineol embedded on nanoporous matrix @ 1 trap/ha was found effective in mass trapping of weevils (Figure 1.14). Impregnation of kairamonal blends containing host-induced volatiles enhanced the weevil catches substantially. Slow and sustained release of pheromone blends for a period of six months was achieved in nanoporous matrix along with the reusable strategy of the matrix (Subaharan *et al.*, 2014). A farmer-participatory community approach would be the key factor in successful field realization. Palms around the traps would be monitored strictly to avoid slippages, if any.

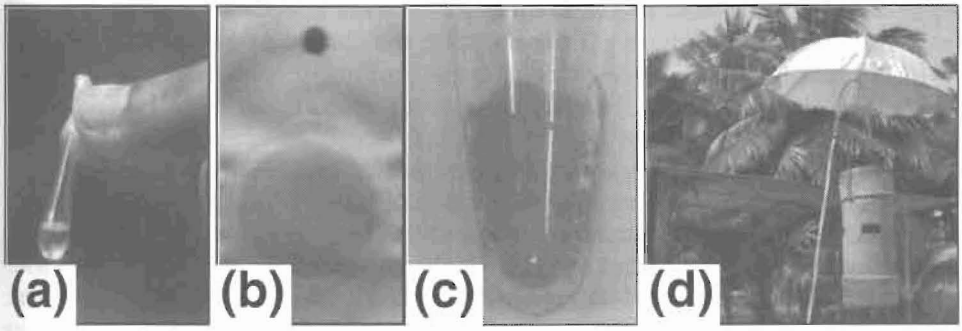


Figure 1.14: Pheromone Dispensation Strategies.

(a) Capillary vial, (b) Polymembrane matrix, (c) Nanoporus matrix and (d) Modified PVC pipe based pheromone trap.

4. Black Headed Caterpillar (*Opisina arenosella*) (Lepidoptera: Oecophoridae)

The black headed caterpillar, *Opisina arenosella* Walker is a serious defoliator pest of coconut in India and Sri Lanka (Rao *et al.*, 1948; Nirula, 1956a,b). The pest was reported to be a serious menace in other countries *viz.*, Myanmar (Ghosh, 1923), Sri Lanka (Jayaratnam, 1941) and Bangladesh (Alam, 1962).

4.1. Bioecology

Adult moth is grey coloured, 10-15 mm long with wing expansion of 20-25 mm. The male is smaller than female, with a slender abdomen ending in a short brush of scales. Female lays eggs on the abaxial leaf surface near old larval galleries which hatch in 5 days. Fecundity is about 137 eggs/female. Larval body is cylindrical, slightly compressed with three longitudinal reddish brown stripes dorsally and a black head. Average larval period is 42 days and the final instars measure about 154 mm long. There is a distinct pre-pupal stage for 2 days when the larva spins a whitish cocoon around its body and enters the pupal stage. The moth emerges out in about 12 days (Figure 1.15). The total life cycle from egg to adult takes about 8-10 weeks. The adult moths live for about 5-7 days (Nirula, 1956a; Nirula *et al.*, 1951; Chandrika and Sujatha, 2006).

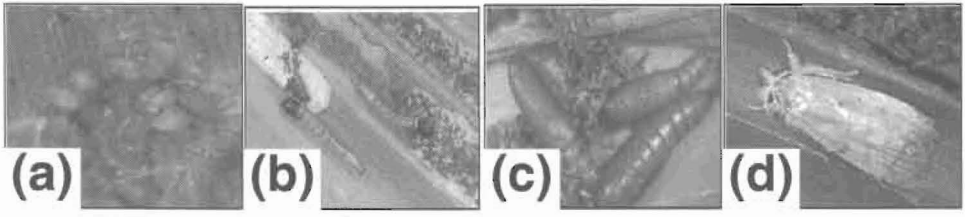


Figure 1.15: Life Stages of Coconut Black Headed Caterpillar.
a) Eggs, b) Larvae, c) Pupae and d) Adult moth.

4.2. Damage

The caterpillars of *O. arenosella* make silken webs supported with excreta and leaf bits and hiding in these galleries feed on the chlorophyll containing abaxial leaf tissues. The damage symptom is quite prominent with conspicuous grey patches on the upper frond surface. Infestation starts from the outer whorl of fronds and proceeds inwards. Damage results in drying of leaves, reduction in rate of production of spikes, increased premature nut fall and retarded growth (Lever, 1969). In extreme cases drying of 80-90 per cent of leaves on the palm crown leaves a burnt appearance to the plantation (Figure 1.16). In coconut frond, drying occurs due to many reasons like lightning, drought and diseases *etc.* and hence close examination of leaves for presence of pest stages is essential to identify pest problem. As the pest attack directly affects chlorophyll content of leaves, it get reflected in yield and a crop loss of up to 45 per cent in terms of nut yield was recorded from infested palms in the succeeding year of severe pest incidence apart from rendering the leaves unsuitable for thatching and other purposes (Chandrika *et al.*, 2010a).

Figure 1.16: Coconut Palms Infested by *O. arenosella.*

Sporadic pest outbreaks occur usually under favourable conditions. The pest infestation on coconut palms is usually severe during dry spells of summer which gets worsened in drought and water stress conditions especially in certain localities of Karnataka and Andhra Pradesh. Generally in the West Coast of India, pest infestation reaches peak in hot summer months of February to May. On the East Coast maximum population is reported from April to June. After the onset of monsoon, there will be decline in the population of the pest, but there is a chance of pest build up in the endemic areas from November – December. Hence, monitoring the endemic areas regularly at monthly intervals from November onwards helps in locating pest attack at a very early stage itself.

4.3. Pest Management

The pest can be effectively managed by the biological control methods. However, an Integrated Pest Management (IPM) strategy is recommended in severe out break conditions.

4.3.1. Mechanical Method

Cutting and burning the infested leaves/leaflets at the early infestation stage can be practiced to prevent pest buildup. In case of very severe infestation also, removal and burning of fully dried 2-3 outer whorl of leaves is recommended to kill the pupae and other pest stages. Careless discarding 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 leaves/leaflets to pest free areas as such or using pest-infested leaves for wrapping other commodities for transporting to newer areas.

4.3.2. Chemical Method

Since a very rich natural enemy fauna is associated with the pest in the field, chemicals are generally not being encouraged for pest management of *O. arenosella*. In case of very severe outbreaks, one spray of chlorantraniliprole @ 0.1ml/L of water (0.002 per cent) is recommended. Spray solution has to reach the underside of fronds to drench the larval galleries of the pest. Due to the difficulty experienced in palm climbing and spraying tall palms, chemical spraying recommendation is at a low profile in IPM.

4.3.3. Biological Method

Parasitoids and predators play an important role in the natural biological suppression of *O. arenosella* (Pillai and Nair, 1993). A checklist of the parasitoids, predators and pathogens of *O. arenosella* occurring in India and SriLanka was prepared by Dharmaraju (1962). Information on natural enemies of the pest was documented by various workers (Mohamed *et al.*, 1982, Narendran, 1985; Sathiamma, 1993; Pillai and Nair,1993). As the perennial nature of the crop permits a continuous interaction between the natural enemy and the pest without ecological upheavals, bio intensive-IPM has been recommended as the ideal and sustainable solution for the management of *O. arenosella* (Cock and Perera, 1987; Sathiamma, 1993). Field performance on biological suppression of coconut leaf eating caterpillar through release of stage specific parasitoids was established as early as 1920s (Nirula, 1956a; Rao *et al.*, 1948) and successful field biosuppression of this pest by release of parasitoids is well documented (Sathiamma *et al.*, 1996; Cock and Perera, 1987; Sathiamma, 1993; Mohanty *et al.*, 2000; Chandrika and Sujatha, 2006; Venkatesan *et al.*, 2006; Sujatha and Chalam, 2009).

Among coconut pests, the black headed caterpillar in the natural environment is attacked by the highest number of parasitoids and predators. The major parasitoids include the larval parasitoids *Apanteles taragamae* Wilkinson, *Bracon hebetor* Say, *Goniozus* (*Perisierola*) *nephantidis* Mues., the pre pupal parasitoid *Elasmus nephantidis* Rohw., and the pupal parasitoids *Brachymeria nosatoi* Habu, *B.nephantidis* Gahan, *B.atteviae* Joseph, *B.lasus* Walker, *Antrocephalus hakonensis* Ashmead, *Trichospilus pupivorus* Ferr., *Xanthopimpla punctata* F.,and *X.nana nana* Schulz.

Among the 40 species of parasitoids recorded from India (Pillai and Nair, 1993), the larval parasitoids *G. nephantidis* (Bethylidae), *B. brevicornis* (Braconidae), the prepupal parasitoid, *E. nephantidis* (Elasmidae), and the pupal parasitoid *B. nosatoi* (Chalcididae) are the most promising ones (Figure 1.17). The major desirable attributes of these parasitoids are their greater host searching ability, production of higher proportion of females, occurrence throughout the year and their distribution in all pest infested areas. Techniques have been developed for mass production of the promising parasitoids. The pest-infested area should be monitored regularly and parasitoid releases should be initiated at the post-monsoon period during November

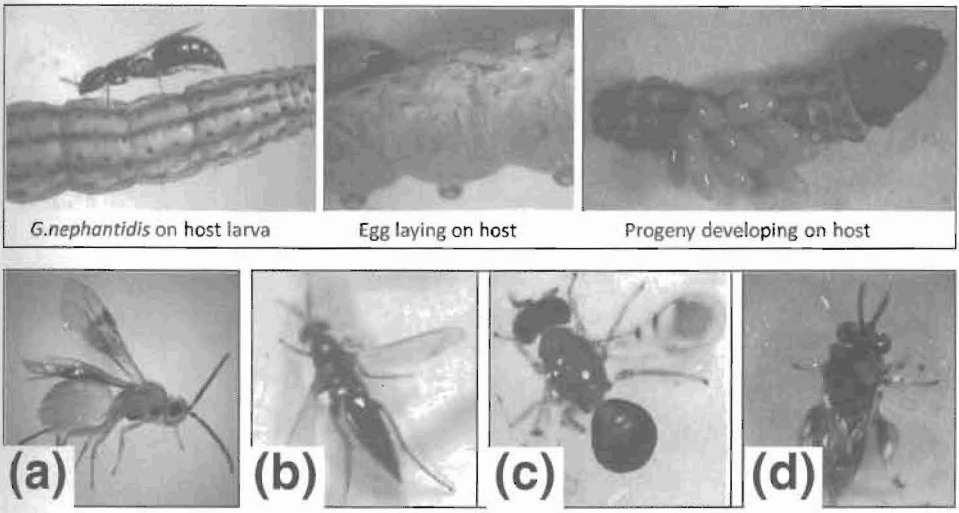


Figure 1.17: Parasitoids of *O.arenosella*
(a) *B. brevicornis*, (*b*) *E. nephantidis*, (*c*) *T. pupivora* and (*d*) *B. nephantidis.*

– December at the very beginning of pest incidence. Releases of parasitoids are to be synchronized with the stage of pest in the field at fixed dosages at fortnightly intervals till the pest population is suppressed. Presence of larvae in the leaflets should be confirmed before release of parasitoids to avoid unnecessary wastage of parasitoids. The parasitoid *G. nephantidis* is released if the pest is at 3rd instar larval stage or above at the rate of 20 parasitoid/palm and *B. brevicornis* at the rate of 30 parasitoid/palm. The pre-pupal parasitoid, *E. nephantidis* and pupal parasitoid, *B. nosatoi* are also very effective in managing the pest. They are released at the rates of 49 and 32 per cent respectively for every 100 pre-pupa and pupae estimated to be present on the palm (Sathiamma *et al.*, 1996; Chandrika *et al.*, 2010b). *G. nephantidis* adults could be released at the trunk (at 1.2 metre height from the ground level) of the coconut palm for the management of *O. arenosella* instead of releasing at the crown region of the palm or arbitrarily on unit area basis (Venkatesan *et al.*, 2003). Feeding the parasitoids with honey and exposing the newly emerged parasitoids to the host odours (smell of the volatiles of the injured *O. arenosella* larvae and host feeding gallery volatiles) was found to improve the host searching efficiency of *G. nephantidis* (Subaharan *et al.*, 2005). *G. nephantidis* and *B. brevicornis* could easily be mass multiplied on larvae of the rice moth *Corcyra cephalonica*. The pre-pupal parasitoid, *E. nephantidis* is a highly host and stage specific parasitoid and always requires a steady supply of pre-pupa of *O. arenosella* for mass multiplication. Techniques were evolved for mass multiplication of the promising parasitoids (Sathiamma *et al.*, 1999). Venkatesan *et al.* (2006) demonstrated that four releases of *G. nephantidis* @ 10 adults/palm at fifteen days interval could suppress the pest population and the cost of release of the parasitoid/ha is Rs. 2100.

The cost of production is calculated on the basis of the production of the host insect as well as the parasitoid. Cost-Benefit Ratio (CBR) of the production of *G. nephantidis* was 1:1.45. This technology is highly feasible and can be adopted for the large scale production of the parasitoid. Localized production of *G. nephantidis* could be taken up at village or district level especially by farmers, unemployed graduates, private and public sector units and NGOs. This module can be scaled up to any level (Venkatesan *et al.*, 2007).

Insect and spider predators are abundant in the coconut ecosystem. The dominant insect predators are the carabid beetles *Parena nigrolineata, Calleida splendidula;* anthocoreid *Cardiastethus exiguus,* Chrysopids *Ankylopteryx* sp. *Chrysopa* sp. *etc.* A total of 26 species of spiders were recorded along the pest of which *Rhena, Sparassus* sp. and *Cheiracanthium* sp. are the major predators (Sathiamma *et al.*, 1987). Predatory ants also play major role in population reduction of *O. arenosella* in the field. Although some pathogens such as *Serratia* sp. and *Aspergillus* sp. were reported on *O. arenosella* they are not so far exploited as effective biocontrol agents (Sathiamma *et al.*, 2000).

4.4. Area-wide Farmer Participatory Demonstration

Field release of the three stage-specific parasitoids *viz. G. nephantidis, E. nephantidis* and *B. nosatoi* at fixed norms and intervals in a heavily infested coconut garden (2.8 ha) for a period of five years resulted in highly significant reduction (94 per cent) in *O. arsenosella* population (Sathiamma *et al.*, 1996). The control plot where no release was made, the population was highly fluctuating. In the parasitoid released plot the percentage of parasitism also remained high 3.7-47.6 (*G. nephantidis*), 0-55.6 (*E. nephantidis*) and 0-71.4 per cent (*B.nosatoi*) and the parasitoids continue to exert check on the buildup of the population (Sathiamma *et al.*, 1996). Follow up observation revealed that even after three years no build up of the pest was noted in the released site. Chandrika and Nair (2002) had reported 52.6 and 94.7 per cent reduction in pest population after one and two years respectively, of parasitoid release in a *O. arenosella* infested tract in Kerala.

Chandrika *et al.* (2008) has reported 93-100 per cent reduction in *O. arenosella* population in coastal Kerala and Karnataka in a period of two years with regular monitoring and release of stage specific parasitoids *viz., G. nephantidis, B. brevicornis, E. nephantidis* and *B. nosatoi.* Mohanty *et al.* (2000) had reported biological pest suppression of *O. arenosella* in coastal districts of Orissa by the release of parasitoids. Sujatha and Chalam (2009) had reported biological suppression of *O.aerenosella* in Andhra Pradesh by release of parasitoids. ICAR-CPCRI has undertaken biosuppression of the pest in Arsikere, Karnataka resulting in complete recovery of palms from black headed caterpillar attack (Figures 1.18 and 1.19).

5. Nut Infesting Eriophyid Mite (*Aceria guerreronis* Keifer) (Eriophyidae : Acarina))

Among the various acarine fauna affecting coconut palm, the eriophyid mite, *Aceria guerreronis* is the most destructive pest. The history of the occurrence of *A. guerreronis* on coconut starts with the first report from the Guerrero State, Mexico

Figure 1.18: Black Headed Caterpillar Infested Area– Jajur Village, Arsikere during 2013.

Figure 1.19: Palms Completely Recovered from Black Headed Caterpillar Infestation.

by Keifer in 1965. *A. guerreronis* is reported globally from 30 countries of Tropical America, Africa and Asia (Mariau, 1969; Mariau, 1977, 1986; Hall and Bacerril, 1981; Medina and Abreu, 1986; Griffith, 1984; Howard *et al.*, 1990; Flechtmann, 1989; Moore and Alexander, 1985; Fernando *et al.*, 2000; Seguni, 2002). In India, the first report of this mite was from Amballur Panchayat in Ernakulam district of Kerala by Sathiamma *et al.* (1998). Within a short period of time the mite had spread rapidly and at present its occurrence is seen in entire coconut growing tracts of India covering West and East Coast, North-East regions and Lakshadweep Islands (Nair, 2000; Ramaraju *et al.*, 2000; Mallik *et al.*, 2003; Khan *et al.*, 2003, Mullakoya, 2003). An exhaustive bibliography of coconut eriophyid mite was published by Rethinam and Muhartoyo (2003).

5.1. Bioecology

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, finely ringed and bears two pairs of legs at the anterior end (Figure 1.22). Fecundity is 100-150 eggs. The eggs hatch into protonymphs which moult to deutronymphs and finally to adults and the total life cycle is completed in 7-10 days. Under favourable conditions, the high reproductive potential and shorter life cycle of the mite results in the enormous multiplication of the colonies. In India, the pest activity has been observed throughout the year with the population peak during the summer months (Rajan *et al.*, 2010). Observations on the population of the mite within various age groups of the nuts showed that third and fourth bunches harbour maximum mite population.

Figure 1.20: Eriophyid Mite Damage Symptoms on Nuts of Varying Maturity.

5.2. Nature of Damage and Crop Loss

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. The dispersal of the pest takes place mainly through wind. Honeybees and other insects visiting inflorescence of coconut also act as agents for dispersal. Appearance of elongated white streaks below the perianth of the developing nut is the first external symptom of mite infestation on young buttons (Figure 1.21). Further these streaks form triangular

Figure 1.21: Progression of Eriophyid Mite Infestation.

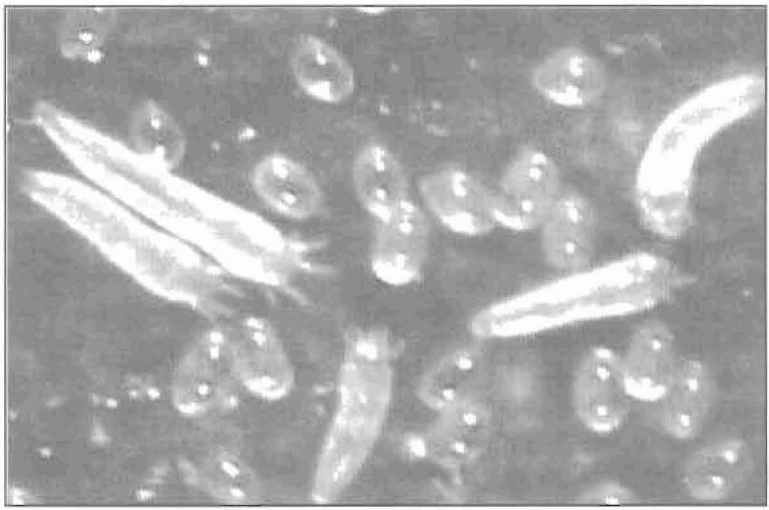


Figure 1.22: Eriophyid Mite Colony under Microscope.

yellow patches. Draining of sap by the feeding activity of the mite colony results in drying of infested tissues and subsequently browning of affected portion. As the nut grows, warts and longitudinal fissures appear on the nut surface (Figure 1.20). 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 (Nair, 2000).

In India, during 1998 when the pest outbreak was reported almost 70 per cent of nuts were affected showing malformation and reduction of nut size (Nair, 2000). Surveys carried out in Alappuzha district, Kerala during 2000 has shown significant reduction in crop loss due to mite incidence indicating an average loss of 30.94 per cent in terms of copra and 41.74 per cent in husk production (Muralidharan *et al.*, 2001). An average loss of copra yield to the tune of 27.5 per cent was reported from Tamil Nadu (Ramaraju *et al.*, 2000) and 18-42 per cent in Karnataka (Mallik *et al.*, 2003). Naseema Beevi *et al.* (2003) reported 26-53 per cent reduction in fibre length due to mite infestation. But observations recorded during subsequent years revealed overall reduction in incidence and intensity of pest in areas of its initial occurrence (Nair *et al.*, 2003). Rajan *et al.* (2007) reported that the loss in terms of copra in Southern districts of Kerala ranged from 8-12 per cent compared to an

average loss of 25 per cent in initial years. With acute summer and drastic increase in temperature pest incidence was found to be higher especially in dwarf genotypes and segregants leading to excessive miniature nuts.

5.3. Varietal Preference

The nut traits *viz.*, colour, shape and size influence the severity of mite infestation. A coconut variety exhibiting complete 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 x West African Tall (WAT)] were reported to show different degrees of tolerance to mite attack in different countries of the world (Mariau, 1986). Field observations indicated lesser mite incidence in Chowghat Orange Dwarf (COD) variety. Kalpaharitha (a selection of Kulasekaram Tall) recorded lowest mite incidence in the field at ICAR-CPCRI and could be a preferred choice in endemic zones (Josephrajkumar *et al.*, 2016).

5.4. Pest Management

Over five dozen systemic and contact insecticides have been evaluated world over and recommended from time to time for management of coconut mite (Nair *et al.*, 2005). 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.*, 2005; Ramaraju *et al.*, 2000; Saradamma *et al.*, 2000; Mallik *et al.*, 2003). Owing to the concern over environment contamination by repeated chemical pesticides application, currently botanical pesticides *viz.*, neem based biopesticides are recommended for management of the pest in the field.

5.4.1. Cultural

Removal of dried spathes, inflorescence parts, fallen nuts *etc.* and burying them in the soil or burning them reduces the pest inoculum and consequent infestation.

5.4.2. Botanicals

Spraying 2 per cent neem oil –garlic-soap mixture or azadirachitn 10,000 ppm @ 0.004 per cent or root feeding with neem formulations containing azadirachtin 50,000 ppm at 7.5 ml or azadirachtin 10,000 ppm at 10 ml with equal volume of water three times during March-April, October-November and December-January is recommended for the management of the pest (Mallik *et al.*, 2003; Nair *et al.*, 2003; Rajan *et al.*, 2009). Three sprayings of palm oil (200 ml) and sulphur (5g) emulsion on the terminal five pollinated coconut bunches during January-February, April-May and October-November evinced significant reduction (67.4 to 69.8 per cent) of mite incidence (Josephrajkumar *et al.*, 2016).

Preparation of Spray Solution

To prepare one litre of 2 per cent neem oil-garlic soap emulsion, 20 ml pure neem oil, 20 g cleared garlic pearls and 5g washing soap are required. Dissolve the soap in 500 ml of water and add neem oil to this solution and mix it well. Grind garlic pearls well, mix it well in 500 ml of water and add this to the soap-neem oil

mixture by sieving through a cloth to remove debris of garlic pearls. The mixture is stirred well and can be used for spraying. The pesticide mixture shall be used on the day of preparation. Pesticide should be applied as fine droplets on 2 to 6 months old bunches so as to provide its penetration into the perianth lobes.

Root Feeding Method

In root feeding method, an active semi hard, pencil thick and brownish coloured root was selected and a slanting cut of 45° at the tip portion was made with a sharp knife. Botanical formulation containing 7.5 ml of Azadirachtin or 10 ml Azadirachtin was mixed with equal volume of water and dispensed in a polythene pouch. The cut end of the root was immersed in the botanical formulation up to the bottom of the pouch and tied with a twine. Care should be taken to avoid any injury or spillage of the pesticide solution and cover the root gently with leaf mulch or loose soil.

5.4.3. Biological Methods

Presently, emphasis is given for development of biocontrol strategies as they are safe and ecofriendly and vital in sustainable management of the pest. The fungal pathogen, *Hirsutella thompsonii* (Figure 1.23) has received considerable attention throughout the world as the most effective natural enemy of eriophyid mite of coconut (Kumar, 2002; Beevi *et al.*, 1999; Kumar *et al.*, 2001). Application of talc-based preparation of *H. thompsonii* @ 20 g/1/palm containing 1.6 x 10^8 cfu with a frequency of three sprayings per year reduced mite population significantly (Chandrika *et al.*, 2014). The predatory mite *Neoseiulus baraki* is effectively utilized for biomanagement of the pest in Sri Lanka. Release of 5000 *N. baraki* at 3-4 month intervals on to quarter of the coconut plantation for 2 years has been recommended to control the coconut mite (Aratchige *et al.*, 2012).

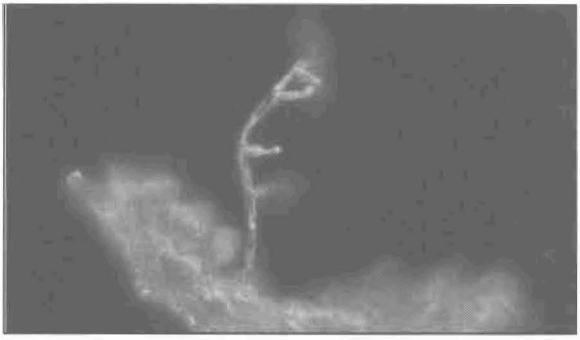


Figure 1.23: Mycelia of *H. thompsonii* Emerging from Infected Mite.

5.4.4. Palm Health Management

The nutritional status of the palm plays a significant role in the management of the pest. The nutrient management package consists of balanced application of NPK fertilizers at recommended doses in two splits (Urea 1.0 kg, super phosphate 2.0 kg, muriate of potash 2.5 kg); application of neem cake @ 5 kg per palm per year; *in*

situ growing of green manure crops like cow pea or Sunn hemp (seed rate of 100g/ palm basin) in the garden and its incorporation in coconut basin and conservation of soil moisture by appropriate mulching methods (Rajan *et al.*, 2009). IPM package was demonstrated in farmer's fields at Krishnapuram village, Kerala covering 25 ha area of coconut gardens in 208 farmer holdings. Here the integrated nutrient management technology was implemented along with recommended practice of azadirachtin spraying thrice a year and the mite incidence could be brought down to 15.3 per cent from 68 per cent over a period of three years (Rajagopal *et al.*, 2003).

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

6.1. Damage and Symptoms

The major white grub species infesting coconut is *Leucopholis coneophora* and occurs mainly in sandy loam soil and attains pest status in discontinuous patches along the Western coastal tracts especially of Kerala and Karnataka. Two closely related species *viz.*, *Leucopholis burmeisteri* Brenske and *Leucopholis lepidophora* Blanchard were also reported to infest coconut especially in Karnataka. The subterranean grubs are highly polyphagous and feed on tuber crops, banana, arecanut, rhizomes and vegetables *etc.* which are grown as intercrops in coconut gardens. In nursery seedlings the grubs (Figure 1.24) feed on tender roots and also tunnel into the bole and collar regions resulting in the drying of the spindle leaves followed by gradual death of the seedlings. Continuous feeding by the grubs on mature palms results in yellowing of leaves, premature nut fall, tapering of stem, delayed flowering, retardation of growth and reduction in yield. The pest has an annual life cycle. Adult beetles are chestnut brown coloured (Figure 1.24) and they emerge out of soil after pre-monsoon showers in May–June. Peak grub population is seen in the coconut basin during August–October (Abraham and Mohandas, 1988; Chandrika and Vidyasagar, 1993).

6.2. Pest Management

Deep ploughing during pre and post-monsoon periods exposes the grubs to predators. Mechanical collection and destruction of beetles during peak emergence period is deemed as an effective management practice and was found to be the highly

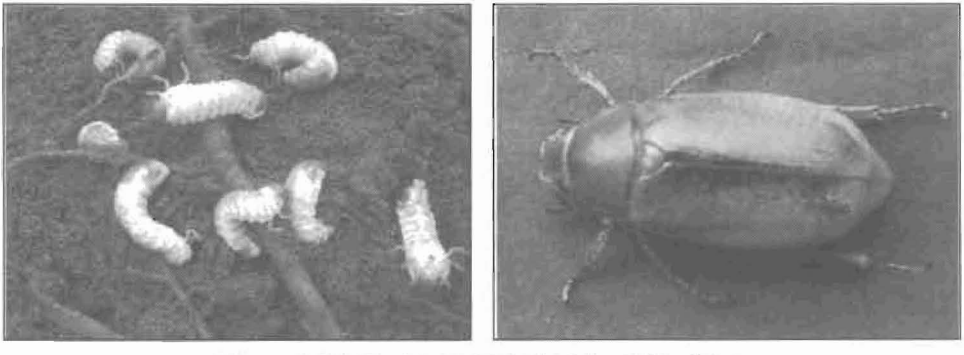


Figure 1.24: Grubs and Adult of *L.coneophora*.

significant than light trap collection. Drenching the root zone with chlorpyrifos 20EC @ 2.5ml/L or imidacloprid 17.8 SL @ 675 ml/ha or bifenthrin 10 EC @ 20 litre/ha during May-June and September- October are recommended for management of root grubs of coconut (ICAR-CPCRI, 2015). The insecticide has to be applied evenly in the active root zone of the palm. A scoliid wasp, *Campsomeriella collaris* (Fabricius), eugregarine protozoan pathogen *Pseudomonocystis* sp., and *Codyceps* sp. were found to parasitize the grubs in the field under natural condition. Predatory birds *viz.*, king fisher, brahminy kite and crow were effective predators of cockchafers during ploughing and adult emergence period. Drenching aqua suspension of entomopathogenic nematode, *Steinernema carpocapsae* in the interspaces at 5-10 cm depth with 1.5 billion IJ/ha and need based repeated application is effective for reducing grub population.

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

The coreid bug, *Paradasynus rostratus* Distant is a potential emerging pest of coconut palm. Eggs are laid on the spadix and leaf sheath and the emerged first and second instar nymphs congregate on spadix and buttons. Nymphs and adults puncture the meristematic regions of tender buttons (1-3 months old) injecting toxin around the feeding site causing necrosis and these spindle-shaped depressions could be visible when the perianth of shed button is removed (Figure 1.25). Infested female flowers get dried and stay attached to the inflorescence. Most of the infested buttons and tender nuts shed down. Retained nuts on the bunch develop furrows and crinkles on their husks and are malformed. In many cases gummosis can be seen on such damaged nuts. Crop loss inflicted by coreid bug on coconut include production of barren inflorescence (8-9 per cent), shedding of button and immature nuts (18-66 per cent), qualitative and quantitative loss in fruit components [reduction in nut water (52 per cent) and husk weight (38.2 per cent)], incomplete kernel formation in severely infested nuts and puny nuts (12 per cent) in severely infested plantations.

7.1. Pest Management

Regular crown cleaning has to be undertaken to destroy eggs and immature stages of the pest. Spraying of azadirachtin 300 ppm @ 0.0004 per cent (13 ml/l) or chlorantraniliprole (0.018 per cent) @ 0.3ml/l on young pollinated coconut bunches during May-June and September-October was found effective for satisfactory control of the pest in the field (Chandrika *et al.*, 2016b). Among the natural enemies, the weaver ant, *Oecophylla smaragdina* is found to be the most efficient predator of coreid bug in the field. *Chrysochalcisea indica. Chrysochalcissa oviceps* and *Gryon homeoceri* were identified as potential egg parasitoids.

8. Scale Insects

In coconut, four species of armoured scales *viz.*, *Aonidiella orientalis*, *Aspidiotus destructor*, *Lepidosaphes megregori*, *Chionaspis* sp. and three species of soft scales *viz.*, *Ceroplastes floridensis*, *Coccus hesperidum*, *Vinsonia stellifera* were recorded from Kerala, Tamil Nadu and Minicoy (Lever, 1969; Rajan *et al.*, 2009; Howard *et al.*,

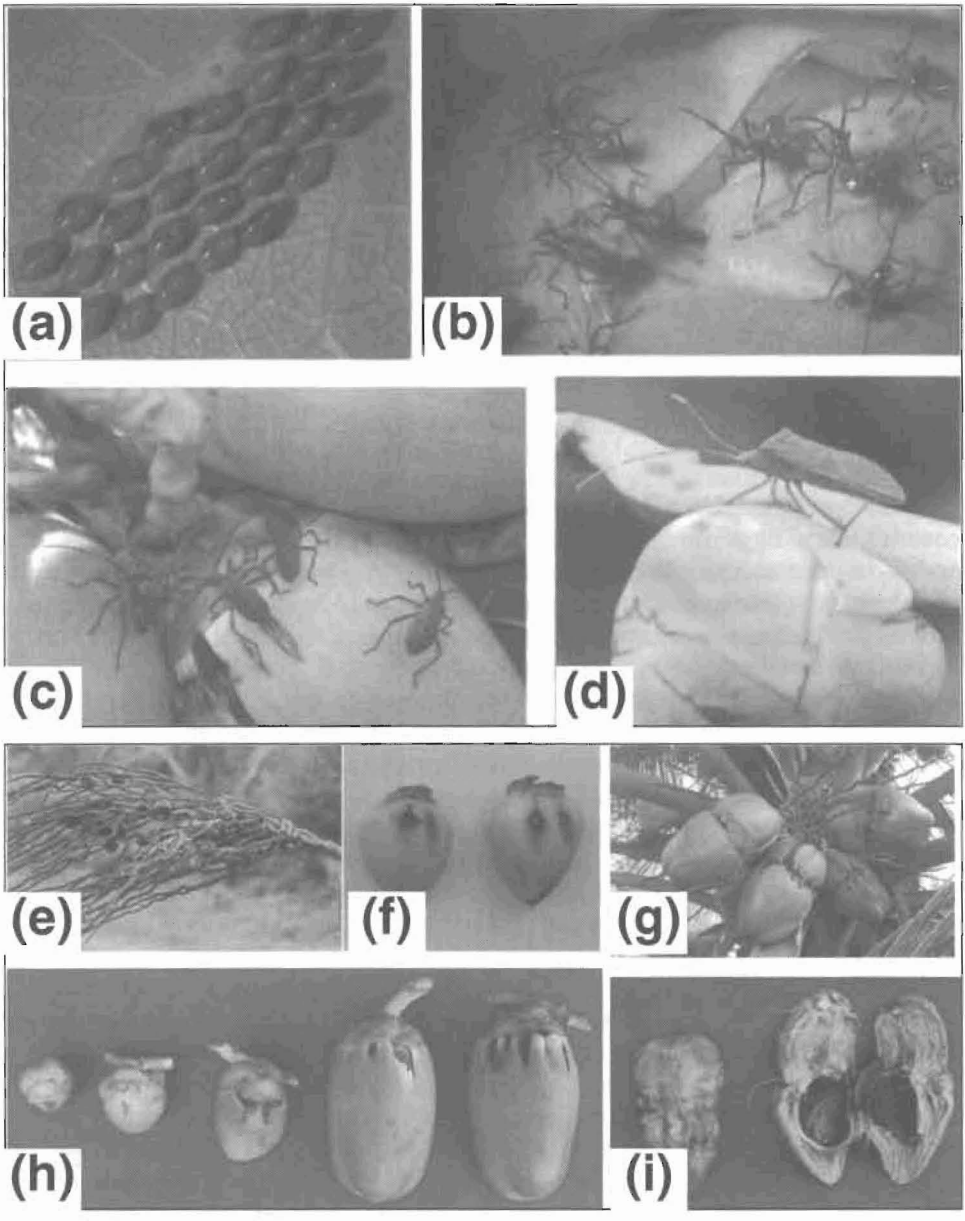


Figure 1.25: Life Stages and Damage Symptoms of Coreid Bug.
(a) Eggs, (b, c) Nymphs, (d) Adult, (e) Drying of inflorescence, (f, h) Infested buttons, (g) Infested mature nuts, (i) Barren nuts.

2001) (Figure 1.26). Scale insects are distributed throughout tropical and subtropical regions of the world, particularly on Islands and is present in all coconut growing tracts globally. Young coconut palms aged 10-15 years are more vulnerable to

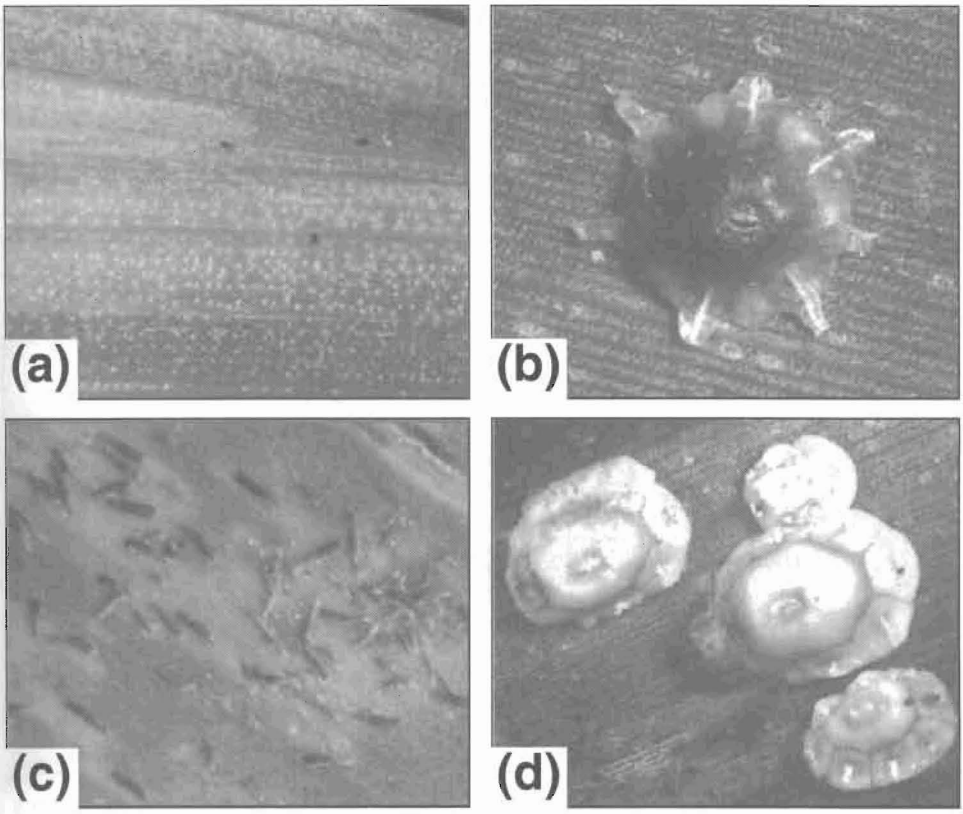


Figure 1.26: Scale Insects

(a) *Aspidiotus destructor;* (b) *Vinsonia stellifera,* (c) *Lepidosaphes megregori,* (d) *Ceroplastes floridensis.*

coconut scale damage. The scale infests mainly on the undersurface of leaves, but occasionally they attack frond stalks, flower clusters and young fruits.The bright yellow colour of affected palms is clearly visible from a great distance. In extreme cases, the leaves dry out and entire fronds drop off. The coconut scale *Aspidiotus destructor* Sign. is one of the emerging problem especially in tune with climate change. The scale insect forms encrustations on the lower surface of the leaves. They suck sap from the leaves and the encrustations block the stomata. Affected leaves became yellow in color. *Aspidiotus destructor* completes the egg to adult period in 30-35 days. They also infest the inflorescence and nuts, which under severe infestation results in bottom shedding and decrease in nut production. Periodic outbreaks have been reported from several places during the hot months of the year. *Lepidosaphes megregori* Banks is the pink colored hard scale infesting the upper leaf surface and also on nuts. *Aonidiella orientalis* Newstead is another species infesting the upper leaf surface and also on nuts. Other scale insects recorded on coconut are *Hemiberlesia lataniae* Sign., *Coccus hesperidim* L. infesting nuts and spikes, *L. taplevi* Williams infesting leaves, spike and nut and *Pseudaulacaspis cockerelli* Cooley infesting leaves and nut (ICAR-CPCRI, 1987; Jalaluddeen *et al.*, 1991).

Strict surveillance on the transport of infested plant parts across borders should be accomplished. Heavily infested twigs and branches are to be pruned off to eliminate scales when infestations are on limited parts of the plant. Three sprays of 2.5 per cent fish oil rosin soap or neem oil 0.5 per cent were found to be effective in reducing the population of *A. destructor*. Coccinellid beetles, *Chilocorus nigritus, Cryptognatha nodiceps, Pseudoscymnus anomalus, Pseudoscymnus dwapikalpa, Scymnus luteus, Rhyzobius* spp. and *Telsimia nitida* suppresses the pest population by predation. A moderate level outbreak of *Aspidiotus destructor* in Kerala was effectively suppressed by the lady beetle and immature grubs of *Sasajiscymnus dwapikalpa* (Figure 1.27).

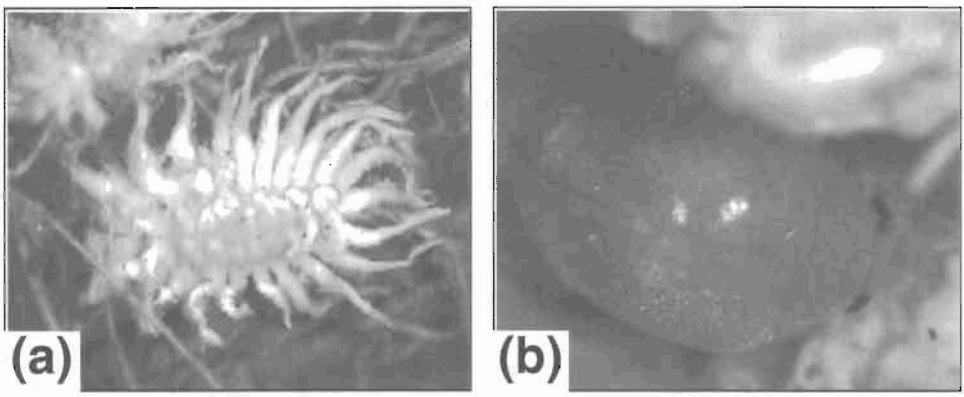


Figure 1.27: Predators of Scale Insect–*Sesajiscymnus dwapikalpa*
(a) Grub and (b) Beetle.

9. Mealybugs

Mealybugs are soft-bodied, sap feeding insects with white, powdery to granular waxy filaments protruding from margins and tail end. The insects appear as covered with cotton which are hydrophobic sappy secretions from numerous fine pores of diverse structure over the insect's body (Howard *et al.*, 2001). Presence of triocular pores with three elongated loculi is typical of mealybugs. Antennae are present and legs are well developed. Mature females measure 3-5 mm in length and are elliptical from the dorsal view and convex from side view. Nymphs and adult mealybugs suck the sap by inserting their long and thin stylets into the epidermis. Growing points of palms like spindle leaves, floral parts, leaflets and roots are primarily infested by mealybugs. They are mostly aggregated, feed continuously at the same site for a longer period of time and remain sedentary in most cases to disturbances due to slow retraction of stylets. Feeding symptoms include chlorosis, stunting of seedlings, leaf deformation, early fruit drop, heavy build up of honey dew and severe infestation leads to stunted growth of seedlings. Ants are consistently attracted by honey dew which also assist in phoretic dispersal of crawlers.

Palmivorous mealybug species are distributed widely but 50 per cent are in the genera *Dysmicoccus, Planococcus, Pseudococcus* and *Rhizoecus*. The most common reported mealybugs of palms are known primarily as pests of other crops on account

of their wide adaptability, dissemination, establishment and long-term survival in diverse localities (Howard *et al.*, 2001). Six species of mealybugs are associated with coconut in India. They are *Palmicultor palmarum*, *Pseudococcus longispinus*, *Pseudococcus cocotis*, *Dysmicoccus* sp., *Nipaecoccus nipae* and *Rhizoecus* sp. (Figure 1.28) (Josephrajkumar *et al.*, 2012; Chandrika *et al.*, 2016). Destruction of highly infested plant parts at the initial stages of infestation and removal of alternate weed hosts in the immediate vicinity is practiced for pest management. As the pest is naturally suppressed by predators especially coccinellid beetles, conservation of coccinellid lady beetles in the ecosystem is recommended. In case of pest outbreak, regular monitoring and spot application with 0.5 per cent neem oil emulsion two-times in fortnightly intervals during summer was recommended to avoid further spread of mealybugs from infested fields.

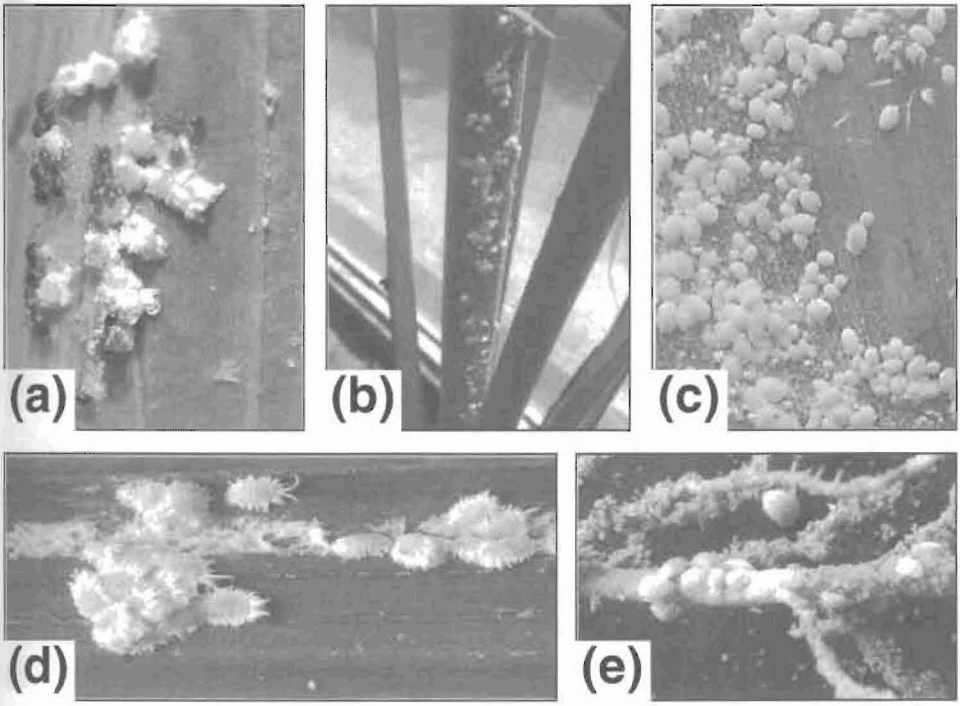


Figure 1.28: Mealybugs.

(a-b) *Palmicultor palmarum*, (c) *Dysmicoccus finitimus*, (d) *Pseudococcus cryptus*, (e) *Nipaecoccus nipae*.

10. Whiteflies

Two types of whiteflies *viz.*, areca whitefly, *Aleurocanthus arecae* and spiralling whitefly *Aleurodicus* dispersus (Figure 1.29) have been recorded from coconut in India (David and Manjunatha, 2003; Chandrika *et al.*, 2007; Josephrajkumar *et al.*, 2010). Recently outbreak of a new invasive rugose spiralling whitefly *Aleurodicus rugioperculatus* Martin in parts of Kerala, Tamil Nadu, Andhra Pradesh and

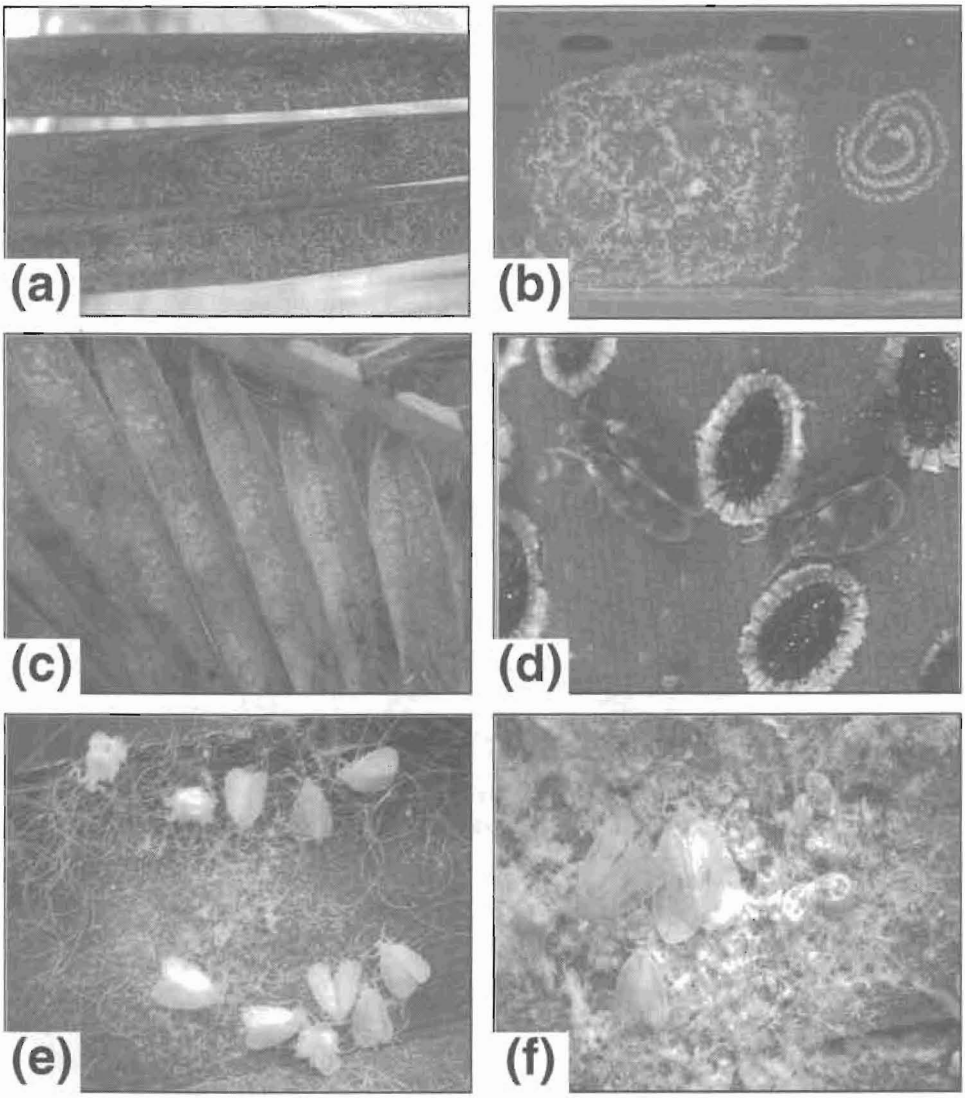


Figure 1.29. Whiteflies.

(a, d) *Aleurocanthus arecae*, (b, e) *Aleurodicus dispersus* and (c, f) *Aleurodicus* sp. *rugioperculatus*.

Karnataka in the year of deficit monsoon and weather changes is documented. Though observed in large-area, it was effectively suppressed by the parasitoid, *Encarsia guadeloupae* (Chandrika *et al.*, 2016, Shanas *et al.*, 2016). Adults of *A. arecae* are small (1-3 mm), fly-like, fragile and often smoky-greyish in colour. They are found feeding on mature coconut leaflets. Eggs are laid in circular to spiral rings on the abaxial surface of leaves. Immature stages secrete waxy substances in the exuviae. Nymphs and adults insert the stylets on plant tissues, feed on the phloem sap and secretes honeydew. Puparia are black coloured. These sugar-rich excreta support

sooty mould fungus interfering with photosynthesis (David and Manjunatha, 2003). The typical spiralling fashion of egg laying and feeding damage by *A. dispersus* was also recorded on various cultivars of coconut ranging from 1-6 colonies/leaflet. Dwarf coconut varieties *viz.*, Laccadive Green Dwarf, Laccadive Orange Dwarf and Laccadive Yellow Dwarf evinced more number of colonies than the tall cultivars *viz.* Benaulim, Laccadive Tall and Laccadive Micro. The susceptibility of dwarf cultivars was mainly attributed due to low canopy level that is in close proximity with other host plants in the immediate vicinity, whereas, in tall accessions the canopy is well isolated from other host plants. Young palms of tall varieties were also attacked by the pest (Josephrajkumar *et al.*, 2010). Whiteflies are naturally under ckeck attributing to the presence of effective bio-suppression agents

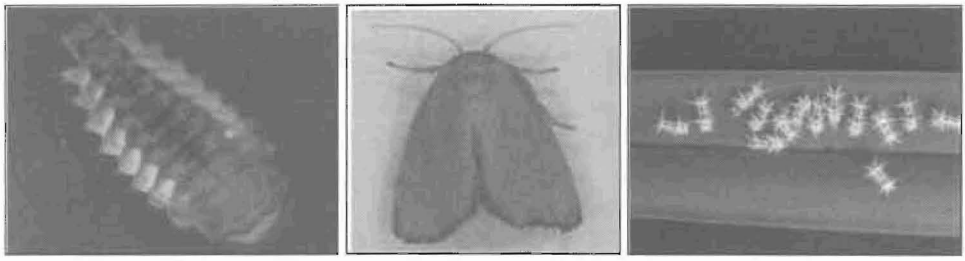
Lady beetles *viz.*, *Seragium parcesetosum*, *Jauravia pallidula* and a hump-backed nitidulid predator, *Cybocephalus* sp. were found predaceous on adults and nymphs of whiteflies. Eggs of *A. arecae* were also fed by an anthocorid bug in Kerala. Natural biological suppression is found to be very successful and no intervention with insecticides is recommended at this point of time (Chandrika *et al.*, 2007). *Encarsia* sp. nr. *haitiensis* and *Encarsia guadeloupae* were identified as potential parasitoids against *A. dispersus* (Ramani, 2000). Two different species of lady beetles *Chilocorus subindicus* and *Scymnomorphus* sp. were found predatory on spiralling whitefly as well as on coconut scale insects in the Minicoy island. Conservation of these lady beetles is therefore required for the natural suppression of the spiralling whitefly (Josephrajkumar *et al.*, 2010).

11. Slug Caterpillars, Darna (*Macroplectra*) *nararia*, *Contheyla rotunda*, *Latoia lepida* (Limacodidae : Lepidoptera)

Early-instar caterpillar feeds on undersurface of coconut leaflets by scrapping the surface tissues giving a glistening appearance on the feeding area. Leaf spot-like black halo marking develops on the feeding areas which later coalesce and form bigger lesions (Figure 1.30). Late instar caterpillars feed voraciously the leaf tissues leaving only the midribs and the feeding injury is often intensified by grey leaf blight fungus, *Pestalotiopsis palmarum*. Scorched/burnt appearance of leaves is the characteristic symptom observed in the field on severe infestation. In severely infested palms, premature drooping of leaves and shedding of nuts were also observed bringing drastic reduction in nut yield (Rajan *et al.*, 2011). High temperature (>39°C) and relative humidity (>85 per cent) flares up the pest as noticed in East Godavari during April-May. Establishment of light traps in endemic tracts could help in monitoring of the pest as well as reduce the population of moths (Sujatha *et al.*, 2011). Larvae of *M. nararia* are parasitized by *Eurytoma tatipakensis* Kur., *Euplectromorpha natadae* Kur. and *Secodes narariae* Kur under natural condition. Good nutrition as well as irrigation is required to recoup the infested palms which take about 20-24 months.

12. Rodents, *Rattus rattus wroughtoni*

Rats damage tender coconuts by scooping a small hole about 5 cm diameter near the stalk region (Figure 1.31) and these damaged nuts are retained in the bunch



Contheyla rotunda Grub and Adult Moth *Latoia lepida*

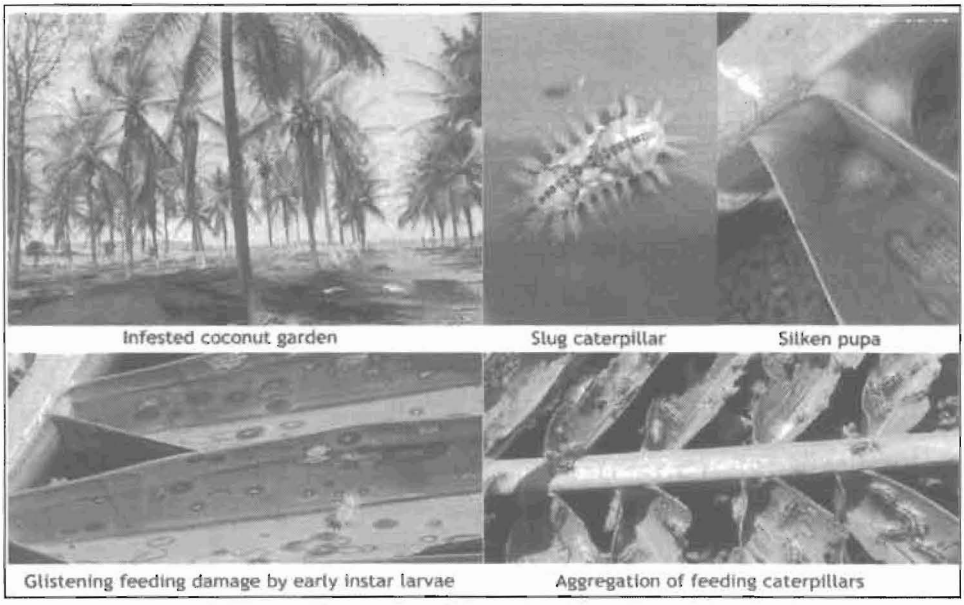


Figure 1.30: *Darna nararia* Infestation on Coconut.

for 2-6 days and later shed off. Fallen nuts with typical hole are seen around the basin of the palm. Three to six months old tender nuts are mostly preferred by this mammalian pest. Rats also damage leaf stalks, unopened spathe, female flowers and mature nuts in the field as well as the stored nuts. The intensity of damage is more during summer and early monsoon (April-June) and less during post-monsoon (August-October). Further, the damage increases when certain intercrops such as cocoa and cassava are cultivated along with coconut.

In coconut plantations, the black rats generally live on the crowns of the coconut palm by constructing nests. Hence, removal of dried leaves, spathes and matrix regularly expose the nesting placing of these rats to predators. A habitat alteration discourages rats from population build up on the crown. Application of 10 g Bromadiolone (0.005 per cent) blocks two times at an interval of 12 days on the crown of one tree out of every five trees is recommended for effective control of black rat. This method is highly cost-effective. If the damage is restricted to certain

Figure 1.31: Tender Coconuts Damaged by Rats.

palms, only such palms require baiting (Bhat *et al.*, 1993). Planting coconut seedlings in correct spacing as well as destruction of fallen fronds and other palm residues at regular intervals ward off the rat activity from coconut gardens. This method is highly cost-effective. If the damage is restricted to certain palms, only such palms require baiting. Wrapping the trunk of coconut trees using polythene sheets was found to reduce the damage by rats in Minicoy. Hanging a used fertilizer bag on the top of the crown could avoid nut damage effectively. Rat snakes and Barn owls are the common predators that control the rat population.

13. Menace of Invasive Pests

Accidental introduction of plant and animal pests, diseases and invasive alien genotypes poses threat to biosecurity. In this context we have to be alert and prepared on the major invasive pests of coconut in our bordering countries *viz.*, coconut leaf beetle (CLB), *Brontispa longissima* Gestro (Chrysomelidae: Coleoptera) and armoured scale insect, *Aspidiotus rigidus* Reyne (Diaspididae: Hemiptera) which are posing economic loss to coconut industry (Josephrajkumar *et al.*, 2015b,c).

13.1. *Brontispa longissima* Gestro (Chrysomelidae : Coleoptera)

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. Coconut leaf beetle (CLB) was originally described in 1885 from Aru Islands in Indonesia and from Papua New Guinea. Over a period of 130 years, it has widely spread in over 25 countries in Asia, Australia and Pacific Ocean Islands attacking a number of of cultivated and wild ornamental palm species in addition to coconut palms. Adult beetles measure 7.5-10.0 mm long and 1.5-2.0 mm wide, with a conspicuous orange to reddish pronotum (Figure 1.32). 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 (Figure 1.32).

Figure 1.32: *Brontispa longissima* and Infested Palm.

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 pupal parasitoid and *Asecodes hispinarum* Boucek (Hymenoptera : Eulophidae), a larval parasitoid have been successfully used in several countries to control the beetle.

13.2. *Wallacea* sp.

The chrysomelid beetle *Wallacea* sp. feeding on the spear leaf region of coconut seedlings (Figure 1.33) was recently recorded from South Andaman and little Andaman Islands (Prathapan and Shameem, 2015). Though 80-90 per cent of seedlings were infested by the pest damaging 40 per cent leaf area, seedling mortality was not observed. The feeding niche of *Wallecae* sp. confining on coconut spear leaf is a matter of concern, however, the pest was not observed from any adult palm during the snap survey conducted in October 2014 by ICAR-CPCRI (ICAR-CPCRI, 2015). Invasive nature of *Wallacea* sp. is under scrutiny, as a close relative *Wallaceana* sp. 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. Grubs and adults remain within the folds of the spindle leaves and feed from within. Typical feeding damage was seen within the leaf folds before unfurling along with faecal matters. In severe cases, the feeding streaks coalesce forming broader lesion with brown margin (Figure 1.33). 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. Domestic quarantine need to be strengthened to avoid entry of *Wallacea* sp. in the mainland.

13.3. *Aspidiotus rigidus*

Hard scale, *A. rigidus*, is a close relative of *Aspidiotus destructor*. Though *A. destructor* is under check by natural enemies, *A. rigidus* is ravaging Philippines incurring huge loss to coconut growers in that country. Bioinvasion of *A. rigidus* in Philippines has infested approximately 7,80,000 trees affecting 50-70 per cent of the coconut farms in Batangas and the nearby provinces (Watson *et al.*, 2014). So far

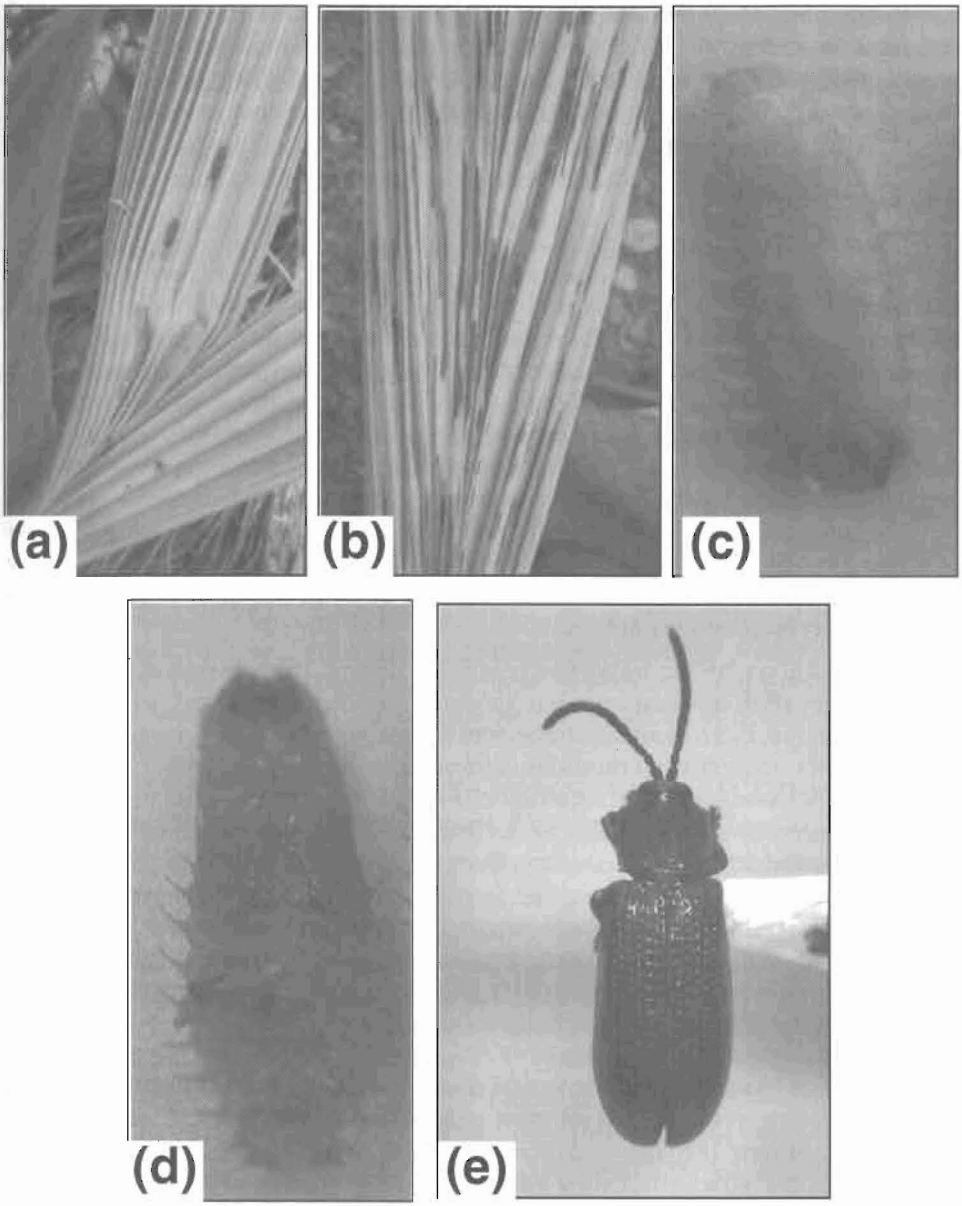


Figure 1.33: (a) *Wallacea* sp. infested coconut seedling, (b) Feeding damage lesions, (c) Grub, (d) Pupa and (e) Adult.

there is no report of *A. rigidus* infesting coconut palm from India. Strict quarantine regulations have to be imposed as these pests can be passively carried through any inert packaging materials, nuts *etc.*

Incursion management of invasive pests involves strengthening quarantine, surveillance and monitoring as well as sensitization campaign. 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 in to the country.

14. Conclusion

Coconut, the perennial palm crop is subject to infestation by coleopteran, lepidopteron and hemipetran insects during its long life span including fatal pest like red palm weevil. IPM in harmony with complete palm health care has to be resorted to manage the immediate pest problem as well as to bring the palm to the sustainable potential productive stage. Very minimal chemical intervention is recommended in coconut IPM, that too to life saving spot application for red palm weevil infestation. Proven cases of biomanagement of pests *viz.*, rhinoceros beetle and black headed caterpillar have confirmed a meaningful way of pest management utilizing the indigenous fauna for the biological suppression of the pests of coconut. The current scenario warrants an augmentative release of these promising bioagents in areas wherever pest infestation is found. Natural enemy fauna build up was witnessed in many cases of upsurge of minor pests *viz.*, scale insects, mealybugs and whiteflies.

Spider fauna plays an important role in the natural suppression of pests in the field. Conservation of these promising biocontrol agents of the pests has become quite imperative. Palm health management by proper adoption of nutritional care, soil and water conservation modules is imperative for crop protection. Biological control of pests assume special significance as it can bring safe, economic and useful results in preventing the loss due to the important pests and there by strengthen the coconut production in the country. Even though awareness on green and clean cultivation is building up among the farming community, pest management in synergy with environmental health aspect has to be adequately stressed among the coconut growers and the farming community. Coconut being a long standing palm, allows light penetration for growing sufficient intercrops if proper spacing is envisaged at the planting time itself. Volatile cues from intercrops help in reducing pest orientation towards the palm in addition to optimizing income per unit area. Availability of biocontrol agents to stakeholders has to be assured by field level capacity building programmes on mass production technologies. A planned and holistic programme through awareness creation, capacity building on incursion management and strict quarantine are essentially warranted to combat accidental invasion of new species.

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