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Integrated management of pests and diseases for the successful cultivation of Coconut, Arecanut and Cocoa

Coconut (*Cocos nucifera* L.) and arecanut (*Areca catechu* L.) are the palms of the Arecaceae family, cultivated by millions of small and marginal farmers who depend on these crops for their livelihood. Cocoa (*Theobroma cacao* L.) on the other hand, is grown as an intercrop in coconut and arecanut gardens for its beans which are used in confectionary industry. All these three crops are cultivated mainly in humid tropics. Being perennial trees, these crops need to withstand the adverse climatic vagaries, including the outbreak of biotic and abiotic stresses throughout their life. Though these crops are comparatively hardy, they are affected by several diseases, some are lethal and some cause economic loss by reducing the quality/ quantity of nut yield.

PESTS and disease attack alone causes 15 to 20% loss annually in these crops. Though more than 100 microbial pathogens are known to infect these crops, major diseases are caused by a few pathogenic fungi namely *Phytophthora, Ganoderma, Lasiodiplodia, Colletotrichum, Thielaviopsis* and Phytoplasma. Among the pests, rhinoceros beetle, red palm weevil, black-headed leaf eating caterpillar, eriophyid mite, white grubs and white flies on coconut; root grubs, spindle bug, pentatomid bug, mites, scale insects, inflorescence caterpillar, red palm weevil on arecanut; and tea mosquito bug, mealy bugs, aphids, stem and fruit borers, thrips, rats and squirrels on cocoa cause severe damage during different stages of the crop. Regular monitoring for early diagnosis of pests and diseases and integrated pest and disease management strategies are indispensable.

Phytophthora diseases – Recurring constraint in plantation crop production

Diseases caused by *Phytophthora* are the major constraints in the cultivation of all three crops, viz. coconut, arecanut and cocoa, causing huge losses annually. In coconut, hundreds of trees succumb to bud rot disease caused by *Phytophthora palmivora* every year. Bud rot is a lethal disease killing palms of any age. The initial symptoms appear as withering and drying of spear leaf which comes out by pulling the spindle. The basal portion of the spindle is completely rotten emitting a foul smell. Subsequently, younger leaves next to the spindle also fall away one after the other, leaving only the outer whorl of mature leaves in the crown. Ultimately, the palm succumbs to the disease with the death of the growing bud (Fig. 1). The bud rot pathogen also causes water-soaked lesions on nuts, quite independent of bud rot, and results in nut shedding. Similarly, arecanut fruit rot is caused by *Phytophthora meadii* and leads to severe shedding and rotting of immature nuts causing huge loss. The same oomycete species can also cause crown rot and bud rot, thereby killing the arecanut palms (Fig. 2). In cocoa, the *Phytophthora palmivora* causes the black pod disease, stem

Fig.1. Bud rot of coconut caused by *Phytophthora palmivora*: A) Whithering of spindle leaf, B) Death of growing bud, C) Severe incidence of bud rot.

Fig. 2. Bud rot and crown rots of arecanut caused by *Phytophthora meadii:* A) Seedling with withering spindle, B) Rotten portion of spindle could be pulled, C) Yellowing of crown region of the adult palm, D) Crown rot affected palm showing intact bud but rotten and dried leaves, and E) Dead areca palm due to crown rot

canker and seedling dieback. Black pod disease (BPD) occurs during the South-West monsoon season as a small circular water-soaked lesion on pods and then turns into a dark brown lesion. Within, four to seven days, the lesion enlarges and assumes an elliptical shape. As the disease progresses, the entire pod turns into black colour with a white mycelial mat, containing sporangia (Fig. 3). As visible symptoms progress, the pathogen moves deeper into the pod, infecting the beans. Infected beans rot and pods mummify. The pathogen infection on the stem either at the soil level or at the branches causes stem canker which in severe cases leads to drying of leaves and death of the trees. The seedling dieback is commonly observed in cocoa nurseries.

Fig. 3. Black pod disease of cocoa caused by *P. palmivora*

Integrated management of *Phytophthora* disease: Managing the phytophthora diseases in crops like coconut and arecanut in endemic areas with high rainfall (>2000 mm) is a challenging task. ICAR-CPCRI has developed and recommended integrated disease management practices to reduce the loss due to *Phytophthora* diseases in plantation crops. It is important to adopt prophylactic treatment in disease endemic areas before the onset of monsoon by spraying 1% Bordeaux mixture and one more spray after 45 days. If the rainy period is extended, one more spray is also required. Spraying of 0.5% mandipropamid 23.4% SC, a contact and translaminar fungicide was found equally effective in managing the fruit rot of arecanut in disease endemic areas. Though prophylactic spraying is of immense help in preventing the disease, manual climbing of tall coconut or arecanut palms during the rainy season and spraying is a difficult task. ICAR-CPCRI has attempted to introduce drone based sprayer and tractor-mounted air blast sprayer for prophylactic spraying against *Phytophthora* diseases of coconut and arecanut (Fig. 4). However, initial experiments suggest the requirement of modification in both the type of sprayers to target the spray to disease-prone tissues namely tender nuts and the spindle base of the palms. In recent years, the light weight carbon fibre pole is being used by arecanut farmers for spraying. Using the pole, one can spray from the ground up to 60-65 ft height and further improvements and evaluations of the sprayer are essential.

Fig. 4. Arecanut farmers using carbon fibre pole for harvesting and prophylactic spraying in arecanut

Phytosanitation and good agricultural practices are equally important in managing diseases. Improved drainage and wider spacing will help in reducing the relative humidity. Field sanitation would reduce the inoculum build-up in the plantations and check the spread of the disease. The rotten portion of the crown, fall, affected nuts, cocoa pods, etc. should be destroyed. The common slugs, *Deroceras* sp. in coconut and arecanut gardens during the rainy season were found feeding on the mycelia of the *Phytophthora* on the rotting immature fallen nuts (Fig. 5). They were found in the garden soil and also found moving along the trunk, especially along the area where the water flows down from the crown during the rainy season. Slugs and their faeces were also observed

Fig. 5. Common slug *Deroceras* sp. on coconut affected by *P. palmivora*

in the leaf axils of the crown of palms. Microscopic examination of faecal matters of the slugs collected from different coconut gardens in disease-endemic areas revealed the presence of *Phytophthora* propagules.

***Ganoderma* diseases**

The basidiomycete fungus *Ganoderma* causes basal stem rot or Ganoderma wilt disease in arecanut, coconut, oil palm and many other ornamental palms and trees. In India, the disease on coconut was first reported in the Thanjavur district of Tamil Nadu in 1952, hence the disease is also popularly known as "Thanjavur wilt". Later the basal stem rot was also noticed on arecanut. Unlike *Phytophthora* diseases, the diseases caused by *Ganoderma* are more severe in the moisture-stress areas and gets aggravated due to continuous drought and negligence in farming. The initial symptom of the disease is decay and death of the fine roots. The characteristic symptom of the disease is extensive rotting and discolouration of the root system. In severely diseased palms, more than 70% root rotting is observed. The infection progresses from the bole region to the basal portion of the stem. The first above-ground symptom of the disease is the exudation of reddish brown viscous fluid from the basal portions of the trunk. As the disease progresses, bleeding patches extend up to 3 m from the base of the palm. In advanced stages, the basal portion of the stem decays completely. Occasionally, some infected palms do not show bleeding symptoms. In some palms, the bark from the base of the stem peels off. Fruiting bodies of *Ganoderma lucidum* appear at the base of the trunk in some palms just above the soil level before wilting or after the death of the palm. Crown symptoms include wilting of leaflets and yellowing, followed by drying and drooping of leaves in the outer whorls of leaves. The spindle leaf and surrounding two or three young leaves will remain erect and healthy. Ultimately, all the leaves droop and fall-off leaving the decapitated stem. Heavy button shedding is also witnessed. The affected palms produce barren nuts. The decapitated stem shrivels and dries up. The time taken from the initial bleeding in the stem to the death of the palms is from 6 to 54 months, the average being 24 months. Trunk infestation with the scolytid beetle, *Xyleborus perforans* and the weevil, *Diocalandra stigaticollis* accelerates the death of the palm. Similar types of symptoms are also noticed in basal stem rot affected arecanut.

Ganoderma lucidum and *G. applanatum* are major species associated with the basal stem rot disease of coconut and arecanut. Recently other species namely *Ganoderma keralense* and *G. pseudoapplanatum* are also reported to cause the disease. For detecting *G. lucidum* inoculum in coconut plantations, subabul (*Leucaena leucocephala*), *Glyricidia maculata* or pigeon pea (*Cajanus cajan* (L.) Millsp.) can be used as indicator plants since these plants show natural infection under field conditions at least six months earlier to visible symptom on coconut palms. The disease is generally observed in sandy or sandy loam soils in coastal areas on the east coast where coconut is grown under rainfed conditions and also in neglected plantations. Soil moisture stress during summer months, water stagnation during rainy seasons, presence of old infected stumps in the garden also aggravates the disease. Ganoderma wilt is a slow decline disease and can be managed by following good agricultural practices and integrated disease management approaches in the early stage of symptom expression itself. In the disease endemic area, regular application of 2 kg neem cake (5 kg in coconut) enriched with *Trichoderma harzianum* (1 kg *Trichoderma* + 100 kg neem cake) per palm per year is recommended. Soil drenching with 1% Bordeaux mixture (40 L/palm) or 0.2% hexaconazole 5EC about 40 L/palm thrice a year for one year or root feeding of hexaconazole 5EC (5 mL per 100 mL of water) at quarterly intervals till complete recovery of the palm.

Phytoplasma diseases – A major threat to palms

Root (wilt) and lethal wilt diseases of coconut and yellow leaf disease (YLD) of arecanut are the major phytoplasma diseases prevalent in India. Root (wilt) disease (RWD) and yellow leaf disease were reported in India more than 100 years back. RWD has now established itself almost contiguously in eight southern districts of Kerala and it has also made its sporadic appearance in the northern districts of Malapuram, Palakkad, Kozhikode, Wayanad and Kannur and some groves in the neighbouring states of Tamil Nadu, Karnataka and Goa. Yellow leaf disease of arecanut is a major setback to areca growers in all arecanut growing districts of Kerala and Chikkamangaluru and Dakshina Kannada districts of Karnataka. The association of phloem-bound mollicute phytoplasma with RWD and YLD has been established by electron microscopy, antibiotic therapy and transmission studies. The phytoplasma associated with RWD and YLD has been identified as '*Candidatus phytoplasma oryzae*' related strain belonging to the 16S rRNA group. The insects, lace bug (*Stephanitis typica*) and plant hopper (*Proutista moesta*) have been identified as the vectors

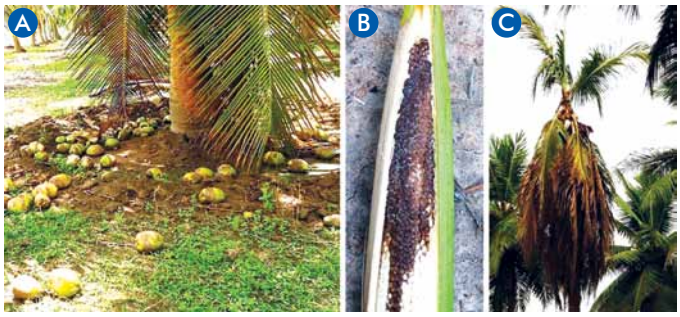

Fig. 6. Lethal wilt disease: (A) Abnormal nut fall, (B) Inflorescence necrosis, (C) Drying and drooping of leaves

transmitting the disease. RWD and YLD are debilitating diseases, and hence the diseased palms become weak and are more vulnerable to other pests and diseases. Integrated management strategies have been developed to reduce RWD and YLD intensity and rate of spread. In disease-endemic areas, thrust is given to integrated management to enhance palm health and farmers' income whereas, in disease emerging tracts, eradication of diseased palms forms a key strategy. In the endemic area, removal of severely affected uneconomic adult palms (yielding less than 10 nuts) and diseased juvenile pre-bearing palms and replanting with resistant/tolerant varieties, viz. Kalparaksha (selection from Malayan Green Dwarf), Kalpasree (selection from Chowghat Green Dwarf) and the hybrid Kalpa Sankara (Chowghat Green Dwarf × West Coast Tall) is recommended. Apart from RWD and YLD, lethal wilt disease (LWD) of coconut, is a new and recently reported phytoplasma disease of major concern that killed several coconut palms in small pockets of Thanjavur, Thiruvarur and Puthukotai districts in Tamil Nadu. The symptoms of LWD are akin to the typical symptoms of lethal yellowing in palms. Abnormal shedding of nuts is the initial symptom which is followed by inflorescence necrosis and yellowing of outer whorls of leaves (Fig. 6). Subsequently, the chlorotic leaves dry and droop down resulting in the skirting of leaves around the trunk. With the progression of yellowing to younger inner fronds, the disease advances and spear leaves and bud region start rotting. This results in crown collapse and the diseased palms die within 3-5 months leaving a bare trunk. '*Candidatus* Phytoplasma asteris'-related strain belonging to subgroup 16SrI-B has been reported to be associated with the disease. Considering the limited distribution of the disease on the east coast of Tamil Nadu in India, periodic surveillance and eradication of diseased palms form the primary management strategy.

Emerging diseases

Diseases caused by *Colletotrichum* and *Lasiodiplodia* which were of minor importance earlier have emerged as major diseases.The recent outbreak of leaf blight in certain arecanut (Fig. 7) growing areas of Karnataka, Kerala and Tripura are found to be associated with different species of *Colletotrichum*. They produce characteristic leaf spot symptoms individually or in combination. Earlier association of other fungi namely *Curvularia* sp., *Phomopsis palmicola* (Wint.) Sacc. *arecae* and *Pestalotia palmarum* Cooke, *Helminthosporium* sp. and *Alternaria tenuis* with leaf spots/blights were also reported. The incidence and severity of inflorescence die back of arecanut caused by *Colletotrichum* sp. has also also increased over the years. The increase in incidences could be due to climate change, nutrition deficiency and emergence of new strains. Initial studies have revealed different species of *Colletotrichum* are involved in arecanut leaf blight and inflorescence die back. Similarly, the leaf blight (Fig. 8) and nut fall

Fig. 7. Leaf blight of Arecanut

Fig. 8. Leaf blight of Coconut

of coconut and dieback of cocoa caused by *Lasiodiplodia theobromae* have emerged as major diseases in certain coconut growing areas of Tamil Nadu, Karnataka and Andhra Pradesh.

Pest management – Changing scenario

Coconut, arecanut and cocoa are the preferred niche for a spectrum of insects, mites, rodents. Key pests of coconut in India include rhinoceros beetle (*Oryctes rhinoceros* Linn.), red palm weevil (*Rhynchophorus ferrugineus* Oliv.), black headed caterpillar (*Opisina arenosella* Wlk.), white grub (*Leucopholis coneophora* Burm.) and the invasive pests, viz. coconut eriophyid mite (*Aceria guerreronis* Keif.) and rugose spiralling whitefly (*Aleurodicus rugioperculatus* Martin). Rhinoceros beetle, red palm weevil (RPW) and eriophyid mite are widely distributed in all coconut growing regions of India, whereas the infestation of black-headed caterpillar and white grubs are limited to certain coconut growing tracts. Adult rhinoceros beetles invade different parts of palms such as spear leaf, inflorescence, collar region of juvenile palms and of late even on tender nuts incurring a crop loss as high as 10%. Feeding by coconut rhinoceros beetle on adult coconut palms is not lethal, whereas it has a significant impact on juvenile palms affecting the initial establishment. Juvenile and pre-bearing palms, mostly below 20 years of age, are more susceptible to RPW infestation. Since it is a lethal pest even one per cent damage is regarded as an economic threshold level. The defoliator pest *O. arenosella* attack affects the chlorophyll content of leaves and a crop loss of up to 45% in terms of nut yield was recorded from infested palms in the succeeding year of severe pest incidence. The black-headed caterpillar infestation is severe during summer which gets worsened under water stress conditions in coastal regions of India. The coconut white grub species *Leucopholis coneophora* occurs mainly in sandy loam soil and attains pest status in discontinuous patches along the Western coastal tracts, especially in Kerala and Karnataka. In India, coconut eriophyid mite had spread rapidly to all major coconut-growing regions of the country within a short span of time since its first report from Kerala in 1998.

Similarly, in arecanut, root grubs, spindle bug, pentatomid bug, inflorescence caterpillar, leaf mites are the major pests causing various kinds of losses. Recent reports of ambrocia beetle (*Euplatypus parallelus*) and red palm weevil on arecanut in few arecanut growing areas is of major concern. The latest report of *Xylosandrus crassiusculus*, a scolytid beetle was found in young arecanut gardens (Fig. 9 A and B), though incidence is limited to few arecanut gardens at present, regular monitoring of these pests is needed. The adult female beetle bore the husk by making a gallery of 1.06-2.39 mm and enters the kernel. It then feeds on the internal content and breeds in these galleries. Infestation can be identified based on the hole made by the insect and extrusion of frass noodles from the bored hole. The scientists also discovered the symbiotic association of fungi, *Ambrosiella roeperi*, with the pest. Interestingly, this fungus serves as a nutrition-rich food source for larvae and adults. The fungus causes black staining of kernel tissues and profuse growth of greyish fungal colony. This reduces the weight of the nut, and affect its storage life and marketable quality. In cocoa, mirids, mealy bugs, aphids, fruit borer and stem borers are the important pests causing significant losses. Mirids or Tea mosquito bugs, viz. *Helopeltis antonii, H. theivora* and *H. bradyi* are major pests of cocoa (Fig. 10) in South India. Among them, *H. bradyi* and *H. theivora* are more predominant. Apart from insect pests, damage of cocoa pods by rats and squirrels are the major impediments in cocoa cultivation.

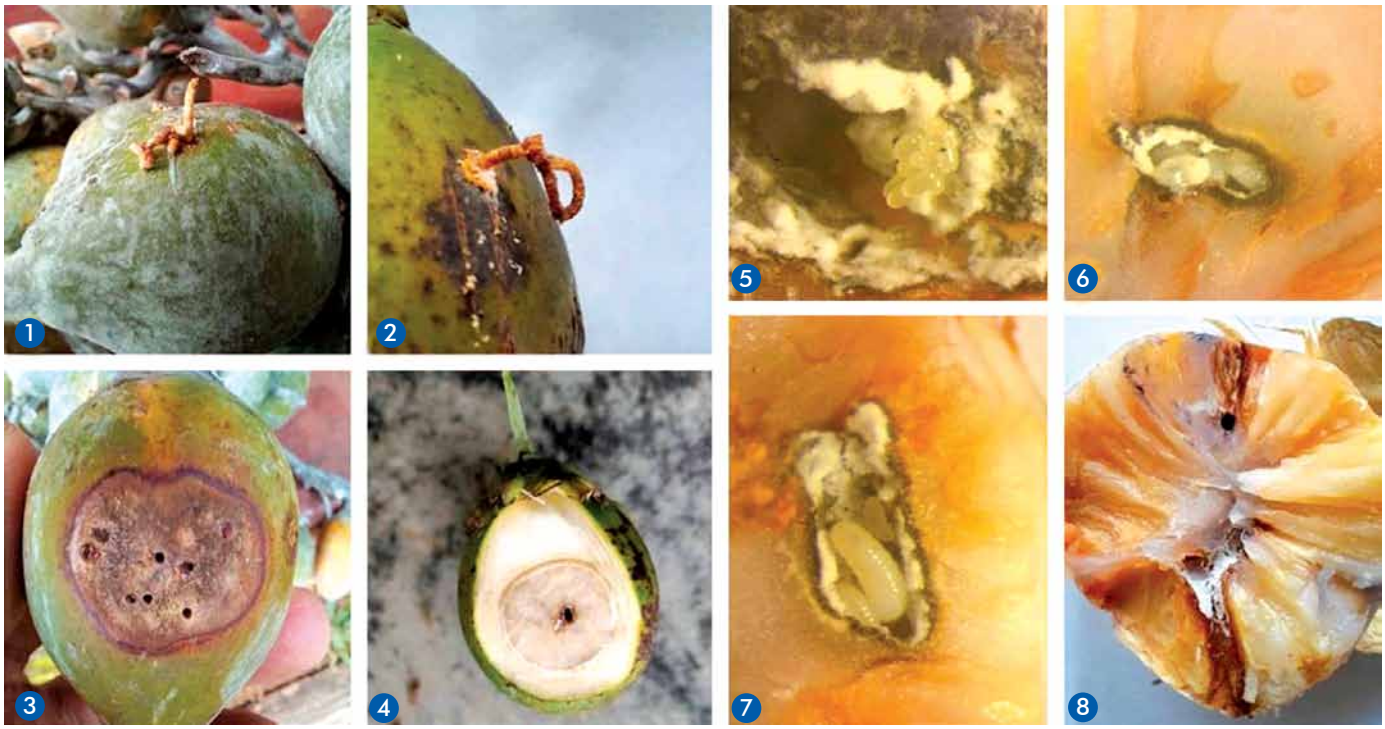

Fig. 9. (A) Arecanuts showing symptoms of the attack by *Xylosandrus crassiusculus*

Fig. 9. (B) Arecanut infested with ambrosia beetle: (1) Oozing of yellowish brown resinous exudation from young infested stems, (2) extrusion of sawdust frass in the form of loose, cylindrical strings in older stem

Integrated management strategies – The systems approach

Crop protection strategies in coconut and arecanut cropping systems require a holistic approach that takes into account the integrated management of pest and diseases of main as well as the intercrops. Rhinoceros beetle infestation is very common in all coconut growing areas and the wound caused by the beetle could be considered as one of the major predisposing factors for the higher incidence of bud rot and leaf rot diseases. These diseases in turn attract the red palm weevil infestation. Hence a customized integrated management strategy based on the pests/diseases and intercrops in a particular geographic region will yield sustainable results. The strategy is multipronged encompassing surveillance, field sanitation, host resistance, intercropping, soil and moisture conservation, crop nutrition along with plant protection for the total enhancement of palm heath. This approach considers cropping system as a single unit where the intercrops and the bioresources generated in the system will be utilized effectively for pest/disease management.

Biological control – An indispensable and viable option

The coconut rhinoceros beetle (Fig. 11) is effectively managed by the green muscardine fungus, *Metarhizium majus* and its area-wide delivery at the breeding sites is a viable option. The release of *Oryctes rhinoceros* nudivirus infected beetles @12/ha could subdue the pest incidence in Bay and Lakshadweep Island systems. Application of talc-based formulation of *Hirsutella thompsonii* three times a year on buttons after pollination, reduced the aggressiveness by coconut eriophyid mite. Augmentative release of stage-specific parasitoids, *Goniozus nephantidis* and *Bracon brevicornis* in the black headed caterpillar infested coconut garden effectively suppressed the incidence of the pest. Soil application of *Steinernema carpocapsae* @1.5 billion infective juvenile (IJ)/ha subdued the white grub incidence and improved the nut yield of palms. Use of *Steinernema* sp. (CPCRISO804) in the bio-suppression of red palm weevil is encouraging. Conservation biological control using *Encarsia guadeloupae* and the sooty mould scavenger beetle, *Leiochrinus nilgirianus* could suppress the invasive potential of the exotic rugose spiralling whitefly in India (Fig. 12). Furthermore, conservation biological control using the lady beetles and the parasitoid, *Aphytis* sp. always kept the coconut scale population as minimum as possible. Use of *Trichoderma harzianum* for the bio-suppression of basal stem rot and stem bleeding diseases and *T. harzianum* cakes for the management of bud rot disease is well proven. Any loss of these bioagents, parasitoids, predators and other defenders will have severe repercussions in the perennial system like coconut, for which indiscriminate use of chemicals should be dispensed-off.

Botanicals and semiochemicals – Safe and powerful defenders

Application of neem cake admixed with sand as a prophylactic management of rhinoceros beetle is still effective and eco-friendly. Use of botanical cake and paste developed by ICAR-CPCRI is another option for pest avoidance. Nylon nets tied on the spear leaf would entangle beetles and reduce pest incidence. Aggregation pheromone lures for rhinoceros beetle and red palm weevil (Fig. 13) offer effective trapping tools for catching the floating population under right placement of

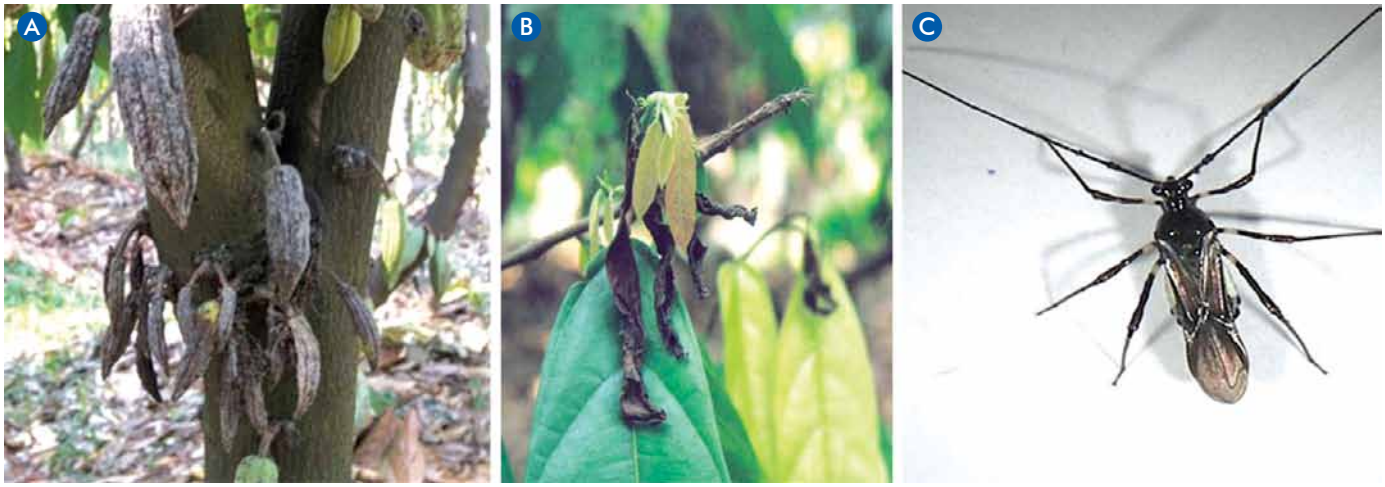

Fig. 10. Tea mosquito bug on cocoa

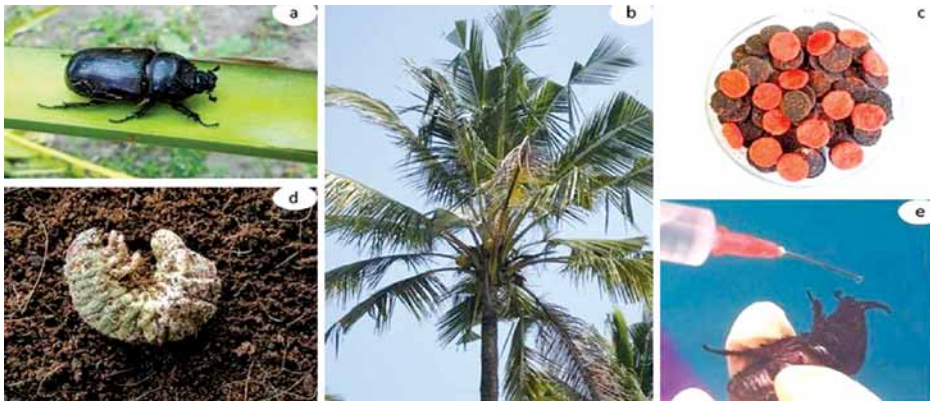

Fig. 11. Coconut rhinoceros beetle damage symptom and IPM

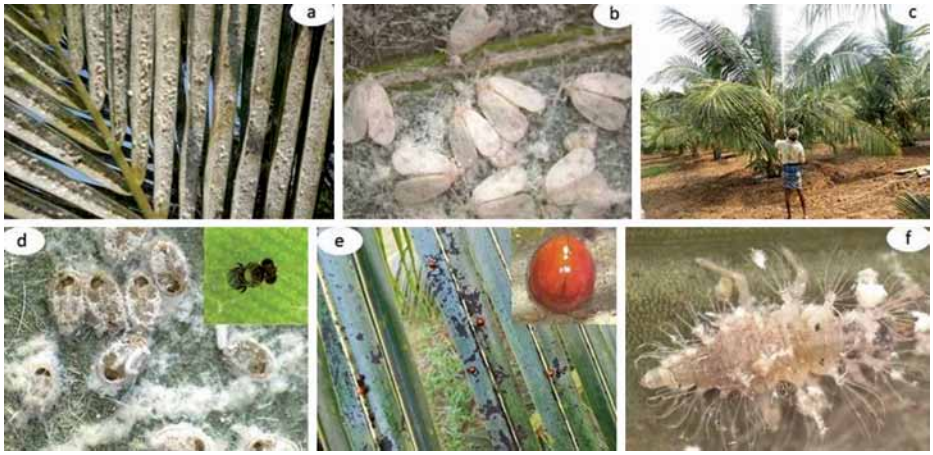

Fig. 12. Rugose spiralling whitefly

traps. Heterogenous landscaping with crop cafeteria in coconut plantation produce mixed odour cues for pest avoidance. Nutrient stimulus based on soil-test analysis is very important to maintain palm health and vital for safeguarding from invasion by pest and diseases. With the availability of good eco-friendly options as pest management tools, it is high time that such options are practiced and popularized in the coconut sector to avoid ill-effects of excessive use of chemical pesticides. Pest surveillance through digital technology with unmanned aerial vehicle could identify the affected palms in a locality for which targeted application of bioagents would be the good management solutions.

Crop pluralism

A cropping system with compatible intercrops attracts more pollinators and admixture of volatile cues from various crops repels pests, reducing pest incidence and enhancing productivity. A crop habitat-based pest regression module has been developed at ICAR-CPCRI with Kalpa Sankara (Chowghat Green Dwarf × West Coast Tall) coconut hybrid and intercrops such as nutmeg, rambutan, banana, curry leaf, jack, marigold, custard apple, etc. for framing farming to fullness. Rhinoceros beetle, red palm weevil and whiteflies were significantly low in the ecological engineering plot compared to that of the mono-cropped coconut garden wherein two to four folds increase in pest incidence could be observed. For non-lethal phytoplasmal diseases like RWD in India, coconut farmers are advised to adopt intercropping and mixed farming along with scientific cultivation practices to ensure a satisfactory and sustainable yield even in disease prevalent areas.

Fig. 13. Red palm weevil symptom on coconut and IPM

CONCLUSION

Pest and disease management through nature-protective technologies including bioagents and botanicals accomplish environmentally responsible farming strategies auguring sustainable development goals. Mechanization and automation in the delivery of bioagents/pesticides in the small farm holdings of palm-based cropping systems are very much essential for the successful implementation of IPDM. Early diagnosis of pests and diseases in the perennial plantation sector is a real challenge hence, adoption of unmanned aerial vehicles and internet of things to perform digital surveillance would be of great help. ICAR-CPCRI had standardized techniques for timely detection of key pests and diseases on palms. Sustained surveillance and strengthening quarantine are key approaches to evade biosecurity risks emanating from invasive pests and diseases. Tackling climate change and the emergence of alien invasive species through heterogenous landscaping, biodiversity conservation and farmer-participatory deliverance of implementable IPDM technologies provides sustainable and profitable income and reduces carbon footprint as well. Restoring ecosystem vitality and ecological integrity through climate-smart farming is the need of the hour.

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