MANAGE OFF-CAMPUS TRAINING MANUAL ON

Integrated Pest And Disease Management In Coconut

24-28 April, 2018

Published By

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MANAGE Off-Campus Training programme on
INTEGRATED PEST AND DISEASE MANAGEMENT IN COCONUT
24-28 April 2018

Day - 1 : 24/4/2018 (Tuesday)		
0830-0900	Breakfast	
0900-1015	Registration/Pre-evaluation	V. H. Pratibha, Girija Chandran, Arati
1015-1130	Technologies of commercial importance	K. Muralidharan
1130-1200	Tea; Group Photo	
1200-1315	Advances in Health Management in Coconut	Vinayaka Hegde
1315-1400	Lunch	
1400-1515	Subduing Fungal Diseases in Palms	V.H. Prathibha
1515-1530	Tea	
1530-1700	Mass Production of Antagonistic Fungus- *Trichoderma* sp.	V.H. Prathibha
1930-2000	Dinner	
Day - 2 : 25/4/2018 (Wednesday)		
0830-0900	Breakfast	
0900-1015	Biological Pest Suppression and GAP in Coconut	Chandrika Mohan
1015-1130	Technology Translation through Social Engineering	P. Anithakumari
1130-1200	Tea	
1200-1315	Success Stories on Area-wide Pest Suppression in Coconut	Chandrika Mohan
1315-1400	Lunch	
1400-1515	Nutrition and Palm Health	Ravi Bhat
1515-1545	Tea	
1545-1700	Advances in Coconut Farming/ Visit to Experimental Plots	P. Subramanian
1930 – 2000	Dinner	

Programme Director: K. Muralidharan (9446169526)
Course co-ordinators: Vinayaka Hegde (9447245649)
Rajkumar (8848988319)

Day - 3 : 26/4/2018 (Thursday)		
0830-0900	Breakfast	
0900-1015	Global Scenario on Coconut Pests and Diseases	P. Chowdappa
1015-1130	Innovative Approaches in Pest Management	A. Joseph Rajkumar
1130-1200	Tea	
1200-1315	Overview on Coconut Phytoplasma : Diagnosis and Management	Merin Babu
1315-1400	Lunch	
1400-1515	Biodiversity and Bio-security Risks in Coconut	A. Joseph Rajkumar
1515-1545	Tea	
1545-1700	Mass Production of Entomophaga and Entomopathogens invading Coconut Pests	M. Sujithra /Rajkumar
1930 -2000	Dinner	
Day - 4: 27/4/2018 (Friday)		
0830-0900	Breakfast	
0900-1015	Pest and Disease Management in Coconut Nursery	A. Joseph Rajkumar
1015-1130	Bio-priming Coconut Seedlings for Inducing Resistance	Dr. Murali Gopal
1130-1200	Tea	
1200-1315	Visit to APC and Collection of *Kalparasa*	Dr. K.B. Hebbar
1315-1400	Lunch	
1400-1900	Demonstration of disease management in farmers' field	Vinayaka Hegde
1930 – 2000	Dinner	
Day - 5 : 28/4/2018 (Saturday)		
0830-0900	Breakfast	
0900-1015	Containing Palm Pests and diseases through Host Plant Resistance	Regi J. Thomas
1015 -1045	Quarantine and Diagnosis of Plant Pathogens in Palms	Dr. Vinayaka Hegde
1045-1145	Entomopathogenic Nematodes and Bio-suppression of Coconut Pests	Rajkumar
1145-1200	Tea	
1200-1315	Climate Change and Pest Outbreak in Palms	M. Sujithra
1315-1400	Lunch	
1400-1515	Biotechnological approaches in pest management	M. K. Rajesh
1515-1545	Tea	
1545-1700	Valedictory function	
1930 – 2000	Dinner	

Nutrition and Palm Health

Ravi Bhat, Selvamani, V. and Jeena Mathew

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Introduction

Green plants which are autotrophic require some inorganic mineral nutrients for their growth and development. As many as 92 elements / nutrients have been found, out of which 23 are essential nutrients *i.e.,* without them plants do not complete their life cycle. Out of these 23 essential nutrients, carbon, hydrogen and oxygen are derived from the atmosphere and soil water, and the rest are supplied either from soil minerals and soil organic matter or by organic or inorganic fertilizers. Arnon and Stout in 1939 laid down the following criteria for judging the essentiality of mineral nutrients to the plants. The nutrient must be absolutely essential for normal growth and development. The requirement of the nutrient must be specific and not replaceable by another nutrient *i.e.,* non-availability of the nutrient to the plant causes a deficiency symptom. As expression of abnormality through symptoms in plants arise due to several factors like pests, diseases, nutrient deficiency, toxicity *etc*., it becomes important to identify the exact reason. Nutrient deficiency/ toxicity symptom is due to inadequate / excessive application of fertilizers or nutrient sources. The actual disorder can be ascertained only with proper soil and tissue testing results that are obtained from soil and tissue testing laboratories. After identification of the actual deficient nutrient only, the management should be undertaken in the field**.** The fertilizers need to be applied based on the soil test data, to correct the deficiency as the supply of specific nutrient alone can correct it.

Nutrient Deficiency Symptoms, Diagnosis and Remediation in Coconut

ROLE OF NITROGEN (N)

- It promotes growth
- Facilitates better leaf production and chlorophyll production
- It encourages vegetative growth of plant and imparts deep green colour to the leaves
- Nitrogen is a constituent of amino acids, proteins and nucleic acids.

Nitrogen deficiency symptoms are commonly seen in light textured sandy soils poor in organic matter and also in water logged conditions. Nitrogen being mobile in the plant system deficiency symptoms first appears in the older leaves

Deficiency symptoms

- Loss of normal healthy green colour in the initial stage and becomes yellowish green and the whole foliage exhibits slight and continuous yellowing
- As the deficiency progresses, the older leaves develop a uniform golden yellow colour, whereas, the younger leaves turn pale green giving the leaflets a dull appearance
- Reduction in chlorophyll content with golden yellow colouration of older leaves near the petioles and light brown colour near the end, which later dries out
- Yellowing starts from the tip of the leaf and leaflets and progresses along the midrib
- Mid rib turns yellow
- The size of the leaves gradually gets reduced and the number of functioning leaves becomes less
- In advanced stage, the stem below the crown narrows down to a 'pencil point' with a few short leaves on the crown
- Abortion of inflorescences and fail to emerge. If emerges, it will be with little or very little female flowers. Growth virtually stops when N deficiency is very severe and the palm turns barren.

N deficiency can be confused with Fe or S deficiency, although the chlorosis in those deficiencies is typically most severe on the youngest leaves, whereas, the older leaves are affected in the case for N deficiency.

Remediation

The deficiency can be managed through the application of nitrogenous fertilizers depending on the soil test data.

ROLE OF PHOSPHORUS (P)

Phosphorus (P) is an important constituent of nucleic acid and is abundant in the young tissues. Initial flowering of young palms is greatly influenced by the supply of P. Phosphorus, essential macronutrient, is involved in photosynthesis, respiration, energy storage and transfer, cell division, and enlargement. Phosphorus promotes early root formation and growth. The content of P in the leaves will be lower in summer indicating the minimum flux during such period.

P deficiency in coconut

P deficiency occurs in crops grown in the lateritic and poor sandy soils. But due to continuous application of chemical fertilizers, there will be build up of P in the soil which increases the availability in soils.

The deficiency symptoms are usually seen in palms grown in extremely acidic as well as in calcareous soils.

Deficiency symptoms

- Leaves become purple coloured, and in severe cases, leaves may turn yellow.
- Premature drying and shedding of leaves are also seen.
- The symptoms of slowing down of growth and shortening of fronds are found to be associated with P deficiency.

Remediation

Application of P fertilizers based on soil test value. Correction of P deficiency improves overall nutrition of the palm and produces beneficial effects on the number of nuts and yield of copra per nut.

ROLE OF POTASSIUM (K)

Potassium is required in relatively large amounts in palms and it facilitates several major functions. This nutrient is involved in photosynthesis, enzyme activation and osmoregulation. It plays vital role in the formation of amino acids and proteins and in the photosynthetic activities of the plant. It is essential for starch formation and the translocation of sugars and also in the development of chlorophyll. It increases leaf area, improves leaf angle and leaf colour which result in better utilisation of sunlight and ultimately causes increased number of fronds, inflorescences, female flowers, nut set and weight of copra per nut. It imparts resistance to pest and disease attack along with regulating water balance of the plant. It also enables the plant to withstand drought. Osmoregulation affects the pressure within a plant cell: potassium controls the opening and closing of stomata. If potassium levels in soils are low, plant leaves develop symptoms of water stress. Palms may also become more susceptible to disease if important elements, including potassium, nitrogen, boron, and magnesium, are out of balance in soils.

K deficiency in coconut

The deficiency is common in light sandy soils as well as in laterite soils. High levels of calcium and magnesium in soil results in depletion of this nutrient from the root zone. Intercropping with potassium exhaustive crops such as tapioca, fodder grass, banana and pineapple without proper addition of fertilizers would also result in the depletion of potassium.

Deficiency symptoms

- Development of orangish yellow discoloration from the tip of the leaflets, progressing along the margin towards the base.
- If severe, tip of leaflets withers and become necrotic
- The midrib remains green and some leaves exhibit a scorched appearance
- Appearance of a green triangle with it’s base in the lowest leaflets and apex towards the tip is a characteristic feature of potassium deficiency in coconut.
- Newly emerging leaves are short and chlorotic or yellow.
- Reduced growth, slender stem, short leaflets and reduction in inflorescences, nut set and nuts per bunch

Remediation

Application of K fertilizers based on soil test prevents K deficiency

ROLE OF CALCIUM

Calcium (Ca) is an immobile element in plant. It is a constituent of cell walls and is essential for the growth of meristems, cell division, particularly for the growth and functioning of root tips, and bud formation. In coconut, apart from the role of a nutrient, it acts as a soil ameliorant, especially under acidic conditions. This is also involved in nitrogen metabolism, reduces plant respiration, aids in translocation of photosynthesis from leaves to fruiting organs and stimulates microbial activity

Deficiency symptoms

Clear cases of Ca deficiency in coconut are not usually found. However, the deficiency symptoms first appear on the youngest leaves.

- Young leaves exhibit narrow white bands at margins. Later it gains a rusty appearance in leaf margin.
- Along with this there will be rolling up of leaves.
- Yellowing of leaflet tips with yellow to orange ring shaped spots spread on the leaflets, later turn necrotic and further drying up of leaf. These symptoms appear in the middle leaves earlier than in the older leaves. Severe distortion of leaflets and leaves also occur.

Remediation

Regulated applications of Ca bearing fertilizers like rock phosphate, super phosphate, bone meal or soil application of lime or dolomite @ 1 kg per palm per year depending on the lime requirement of the soil is recommended.

ROLE OF MAGNESIUM (Mg)

Magnesium (Mg) is the only metal constituent of chlorophyll, the green colouring matter of plants and hence has a definite role in the pigment system and affects the photosynthetic capacity of the plant. It plays an important role as a 'carrier' in the transport of P in plants. It also plays an important role in the production of carbohydrates, proteins and fats. Magnesium is the key element of chlorophyll production. It improves utilization and mobility of phosphorus and also acts as an activator and component of many plant enzymes. It facilitates increased iron utilization in plants.

Deficiency symptoms

- Mg deficiency appears on the older leaves of palms
- Presence of broad chlorotic (yellow) bands along the margins
- Leaves in the lower half of the crown are bright yellow, while leaves on the upper half remain green

- Yellowing of the older leaves, which starts from the tip and extends towards the base and later the younger leaves also turns yellow
- Mg deficient leaves have distinctly green leaf centres and bright lemon yellow to orange coloured margins
- Yellowing occurs principally in those parts of the leaf which are exposed to sunlight, whereas, the shaded part remains green
- Bronzed appearance of older leaves which dry out later
- Necrosis of leaflets which turn reddish brown with translucent spots

Mg deficiency symptoms differ from those of K deficiency wherein, the symptom severity of discoloration in K deficient leaves is usually orange to bronze, shading gradually to green at the base of the leaf, whereas Mg deficient leaves have distinctly green leaf centres and bright lemon yellow to orange margins. Mg deficiency reduces coconut yield by about 40 %. Dwarf palms are more sensitive to Mg deficiency than tall and hybrids.

Mg deficiency symptom on coconut

Remediation

Application of dolomite @ 1 kg per palm, two weeks prior to fertilizer application, or magnesium sulphate @ 500 g per palm along with second dose of fertilizer application would help in managing the deficiency.

ROLE OF SULPHUR

Sulphur (S) is a constituent of protein and it aids in the formation of chlorophyll. It helps in the development of dark green leaves and an extensive root system.

Diagnosis

- Leaflets become yellowish - green or yellowish – orange
- Chlorosis and necrosis increase with the age of the leaves
- In severe cases, second or even the first leaf may show yellowing

- Drooping of the leaves as the stem becomes weak
- In older palms, leaf number and size are reduced
- The number of live fronds becomes fewer.
- In the advanced stage, the crown loses most of the leaves and severe necrosis is found on the older leaves.
- The yield of nuts is reduced and the nuts are usually small with normal kernel thickness.
- On drying, the kernel collapses into soft flexible and leathery copra, often brown in colour which is usually referred to as "***rubbery copra*".**
- It has very poor physical and chemical characteristics, particularly with very low oil content.

Remediation

S deficiency in coconut can be prevented by the regular use of S containing fertilizers like Ammonium Sulphate, Super Phosphate, Magnesium Sulphate *etc*.

ROLE OF IRON (Fe)

Iron (Fe) is a catalyst for the formation of chlorophyll and is also a constituent of enzymes associated with respiration and oxidation systems. Usually appears on palms grown in poorly aerated soils or those that have been planted too deeply. Water logged soils and deep planting suffocate the roots and reduce their effectiveness in taking up nutrients such as Fe. Under acidic soil conditions, deficiency of Fe is usually not encountered.

Deficiency symptoms

- Uniform chlorosis *ie.*, a pale green or dark yellow discolouration occurs to all the leaves from the top of the crown to the base
- Gradual yellowing of the leaflets in longitudinal strips parallel to the veins
- In the advanced stages the leaf becomes completely yellow
- Shortening of the rachis and the leaflets
- Absence of necrosis in any part of the leaf is a characteristic symptom of iron deficiency.

Fe deficiency symptoms on coconut

Remediation

Application of $FeSO_4$ @ 0.25 to 0.5 kg / palm / year is recommended as the management practice for correcting the deficiency.

ROLE OF MANGANESE (Mn)

Visual symptoms may be sufficient to diagnose this disorder, but leaf nutrient analysis is also suggested, since symptoms of boron (B) deficiency can be similar. Mn deficiency is caused primarily by high soil pH and as in the case of Fe, deficiency of Mn occurs in alkaline and calcareous soils, where it gets immobilized in the coconut root zone.

Deficiency symptoms

- Newer leaves with chlorotic and longitudinal necrotic streaks
- As the deficiency progresses, newly emerging leaflets appear necrotic and withered on all except the basal portions of the leaflets
- This withering results in curling of the leaflets about the rachis giving the leaf a frizzled appearance (***'frizzle top'***).
- In severely Mn - deficient palms, growth stops and newly emerging leaves consist solely of necrotic petiole stubs.

 

Mn deficiency in coconut

Remediation

Soil application of $MnSO_4$ @ 25kg/ha is recommended as the management practice for correcting the deficiency.

ROLE OF COPPER

Deficiency of copper (Cu) is seen in highly acid sandy soils and in heavy organic soils, highly calcareous and alkaline sols. Liming reduces the availability of copper in deficient soils.

Deficiency symptoms

- The deficiency symptoms are severe bending of the rachis of the youngest leaves accompanied by yellowing and desiccation of the leaf tip which is rimmed with brown and yellow and the central part remains green.
- As the symptoms develop, dried out part spreads and gives the palm a saggy appearance
- Most of the petioles will be in arc - shape, eventually losing turgidity
- The leaflets show premature dry up and necrosis of the tips and change in colour from dark green to yellow from the tips towards the leaf petiole

ROLE OF ZINC (Zn)

Zinc (Zn) catalyses oxidation in plant cells, is essential for the transformation of carbohydrates, helps in the formation of auxins, and promotes water absorption. Zn deficiency usually occurs in saline soils.

Deficiency symptoms

- Button shedding along with the shortening of the crown is the reported symptom of zinc
- Zinc deficiency is characterized by formation of small leaves wherein the leaf size gets reduced to 50 %
- Leaflets become chlorotic, narrow and reduced in length
- In acute deficiency, flowering is delayed

Remediation

Soil application of $ZnSO_4$ @ 25 kg / ha is recommended as the management practice for correcting the deficiency

ROLE OF CHLORINE (Cl)

Chlorine (Cl) has a role in the stomatal conductance and in the maintenance of water balance. The deficiency of Cl is seen the palms located in the inland areas. Chlorine is normally considered as a micronutrient element for higher plants. It's importance in the nutrition of coconut has been emphasized recently. Since Cl requirement of coconut is comparatively very high, it is considered as a major nutrient for the crop. It enhances the growth of young palms and increases the yield of bearing palms. The effect of Cl is manifested more on the thickness of the kernel and the copra out turn.

Deficiency symptoms

- Presence of abnormal leaves

- Reduced growth rate of the palms with reduction in size and number of nuts
- Drooping of leaves that indicates signs of moisture stress which may result in the breakage of fronds
- Stem cracking and frequent occurrence of stem bleeding
- Marked incidence of grey leaf blight is also reported
- The leaflets become susceptible to fungal attack and cause ***"leaf spots".***

Remediation

Sodium Chloride (NaCl: common salt) can be used for supplementing the Cl requirement of the palm, particularly in the case of plantations situated away from sea coast.

ROLE OF BORON

Boron is an essential micronutrient for coconut, which helps in the multiplication of meristematic tissues. It helps in the metabolism of protein, synthesis of pectin, maintenance of water relation, translocation of sugars, tissue respiration, fruiting process, growth of pollen tube and in the development of flowers and fruits. Wide spread deficiency of boron is noticed in the coconut growing areas, which may be attributed to the continuous removal through cropping and due to the non-replenishment of the same along with regular fertilizer application. The deficiency symptoms of boron are very much specific. Boron deficiency has been reported from different coconut growing countries of the world and the problem is commonly known as ***'crown rot / choking'*** disease of coconut. Since boron is an immobile element in plant, initial symptoms appear on the youngest leaf.

Deficiency symptoms

- Initial symptoms of boron deficiency are manifested by reduction in the elongation of young leaves.
- The leaflets, when unfolding, are crinkled and will be shorter than normal.
- In more advanced stages, terminal leaflets remain fused.
- The tips of these leaflets may be 'knife shaped', with or without a brown solution oozing out through the hook. This symptom is also called ***'hook leaf'***.
- The basal part of the petiole may be without leaflets.
- In adult palms, the deficiency leads to production of ***branched spikes***, premature death of inflorescence, and production of inflorescence with lesser female flowers, and shedding of buttons (female flowers).
- Other associated symptoms include '***Hen and Chick'*** symptom (a few under developed nuts / small sized nuts along with full developed nuts),
- Cracking of nuts externally /internally with meat protruding towards the mesocarp and barren nuts with partial/unevenly developed kernel having poor quality copra. Pollen production, pollen grain germination and pollen tube development will be affected.

- Often, the malformations may be exhibited either singly or by various combinations based on the intensity of the deficiency. Drought may aggravate boron deficiency and in some cases seasonal boron deficiency *i.e.*, the symptoms appearing in the dry season and disappearing in the wet season could be noticed.

Boron deficiency symptoms in coconut

Subduing Fungal Diseases in Coconut

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Coconut (*Cocos nucifera* L.,) is popularly known as ‘‘Kalpavriksha’’ and plays an important role in the social, economic and cultural activities of the people. The coconut palm is affected by a number of diseases and the major fungal diseases are Bud rot, Stem bleeding, Basal stem rot, diseases. These diseases are responsible for enormous economic losses in the different coconut growing countries of the world. A brief account of the fungal diseases of Coconut is provided in this chapter and which will be helpful for easy diagnosis and effective management of diseases.

1. Bud rot disease

Bud rot is a lethal disease and it occurs commonly in west and east coasts of India. In recent years the disease has attained a serious proportion in some of the localities especially in hilly tracts of southern India. Heavy incidence of bud rot has been reported in Kerala and Karnataka during the South West monsoon period in 1994 and 2013. Bud rot disease was also noticed in other states like Andhra Pradesh, Maharashtra and Goa on a large scale, particularly in the newly planted gardens.

Symptoms

- The Initial symptom is wilting of the spindle leaf marked by pale color and the spindle leaf turns brown. The affected spindle leaf can easily be pulled out as the basal portion of the spindle is completely rotten emitting a foul smell.
- In the middle stage inner leaves also fall away one by one leaving only outer whorl of matured leaves in the crown.
- As the disease advances all the leaves fall off and ultimately death of the palm.

Initial stage

Middle stage

Advanced stage

Etiology

Bud rot disease caused by the fungus *Phytophthora palmivora* Butl.

Extended period of relative humidity, high rainfall, intermittent sunshine hours and prevalence of cooler temperatures were congenial for bud rot disease incidence. Coconut palms died due to bud rot disease will serve as a source of inoculum for subsequent season since *Phytophthora* propagules are survive in the crown debris of dead palms even after one year. Rain water and slugs (*Deroceros* spp.) acts as a carrier for the infectious propagules and plays an important role in the spread of the disease.

Sporangia of *Phytophthora palmivora*

Slugs (*Deroceros* spp) carrier of *Phytophthora*

Disease Management

Integrated disease management strategies should adopt in three seasons especially in endemic areas for effective management of the disease.

I. Before the onset of rainy season

1. Removal of all disease advanced and dead palms
2. Crown cleaning and Field hygiene should follow before the monsoon season
3. Control of other pests and diseases
4. Application of 1 % Bordeaux mixture in the inner most leaf axils just before the onset of monsoon season (May end).

II. During rainy season

1. Repeat the prophylactic fungicide treatment at 2 months interval
2. Observe all the palms at 15 days interval
3. Identify bud rot incidence, if any, in the initial stage
4. Removal of infected tissues completely in the early stage of disease and pouring of 10% Bordeaux paste and cover with a polythene sheet to prevent entry of rain water.

III. Post-monsoon

1. **C**ontinue prophylactic fungicide treatment bi-monthly till the end of December.
2. Observe all the palms at 15 days interval and take up curative treatment , if necessary
3. Follow Integrated Nutrient Management practices

Prophylactic treatment by pouring 1 % Bordeaux mixture

Removal of infected tissue and covering with polythene sheet after treating with 10% Bordeaux paste

Recovered seedling

2. Stem bleeding disease

Stem bleeding disease was first reported from Sri Lanka and in India during 1922. Presently the disease is prevalent in all the major coconut growing states of India. In the early stages of the disease, there is not much yield loss. However, in later stages, there is a steady yield decline causing considerable loss and in advanced stages even death of affected palms occurs.

Symptoms

- Development of dark brown patches at the basal portion of the trunk and exudation of dark reddish brown liquid.
- The exudates eventually dry up to form black encrustations with brownish orange margin.
- The tissues beneath the discolored patch show decay.
- In the crown region, outer whorl of leaves becomes yellow rather prematurely, droops and finally dries up.
- The trunk gradually tapers towards the apex and the crown size is reduced
- The production of bunches is affected and nut shedding takes place.

Exudation of dark reddish brown liquid and tapering of palm

Etiology

Stem bleeding disease is caused by *Theilaviopsis paradoxa* (De Seynes) Höhn. It is a soil born weak pathogen, enters the trunk through wounds/growth cracks and multiplies in the host tissue by producing endoconidia and chlamydospores. The chlamydospores survive in the soil during unfavorable conditions and germinate in favorable conditions and infect the coconut. More disease severity was observed during July to November, when high relative humidity and optimum temperature prevails. The disease has been found to occur in all soil types, but more in laterite soils and sandy soils on the seashore or backwater areas.

Conidia of *Theilaviopsis paradoxa*

Disease Management

- Removal and destruction of disease advanced and dead palms.
- Application of recommended dose of fertilizers (N(560g), P(320g) and K(1200g) in two equal splits during June-July and December –January) and provide irrigation (45 to 50 l per palm per day) during summer.
- The affected tissues should be completely removed using a chisel and smear the wound with 10% Carbendazim (10g in 100 ml of water) and basin drenching with 40 liters of 0.1% Bavistin at quarterly intervals up to one year.
- Root feeding with 100 ml of 5% Carbendazim at quarterly intervals up to one year.
- Smearing of *Trichoderma* talc powder paste on the bleeding patches of the stem (The paste can be prepared by adding 50g of Trichoderma talc powder to 25 ml of water).

- Soil application of *Trichoderma harzianum* (CPTD 28) enriched neem cake @ 5 kg/palm at quarterly intervals up to one year, irrigate the palms once in a week and followed by mulching around the palm basin.

Root feeding with 5% Carbendazim

No bleeding patches after application of *Trichoderma* talc powder paste

Mass production of *Trichoderma* in neem cake

- Salt free neem cake to be powdered about 1to 2 cm size and mix by sprinkling the water and moisture level should maintain to 50%.
- Inoculated with *Trichoderma harzianum* talc powder at the rate of 1Kg per 100Kg of neem cake and covered with wet gunny bag.
- Incubated for seven days with the intermittent mixing once in two days and maintained the moisture level up to 50%.

Mass multiplication of *Trichoderma harzianum* (CPTD 28) in neem cake

3. **Basal stem rot/Ganoderma wilt disease**

Ganoderma wilt was first observed in Thanjavur district of Tamil Nadu during 1952 hence termed as Thanjavur wilt. In Karnataka it is known by the popular Kannada name 'Anabe roga' and in Andhra Pradesh, Ganoderma wilt. In Andhra Pradesh, the disease is mainly prevalent in lighter soils in the coastal districts than in heavy soils.

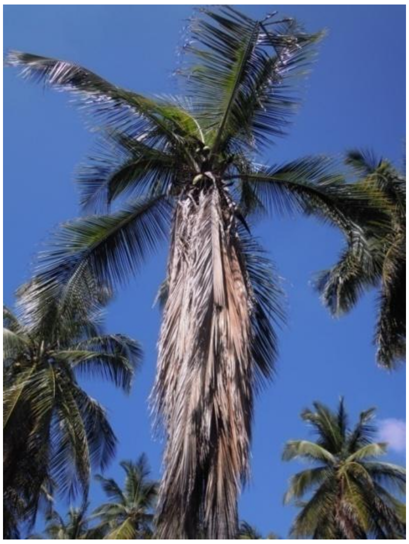
Symptoms

- Yellowing of the leaves of lowest leaf whorl, decay and death of fine roots.
- Later bleeding patches appear at the base of the stem near the ground level, roots decay extensively and there is no new bunch production.
- As the disease advances leaves droop in the outer whorl followed by heavy button shedding and barren nuts.

- Ultimately all the leaves droop and fall off leaving the decapitated stem with the formation of fruiting body near the base of palm.

Yellowing of leaves in lowest leaf whorl

Formation of bleeding patches at the base of the stem.



Drooping of lower leaves

Formation of sporocarp (fruiting body)

Etiology

Ganoderma disease of coconut is caused by two *Ganoderma* spp, *G. applanatum* (pers.) Pat., and *G. lucidum* (leys) Karst. These were isolated from roots of infected palms irrespective of the extent of bleeding symptom. The pathogenicity of *G. lucidum* has been established by inoculating the fungus in the trunk region. *Ganoderma* wilt disease is prevalent in sandy or sandy loam soils in coastal areas where coconut is grown under rainfed conditions and also in neglected plantations. Lack of soil moisture during summer months, water logging in rainy seasons, presence of old infections in the gardens and neglect of cultural operations were found to be conducive to the spread of the disease. The disease incidence was more between

March and August. Trunk infestation with the scolytid beetle, *Xyleborus perforans* and the weevil, *Diocalandra stigmaticollis* accelerate the death of the palm.

Disease Management

- Removal of dead palms, palms in advanced stages of the disease and destruction of the bole and root bits of these palms.
- Application of recommended dose of fertilizers (N(560g), P(320g) and K(1200g) in two equal splits during June-July and December –January) and provide irrigation (45 to 50 l per palm per day) during summer.
- Isolation of diseased palms from healthy palms by digging isolation trenches of 1 m deep and 60 cm wide.
- Regular basin irrigation during summer months or moisture conservation by coconut husk burial (250 husk/palm).
- Avoid flood irrigation or ploughing in infected gardens to prevent spread of the inoculum.
- Raising banana as intercrop wherever irrigation is possible.
- Soil application of *Trichoderma harzianum* (CPTD 28) enriched neem cake @ 5 kg/palm at quarterly intervals up to one year, irrigate the palms once in a week and followed by mulching around the palm basin.
- Root feeding of Hexaconazole @ 2% (100 ml solution per palm) at quarterly intervals and soil drenching @ 0.2% of Hexaconazole (40L solution per palm) or with 40L of 1 % Bordeaux mixture.

6. Immature nut fall or Fruit rot

Buttons and immature nut shedding before and after fertilization is a common problem in coconut. The immature nut fall is observed in all the coconut growing areas, however it is sporadic in nature. Immature nut fall has been attributed to several factors viz., characteristic feature of mother palm, high soil acidity or alkalinity, drought condition or water logging and sudden changes in soil moisture and also imbalance or deficiency of nutrients. Poor pollination is also one of the major factors responsible for button shedding in coconut. Shedding of buttons is also caused by insect attack and Eriophyid mite attack also leads to immature nut fall to some extent.

Symptoms

By *Phytophthora palmivora*

- Appearance of water-soaked lesions on the surface of the nuts
- The lesions turn brown and the nut detaches from the bunch
- More common during rainy season and occurs in high humid area

Symptoms of Phytophthora infection on coconut causing nut fall

By *Lasiodiplodia theobromae*

- Dark grey to brown lesions with wavy to undulated margins appear from the apex of the nuts
- Decay and discoloration of mesocarp and endosperm of nuts
- Desiccation, shriveling, deformation and premature dropping of nuts
- Infection severe in mite infested nuts.
- Occurs throughout the year more prevalent in dry areas

Nut infection and nut fall by *Lasiodiplodia theobromoae*

Etiology:

Nut fall or fruit rot is caused by *Phytophthora palmivora* (Butl.) and *Lasiodiploida theobromae* Pat. This disease is common in high rainfall areas during monsoon season. *P. meadii* Mc Rae has also been found to cause the immature nut fall for the first time in Kodagu district of Karnataka (Chowdappa *et al.*, 2002).

Disease Management

1. Nut fall caused by *Phytophthora palmivora*

- Removal of bud rot affected dead coconut palms from the orchard before monsoon and burning.
- Crown cleaning just before monsoon and prophylactic spraying of Bordeaux mixture 1% to the bunches two sprays at 30 days interval depending on severity of disease.

2. Nut fall caused by *Lassiodiplodia theobromae*

- Removal of all the infected nuts from the palm.
- Spraying of 0.1% carbendazim 50 WP to bunch of the affected palms at 30 days interval depending on severity of disease.

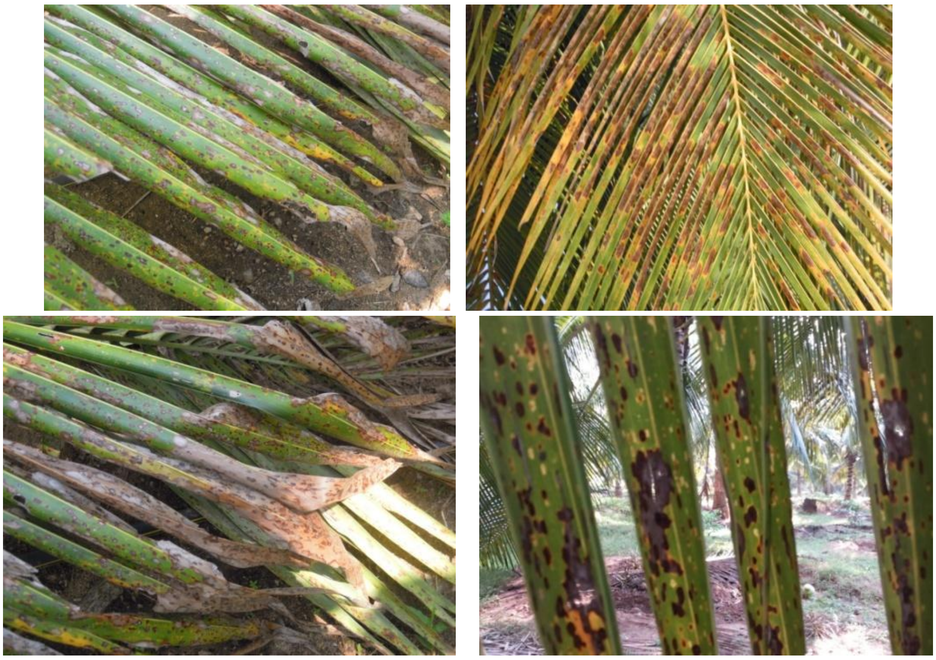
Grey leaf spot/blight disease

Leaf spot and leaf blight are common in most of the coconut growing areas. However the severity of the disease and extent of damage or loss they cause is seasonal and depends on climatic factors, nutritional status and varieties.

Symptoms

Grey leaf spot/grey leaf blight

- Minute yellow spots with grey margin appear on the outer whorls of leaves
- Spots gradually turn brown with greyish white centre
- Spots enlarge and coalesce causing extensive leaf blight
- Complete drying and shriveling of the leaf blade giving a blighted appearance and hence the name leaf blight



Symptoms of leaf spots and blights caused by *Pestalotiaopsis palmarum*

Leaf blight

- The pathogen causes damage in leaf and nuts.
- Affected leaflets start drying from the tip downwards and exhibit a charred or burnt appearance
- On coconuts, small black sunken region appear near the perianth of immature nuts.
- When nearly mature/mature nuts were infected the infection spread internally into mesocarp without any external lesion or with a minute lesion on the husk surface.

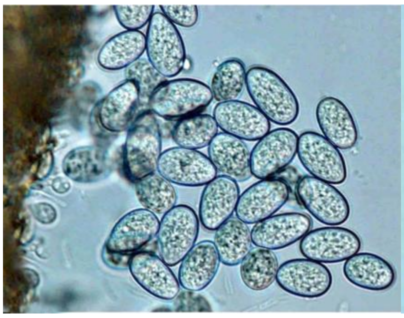
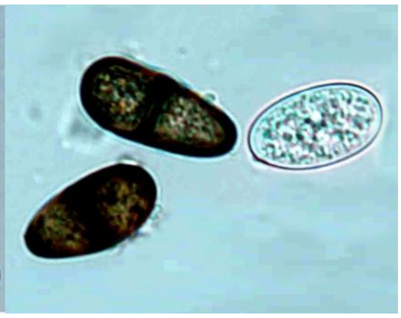
Symptoms of leaf blight caused by *Lasiodiplodia theobromae*

Etiology:

Major fungi associated with leaf spot/leaf blight in coconut are.

i) Grey leaf spot or blight**:** *Pestalotia palmarum* Bubák & Kabát

ii) Leaf blight, frond and nut infection: *Lasiodiplodia theobromae* **(**Pat.) Griffon & Maubl

Conidia of *Pestalotiopsis palmarum*   Conidia of *Lasiodiplodia theobromae*

Disease Management
Grey leaf spot/grey leaf blight

- Removal and burning of severely affected older leaves.
- Spraying with 1% Bordeaux mixture
- Application of recommended dosage of chemical fertilizers (N(560g), P(320g) and K(1200g) in two equal splits during June-July and September – October) and green leaf manure or FYM (25 -30 kg per palm), provide irrigation (45 to 50 l per palm per day) during summer.

Leaf blight

- Removal and burning of severely affected leaves to avoid further spread.
- Bio-control: Application of (200 g) *Pseudomonas fluorescens* along with FYM (50 kg) + Neemcake (5 kg) /palm/yr.
- Spraying of Bordeaux mixture (1%) or Copper oxychloride (0.25 %) - two times at 45 days interval during summer months.
- Root feeding with carbendazim 2g or hexaconazole 2ml in 100 ml water three times at 3 months interval.

Biological Pest Suppression and GAP in Coconut

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Introduction

Coconut (*Cocos nucifera* L.) is grown as homestead crop as well as in organized plantations in Peninsular India. The perennial nature of coconut palm along with its associate crops in most cases provides an ideal niche for the build of several pest species. Biological methods of pest control using parasitoids, predators and pathogens play vital role in pest suppression of coconut palm and use of chemical pesticides are the last option. Crop Habitat manipulation like shade regulation, pest repulsive intercrops and field sanitation are important aspects in IPM. The coconut palms exerts a profound influence on the rural economy of the many states where it is grown extensively and it provides sustenance to more than 10 million people. Although production and productivity of coconut in India has grown up noticeably in the past decades, dominance of phytophages attacks in majority of the coconut areas in the country has threatened coconut industry to a large extent. Rhinoceros beetle (*Oryctes rhinoceros* Linn.), red palm weevil (*Rhynchophorus ferrugineus* Oliv.), black headed caterpillar (*Opisina arenosella* Wlk.) nut infesting eriophyid mite (*Aceria guerreronis* Keifer) and white grub (*Leucopholis coneophora* Burm.) are the major pests of coconut enjoying wider distribution in all coconut growing tracts of India. Rodents also cause heavy crop loss in certain areas like Island ecosystem and lands locked with water bodies. Minor pests include coreid bug, slug caterpillars, scale insects, mealybugs and termites. Vey recently the palm had also witnessed ravage by the invasive pest, rugose spiralling whitefly (*Aleurodicus rugioperculatus* Martin)

Good Agricultural Practices (GAP)

GAP is an integral part of bio-intensive pest and disease management as defective or bad practices always paves way for increased pest incidence. Good Agricultural Practices encompasses those practices that ensure environmental, economical and social sustainability for all on-farm processes resulting in safe, hygienic and quality food and non-food agricultural products (FAO, 2003).

In the dynamic globalized food network, concerns on food security, safety, livelihood security along with ecological sustainability are viewed very critically and GAP, thus, evolved safeguard and provide viable options for these issues. Coconut being a perennial and cosmopolitan plantation crop in India, needs a systematic and timely care through GAP for successful establishment and sustained production in the field. Some of the problems encountered in farmers gardens are obtaining planting materials, often sub standard, from unrecognized nurseries, irrelevant site of planting particularly beneath big trees denying the basic source of light or planting in areas of improper drainage, inappropriate spacing adopted leading to intense odour cues attracting pests, adopting unscientific crop management techniques, pest and disease incidence in the initial phase of establishment, and farmers unaware of new technologies in crop management. Most of these could be over by adopting GAP. Eco-friendly and biological-system based technologies have been evolved for the successful management of key pests and diseases of coconut palm. Systematic nutrient application as well as crop management rejuvenate palms and often provides tolerance to ravage by pests. Field and palm hygiene by proper disposal of breeding sites of rhinoceros beetle, destroying the beyond recovery palms as well as avoiding any kind of injury on healthy palms are crucial for effective field management of rhinoceros beetle and red palm weevil. Creating a conducive environment for natural enemies is an essential component in biomanagement of pests. Planting seedlings with reduced spacing would induce odour cues in favour of pest orientation enhancing palm susceptibility to pest attack. However, intercropping of palms with compatible intercrops with repelling odour volatiles viz., nutmeg, curry leaves, banana etc. or egg laying attractants like *Tagetes* along the interspaces disorients the pest away from the source due to crop-habitat diversification induced pest-repulsion cues

Rhinoceros beetle (*Oryctes rhinoceros* Linn.)

Oryctes rhinoceros commonly known as rhinoceros beetle or black beetle is a major pest of coconut in all the coconut growing regions of the world. The beetle is a major pest of oil palm (*Elaeis guineensis*) and also infests other palm species like date palm (*Phoenix dactylifera*) and palmyrah (*Borassus flabellifer*) etc.

Damage and symptoms: The stout adult beetles cause damage to palms at all age groups by tunnelling into the unopened spindle leaves and spathes and chew off the soft internal tissues. As the pest enters deeper into the host it pushes out the chewed up tissues as fibres, which are seen extruding from the entry points. Once these injured spindles open up, the green leaves present a geometric 'V' shaped cut pattern. The damage to inflorescence is seen as round oblong holes on the spathes which soon dry up resulting in complete loss of nuts in the affected bunch. Attack in young seedlings results in stunted growth and delayed flowering. 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 and for entry of fungal pathogens.

Bioecology:
The adult is a stout black beetle 35-50 mm in length and 14-21 mm in breadth. It has a cephalic horn, which is longer in males. The pygedium has reddish brown hairs in the female. The beetle breeds in the decaying organic matter like cattle dung, compost pits, dead and decaying coconut logs, saw dust, coir pith, rotting paddy straw, sugarcane waste etc., where the adults lay eggs and complete the larval and pupal stages. The larvae are creamy white in colour with the body strongly arched dorsally. Grub period is about 130 days with three instars. The pupal period varies from 20-29 days. Adult longevity is 3 - 4 months. Adults are active during night and remain hidden during day time in the feeding or breeding sites. Average fecundity per female is 108 eggs.

Pest Management: Integrated Pest Management adopted on a community basis essential to bring an effective control of Rhinoceros beetle population. The components of IPM package are listed below.

Mechanical control: This method involves periodical examination of the palm, crown and extracting the adult beetles by menace of a beetle hook. During peak period of pest infestation (June – September).

Prophylactic control

- Application of oil cakes of neem (*Azadirachta indica*) or marotti (*Hydnocarpus wightiana*) in powder form @ 250 g. mixed with equal volume of sand in to the top most three leaf axils around the base of the spindle leaf during May, September and December is an effective prophylactic method against Rhinoceros beetle and Red Palm Weevil.

- Application of naphthalene balls in the leaf axils at the base of the spindle @ 12g. per palm covered with sand also provide good protection against the pest especially in young palms.
- Recently ICAR-CPCRI has developed a botanical soap based tablet and gel based product for repulsion and avoidance of feeding. Tablet can be placed on the top most three axils and paste can be swiped around the spear leaf

Biological control: This method is the most important component in the IPM of *O. rhinoceros* and two microbial pathogens are employed for the control. Wide and successful control of *Oryctes rhinoceros* has been achieved using *Oryctes rhinoceros nudivirus* (OrNV) and *Metarhizium anisopliae*.

***Oryctes rhinoceros* nudivirus:**
This was first isolated in Malaysia by Huger in 1966. Mohan *et al*. reported 54% natural virus infection in adults for the first time in India from Kerala in 1983. It is a rod shaped virus belonging to Baculoviridae, which mainly infects the nuclei of the midgut epithelium, and the fat bodies of grubs and adults. This virus gains entry in to the host only orally through contaminated food.

As the virus multiply in the midgut epithelium, the fat body disintegrates and the haemolymph content increases. This causes translucency of the thoracic region, which is an important exopathological symptom for identification of the disease. In certain cases increased turgor pressure may cause extroversion of the rectum. On dissection, the midgut filled with white fluid is clearly seen in advanced infection stage. The infected grubs die within 15-20 days and do not pupate. Giemsa staining (3%) of the midgut fluid and its epithelial tissue show pink coloured enlarged nucleus with vacuoles under light microscope. The viral particles are seen only under Electron Microscope. Adults become inactive lay less number of eggs (1-2 as compared to 108 eggs/female) and become short lived (25 days as compared to 142 days) than the healthy ones. Infected adults disseminate virus through their fecal matter into surroundings at the rate of 0.3mg virus/adult/day. The virus- infected cadavers or virus triturate could be stored at - 40^0C indefinitely. The best practical method of dissemination of this virus is by releasing the infected adults in the field @ 10-15 number/hectare. Creditable control of *Oryctes* has been achieved in many coconut growing countries by using this viral agent. The percentage of petiole damage and spathe damage show significant reduction after 6-8 months. Reduced site occupancy of the pest in breeding places, reduction in the pest incidence in the field and presence of virus infected grubs with typical visual symptoms of the viral infection in the breeding grounds are the indicators of the establishment of the viral pathogens in the induced areas.

Metarhizium anisopliae
This is also known as the “green muscardine fungus” and is pathogenic to all life stages of the *Oryctes rhinoceros*. It is very active during the monsoon when the relative humidity is high (90%) and the temperature is at the range of 26-28^{o}C. This fungus gains entry into the body of host through the cuticle region. Grubs become sluggish and ultimately die after 12 to 15 days and get mummified. Few days later these mummified specimen becomes green in colour because of the production of spores externally.The fungus can be cultured either in solid substrate, Cassava chips and rice bran mixture supplemented with nitrogen source, or by using sterilized coconut water. Using coconut water as the medium mass multiplication technique was developed in CPCRI. Coconut water supports better mycelial growth and sporulation of the fungus. The farmers themselves can adopt this method with some amount of training on the culturing of the fungus.

Spores @ $5x10^{11}$spores/m^3 of breeding area of *Oryctes* gives a successful establishment of this fungus. Once the fungus establishes itself, it will survive in the site for more than two years. This fungus is being widely used in India, Indonesia, Sri Lanka, Brazil and other South East Asian countries where *Oryctes rhinoceros* damage is prevalent in coconut and oil palm. The percentage of control of the pest is very high during the favourable season for the fungal growth

Predators:

Insect predators are frequently observed in the natural breeding site of the beetle, which feed on the eggs and the early instar grubs of the beetle. The important predators are *Santalus parallelus* Payk., *Pheropsophus occilitalis* Macleay, P. *lissoderus*, *Chelisoches morio* (Fab) and species of *Scarites, Harpalus* and *Agrypnus*. As these predators help in the natural check of the pest population, conservation of the predator fauna is essential.

Treatment of breeding sites.

Restricting and managing the breeding sites could check the proliferation of the pest. Proper disposal of breeding grounds and field sanitation are important step steps in IPM of *Oryctes*. Incorporation of the weed plant *Clerodentron infortunatum* Linn. in the compost pit is suggested as cheap and effective method for managing *Oryctes rhinoceros* in the breeding grounds as the principles contained in the plant arrests the development of different stage of the pest.

Pheromone traps

Specially designed PVC tube trap employing synthetic pheromone ethyl 4-methyl-octonate was found quite feasible for trapping black beetles in good numbers. This can be employed in community based pest management approach with close monitoring. While placing traps in the field, plantations with juvenile palms have to be avoided.

Red palm weevil (*Rhynchophorus ferrugineus* Olivier)

Red palm weevil (RPW), a concealed tissue borer is the lethal pest of palms and is reported to attack 17 palm species worldwide. It is one of the key pests of coconut causing mortality of young palms to the tune of 7-10% in different tracts of country. In addition to coconut, RPW has become a devastating pest of date palm (*Phoenix dactylifera*) in Middle East countries. it enjoys a wide distribution in all coconut growing tracts of India. Young and dwarf palms are more susceptible to the pest infestation. Incidence of red palm weevil is relatively high in those areas having high incidence of rhinoceros beetle, bud rot disease and leaf rot disease. Shallow methods of planting and mechanical injuries on the palms also pave way for the pest attack. High multiplication rate of the pest coupled with continuous egg laying throughout the year hinders effective management of the pest.

Bioecology: The adult red palm weevil is medium sized measuring 35 mm long and 20mm wide with ferruginous brown colour. Snout is elongated and the dorsal apical half of the rostrum in males are covered with a tuft of brown hairs, where as rostrum is females are bare and longer. Mean fecundity is 275 eggs/female. The creamy white oval eggs are laid in small holes scooped out on soft tissues or on cuts, wounds or other decaying parts of the palm trunk/crown. Even cut ends of fronds act as oviposition sites. The odour of plant sap exuding from injuries or fermenting sell of fungal infections attract adult females for egg laying. Grubs of this internal tissue borer feed on the soft tissues of the palm crown. The full grown grub is stout, fleshy, apodous, body bulged in the middle and creamy white in colour with a brownish black head. Larval period is the destructive phase and lasts for 55-60 days. The full grown grubs measure 50 mm in length and 20 mm in width. They pupate near the periphery of the palm in elongate fibrous cocoons for 12-20 days. The weevil takes about 3-6 months for completion of the life stages from egg to adult depending up on weather conditions and type of food source. The adults have a prolonged life span extending up to 76 to 133 days.

Damage: Being an internal tissue feeder with all the life stages inside the palm tissues, it is very difficult to detect the pest attack during early stages. Wilting of central spindle, presence of chewed up fibres in the leaf axils, presence of holes in the crown or soft trunk portion with oozing out of a brown viscous fluid, splitting of leaf bases and gnawing sound produced by feeding grubs enable the detection of pest infestation *etc.* are characteristic symptoms of pest attack. Severe infestation results in toppling of the crown.

Pest Management: IPM for managing red palm weevil comprises the following important components *viz*., phytosanitation, prophylactic treatments, curative chemical treatments and pheromone trapping. Coconut palms dead due to red palm weevil and retained in the field serve as ideal source of inoculum for further build up of the pest in the field. Hence, the importance of field sanitation is very important to protect the palms. The pest is attracted to kairomones emanating from fresh injuries inflicted on the palms. Due to mechanical farm operations such as ploughing, cutting of steps for climbing the palms, the injured palm becomes more susceptible to weevil infestation. Timely treatment of wounds or injuries is unavoidable to ward off pest infestation.

New molecules viz., , imidacloprid @ 0.02%, Spinosad @ 0.013% and Indoxacarb @ 0.04% were promising for curative treatment and have given more than 80% recovery of infested palms. With the synthesis and availability of ferrugineol based pheromone lure 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 which have proved that trapping of red palm weevil using pheromone lures (4-methyl 5-nonanone (Ferrugineone) and 4-methyl 5-nonanol (Ferrugineol) in food baited bucket traps can be one of the effective IPM tools to manage red palm weevil provided all the precautionary steps involved in the use of pheromone traps are meticulously followed by the user. Efficacy and synergistic interaction of entomopathogenic nematode, *Heterorhabditis indica* (1500 IJ) with imidacloprid (0.002%) against red palm weevil grubs was reported

Black headed caterpillar (*Opisina arenosella* Walker)

The black headed caterpillar, *Opisina arenosella* Walker (Lepidoptera: Oecophoridae) is a serious defoliator pest of coconut in India and Sri Lanka.

Bioecology: The adult moth is 10-15 mm long, 20-25 mm wide (wing expanded) and ash grey in colour. The male is smaller in size, with a slender abdomen ending in a short brush of scales, while in the females the abdomen is stouter and pointed towards the tip. Eggs are laid on the lower surface of leaflets near old larval galleries. Adult moth lays on an average of 137 eggs. Larval body is cylindrical, slightly compressed with a tapering hind end with three longitudinal reddish brown stripes dorsally and with the black head. Final instars measure about 154 mm long. Average larval period is 42 days and total life cycle from egg to adult takes about 8-10 weeks. The adult moths live for about 5-7 days.

Damage: First noticeable symptom of infestation is the drying of leaflets in patches. The caterpillars are voracious feeders and feed on the chlorophyll containing leaf tissues leaving the thin upper epidermis. They live in galleries made up of silken webs with scraped leaf bits and excreta on the lower side of leaves. The affected portions get dried and form conspicuous grey patches on the upper surface of the leaves. Usually the feeding and drying starts from the outer whorl of leaves and proceeds inwards. Close examination of leaflets shows presence of larval galleries on the lower side with live or dead stages of the pest. Severe pest damage results in complete drying of middle to inner whorl of leaves also. As the palms succumb to heavy loss by the non functioning of affected leaves 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 apart from rendering the leaves unsuitable for thatching and other purposes.

Pest Management: Biological method of pest suppression has been accepted as a long term strategy to curb the pest problem in this perennial crop on account of increasing ill effects by the use of chemical methods for pest management. Parasitoids and predators play an important role in the natural biological suppression of *O. arenosella*. 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 against coconut black headed caterpillar.

The larval parasitoid *Goniozus nephantidis* (Bethylidae) is released if the pest is at 3rd larval stage or above @ 20 parasitoid /palm and *Bracon brevicornis* (Braconidae) @30 parasitoid/palm. The pre-pupal parasitoid, *Elasmus nephantidis* Rohw. (Elasmidae) and the pupal parasitoid *Brachymeria nosatoi* Habu.(Chalcididae) are also very effective in managing the pest. They are released @ 49 and 32% respectively for every 100 pre- pupae, pupae estimated to be present on the palm. 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 gallery volatiles) is found to improve the host searching efficiency of *G. nephantidis.* Effective field biocontrol of this pest by release of parasitoids are well documented success stories in Kerala, Karnataka, Tamil Nadu and Andhra Pradesh. Cutting and burning the heavily infested and fully dried outermost 2-3 leaves removes the pupae and other life stages of the pest.

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 A*nkylopteryx* sp. *Chrysopa sp, etc*. A total of 26 species of spiders are recorded with the pest of which *Rhena*, *Sparassus* and *Cheiracanthium* are the major predators. Predatory ants also play major role in population reduction of *O. arenosella* in the field. Nutritional management of the palm with balanced dose of recommended fertilizers and proper irrigation to rejuvenate the pest affected palms are essentially required to regain the yield potential of pest infested palms.

Nut infesting eriophyid mite (*Aceria guerreronis* Keifer)

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. Mites attain sexual maturity within a week's time and start laying eggs. An adult mite lays about 100-150 eggs. The eggs hatch into protonymphs, deutronymphs and finally to adults. The total life cycle is completed in 7-10 days. Coconut buttons of third and fourth bunches harbour maximum mite population. The pest activity has been observed throughout the year with the population peak during the summer months.

Damage: The mite infestation symptoms are observed approximately one month after the initial colonization of the mite inside the fertilized buttons. Appearance of elongated white streaks below the perianth is the first external visual symptom on young buttons. In many cases, an yellow halo develops around the perianth. Within a few days this halo develops into yellow triangular patch pointing towards the distal end of the button. This can be clearly seen in 2-3 month old buttons. In a short time the yellow patch turns into brown and show necrotic patches on the periphery of the perianth. As the nut grows the injuries form warting and longitudinal fissures on the nut surface. In severe infestation the husk develops cracks, cuts and gummosis. Shedding of buttons and young nuts and malformation of nuts as a result of retarded growth are the other indications associated with severe attack of the pest.

Pest Management: 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. Spraying of neemoil-garlic soap mixture at 2% or commercial botanical pesticides containing azadirachtin 10,000 ppm @ 0.004% or root feeding with neem formulations containing azadirachtin 50,000 ppm (7.5 ml) or azadirachtin 10,000 ppm (10 ml) mixed with equal volume of water is recommended for mite management. 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* has received considerable attention throughout the world as the most effective natural enemy of eriophyid mite of coconut. Conservation of the predatory fauna in the ecosystem is beneficial to regulate the coconut mite in nature. The nutritional status of the palm plays a significant role in the management of the pests. The nutrient management package consists of balanced application of NPK fertilizers at recommended doses in two splits (Urea 1.0 kg, rock phosphate 1.5 kg, muriate of potash 2.0 kg), recycling of organic biomass in coconut ecosystem using *in situ* vermi composting or growing of green manure crops like cow pea or sunnhemp and its incorporation in coconut basin and conservation of soil moisture by appropriate mulching methods.

White grub (*Leucopholis coneophora* Burm.)

White grubs are major pests of coconut palm mostly found in sandy loam soil tracts of Kerala and Karnataka. Grubs are polyphagous and feed on roots of coconut palm as well as other intercrops like tubers, rhizomes, vegetables *etc*.

Bioecology: Adult beetles are chestnut brown coloured and they emerge out of soil after pre-monsoon showers in May-June. Adult emergence from soil was observed in the field after 4-5 rainy days combined with a sudden fall in soil temperature, which invariably begins after sunset and completes within half an hour. Eggs are laid in soil and the hatched out grubs feed on the root of coconut and intercrops. Average fecundity is 23 eggs. Incubation period is 24 days and the I, II and III larval stages were completed in 40, 55, and 175 days respectively followed by pupal period of 25 days. Grubs are creamy white in colour with a brown head. Pest completes its life cycle in 300-310 days.

Damage: In nursery seedlings the grubs 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. In older coconut plantations continuous infestations by the grubs results in yellowing of leaves, premature nut fall, delayed flowering, retardation of growth and reduction in yield. Peak grub population is seen in the coconut basin during September-October

Pest Management

- Hand picking and destruction of adult beetles during emergence period (May/ June)
- Soil application of bifenthrin @ 2 kg ai / ha when first instar stage of grubs dominate in the field (July-August)

- Root zone application of entomopathogenic nematode, *Steinernema carpocapse* @ 1.5 billion IJs / ha and imidacloprid 17.8 SL @ 0.25 ml / litre during September-October. Need based repeated application of EPN.
- Regular ploughing to expose the grubs to predators

Coreid bug: *Paradasynus rostratus* Dist.

The widespread occurrence of the coreid bug, *Paradasynus rostratus* Dist. (Heteroptera: Coreidae) was reported as a serious emerging pest on coconut from Southern districts of Kerala. The bug causes heavy crop loss by shedding of developing buttons and immature nuts. Nymphs as well as adults feed on female flowers and tender nuts. While feeding, the saliva is injected into the feeding site through the proboscis and the toxin present in the saliva damaged the tissues around the feeding site. These feeding punctures develop into necrotic lesions and these eye-like depressions can be clearly seen if the perianth of the shed button is removed. When female flowers are attacked prior to pollination such flowers get dried and can be seen attached to inflorescence on the crown resulting in production of barren buttons. Most of the infested buttons and tender nuts shed down. The retained nuts on the bunches develop furrows and crinkles on their husks and are malformed. In many cases gummosis can be seen on such nuts. In severe infestation, the kernel of infested nuts become thin, malformed and cannot be used for edible purposes. Guava, cashew, cocoa, tamarind, anona and neem are alternate hosts of *P. rostratus.*

Pest Management: Application of neem seed oil plus garlic emulsion 2% was found effective in the suppression of the pest. Spraying of azadirachtin 300 ppm @ 0.0004% reduced the pest incidence at the highest level. Two rounds of azadirachtin spray on young coconut bunches of 1-5 months old during May-June and September-October are quite essential for satisfactory control of the pest in the field. In gardens where coreid infestation persists a third round of spraying is recommended during December-January. Among the natural enemies, the weaver ant, *Oecophylla smaragdina* is found to be the most efficient predator of coreid bug in the field. This ant is found predating on all stages of the bug and is observed on coconut as well as all alternate host plants. It has been observed that coconut and other collateral host plants where ant colonies exist, such plants are free from coreid bug incidence. Crown cleaning to destroy eggs and immature stages of the pest along with pesticide application on the affected young bunches is recommended for coreid bug management.

Scale insects, mealy bugs

In coconut, four species of armoured scales *viz., Aonidiella orientalis, Aspidiotus destructor, Lepidosaphes megregori, Chionaspis* sp. were recorded from Kerala and Minicoy. Three species of soft scales *viz*., *Ceroplastes floridensis, Coccus hesperidum, Vinsonia stellifera* were also observed on coconut from these regions. Five species of mealybugs are associated with coconut in India. They are *Palmiculter palmarum, Pseudococcus longispinus, Pseudococcus cocotis, Dysmicoccus* sp. and *Rhizoecus* sp.

Pest Management: 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 them in the ecosystem is recommended. Scale insects are spread by transport of infested plants or plant parts. Surveillance should be strict on the movement of planting material to avoid spread of scale insects across the transcontinental borders. Plants need to be provided with good growing conditions and proper cultural care, especially appropriate irrigation so they are more resistant to scale damage. Healthy plants in well drained soils are seldom seriously infested. In case of out breaks, three sprays of 2.5% fish oil rosin soap were found to be effective in reducing the population of *A. destructor.*

Whiteflies

Two types of whiteflies viz., areca whitefly, *Aleurocanthus arecae* and rugose spiralling whitefly (RSW) *Aleurodicus rugioperculatus* have been recorded from coconut in India. They are naturally under check attributing to the natural presence of effective bio-suppression agents viz., *Encarsia* sp. nr. *haitiensis* and *Encarsia guadeloupae*. Predatory coccinellids like *Chilocorus nigritus*, *Chilocorus subindicus* and *Scymnomorphus* sp. keep pest under check in field. It was observed that more than 50 % of the whitefly was parasitized naturally by the aphenilid parasitoid, *Encarsia guadeloupae* which is playing an important role in natural biosuppression of the pest. Use of insecticides is not a viable option for the management of whitefly as causes a reduction in the build of natural enemies, especially *E. guadeloupae*.

The integrated pest management strategies to be adopted are as follows:

1) The pest population is likely to recede with monsoon showers and build-up of natural enemies and hence, insecticide application should be totally avoided.
2) Application of 1% starch on the sooty mould affected leaves to flake out the mould,
3) Fixing of yellow sticky trap of one meter width painted with white grease or castor oil on the trunk of infested palms to trap the adult whiteflies.

Rodents

Rattus rattus wroughtoni Hinton

In India about ten species of rodents are found to co-exist in coconut cropping system. Of these only seven species are considered to be the pests of coconut. Among them, the black rat, *Rattus rattus wroughtoni* is the most important one. It is the major mammalian pest of coconut in the island ecosystem of Lakshadweep and Andamans as well as in the mainland. The extent of rate damage to tender coconut varies from 8.7% in certain parts of Andhra Pradesh to 50% in Lakshadweep Islands, where close planting is practiced. These rats breed all through the year with peaks during early summer (February and March) and late monsoon (July and August) periods. Typical rat damage to tender coconut consists of a small hole about 5 cm diametre near the stalk region. The rat after gnawing the husk consumes the inner contents including the soft shell of the nut and such damaged nuts usually remain on the bunch for a further period of 2-6 days. The fallen nuts are seen around the basin of the palm. Three to six months old tender nuts are mostly preferred by this mammalian pest.

Pest Management: Planting coconut seedlings in correct spacing as well as destruction of fallen fronds and other farm wastes at regular intervals would ward off the rat activity from coconut gardens. Wrapping the trunk of coconut trees using polythene sheets was found to reduce the damage by rats in Minicoy. 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 from the crowns expose the nesting placing of these rats to predators. A habitat alteration discourages rats from population build up on the crown. The more effective and economic way of managing this pest is by the use of single dose anticoagulant rodenticide, Bromadiolone (0.005%) is wax cake formulation. In coconut, application of 10 g Bromadiolone (0.005%) 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 palms, only such palms require baiting.

Conclusion

Careful understanding of pests and its diagnostic symptoms are very crucial for successful implementation of pest management strategies in plantation crops. A holistic approach in the execution of IPM with greater emphasis on pest-defender relationship and crop-habitat diversification strategies are the need of the hour. Adequate and timely nutrition of crops with need-based irrigation are very essential components in the field level suppression of pests. Farmers field school and farmer participatory approaches in pest management have emerged as effective tools in pest management. Impact of climate change and transformation of minor pests as key pests need to be closely scrutinized. Crop production and protection systems should therefore work in synergy for realizing highest returns from plantation crops farming.

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Mass Production of Antagonistic Fungus, *Trichoderma* sp.

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The fungus *Trichoderma* is widely used as biocontrol agent against several pathogenic fungi causing plant diseases throughout the world. These antagonistic fungi are the most commonly used biocontrol agents because of their multiple modes of action namely mycoparasitism, competition for space and nutrients, production of inhibitory compounds, inactivation of the pathogen's enzymes, induced resistance and plant growth stimulation.

Mass production of *Trichoderma*

a. Isolation of *Trichoderma* from Soil

Dilution plate technique is followed for the isolation of *Trichoderma* from rhizosphere soil

- Collect rhizosphere soil sample from the field.
- Suspend ten gram of soil sample in 100 ml of sterile distilled water and stir well to get (1:10) dilution.
- Transfer one ml from this suspension to 9 ml of sterile water in a test tube to get 1:10 dilution and make serial dilutions by transferring one ml of suspension to subsequent tubes to get dilution of 10^{-4} to 10^{-6}
- Transfer one ml of the desired soil suspension to sterile Petri plates.
- Pour 15 ml of melted and cooled *Trichoderma* selective medium in the same Petri plates. Rotate the plate gently and allow the medium to solidify.
- Incubate the Petri plates at room temperature for 4-5 days and observe for the development of fungal colonies.
- *Trichoderma* colonies will be white initially and turn to green. Transfer the individual Trichoderma colonies to potato dextrose agar slants.

Composition of specific media used for isolation of *Trichoderma*
Improved *Trichoderma* specific medium (TSM) (Elad and Chet, 1983)

$MgSO_4 . 7 H_2O$	:	0.2g
K_2HPO_4	:	0.9g
KCl	:	0.15g
NH_4NO_3	:	3.0g
Glucose	:	3.0g
Chloramphenicol	:	0.25g
Fenaminosulph	:	0.3g
PCNB	:	0.2g
Rose Bengal	:	0.15g
Benomyl	:	0.02g
Captan	:	0.2g
Water	:	1L

b. Selection of isolates with antagonistic activity

Antagonistic activity of the isolates is tested by dual culture technique and the most effective isolate is selected for mass multiplication.

c. Mass multiplication

Mass multiplication can be done on potato dextrose/jaggery broth

Potato Dextrose Broth (PDB)

Potato	:	200g
Dextrose	:	20g
Distilled water	:	1000ml

200 g of fresh potato is used for preparing one liter of medium. It is washed thoroughly in tap water, peeled and cut into thin slices. Boil the potato pieces in 500ml of distilled water and filter through a double layer of muslin cloth. Add 20g dextrose into the filtrate. Make up the volume to one litre with distilled water .Dispense the broth to conical flasks. Plug the flasks with cotton and wrap with paper. Sterilize the broth at 121^0C for 20 min. Inoculate the broth with *Trichoderma* disc from highly sporulated seven day old culture.

d. Formulation

Formulation can affect many aspects of biocontrol performance, shelf life and safety. As with any biological systems, three parameters that greatly affect success are water, food and environment. Water activity can profoundly affect survival of biocontrol agents in formulations. A dry product is less weight to ship and at a lower risk of possible contamination. Some biocontrol agents forms life stages that are relatively simple to formulate, such as bacterial endospores, yeasts, and the resting-spore stages of many fungi. In these cases, revival of the spores must be considered.

Production of Talc based formulation of *Trichoderma* (1 kg)

Materials required

Trichoderma biomass (homogenized) : 400 ml
Carboxy methyl cellulose : 5g
Talc powder : 1 Kg
Polythene cover
Sealing machine

Procedure

- Sterilize the talc powder for two successive days
- Homogenize the biomass multiplied in coconut water
- Mix 400 ml of homogenized biomass in 1Kg of sterilized talc powder
- Shade dry to 8% moisture.
- Carboxy methyl cellulose should be added @5g/Kg of talc powder during mixing.
- After drying break the clots
- Pack the formulation in milky white polythene bags

Quality control specifications for *Trichoderma*

- Fresh product should not contain less than 2.0 X 10^6 cfu/g
- Moisture content of the final product should not be more than 8%
- Maximum storage period using talc as carrier is 120 days
- Pathogenic contaminants such as *Salmonella* or *Vibrio* should not be present
- Other microbial contaminants should not exceed $1x10^4$ count per ml or gram

Farm level multiplication of *Trichoderma* spp. on locally available substrates

The success of biological control depends on the development of economic and easier technique for the mass multiplication of biocontrol agents. The commercial success of biocontrol agents depends upon the bioefficacy, shelf life and quick but easy multiplication on suitable, readily available and economical substrate. For large scale application of biocontrol agents in the field, a suitable medium is essential for mass production. Conventionally used costly raw materials for commercial production of biocontrol agents is one of the major limitations behind the restricted use. In order to overcome the cost limitations, many researchers have successfully used various agricultural wastes for the mass multiplication of *Trichoderma*.

Coconut water

Coconut water is discarded as an agricultural waste in copra industry. Coconut water which is rich in nutrients supports faster growth of the biocontrol agents. The suitability of mature coconut water for multiplying biocontrol agents like *Trichoderma hamatum* and *Gliocladium virens* has been studied by different workers.

Materials required

Coconut water
Tap water
Transparent glass bottles
Pressure cooker (20 L) for sterilizing the medium
Inoculation chamber

Procedure

- Take coconut water from mature nuts
- Filter it through a clean muslin cloth to remove the residue
- Mix the equal quantity of coconut water with equal quantity of tap water (1:1) to produce coconut water broth
- Distribute the 100 ml of broth to glass bottles
- Plug the bottles with cotton and wrap with paper
- Sterilize the broth
- Inoculate the coconut water broth with *Trichoderma* disc from highly sporulated five days old culture
- Incubate the inoculated bottles on a clean bench for 5-6 days
- Initially *Trichoderma* growth appear as a white mycelial mat which later turns dark green After 5 days it forms a thick green mat of spores on the surface of coconut water broth. This biomass is used for the preparation of the talc formulation

Neem cake

A Combination of coir pith and neem cake (1:1) with 50% moisture is a very good substrate for multiplication of *Trichoderma* and also provides longer shelf life to *Trichoderma* propagules and hence this can be used as a carrier for the biocontrol agent.

Procedure

- Neem cake to be powdered and mix with coir pith by sprinkling the water and moisture level should maintain to 50%.
- Inoculated with *Trichoderma* talc powder at the rate of 1Kg per 100Kg of substrate and covered with wet gunny bag.
- Incubated for seven days with the intermittent mixing once in two days and maintained the moisture level up to 50%.

Calculation of colony forming units (cfu) in *Trichoderma* substrate

The number of colony forming units (cfu) per gram of *Trichoderma* enriched substrate is calculated using formula given below, Number of cfu of *Trichoderma* per gram of substrate = No. of colonies x Dilution facor

Advantages of mass production of biocontrol agents in crop wastes/ organic manures

1. Low cost of raw material
2. Easy to multiply
3. Ecofriendly
4. Easy to handle and apply
5. Multiplication of biocontrol agents in soil protect the plants from pest/ diseases
6. Application of organic matter improves the soil texture and enhance the root development

***Trichoderma* isolation using TSM**

***Trichoderma* growth in PDA**

***Trichoderma* mass multiplication in coconut water br**

***Trichoderma* talc formulation (1:1)**

***Trichoderma* growth in neem cake+coir pith formulation**

Biosuppression of Coconut Pests with Entomopathogenic Nematodes

Rajkumar and Sujithra M

Entomopathogenic nematodes (EPNs) as a bio-control agent have proven successful and are now commercially mass produced in six of the seven continents to treat pest problem in agriculture, horticulture and forest crops. They actively search for the host, including those in cryptic habitat stages of insect pests in soil environment. They can be considered as good candidates for integrated pest management in sustainable agriculture due to plants and mammals which are not adversely affected and have ease of mass production. We present a general overview on the current state of knowledge of EPN and their mutualistically associated bacteria and their utilization as biological control agent against insect pests in world and India are briefly presented in this chapter.

Key words: Entomopathogenic nematodes, steinernematids, heterorhabditids, mass production and coconut

The application of insecticides has been the control method commonly used, but its rejection by society is increasing, due to effects on non-target organisms, water contamination, residues found in fruit and vegetables and development of resistance among insect pests. In this context, biological control is becoming a useful alternative, as part of an integrated pest management (IPM) strategy. Entomopathogenic nematodes (EPNs) play an important role as biocontrollers additionally, EPNs focus on the soil stages, which are difficult to control with chemical pesticides.

The interest in the use of entomopathogenic nematodes as biological pest control agents has increased exponentially over the past decades. A hundred different laboratories explore these nematodes and their bacterial symbionts in more than 60 countries from every inhabited continent. Despite research breadth that extends from molecular biology to field ecology, the discipline is unified by common interest in biological control. Thirty years ago, the idea of using nematodes to control pest populations was vague promise held by the handful of researchers working with these obscure insect parasites. Today, they are no longer a laboratory curiosity but have begun to gain acceptance as environmentally benign alternatives to chemical insecticides. The entomopathogenic nematodes have proven particularly successful and are now commercially mass-produced in six of the seven continents to treat pest problems in agriculture, horticulture and human husbandry. The ease of mass production and exemption from registration requirements are the two major reasons for early interest in the commercialization of entomopathogenic nematodes. However, demonstrations of practical use, particularly in Europe and North America and subsequently in Japan, China and Australia, spurred developments across the world that have led to the availability of nematodes against pests that were once thought impossible to control. Entomopathogenic nematodes (EPNs) of the families, Steinernematidae and Heterorhabditidae are known to be lethal pathogens of insect pests. These pathogens contribute to the regulation of natural populations of insects, but the main interest in them is an inundatively applied biocontrol agent (Kaya and Gaugler, 1993). Their success in this role can be attributed to the unique partnership between a host-seeking nematode and a lethal insect pathogenic bacterium. Because of their biocontrol potential, considerable attention has been directed over the past few decades to genus, Heterorhabditis and Steinernema and their respectative bacterial partners, Photorhabdus and Xenorhabdus (Forst and Clarke, 2002).

Entomopathogenic nematodes

Entomopathogenic nematodes (genera Steinernema and Heterorhabditis) are biocontrol agents used to target a variety of economically important insect pests (Grewal et al., 2005), kill insects with the aid of mutualistic bacteria (*Xenorhabdus* spp. and *Photorhabdus* spp. for steinernematids and heterorhabditids, respectively) (Poinar, 1990; Lewis and Clarke, 2012), which have been described from 23 nematode families (Koppenhofer 2007). So far more than 100 species in families Steinernematidae and Heterorhabditidae have been described from all continents except Antarctica and this number is growing every year (Nguyen & Hunt, 2007). A major difference between steinernematids and heterorhabditids is that all but one species in the former group are amphimictic, whereas species in the latter group are hermaphrodites in the first generation but amphimictic in the following generation. Thus, steinernematids require a male and a female infective juvenile to invade an insect host to produce progeny, whereas heterorhabditids need only one infective juvenile to penetrate into a host as the resulting hermaphroditic adult is self-fertile. These nematodes are unique because, they are the only nematodes which have evolved the ability to carry and introduce the symbiotic bacteria into the body cavity of the insect, they are the only organisms with a wide host range of insects, they can be cultured on a large scale either on hosts or on artificial media, can be easily applied in the field with standard spray equipment and can actively find and penetrate the susceptible host and cause up to 100% mortality within few days. Since their discovery in 1927, EPN have been considered as valuable alternatives to chemical pesticides as they can parasitize a wide range of insects that are agricultural pests and insects in cryptic habitats in many parts of the world (Table 1).

Table 1. Commercial use of EPNs, Steinernema **and** Heterorhabditis **as bio-insecticides.**

EPN species	**Major pest(s) targeted - as recommended by various commercial companies**
Steinernema glaseri	White grubs (scarabs, especially Japanese beetle, **Popillia** sp.
Steinernema kraussei	Black vine weevil, **Otiorhynchus sulcatus**
Steinernema carpocapsae	Turfgrass pests- billbugs, cutworms, armyworms, sod webworms, chinch bugs. Orchard, ornamental and vegetable pests - codling moth, cranberry girdler, dogwood borer and other clearwing borer species, black vine weevil, peachtree borer, shore flies (**Scatella** spp.)

Steinernema feltiae	Fungus gnats (**Bradysia** spp.), shore flies, western flower thrips
Steinernema scapterisci	Mole crickets (**Scapteriscus** spp.)
Steinernema riobrave	Citrus root weevils (**Diaprepes** spp.)
Heterorhabditis bacteriophora	White grubs (scarabs), cutworms, black vine weevil, flea beetles, corn root worm
Heterorhabditis megidis	Weevils
Heterorhabditis indica	Fungus gnats, root mealybug, grubs
Heterorhabditis marelatus	White grubs (scarabs), cutworms, black vine weevil

Because of these attributes, as well as their ease mass production and exemption from registration, a number of commercial enterprises produce these nematodes as biological "insecticides“ that are used to control a variety of economically important insect pests. An excellent example of a situation in which a nematode may replace chemicals for control of an insect is the black vine weevil (*Otiorhynchu ssulcatus*) in cranberries. When *Heterorhabditis bacteriophora* “NC” strain was applied, it provided 70% control of the weevils soon after treatment and was still providing the same level of control a year later, Diaprepres root weevil, *Diaprepes abbreviatus* (L.), fungus gnats (Diptera: Sciaridae), thrips (Thysanoptera), and various white grubs (Coleoptera: Scarabaeidae) (Klein, 1990; Shapiro-Ilan *et al*., 2002, 2014; Grewal *et al*., 2005).Preventative applications of the *Steinernema carpocapsae* (Weiser), can reduce peach tree borer, *Synanthedon exitiosa* infestations at the same level as chlorpyrifos at North America. Specifically, when nematodes were applied prophylactic-ally infestations were reduced by 77% to 100% (Shapiro-Ilan *et al*., 2009& 2015). In India, some of the plantation pests (Table 2) were managed by soil drenching of *S. carpocapsae* @0.5x107 IJs palm^{-1} resulted in 41 per cent reduction of white grub (*Leucopholis* spp.) population in arecanut at Sringeri, Karnataka (India). Nematodes in combination of imidacloprid 17.8 SL (0.004 per cent), 1 ml 5L^{-1} water palm^{-1} found synergistic and reduced root grub population to the tune of 60 per cent (Rajkumar *et al.*, 2014). In coconut, two round root zone drenching of liquid formulation, *S. carpocapsae* @ 0.5 x 10^6 IJs palm^{-1} for two years during June/July and September/October resulted in 61 per cent reduction of root grub (*Leucopholis coneophora*) population in costal sandy soils of Kasaragod, Kerala (India) (Rajkumar and Subaharan 2016). Soil application of native strain of *Heterorhabditis indica* application @ 1, 00,000 nematodes (IJs/plant) against early stage of cardamom root grubs (*Basilepta fulvicorne* (Jacoby)) during April/May and September/October provided significant control (Varadarasan *et al.*, 2009)and they are compatible with most pesticides. The efficacy of entomopathogenic nematode applications, however, can be limited by adverse environmental conditions such as UV radiation or desiccation, extreme temperatures (Shapiro-Ilan et al., 2006).

Table 2. Pest attacking some important plantation crops

Name of the crop	Important pests
Coconut	Rhinoceros beetle (*Oryctes rhinoceros* L.) Red palm weevil (*Rhynchophorus ferrugineus* F.) Leaf eating caterpillar (*Opisina arenosella* Walker) White grub (*Leucopholis coneophora* Burm.)
Arecanut	White grub (*Leucopholis* sp.) Spindle bug (*Carvalhoia arecae* Miller and China)
Oil palm	Rhinoceros beetle (*Oryctes rhinoceros* L.) Red palm weevil (*Rhynchophorus ferrugineus* F.)
Cashew	Stem and root borer (*Plocaederus* sp. and *Batocera rufomaculata* De Geer) Leaf minor (*Conopomorpha syngramma* M.)
Cardamom	***Root grub (*****Basilepta fulvicorne** Jacoby) Capsule borer (*Conogethes punctiferalis* Guen.) Cardamom thrips (*Sciothrips cardamomi* Ramk.)
Tea	Pale mite (*Acaphyllisa parindiae*) Scarlet mite (*Brevipalpus australis*) Cut worm (*Spodoptera litura*)
Coffee	Coffee berry borer (CBB), *Hypothenemus hampei*

Infective Juvenile (IJ) and mode of action

The only stage that survives outside of the host is the non feeding infective third stage juvenile of these nematodes which are found free living in soil under diverse ecological conditions and in all kinds of habitats (Hominick *et al.*, 1996). The IJ is the stage that is purchased in commercial products. These IJ also known as dauer juvenile (DJ) is more resistant than other stages to environmental conditions and survive in the soil environment for extended periods, until they find a suitable host (Lewis and Clarke, 2012; Shapiro-Ilan et al., 2014). The IJ carries cells of bacterial symbionts in its intestine. When the IJ finds susceptible insect host, enter through natural openings (mouth, anus, and spiracles) for Steinernematidae or sometimes through the cuticle for *Heterorhabditis*. After entering the insect's heomocoel, nematodes release their bacterial symbionts, which are primarily responsible for killing the host within 24 to 48 h. The bacterium produces antibiotics that prevent other microorganisms from colonizing the cadaver. In addition to serving as a food source for the nematode, the bacterium digests the host tissues, thereby providing suitable nutrients for nematode growth and development. The nematodes molt and complete two to three generations within the host cadaver, as resources of the insect are depleted and crowding occurs, IJ are produced after which IJs exit the cadaver to find new hosts to attack (Poinar, 1990; Lewis and Clarke 2012). The reproductive potential of entomopathogenic nematodes is very high. Thousands of nematodes can be produced from a single infected insect host.

Recycling of nematodes

Recycling is desirable after an application of entomopathogenic nematodes because it can provide additional and prolonged control of a pest. The abiotic and biotic factors that affect persistence, infectivity, and motility of infective juveniles influence nematode recycling. Because they are obligate pathogens, the availability of suitable hosts is a key to recycling of the nematodes. Recycling is rather common (Klein 1993) after nematode application but is probably not sufficient for prolonged host suppression, and the nematodes have to be reapplied to maintain adequate control of soil insect pests.

Dispersal of juveniles

The juveniles of steinernematids and heterorhabditids disperse vertically and horizontally, both actively and passively (Epsky et al., 1988; Parkman et al., 1993). Passively, they may be dispersed by rain, wind, soil, humans, or insects. Active dispersal may be measured in centimeters, while passive dispersal by insects may be measured in kilometers (Smart and Nguyen 1994).

Survival of juveniles

In general, entomopathogenic nematodes do not have a long shelf life. Many microbial insecticides, including *Bacillus thuringiensis*, have a resting stage facilitating longterm storage. The infective juveniles do not feed but can live for weeks on stored reserves as active juveniles, and for months by entering a near-anhydrobiotic state. This is almost certainly the most important survival strategy for the nematode. The length of time that juveniles survive in the soil in the absence of a host depends upon such factors as temperature, humidity, natural enemies, and soil type. Generally, survival is measured in weeks to months, and is better in a sandy soil or sandy-loam soil at low moisture and with temperatures from about 15-25^0 C than in clay soils and lower or higher temperatures (Ames 1990; Kaya 1990; Kung 1991). Extended exposure to temperature extremes (below 0 °C or above 40 °C) is lethal to most species of entomopathogenic nematodes. In the soil environment, infective juveniles are normally buffered from temperature extremes. For storage, the best longevity of infective juveniles is between 5 and 15 °C. At higher temperatures, the infective juveniles have increased metabolic activity and deplete their energy reserves, shortening their life span (Brown and Gaugler 1996).

UV can kill nematodes within minutes. Direct exposure to UV light (i.e. sunlight) can be minimized by applying infective juveniles early in the morning or evening, or using sufficient amounts of water to wash the infective juveniles into the soil. Infective juveniles can survive low moisture conditions by lowering their rate of metabolism. Gradual water removal from the infective juveniles gives them time to adapt to the desiccating conditions (Patel *et al.,* 1997; Solomon et al., 1999).

Soil texture affects infective juvenile survival, with the poorest occurring in clay soils. The poor survival rate in clay soils is probably due to the lower oxygen levels in the smaller soil pores. Oxygen is also a limiting factor in water-saturated soils and soils with high organic matter content, but pH does not have a strong effect on infective juvenile survival.

Mass Production and Formulation of EPN

Mass production

A key factor in the success of entomopathogenic nematodes as biopesticides is their amenability to mass production. These nematodes were first cultured more than 70 years ago (Glaser *et al.*, 1940), and currently they are commercially produced using three culture methods: *in vivo* and *in vitro* solid and liquid culture (Friedman 1990). Each approach has advantages and disadvantages relative to cost of production, capital outlay, technical expertise required, economy of scale, and product quality, and each approach has the potential to be improved. A variety of formulation options are available (Georgis *et al.*, 1995) Entomopathogenic nematodes are easily cultured either *in vivo* or *in vitro* for laboratory tests or for commercial production (Friedman 1990). *In vivo* culture is a two-dimensional system that relies on production in trays and shelves. The wax worm, *G. mellonella*, is the insect of choice for in *vivo* production because it is produced commercially in large numbers and well defined diet material is available. *In vivo* production is labor intensive, lacks economies of scale, and is costly, but it is also simple and reliable and results in high quality nematodes (Shapiro-Ilan 2003). A system based on the White trap (White 1927), which takes advantage of the infective juvenile's natural migration away from the host cadaver upon emergence. The methods described consist of inoculation, harvest, concentration, and (if necessary) decontamination. Insects are inoculated with nematodes on a dish or tray lined with absorbent paper (e.g., filter paper) or another substrate conducive to nematode infection such as soil or plaster of Paris. After 2–5 days, infected insects are transferred to the White traps; if infections are allowed to progress too long before transfer, harm to nematode reproductive stages may occur, and the cadavers will be more likely to rupture (Shapiro - Ilan 2001). White traps consist of a dish on which the cadavers rest surrounded by water, which is contained by a larger dish or tray (Figure 1). The central dish (containing the cadavers) provides a moist substrate for the nematodes to move upon, e.g., an inverted petri dish lid lined with filter paper (Figure 1) or filled with plaster of Paris. The progeny infective juveniles that emerge migrate to the surrounding water where they are trapped and subsequently harvested. The choice of host species and nematode for in vivo production should ultimately rest on nematode yield per cost of insect and the suitability of the nematode for the pest target. Nematode quality appears to be greater when cultured in hosts that are within the nematode's natural host range (Abu Hatab and Gaugler 2001). Furthermore, nematodes can adapt to the host they are reared on (Stuart and Gaugler. 1996) , which could reduce field efficacy if that host is not related to the target. Therefore, although *G. mellonella* may often be the most efficient host to use, it may not be the most appropriate ''medium'' for maximizing efficacy versus a particular target pest.

There are only a couple of entomopathogenic nematodes not amenable to culture in *G. mellonella* (due to extremes in host specificity): *Steinernema kushidai* is most amenable to culture in scarab beetle larvae (Coleoptera: Scarabaeidae) [Kaya and Stock 1997], and *Steinernema scapterisci* is most amenable to mole crickets (*Scapteriscus* spp.) 9Grewal *et al.,* 1999). Other hosts in which in vivo production has been studied include the navel orangeworm (*Amyelois transitella*), tobacco budworm (*Heliothis virescens*), cabbage looper

(*Trichoplusia ni*), pink bollworm (*Pectinophora gossypiella*), beet armyworm (*Spodoptera exigua*), corn earworm (*Helicoverpa zea*), gypsy moth (*Lymantria dispar*), house cricket (*Acheta domesticus*) and various beetles (Coleoptera) including the yellow meal worm (*Tenebrio molitor*) (Blinova and Ivanova 1987).

For large-scale production, *in vitro* methods using 3- dimensional solid media or liquid fermentation methods have been employed, but it involves high cost and high capital requirement and the inability of the amphimictic adults to mate under liquid culture conditions (Gaugler and Han 2002). Yang *et al* (1997) reported reduced quality in *S. carpocapsae* produced in solid culture compared with *in vivo* culture. Without sophisticated mechanization (e.g., bulk sterilization) solid culture may not offer substantial advantages in cost efficiency relative to *in vivo* production (a cost analysis is warranted). Yet large - scale mechanization for solid culture requires substantial capital. If *in vitro* solid culture is to be adopted on wider scale, efficiency will have to be increased by finding less capital - intensive methods of mechanization.

Formulation

Regardless of culture method, once entomopathogenic nematodes are commercially produced they must be formulated for delivery and application (Georgis 1990). An effective formulation provides a suitable shelf life, stability of product from transport to application, and ease of handling. Shelf life, in most entomopathogenic nematode formulations, is obtained by reducing nematode metabolism and immobilization, which may be accomplished through refrigeration and partial desiccation. Optimum storage temperature for formulated nematodes varies according to species: generally, steirnernematids tend to store best at temperatures near 4–8^{o}C whereas heterorhabditids have longer shelf life at temperatures close to 10–15^{o}C. The climate of origin is predictive of the optimum storage temperature, e.g., *H. indica*, a nematode originating only in warm climates, stores better at 15 – 20 than at 10^{o}C (Shapiro 1999).

Various formulations for entomopathogenic nematodes have been reported including activated charcoal, alginate and polyacrylamide gels, baits, clay, peat, polyurethane sponge, vermiculite, and water-dispersible granules (WDG) (Georgies 1995). Due to cost, *in vivo* producers tend to use low-technology formulations such as sponge and paste. The nematodes are not desiccated and tend to retain high viability. However, these formulations cannot be packaged at high densities and are therefore not appropriate for large - scale usage because of labor requirements in application. Formulations used by most *in vitro* producers include clay, gels, vermiculite, and WDG. For example, a successful non desiccated formulation has been developed for *in vitro* produced nematodes based on vermiculite, which allows a shelf life of at least 1 month for *H. megidis* and 2–3 months for steinernematids (GraemeGowling, MicroBio, Cambridge, UK, personal communication).

Current use of EPN as bio-agents in IPM of coconut

As EPN are compatible with many control measures, numerous opportunities exist for including successfully in IPM programmes with minimal reliance on chemical pesticides, and involving more and more of other natural enemies and pathogens.

Rhinoceros beetle (*Oryctes rhinoceros*)

The entomopathogenic nematode, *Steinernema carpocapsae and S. abbasi* was pathogenic to grubs of rhinoceros beetle at 350 IJS/cc of vermicompost. *Steinernema carpocapsae* was oriented to over 7.3 cm in 72 hours of inoculation using volatile cues in vermicompost to find *O. rhinoceros* grubs. EPN, *S. carpocapsae* infected *G. mellonella* cadaver @ one/500 cm^3 was found effective in the bio-management of rhinoceros grubs (neonates) in vermicompost (Patil *et al*., 2012).

Root grub (*Leucoopholis coneophora*)

The *S. carpocapsae* (900 IJ and 1200 IJ) admixed with imidacloprid (0.250 to 0.008%) exposed to white grub indicated a significantly higher mortality in all nematode - imidacloprid combinations after 7 days. The interaction between imidacloprid and nematodes was found to be synergistic in all combinations (Patil *et al.*, 2013). Two round root zone drenching of aqua formulation of indigenous EPN, *S. carpocapsae* @ $0.5 x 10^6$ IJs $palm^{-1}$ during June-July and September-October resulted in 61% reduction of root grub population in costal sandy soils of Kerala. The reduction of root grub population increased with increase in nematode density per palm and number of years of treatments(Rajkumar and Subharan 2016).

Red palm weevil (*Rhynchophorus ferrugineus*)

In general, 5-7% palms are infested by red palm weevil in the country and being a concealed borer, it becomes fatal enemy of coconut on most occasions.

Placement of three filter paper sachets containing 12-15 *H. indica* infected *Galleria mellonella* cadavers on the leaf axils after application of 0.002% imidacloprid could recover 60% infested palms (Joseph Rajkumar *et al*., 2013).

Conclusion

Entomopathogenic nematodes are economically important bio-control agents and found effective in managing cryptic soil dwelling insects pests , thus attracted wide spread commercial interests in world and India. These EPNs have advantageous of ease of production and application, mammalian safety and exception from registration in many countries. They also possess a broad host range which are compatible with other management components. Not only these, they are widely distributed in different agro-ecosystem and can be formulated and stored for reasonable length of time. Recently, improvement in nematode formulation, application approaches and strain improvement have been made to enhance EPN application efficacy. Advanced research towards lowering the product costs, increasing shelf life and increasing product availability will stimulate the extensive use of EPNs as bio-control. With these progress in research, EPN will serve to reduce insecticide inputs going to agro-ecosystem and contribute to the stabilization of crop yield and the environment.

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Innovative Approaches in Pest Management

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The word "*Entomos*" meaning "having a notch or cut (at the waist) referred by Aristotle and derived from "*in*" plus "*temnein*" meaning "to cut". Insects are exo-skeletonous, hexapods with three tagmata *viz.*, head, thorax and abdomen. Occupying every niche, insects are the dominant living organisms (56%) that had evolved about 400 million years ago. Closely associated with mankind in all aspects of life such as arts and literature, clothing and cosmetics, food & energy, forensic science & forestry, health and medicine, jewelry & museum, transport & communication, wood & construction, science, sports & recreation, they mark an impinging impact. Vastly beneficial, a few of them confront and compete with humans as phytophagous pests and vectors of dreadful human diseases (Pedigo and Rice, 2014). Pests continue to impact on the productivity of crops and quality of crop products worldwide despite many years of research and development on improved methods for their control. It has been estimated that an average of 20-30% of crop yield is lost annually from the field (Oerke, 2006).

Enigma in pest management

Insect-man conflict towards pests took initial stride from **biological control**, wherein entomophaga and entomopathogens were successfully employed in biological pest suppression. In the perennial system like coconut several key pests are bio-suppressed, for instance, bio-suppression of coconut black headed caterpillar by stage specific parasitoids, *viz., Goniozus nephantidis* and *Bracon brevicornis*. With the advent of **insecticides** and after the discovery of insecticidal properties of DDT and other groups, chemical pesticides took an upper hand in pest control with enhanced efficiency and quick knock down effect. To date, several groups of insecticides including organophosphates, carbamates, synthetic pyrethroids, neonicotinoids, *etc* capture greater prominence in the pest control programme. Subsequently, **integrated control** with the combination of biological control and chemical pesticides were wisely combined, but the biasness favouring chemical pesticides emerged centre stage forgoing this strategy.

The most successful and *en masse* accepted concept of "**pest management**" as propounded by Geier Clark in 1960's revolutionized a holistic approach in tackling pests. Broadly pest management can be defined as "the careful consideration of all available pest control techniques and subsequent compatible integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. Pest management emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms leaving a pest residue for sustaining natural enemies" (FAO, 2002). Of late, "integrated pest management (IPM)" has been slowly transformed into "intelligent pesticide management". Consequently an important area of research, beyond simply minimising the use of disruptive chemicals, has been to identify means to conserve, augment or manipulate beneficial populations. IPM systems for future production of many broad acre and horticultural crops will be more complex than the pesticide-based systems currently in place, and will require greater effort on the part of crop managers, professional consultants or farmers themselves. In essence IPM reflects a sound interaction of science and pragmatism to achieve productive, viable and sustainable production systems (Fitt *et al*. 2004).

Agro-ecosystem based pest management

Ecologically based integrated pest management (EBIPM) represent ‘a sustainable approach to manage pests combining biological, chemical, physical and cultural tools to ensure favorable economic, ecological and sociological consequences *i.e.* a system based on the underlying knowledge of the managed ecosystem, including natural processes that suppress pest populations. EBIPM should have the basic objectives of safety to humans and the environment, assured profitability for the farmers and long-term sustainability with a focus on host plant resistance, biological control and cultural IPM. Ecological engineering defined first by Odum (1962) is a human activity that modifies the environment according to ecological principles. Accordingly, it is a useful conceptual framework for considering the practice of habitat manipulation for arthropod pest management. The development of ecological engineering ranged from a simple first approximation that diversity is beneficial, to contemporary understanding that diversity can have adverse effects on pest management.

An agro-ecosystem based pest regression strategy through ecological bio-engineering was designed using the root (wilt) tolerant coconut hybrid, Kalpasankara admixed with spices and fruit trees in the experimental plot at ICAR-CPCRI, Regional Station, Kayamkulam. Inner whorls of 19 Kalpasankara palms (51 months old) under the influence of mixed-volatile cues of crop plurality (rambutan, nut meg, curry leaf, banana, turmeric, red gram, papaya) inflicted lesser rhinoceros beetle damage (15.8%) compared to palms in outer whorls (30%). Infestation by rugose sprialling whitefly was found to be lower in the diversification plot (<5 live colonies/leaflet) than in garden with coconut as monocrop (>15 live colonies/leaflet).

Manipulating moulting in insects

Monumental versatility of epidermis and remarkable mechanical performance and efficiency of cuticle in terms of stiffness, elasticity, toughness and hardness made insects dominant withstanding environmental backlashes and enabled them sustain in inconceivable and inhospitable niches on earth. Chitin, a polymer of acetyl glucosamine is most abundant (>50%) in elastic endocuticle, however, is not responsible for the hardness of exocuticle and epicuticle is devoid of chitin. Hardness of exocuticle is due to the tanned protein, sclerotin, produced by the action of quinones through oxidation of diphenols. Endocuticle infuses toughness with flexibility, but epicuticle is responsible for impermeability and hydrophobicity. Moulting indicating the casting of cuticle, involves apolysis and ecdysis is hormonally regulated. In this process, moulting fluid lying between the newly developed cuticle and the old cuticle serves as lubricant dissolves only the endocuticle, while the exocuticle and epicuticle are untouched and the pressure of blood act as the rupturing force. Ecdysial line, where exocuticle iswanting splits along the line of weakness when the endouticle is digested (Chapman, 1998). Chitin synthesis inhibitors, moulting hormone agonists and antagonists interfere in this process and are exploited in pest management strategies.

Protease inhibitors

Plant protease inhibitor proteins elicited in response to insect attack affect the digestibility of ingested proteins, decreasing the amounts of free amino acids required for growth, development and reproduction. Since proteolysis is an essential part of food digestion in insects, studies on insect proteases are important. Digestive proteinases of insects also catalyze the release of free amino acids from dietary protein and thereby provide a supply of nutrients essentials for normal growth and development. Disruption of protein digestion by protease inhibitors represents an alternative approach to pest management in a world dominated by chemical pesticides. This approach requires a thorough understanding of the biochemical properties of the proteases from the gut homogenate, characterization of these proteases particularly trypsin-like protease in relation to developmental stages and understanding the way it reacts with classical protease inhibitors such as soybean trypsin inhibitor and aprotinin.

While pest-resistant transgenic plant cultivars currently available commercially, employ only Bt toxin genes, the development of transgenic plants expressing protease inhibitors has emerged in recent years as an additional strategy for pest management (Hilder *et al*., 1987). Protease inhibitor derived genes are found to have the advantage of efficient expression in transgenic plants (Ussuf *et al*., 2001). Although the exact mode of action of protease inhibitors is complex, it is fundamentally different from that by which Bt toxins operate. Transgenic plants expressing protease inhibitors may therefore be a useful alternative or adjunct to the use of Bt as a bio-pesticide. Thus, it seems likely that a transgenic plant expressing aprotinin or an equivalent protease inhibitor could be protected from attack by a susceptible pest species.

Sterile Insect Technique (SIT)
In genetic control based on SIT, mass-reared, sterile insects are released into the field, resulting in infertile matings and thereby reducing the pest population. In SIT programs the terms ‘sterility’ or ‘sterile insect’ do not usually indicate that the individuals generate no sperm or eggs,rather refer to the transmission of dominant lethal mutations that kill the progeny (Knipling, 1955; Krafsur, 1988). Because of its species specificity, SIT is considered an ecologically safe procedure and has been successfully used in area-wide approaches to suppress or eradicate pest insects in entire regions, such as the pink bollworm *Pectinophora gossypiella* in California, the tsetse fly *Glossina austeni* in Zanzibar and the New World screwworm *Cochliomyia hominivorax* in North and Central America.

Nano-particles as pesticides
The silica nano-particles were physio-sorbed by the cuticular lipids disrupting the protective barrier and thereby causing death of insects purely by physical means with a mode of action similar to that observed for diatom particles used for protection of stored grain. Application of nano-particles on the leaf and stem surface did not alter either photosynthesis or respiration in several groups of horticultural and crop plants. They did not cause alteration of gene expression in insect trachea and were, thus, qualified for approval as a nano-bio-pesticide. Debnath *et al.* (2011) reported that silica nano-particles caused 100% mortality in adults of the rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae). Despite the extensive research on plant-mediated synthesis of nano-particles for arthropod control, there is a gap between theory and practical applications, especially on a large-scale. Nano-particles are produced by natural resource-based substances, which make them promising ‘‘green’’ alternatives to the use of traditional pest control agents.

Neuro-endocrine system
Hormones are chemicals produced by an organism which circulate in the blood to regulate its long-term physiological, development and behavioral activities. Apart from moulting hormone and juvenile hormone most known insect hormones are peptides.

Moulting hormone (Ecdysone) are ecdysteroids produced by prothoracic glands, which is converted into active hormone 20-hydroxy ecdysone in the fat body or epidermis by cytochrome P-450 enzyme. 20-Hydroxy ecdysone triggers moulting events. Insects cannot synthesize sterols and usually it is diet supplemented. In the honey bee, *Apis* sp. and in Heteroptera, the principal ecdysteroid is makisterone A. The search for ecdysteroid agonists has been very successful and the ecdysteroid mimic, RH 5992 (tebufenozide), is currently marketed under the trade names Mimic, Confirm, and Romdan (Chapman, 1998).

Juvenile hormone (JH) is a sesquiterpine produced by corpora allata, which are glandular bodies usually one on either side of the oesophagous. Different forms of JH *viz.*, JH0, JHI, JHII and JHIII containing 19, 18, 17 and 16 carbon atoms respectively have been isolated. Juvenile hormone III is commonly occurring in all insects, while JHI and JHII in Lepidoptera and JH0 specifically in lepidopteran eggs. In addition to JHIII, corpora allata of cyclorhaphous diptera secrete a bisepoxide of JHII and methyl farnesoate. Two very active JH analogs, methoprene (Altosid) and hydroprene (Altozar), lack the epoxide function present in JH. They are used in controlling many dipteran and household pests, *e.g.* flea larvae, Homoptera on houseplants, and pharaoh ants. More recently, several highly active compounds with less apparent similarity to JH (aromatic non-terpenoidal JH analogs) like fenoxycarb, pyriproxifen and diofenolan, have been synthesized.

Corpora cardiaca are a pair of organs often closely associated with aorta and forming part of its wall which serve as a “neurohaemal” organ for several different hormones. Ring gland of cyclorhaphous diptera surrounds aorta just above the brain is fused from corpora allata, corpora cardiaca and prothoracic glands (Chapman, 1998).

Neuropeptides

Neuropeptides are biologically active peptides that are mainly produced in neurosecretory cells of insects are a diverse widespread class of signaling substances in the nervous system. Insect neuropeptides function as neurotransmitters, neuromodulators and neurohormones and are therefore called ‘master regulators’ of metabolic, homeostatic, developmental, reproductive and behavioural events during an insect life. Insect neuropeptides are named after the first three and two letters of the genus and species name of the insect, respectively. Adipokinetic hormone from *Locusta migratoria* is therefore named as *Locmi*-AKH (Gäde and Goldsworth, 2003).

Proctolin

Proctolin is the first pentapeptide isolated from the gut of American cockroach, *Periplaneta americana* and was proposed to function as a neurotransmitter with myotropic properties. It produces slow graded contraction of longitudinal muscles of proctodeum and modulates muscle excitability. Proctolin was now designated as a releasing factor capable of stimulating the release of adipokinetic hormone from the corpus cardiacum and of stimulating juvenile hormone production from the corpora allata (Gäde and Goldsworth, 2003).

Fine tuning is further required for commercial exploitation especially against major insect pests of our tropical zone. Insect neuropeptides isolated on the basis of its potential inhibitory control will represent a likely antifeedant lead compound. The disruption of any step leading to biosynthesis of neuropeptides, their modification during storage, their release into the haemolymph as well as their interaction with the target-cell membrane-bound receptors offer multiple modes of action for a novel neuropeptide based insect control strategy (fourth generation insecticides). Of course not all biochemical mechanisms will be worth exploiting, nor will all neuropeptides be of equal importance with regard to pest control.

RNA interference in pest management

The manipulation of the post transcriptional gene silencing phenomenon known as RNA interference (RNAi), demonstrated more than a decade ago in the genetic model systems *Caenorhabditis elegans* Maupas (Fire *et al*., 1998) and *Drosophila melanogaster* Meigen (Kennerdell and Carthew, 1998), has provided a powerful reverse genetic tool for the elucidation of gene function. The introduction of exogenous double-stranded RNA (dsRNA) into the cells of diverse eukaryotic organisms has been shown to induce rapid and sustained degradation of mRNAs containing sequences complementary to the dsRNA (Mello and Conte, 2004). The RNAi pathway in the cell is initiated by an RNase III enzyme called Dicer, which processes dsRNAs into short (21-25 nucleotide) small interfering RNAs (siRNAs). These siRNAs become incorporated into a protein complex known as the RNA induced silencing complex (RISC). Once formed, the RISC is guided to a specific mRNA that is complementary to one of the strands of the siRNA causing its degradation. RNAi has been widely and successfully used for gene inactivation in insects, including aphids, where dsRNA administration can be performed either by feeding or microinjection

Application of chemical ecology through volatile engineering as stimulo-deterrant diversionary tactics, semiochemicals and pheromones (intra-specific) and allelochemicals (inter-specific), insect-plant interaction in host selection process, bio-suppression of key insect pests using entomophaga and scavenging action by insects as outcome of insect physiology advancements will be highlighted. Thus advances in physiology rendered insects more wondrous than ever which will be orchestrated by case studies.

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OVERVIEW OF PHYTOPLASMAL DISEASES OF COCONUT: DIAGNOSIS AND MANAGEMENT

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Coconut (*Cocos nucifera* L.) is affected by a number of maladies- while some of them are lethal, others are debilitating in nature. With the advancement in science and technology, the cause of several coconut diseases of previously uncertain etiology has been determined and settled. Phytoplasma (formerly known as Mycoplasma like organisms, MLOs), virus, viroids and protozoan flagellates have been implicated as the cause of some of these diseases. Phytoplasmas belonging to different taxonomic groups have been reported to be associated with diseases of coconut palms. Some of them are widespread, whereas others are limited to certain geographic regions. Most of the phytoplasmal diseases were named based on the symptoms or geographic locations from where they are reported (Table 1).

Table 1. Major phytoplasmal diseases of coconut

Sl. No	Disease	16Sr group	Distribution
1	Lethal yellowing	16SrIV-A	Florida, Jamaica, Honduras, St.Kitts and Nevis, Cuba
		16Sr IV-B	Yucatan (Mexico) and Cuba
		16Sr IV- E	Dominican republic
2	Lethal yellowing type diseases		
a	Cape St. Paul Wilt Disease (CSPWD)	16SrXXII-B	Ghana
b	Kaincope disease (maladie de Kaincopé)	Not characterized	Togo
c	Awka wilt disease (AWD) or bronze leaf wilt	16SrXXII-A	Nigeria
d	Kribi disease	Not characterized	Cameroon
e	Cote d'Ivoire lethal yellowing (CILY)	16SrXXII-B	Cote d'Ivoire
f	Lethal decline/Lethal disease (LD)	16SrXXII-A	Mozambique
		16Sr IV-C	Tanzania and Kenya
g	Bogia Coconut Syndrome (BCS)	New group	Papua new Guinea
3	Root (wilt) Disease	16Sr XI-B	India
4	Tatipaka Disease	Not characterized	India
5	Coconut yellow decline	16SrXIV, 16Sr XXXII- B	Malaysia
6	Kalimantan wilt	16Sr XI and 16Sr XIII	Indonesia
7	Weligama coconut leaf wilt disease	16SrXI	Sri Lanka
8	Blast	Not characterized	Cote'd'Iviore

Phytoplasmas belonging to class *Mollicutes* are wall-less, pleomorphic, unicellular, nutritionally fastidious, phloem limited, vector transmitted phytopathogens with a mean diameter of 200-800nm and genome size ranging from 530-1350kb. Due to the paucity of distinct phenotypic criteria, currently its classification is based on sequencing and RFLP analysis of the conserved 16S rDNA region. Root (wilt) and Tatipaka diseases are phytoplasma induced diseases of coconut in India.

1. Root (wilt) disease

The occurrence of root (wilt) disease of coconut was first noticed in 1882 in Erattupetta area of Meenachil taluk in Kottayam district. Around 1907, the disease was reported from Kaviyoor and Kalloopara areas of Tiruvalla taluk in Pathanamthitta district and later from Kayangulam area of Karthikapally taluk in Alappuzha district. Since then, the disease has spread in all directions from the original focci of infection and according to a survey of 1984-85, the disease occurred in a contiguous manner in 0.41 million ha., in eight southern districts of Kerala state and sporadically in the remaining 6 northern districts of the state and bordering districts of Tamil Nadu, Goa and Karnataka. Based on a sample survey conducted in 1996, the disease intensity in the contiguous diseased tract ranged between 2.1 % in Thiruvananthapuram district to 48.0 % in Alappuzha district .The annual loss due to the disease was estimated to be about 968 million nuts and the monetary loss assessed in terms of loss in husk, copra yield and leaf on the basis of 1984 price index of coconut was of the order of about Rs.3000 million. Root (wilt) disease is non-lethal but debilitating. If the palms are affected at the seedling stage, flowering is delayed and also yield is considerably reduced. The reduction in yield of nuts up to 80% has been reported in palms in the advanced stages of disease.

Symptoms

Flaccidity, yellowing, and marginal necrosis of leaflets of the leaves of central and outer whorls are considered to be the typical foliar symptoms. The characteristic bending or ribbing of leaflets is the earliest consistent visual symptom. Symptom expression varies with the age, nutritional status/management practices, variety, and the time lag after disease incidence. In general, 67% to 97% palms show flaccidity, 38% to 67% develop yellowing and 28% to 48% show marginal necrosis. When palms below the age of 10 years are affected, 96.8% of them exhibit flaccidity while yellowing and marginal necrosis are virtually absent in them. In some palms, the distal ends of leaves at the fourth or fifth position from the spindle, curl (1-1.5 m below the leaf tip), break, hang down, become yellow, dry and drop off. Percentage of root decay varied from 12-94.4% depending upon the intensity of the disease. Anatomy of the roots of diseased palms revealed degenerated phloem, disorganized tracheal elements and tyloses in metaxylem. A number of physiological derangements were noticed in the root functioning, water relations, mineral nutrition, respiration and photosynthesis.

ICAR-CPCRI has developed an indexing method for quantifying the disease intensity giving due weightage to the three predominant foliar symptoms. Disease index, $DI=\sum(F+Y+N)/L \times 10$, where F (0-5), Y (0 - 3) and N (0-2) are the grade points assigned to flaccidity, yellowing, necrosis respectively and L is the total number of leaves in the palm. For indexing young palms below 10 years, more weightage is given to flaccidity as it is found to be the prominent symptom and disease index ($DI=\sum(15F+5Y+5N)/L \times 10$). Disease index can vary from 0 to 100 where 0 represents the total absence of all the symptoms, indicating that the palm is visually disease free (apparently healthy) and 100 means the presence of all the symptoms in the acute stage on all the leaves. Based on the disease index, the palms can be categorised into disease early($DI<20$), disease middle (DI- 20-50) or disease advanced ($DI >50$). The indexing method was further simplified by scoring the symptoms on the leaves present in any of the five spirals. Usually, only 4-5 leaves are present in a spiral and hence the number of observations per palm to be taken for calculation of diseases index is less. The indexing system helps in quantifying disease severity in a simple numerical expression that can be analyzed statistically

Etiology

The causal organism of root (wilt) disease of coconut was established as phytoplasma by electron microscopy (EM), transmission studies with vectors, transmission through dodder and light microscopic staining techniques. The phytoplasma was detected in sieve tubes of roots, tender stem, petiole and developing leaf bases of root (wilt) diseased palms by EM . Remission of symptoms observed in tetracycline treated palms added further evidence to the phytoplasmal etiology of the disease. The phytoplasma causing RWD has been characterized as '*Candidatus* Phytoplasma oryzae' related strain belonging to 16SrXI-B sub group (rice yellow dwarf group).

Transmission

Phytoplasmas are generally transmitted by insects belonging to the Hemiptera group. The vector role of lace bug (*Stephanitis typica)* and plant hopper *(Proutista moesta)* has been conclusively established in transmission experiments.

Detection techniques

Accurate and timely diagnosis of plant diseases is an essential component of integrated disease management. ICAR-CPCRI has standardized protocols for the purification of RWD phytoplasma, production of polyclonal antisera specific to coconut RWD phytoplasma and Direct Antigen Coated-Enzyme Linked Immunosorbent Assay (DAC-ELISA) for the detection of RWD phytoplasma even 24 months before symptom manifestation. Molecular detection of phytoplasma associated with RWD was achieved by modification of phytoplasma enrichment technique for DNA extraction by addition of 5 per cent polyvinyl pyrrolidone, designing six highly sensitive primers and semi-nested PCR technique. A real - time PCR protocol was also developed for detection of RWD phytoplasma.

Management

The perennial nature of the crop coupled with the persistence of the pathogen once acquired and the possible transmission in brief duration of feeding by the vectors rule out the effective prevention of the spread of the disease by control of vector. Since the phytoplasma is not amenable to culturing *in vitro*, screening of chemicals for adopting control measures is not at all feasible. Diseased palms treated with Tetracycline hydrochloride exhibited only temporary remission of symptoms and needs to be applied repeatedly. Prohibitive cost of the antibiotic and caution against its indiscriminate use for treating any plant disease are the other limitations of its use.

One of the significant features of this disease is that it is not lethal but a slow declining malady that responds to ideal management practice. The loss can be reduced to the minimum if palms could be attended immediately on appearance of symptoms. Two strategies, one for the heavily diseased contiguous area, and another for the mildly affected area have been formulated.

Strategy for heavily diseased tracts

In the heavily diseased area, the yield of palms can be sustained or even improved through adoption of integrated management practices:

1.Removal of palms: All disease advanced and uneconomic palms with annual yield of less than 10 nuts are to be removed.
2. Replanting: Replanting with released, disease resistant varieties or elite seedlings from high yielding disease free palms located in heavily disease affected tracts.
3. Biopriming: Biopriming of seedlings with *Pseudomonas fluorescens* to impart tolerance.
4. Application of organic manures: Application of 25 kg farm yard manure or 10 kg vermicompost enriched with *Trichoderma harzianum*@100g.
5. Biomass recycling: Application of leguminous green manure crops and glyricidia leaves.
6. Fertiliser application: Application of recommended dose of fertilisers (500g N, 300 g P_2O_5,1250 K_2 O and 250 g $MgSO_4$ palm^{-1}year^{-1}) in two splits.
7. Liming: Application of lime/dolomite supplemented with magnesium sulphate.
8. Irrigation: Irrigation with 250 L of water palm^{-1} week^{-1}, soil moisture conservation and providing adequate drainage wherever necessary.
9. Inter cropping and farming system: Raise inter crops in rotation, adopting mixed cropping/ mixed farming coupled with recycling of organic matter.
10.Adopting recommended management strategies for leaf rot disease, rhinoceros beetle and red palm weevil.

Strategy for mildly affected area

***Removing all the diseased palms*.** The spread of the disease can be arrested by systematic surveillance and rouging of diseased palms as and when identified. Eradication of disease affected palms to contain the disease within contiguously infected geographic limits can be successful if continuous monitoring for occurrence of the disease and uprooting of suspected and diseased palms are taken up simultaneously. But if the programme is not monitored uninterruptedly the desired goal will not be achieved.

Replanting with disease free healthy seedlings. Replanting with disease free quality seedlings or seedlings of coconut resistant / tolerant varieties (Kalpasree, Kalparaksha) and hybrid (Kalpasankara) released by ICAR-CPCRI for cultivation in the root (wilt) disease prevalent areas is recommended

2. Tatipaka Disease

Tatipaka is a slow debilitating phytoplasmal disease of coconut in India. Its distribution is confined to East and West Godavari, Srikakulam, Nellore, Krishna and Guntur districts of Andhra Pradesh state in India. The disease was first noticed after the cyclone of 1949 by the farmers of Tatipaka village and the disease was named after the village from where it was observed. The disease generally occurs in heavy black deltaic soils than in sandy, sandy loam and red loam soils. It is observed in both well managed and neglected gardens. A survey made during 1985-1990 in the central delta of the river Godavari "Konaseema" (which account for 60 per cent of the area under coconut in the state), revealed that the disease is prevalent in 85 out of 201 villages. Like root (wilt), the disease was found as non-lethal but of a debilitating nature, generally affecting palms in the age groups of 20-60 years. Palms below 20 years are very rarely affected. The spread of the disease is not contiguous but sporadic at a slow pace of 3.5 per cent over a period of five years. Later surveys revealed that the disease incidence in the field is less than one per cent.

Symptoms

The disease-affected palms generally bear profusely for two to three years before the expression of visual symptoms and more number of dark leaves (often fasciated) appear in the crown. With the onset of disease, there is a reduction in both number and size of leaves.

The leaves exhibit characteristic chlorotic water soaked spots and the fronds bend abnormally, sometimes twisting in loops. In the advanced stage with the narrowing of leaflets and reduction in size of crown, the affected palm looks like a date palm. The spathes produced are very small with a very few rachilla. The bunches carry a mixture of normal and atrophied nuts. The atrophied nuts are barren with thinner spongy mesocarp with or without shell, copra and nut water. The under sized nuts show longitudinal cracks with occasional gumming. In the advanced stage of the disease, the stem tapers and produces smaller spathes and inflorescences, which ultimately do not bear any fruit. Reduction in number and size of the roots and extensive rotting of roots are the characteristic underground symptoms of the disease.

Etiology

The disease was listed as one of uncertain etiology till 1990s. The involvement of fungi, bacteria and virus in disease incidence was conclusively ruled out through systematic experiments. Remission of symptoms observed in diseased palms treated with tetracycline hydrochloride indicated the association of a phloem limited phytoplasma with the disease. Electron microscopy, light microscopy using Dienes' stain and fluorescent microscopy with aniline blue as fluorochrome added further evidence to phytoplasmal etiology.

Disease Management

As the disease is confined to a limited geographical region the best strategy adopted is to arrest the spread of disease by systematic surveillance and roguing of diseased palms as and when identified and using disease resistant planting material. The programme was systematically implemented and the disease was kept under check by the timely intervention.

Conclusion

Phytoplasmal diseases continue to be a serious threat to the coconut cultivation as they are non-curable. It is imperative to contain the spread of the disease within the current geographical limits by appropriate quarantine measures. Periodic surveillance in the diseased tract and monitoring for new incidence of disease and prompt removal will go a long way in arresting fresh outbreaks. The best option to control phytoplasma diseases of course is evolving disease resistant/ tolerant planting material and hence priority should be given to this work and efficient robust diagnostic tools are very important for early detection of the disease for screening mother palms.

Biodiversity and Biosecurity Risks in Coconut

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Biodiversity refers to the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes including diversity within species, between species and of ecosystem. There are 1,435,662 identified species all over the world which includes 751,000 species of insects, 250,000 of flowering plants, 281,000 of animals, 68,000 of fungi, 30,000 protists, 26,900 of algae, 4800 of bacteria and 1000 viruses. Approximately 27,000 species become extinct every year. Majority of them are small tropical organisms. Extinction of species leads to further destruction of fragile ecosystems. If this trend of biodiversity depletion continues, one-fourth of the world species may be lost by the year 2050 (Singh, 2010).

The term biodiversity was coined by Walter G. Rosen in 1985 during the first planning meeting of the National Forum on Biodiversity held in Washington DC in September 1986, the proceedings of which brought the notion of biodiversity to the attention of wide field of scientists. However, the credit of popularising this word goes to E.O. Wilson, who is called as Father of Biodiversity. Of the 20 hot spots of the world reported so far, two of them belong to India The Eastern Himalayas and Western Ghats are the two hot spots of biodiversity in India encompassing rich floral and faunal wealth.

Genetic erosion

The twentieth century has witnessed a loss of 75% of the genetic diversity of crop plants. High yielding varieties have occupied more than 60% area of wheat and rice lands. Out of 3000 food plant species only 150 were commercialized. Agriculture is dominated by only 12 species out of which four yields more than 50% of the total production (Rice, wheat, Maize and Potato). Genetic erosion is a matter of serious concern which could hamper the crop improvement programmes. The maintenance of a diversity of crops with different characteristics gives the community a buffer stock of food in case of droughts, floods, pest attack or disease outbreak.

The major factors leading to extinction of a species and consequent loss of biodiversity are a) habitat loss and fragmentation, b) Introduction of exotic species, c) Invasion by alien species, d) Over exploitation, e) Soil, water and atmospheric pollution, f) Intensive agriculture and monocultures (Singh, 2010).

Coconut and pollination

The coconut palm is one of the few plants which flowers throughout the year and for this reason may be the only source of nectar and pollen for the floral visitors at certain times of the year. A wider variation exists between ecotypes and geographic regions with regard to flowering phenology in coconut. Even though anemophily obviously occurs in coconut palm, entomophily is the major pollination source and it can be concluded that coconut is predominantly a bee pollinated palm (Thomas and Josephrajkumar, 2013).

Insect pollination is important for achieving high yield of coconut. Honey bees, *Apis* spp., have been recorded on coconut flowers in Hawaii, India, Malaysia, the Philippines, Trinidad, Ecuador, and Fiji. Stingless bees, both *Melipona* spp. and others, are the dominant visitors in Costa Rica and Surinam. In Trinidad, coconut pollen was occasionally collected by four species of stingless bees but was much more heavily collected by honey bees. Wasps, ants, earwigs, flies, butterflies, and beetles have also been recorded but are not considered effective pollinators. Stingless bees visit both male and female flowers. Most (83%) individuals visiting pistillate flowers in search of nectar carried loads of coconut pollen from previously visited staminate flowers. Many of these (33%) then visits staminate flowers on the same inflorescence. This behavior is conducive to efficient pollen grain transfer. Yields are higher where hives of honey bees are kept in plantations. Thus, there is evidence that both honey bees and stingless bees contribute to the pollination (Heard , 1999).

A curculionid weevil (*Amorphoidea coimbatorensis)* was noticed in large numbers on male flowers of coconut inflorescence and was reported primarily as a minor pest (Subramaniam *et al.,* 1975). Association of *Amorphoidea coimbatorensis* on male flowers of coconut inflorescence was again reported from Kayamkulam, Kerala. The preponderance of the weevil was noticed on dwarf palms and it was found feeding on the male flowers. In India, Devanesan *et al.* (2009) has listed out the insects associated with coconut inflorescence which includes bees, ants, moths and beetles. While bees predominated in tall genotypes, ants were found in large numbers in dwarf genotypes involved in foraging.

Biosecurity issues in coconut

Biological invasions, the routine importation (both accidental and deliberate) of harmful non-native organisms occur daily, and are estimated to cost more than $100 billion loss per year world-wide. Nonetheless, the scientists, policy makers and public over the whole world including India are paying considerably less attention and spending far fewer resources than needed to identify and address bio-invasions and their manifold impacts that include chronic damage to societal infrastructure, agro-ecology, fisheries, the environment and human health. Economic losses due to bio-invasions are substantial in many parts of the world including India. Twenty-five percentages of costs of food consumables accessible to customers are attributed to invasive weeds, pests and diseases. Invasive species are second only to habitat destruction as the major cause of biodiversity loss**.** In the globalized era, goods and services produced in one part of the world are increasingly available in other parts of world and people around the globe are more connected to each other than ever before paving way for accidental introduction of invasive pests. International travel is more frequent resulting in several biosecurity threats. Establishing risk-based biosecurity systems in different countries is vital to safeguard the food supply chain.

Quarantine

The word "Quarantine" took shape from the Venetian dialect form of the Italian ***quaranta giorni***, meaning 'forty days', which is the minimum number of days ships were required to be isolated before passengers and crew could disembark during the pandemics of Black Death. In Old Testament the book of Leviticus 13: 46, stated that anyone with leprosy remains unclean as long as they have the disease and that they must live outside the camp away from others (Paul, 2002) indicating the influence of quarantine suppressing disease spread from time immemorial and its impact that is likely to bring forth benefits in the larger interest of the human well-being.

Plant quarantine is a government endeavour enforced through legislative measures to regulate the introduction of planting materials, plant products, soil, living organisms *etc.,* in order to prevent inadvertent introduction of pests (including fungi, bacteria, viruses, nematodes, insects and weeds) harmful to agriculture of a country/state/region, and if they are introduced, to prevent their establishment and further spread. After the Second World War, FAO convened an International Plant Protection Convention (IPPC) in 1951 to which India became a party in 1956. Currently it has 179 signatory countries.

IPPC is an international treaty that aims to secure coordinated, effective action to prevent and to control the introduction and spread of pests of plants and plant products. It takes into consideration both direct and indirect damage by pests, so it includes weeds. It also covers vehicles, aircraft and vessels, containers, storage places, soil and other objects or material that can harbour or spread pests. The Convention provides a framework and a forum for international cooperation, harmonization and technical exchange between contracting parties. It facilitate safe trade by providing guidance on procedures, regulations and treatments that can be used to manage pest risks associated with the international movement of goods and conveyances (Khetarpal and Kavitha Gupta, 2008) .

Role of IPCC

1) Protect farmers from economically devastating pest outbreaks.
2) Protect the environment from loss of species diversity.
3) Protect ecosystems from loss of viability and function as a result of pest invasions.
4) Protect industries and consumers from the costs of pest control or eradication.
5) Facilitate trade through Standards that regulate the safe movements of plants and plant products.
6) Protect livelihoods and food security by preventing the entry and spread of new pests of plants into a country (https://www.ippc.int/)

National plant quarantine set-up

The Directorate of Plant Protection, Quarantine and Storage (DPPQS) of Ministry of Agriculture is the nodal agency in India for implementing plant quarantine regulations which have recently been revised and known as the **Plant Quarantine (Regulation of Import into India) Order 2003 (henceforth referred to as PQ Order)**. DPPQS deals with the commercial import of consignments of grains, plants and plant products for consumption through its network of 35 Plant Quarantine Stations spread across the country including seaports, airports and land frontiers as well as commercial imports of seeds/ plants for sowing or planting through five major stations at Amritsar, Chennai, Kolkata, Mumbai and New Delhi. Besides the twenty-eight plant quarantine stations, there are seven stations viz., Attari-Wagah Border- Railway Station, Attari-Wagah Border- LCS and Amritsar Railway Station (under RPQS Amritsar); ICD Tughlakabad, Air Cargo, Delhi Airport (under NPQS, Delhi), Air Cargo, Mumbai (under RPQS, Mumbai) and Air Cargo, Kolkata (under RPQS, Kolkata) as working units under the major stations (NAAS, 2010).

ICAR-National Bureau of Plant Genetic Resources (NBPGR) undertakes the quarantine processing of all germplasm including transgenic planting material under exchange for research purposes. NBPGR also deals with testing for absence of terminator technology which is mandatory as per national legislation. This authorization was vested upon NBPGR for germplasm *vide* Article 6 of PQ Order 2003 and for transgenic planting material vide Govt. of India Notification No. GSR 1067(E) dated 05.12.1989 (NAAS, 2010).

For intra-country or internal quarantine of plants/ planting material, domestic quarantine regulations have been promulgated for regulating inter-state movement of agricultural commodities under the Destructive Insects and Pests (DIP) Act of 1914. Presently, there is a provision to restrict the inter-state movement of nine pests viz., fluted scale, San José scale, coffee berry borer, codling moth, Banana bunchy top virus, Banana mosaic virus, potato cyst nematode, potato wart and apple scab. Respective States have also enacted laws for preventing the introduction, spread or re-appearance of plant diseases, pests, parasites and noxious weeds which are or may be destructive to plants, or are likely to contaminate water supply or are obstructive to waterways in the State. For instance.,

1) The Madras Agricultural Pests and Diseases Act, 1919
2) The Travancore-Cochin Agricultural Pests and Diseases Act, 1955
3) The Kerala Agricultural Pests and Diseases Act, 1957
3) The Kerala Plant Diseases and Pests Act, 1972

Invasive pests in India
Alien invasive species have invaded native biota in virtually every ecosystem of earth causing economic damage to biodiversity and the valuable natural agricultural system we depend upon. Such outbreaks of exotic pests *viz*., coffee berry borer *Hypothenemus hampei* Ferrari, serpentine leaf miner *Liriomyza trifolii* (Burgess), (Agromyzidae : Diptera), spiralling whitefly *Aleurodicus dispersus* Russell (Aleurodidae : Hemiptera), coconut eriophyid mite *Aceria guerreronis* Keifer (Eriophyidae : Acari), erythrina gall wasp, *Quadrasticus erythrinae* Kim. (Eulophidae : Hymeonptera), the eucalyptus gall wasp *Leptocybe invasa* Fisher & La Salle Eulophidae : Hymeonptera), cotton mealy bug *Phenacoccus solenopsis* (Tinsley) (Pseudococcidae : Hemiptera) and the papaya mealy bug, *Paracoccus marginatus* Williams and Granara de Willink (Pseudococcidae : Hemiptera) reported in India caused severe economical loss to crops despite several efforts made to combat them. Biosecurity has wider implications since it relates to the livelihood security of nearly 70 per cent of the population, the food, health, trade security and natural resources of plants, animals and farms of the nation (Josephrajkumar, *et al*., 2016).

Invasive pests on coconut already reported in the country
a) Coconut eriophyid mite: The exotic pest, coconut eriophyid mite, *Aceria guerreronis* Keifer was reported from all coconut growing regions ranging from 0.2% in Bay Islands to 57.3% in Karnataka. Ever since the pest was first reported in the country from Kochi, Kerala during 1998, it had spread like a wild fire affecting all coconut plantations in key south Indian states (Sathiamma *et al*., 1998).

b) Asian grey weevil: *Myllocerus undatus* Marshall (Curculionidae ; Coleoptera), a pest of quarantine importance was registered from root (wilt) diseased tracts of coconut in Kerala. Mild to medium level of infestation damaging 5-10% of leaf area of un-split leaves with typical notching-like symptom along the leaf margins was noticed on majority of the coconut seedlings in root (wilt) endemic zones. In the nursery area with nearly 10,000 coconut seedlings, more than 40% seedlings were found infested by the weevil affecting the marketing potential of seedlings. The characteristic feature of this weevil is the presence of three-spined hind femur and is considered as an invasive pest from Sri Lanka.

c) Inflorescence moth: Occurrence of non-native inflorescence moth, *Batrachedra arenosella* (*nuciferae*) was observed from Port Blair-Bay Island, Minicoy-Lakshadweep Island, Kasaragod-Kerala, Ambajipeta-Andhra Pradesh, Jagdalpur-Chhattisgarh and parts of Karnataka. The pest incidence was quite higher in Niu Leka Green Dwarf at World Coconut Germplasm Centre, Port Blair when compared to other Pacific Ocean collections maintained there.

d) Spiraling whitefly: Sporadic incidence of spiraling whitefly, *Aleurodicus dispersus* Russel recorded from Minicoy Island, Kerala and Tamil Nadu was effectively bio-suppressed by natural enemies. As the name suggests, adults of *A. dispersus* has a typical spiralling fashion of egg-laying and found in mild to moderate levels during March-May. It is highly polyphagous pest infesting a wide array of crops in coconut plantations (Mani, 2010).

e) Rugose spiraling whitefly: The latest entry in this series is *Aleurodicus rugiperculatus* Martin introduced from Belize, Central America during 2016 in Pollachi and Palakkad area. It was found to feed and breed profusely from the under surface of the palm leaves, numbering more than 10 live colonies in a leaflet (Josephrajkumar *et al*., 2016; Chandrika Mohan *et al*., 2016; Shanas *et al*., 2016). As rugose spiralling whitefly (RSW) is a highly polyphagous invasive species, a biosecurity alarm was sounded to monitor its spread and extent of damage caused. Though RSW initially created panic by its expansive mode of ovipositional damage in different crops including banana, bird of paradise, custard apple, jack, *Heliconia* sp., *etc.*, it could not sustain feeding on other crops successfully compared to coconut and relatively to some extent, on banana, which are its most favoured host plants. *Encarsia guadeloupae* Viggiani, an aphelinid parasitoid of spiralling whitefly (*Aleurodicus disperses* Russell) fortuitously introduced in India in the late 1990s and well established in South India, turned out to be a very effective parasitoid of *A. rugioperculatus* as well. It parasitized *A. rugioperculatus* to an extent of 60% and kept the pest under check not allowing it to flare up in any of the South Indian States from where RSW has been recorded so far (Josephrajkumar*et al*., 2016; Shanas *et al*., 2016). Extensive deposits of sooty mould, *Leptoxyphium* sp. was found on the upper surface of palm leaves and other intercrops, which forms one of the identification features of pest attack. Of late, scavenging associated novel discovery of a Leiochrini beetle, *Leiochrinus nilgirianus* Kaszab could be identified feeding on the sooty mould and cleansing the palms as *Swachh* palm *Abhiyan* (Josephrajkumar *et al*., 2018).

Impending biosecurity risks

Coconut leaf beetle, *Brontispa longissima* Gestro and the armoured scale insect, *Aspidiotus rigidus* ravaging Maldives and Philippines, respectively though could not be encountered so far in our survey, but are impending dangers at our door steps.

a) *Brontispa longissima* (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. It is feared that the pest will find its way from Maldives to Sri Lanka and Southern parts of India to derail the economy of these important coconut growing regions of the world. Since invasive pests fail to restrict along political / agro-ecological boundaries countries like India, Bangladesh and Sri Lanka are ever in red alert zones. For all those countries, where coconut and coconut based industries support millions of people, the pest incursion would be catastrophic. Coconut leaf beetle (CLB) was originally described in 1885 from Aru Islands in Indonesia and from Papua New Guinea (Rethinam and Singh, 2004).

b) *Wallacea* sp. (Chrysomelidae : Coleoptera)

A close relative of the chrysomelid beetle, *B. longissima*, *viz.*, *Wallacea* sp. feeding on the spindle region of coconut seedlings was recently recorded from South and Little Andaman. The feeding niche of *Wallacea* sp. confining on coconut spindle is a matter of concern, however, the pest was not observed from any adult palm during the snap survey conducted during October 2014. Though 80-90% of seedlings were infested by the pest damaging about 40% of leaf area, there was no seedling mortality. Invasive nature of *Wallacea* sp. is under scrutiny, as a close relative, *Wallaceana* sp. was reported from Indonesia. Adult beetles are brownish with six rows of constrictions on each elytron and measured 4.72 mm long and 0.9 mm wide. They are active fliers may be for a short distance. Grubs possessed short-lateral spines on each body segments with prominent mandibles for active feeding and measured 5.75 mm long and 0.8 mm wide. Grubs and adults remain within the folds of the spindle leaves and feed from within. Typical feeding damage 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. Though a few feeding adult beetles were observed in between the leaf folds of emerged leaves, the grubs were mostly confined within the spindle region only. Pupae are located at the point of leaflet attachment to the main petiole. Pupae are exarate with exposed appendages and well-developed wing pads and are mostly located on the point of attachment of leaflet with the main petiole (Prathapan and Shameen, 2015).

c) *Aspidiotus rigidus* (Diaspididae : Hemiptera)

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

d) Red ring disease in coconut

It is caused by the nematode, *Bursaphelenchus cocophilus* (Cobb) Goodey and transmitted by the palm weevil, *Rhynchophorus palmarum.* Juvenile nematodes are transmitted especially during oviposition and other activities. Young palms between 30 months and 10 years old are susceptible. Yellowing followed by browning and drying of older leaves and premature nut fall are the external symptoms in affected palms. The cross sections of the affected palms show diagnostically, The presence of a reddish brown ring of 2-4 cm width about 2-5 cm inside from the stem periphery is the characteristic diagnostic internal symptom of the disease. This extends throughout the stem but is clearest about 1 m above ground level. Red streaks may appear in the petioles, and the roots become orange to faint red, dry and flaky. The key sign is the presence of the nematode in the reddened tissues. Gradually the affected palms die (Van Hoff and Seinhorst, 1962). It is distributed in Caribbean area (Grenada, St. Vincent and the Grenadines, and Trinidad & Tobago). Central America (Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama), North America(Mexico), South America(Brazil, Colombia, Ecuador, French Guiana, Guyana, Peru, Suriname, and Venezuela)

Incursion management of invasive pests

Three pronged strategies are essentially warranted to keep vigil on the introduction of invasive pest.

(i) Strengthening quarantine:

Strict quarantine laws curbing the movement of all types of coconut materials and other host palms particularly ornamental palms from CLB infested countries should be enforced, as the main source of spread of this pest within the Asia-Pacific region is through shipment of ornamental palms from countries having the pest infestation. Shifting of soil and organic materials also should be passed through strict quarantine measures. In the collection of germplasm materials and exchange of genetic resources between countries rigourous quarantine steps are to be meticulously followed. Passengers traveling from beetle-infested countries should be encouraged to examine their baggage for the presence of the beetle / eggs / larvae to avoid accidental introduction of the pest. Trans-boundary movement of planting materials of palms especially ornamental palms between main lands and Islands as well between countries should be under strict vigil and permit only after producing valid phytosanitary certificate. Quarantine officials need to be educated about the invasive pests and hitherto should focus on biological searches rather than bullion snatches. Both aerial and marine trans shipment have to be covered under the umbrella of quarantine measures. Necessary phytosanitary certification by authorized agencies must be strictly enforced for the import of planting materials especially various palm species from pest affected countries. Domestic quarantine should be further strengthened to keep away from *Wallacea* sp. reaching the mainland. Airports and seaports of Kolkatta, Chennai, Vishakapatnam and Cuttack should be strictly monitored.

(ii) Surveillance and monitoring

Regular surveillance surveys should be carried by all ICAR institutes, SAU and other stakeholders such as Coconut Development Board (CDB) at all strategic points of entry. More closely North-East regions, Lakshadweep and Bay Islands should be under strict surveillance by constant observation on buffer crops in those regions along the airport and seaport zones. With increasing navigation network these days such surveillance surveys on regular mode is found mandatory. A national level 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 including gradient as well as epidemic outbreaks of emerging pests in to the country. Concerted efforts for conservation of different natural enemies in the ecosystem are warranted for preventing emerging pests attaining epidemic levels.

(iii) Sensitization campaign

There is a need for educating the coconut growers and developmental workers about the pest and its bio-ecology so that they will be able to monitor the pest effectively in their areas of operation. Organizing seminars, awareness programmes, pest alert notifications, presentation of bulletins on *B. longissima* and *A. rigidus* are also would be helpful in building up an awareness and vigilance on the pest. Awareness creation and capacity building through training programmes is essential to contain the problem at this point of time. It was also suggested to display big posters at the lounges in airports and sea ports about the invasive pest and the damage symptom for the awareness of the travelers. Clippings can also be made about the invasive pests in Doordarshan news breaks. ICAR-CPCRI has been in the vigil since 2007 and in case if any report on the incidence of invasive pests are located anywhere in the country, the matter can be brought to the attention of us.

Awareness about invasive pests is very crucial for combating these non-native pests in all plantation crops for systematic management in case of accidental entry. Above all, a holistic and system approach with sustainable technology integration is crucial for timely tackling of exotic pests.

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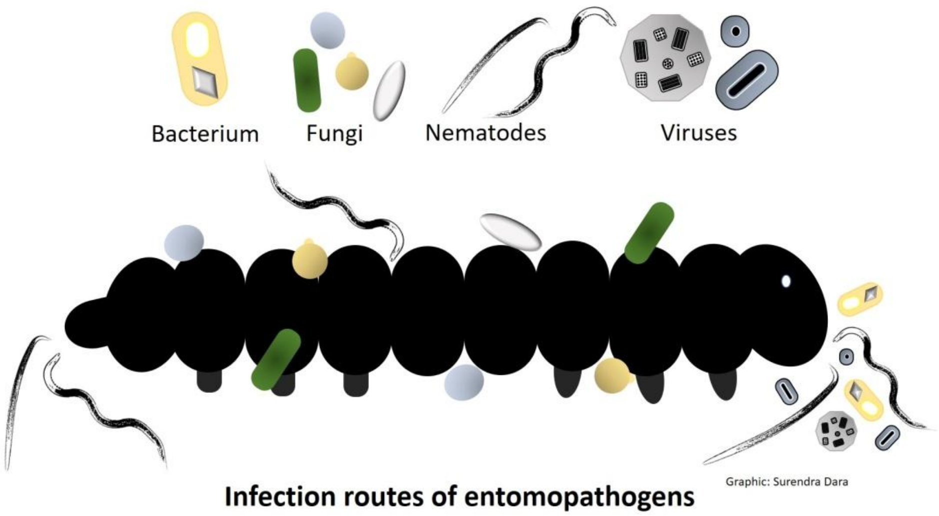
Mass production of Entomophaga and entomopathogens invading coconut pests

Sujithra M and Rajkumar

Entomopathogens are microorganisms that are pathogenic to arthropods such as insects, mites, and ticks. Several species of naturally occurring bacteria, fungi, nematodes, and viruses infect a variety of arthropod pests and play an important role in their management. Some entomopathogens are mass-produced in vitro (bacteria, fungi, and nematodes) or in vivo (nematodes and viruses) and sold commercially. Using entomopathogens as biopesticides in pest management is called microbial control, which can be a critical part of integrated pest management (IPM) against several pests.



Entomopathogen groups

Important entomopathogen groups and the modes of their infection process are described below:

Entomogenous fungi:

Entomogenous fungi have long been known to attack insect pests. They are potentially the most versatile biological control agents, because they have wide host ranges, infect at different ages and stages of their hosts and often cause natural epizootics. An attractive feature of these fungi is that infectivity is by contact and active penetration. Therefore ingestion is not required to initiate infection whereas; most other entomopathogens such as bacteria, protozoa and viruses have to be necessarily eaten, to be infective. Entomogenous fungi comprise a heterogenous group of over 100 genera with approximately 750 species, reported from different insects, many of which offer great potential in pest management. They belong to Zygomycotina, Ascomycotina, Basidiomycotina and Deuteromycotina. Major entomopathogenic fungi are presented in Table 1. Several of these genera are principally or exclusively associated with a single family, genus or a few species of insect pests.

Table 1: List of major taxa containing entomopathogenic species

Zygomycotina: *Conidiobolus, Entomophaga, Entomophthora, Erynia, Massospora, Mueor Neozygites, Pandora, Rhizopus, Strongwellsea, Tariehium, Triplosporium, Zoophthora Zygaenobia*

Ascomycotina: *Aseosphaera, Caloneetria, Cordyeeps, Hypoerella, Massaria, Neetria, Sphaerostilbe, Torrubiella, Laboulbeniales*

Basidiomycotina: *Septobasidium, Stereum, Uredinella*

Deuteromycotina: *Aerostalagmus, Aegertia, Akanthomyees, Asehersonia, Aspergillus,* ***Beauveria****, Cephalosporium, Cladosporium, Culicinomyces, Derexia, Fusarium,* ***Hirsutella****, Isaria,* ***Metarhizium****, Nomuraea, Paecilomyces, Penicillium, Sorosporella, Spicaria,* ***Verticillium***

Some of the most widely used species include *Beauveria bassiana*, *Metarhizium anisopilae*,

Nomuraea rileyi, *Paecilomyces farinosus* and *Verticillium lecanii*. Many of them have been commercialized globally. Some species such as *B. bassiana* and *M. anisipoliae* cause muscardine insect disease and after killing the host, cadavers become mummified or covered by mycelial growth. For about 130 years, entomopathogenic fungi especially *Metarhizium anisopliae* (Metschn.) Sorokin, have been used for biocontrol of pest insects. Besides the two other entomopathogenic fungi Beauveria bassiana and Beauveria brongniartii, M. anisopliae is one of the most widely used fungus and mycoinsecticide throughout the world, mainly as an inundative control agent. *Metarhizium anisopliae* is a well-known entomopathogenic fungus active against many insect pests.The species M. anisopliae was originally described by Metschnikoff (1879) as Entomophthora anisopliae and later transferred to the new genus Metarhizium by Sorokin (1883). The genus is defined on the basis of the arrangement of the phialides bearing chains and columns of dry and generally green, cylindrical or slightly ovoid conidia. The columns are formed by aggregation of the conidial chains. In most cases, the fungus has been isolated from soil using the so-called Galleria bait method or by special selective media.

Mode of action

The infective unit in most of the entomopathogenic fungi is a conidium or spore which when lands on a susceptible host, putforth 'germ tubes' or 'infection pegs' from appressoria. These structures secretes a complex of cuticle degrading enzymes viz., chitinases, proteases and lipases, which are capable of hydrolysing corresponding cuticular constituents namely chitin, protein and lipid in the epicuticle. The infection process of M. anisopliae is similar to other entomopathogenic fungi, i.e. the infection pathway consists on the following steps: (1) attachment of the spore to the cuticle, (2) germination and formation of appressoria, (3) penetration through the cuticle, (4) overcoming of the host response and immune defence reactions of the host, (5) spreading within the host by formation of hyphal bodies or blastospores, and (6) outgrowing the dead host and production of new conidia. The destruxins are the most important metabolites/toxins produced by M. anisopliae after invading the host and chemically, destruxins are cyclic hexadepsipeptides containing five amino acids, i.e. b-alanine, alanine, valine, isoleucine and proline, and an a-hydroxy acid.

The entomopathogenic fungus, *Metarhizium anisopliae* has been used widely as a mycopesticide to control many insect pests including the major palm insect pest, *Oryctes rhinoceros* .The effective isolate was identified in length as *M. anisopliae* variety major with the spore dimension between 9-15 μm .The pathogencity tests showed that at the concentration of 10^8 spores per mL, the fungus killed 100% the third instars larvae of *Oryctes rhinoceros* between 12 – 14 days after treatment, causing 70 -75% mycosis. Field application by directly drenched the fresh spore solution and broadcasting of solid substrate with spores onto the breeding sites was significantly reduced the *Oryctes* population, especially the larvae. Inoculate the breeding sites with green muscardine fungus, M*etarhizium anisopliae* (5x 10^{11}) spores/m^3 of breeding area effectively manages the rhinoceros beetle. *Metarhizium* has a number of advantages as a mycoinsecticide: it is relatively easy to mass produce, strains can be found with appropriate levels of virulence and specificity, and the conidia can be dried to ensure good persistence in the field and storage for over one year in cool conditions.

Fig: *Metarhizium* infested *Oryctes* cadavers

Since 1998, the coconut mite, **Aceria guerreronis**, has been a chronic constraint to coconut farming in India, the third largest producer of coconuts in the world. A mite-specific fungal pathogen, **Hirsutella thompsonii**, as the most important natural regulator of the coconut mite was later identified. *Hirsutella thompsonii* var. *synnematosa* is an important fungal parasite of phytophagous mite, especially those belong to families Eriophyidae and Diptilomiopidae. The fungus invades the internal tissues of the host and eventually kills it within 2-3 days. Subsequently, mycelia penetrate from the cadaver through mite cuticle where spores are produced along the mycelium. It is known that spore is the only infective unit of this fungus.

Mycohit, a powder formulation of the fungus was evaluated as a short-term as well as a long-term biocontrol agent. Spraying of the product on young bunches resulted in high fungus-associated mortality of the mite. The fungus was found to be capable of bringing down the mite population up to 90%, resulting in considerable reduction in pre-harvest nut damage. In several trials, the fungal treatment was superior to azadirachtin, dicofol, triazophos, and/or wettable sulphur.

Bacteria: The bacteria that are used as biopesticides can be divided into four categories: crystalliferous spore formers (such as *Bacillus thuringiensis*); obligate pathogens (such as *Bacillus popilliae*); potential pathogens (such as *Serratia marcesens*); and facultative pathogens (such as *Pseudomonas aeruginosa*). Out of these four, the spore formers have been most widely adopted for commercial use because of their safety and effectiveness. The most commonly used bacteria are *B. thuringiensis* and *Bacillus sphaericus*. *B. thuringiensis* is a specific, safe and effective tool for insect control. Itis a Gram-positive, spore-forming, facultative bacterium, with nearly 100 subspecies and varieties divided into 70 serotypes. The insecticidal property of B. thuringiensis resides in the Cry family of crystalline proteins that are produced in the parasporal crystals and are encoded by the cry genes. The Cry proteins are globular molecules (65–145 kDa, depending on the strain) with three structural domains connected by single linkers. The 200 Cry proteins belong to a single family that contains about 50 subgroups**.**

Mode of Action: When **Bt** is ingested, alkaline conditions in the insect gut (pH 8-11) activate the toxic protein (delta-endotoxin) that attaches to the receptors sites in the midgut and creates pore in midgut cells. This leads to the loss of osmoregulation, midgut paralysis, and cell lysis. Contents of the gut leak into insect's body cavity (hoemocoel) and the blood (hoemolymph) leaks into the gut disrupting the pH balance. This includes starvation and lethal septicemia of the host insect.

Virus: Over 700 insect-infecting viruses have been isolated, mostly from Lepidoptera (560) followed by Hymenoptera (100), Coleoptera, Diptera and Orthoptera (40). About a dozen of these viruses have been commercialized for use as biopesticides.The viruses used for insect control are the DNA-containing baculoviruses (BVs), Nucleopolyhedrosis viruses (NPVs), granuloviruses (GVs), acoviruses, iridoviruses, parvoviruses, polydna- viruses, and poxviruses and the RNA-containing reo- viruses, cytoplasmic polyhedrosis viruses, nodaviruses, picrona-like viruses and tetraviruses. The introduction of *Oryctes* virus into outbreak areas of the rhinoceros beetle, Oryctes rhinoceros (Coleoptera: Scarabaeidae), has been a major success for "classical" biocontrol with a virus and has led to a dramatic reduction in palm damage in many areas of the Asia/Pacific region. In size and structure, the *Oryctes* virus very much resembled the baculoviruses of the many nuclear polyhedrosis and granulosis diseases of insects known at that time. But the main difference was that, with minor exceptions, it is not occluded in paracrystalline proteinaceous bodies .Therefore, this first rod-shaped, non-occluded insect virus was assigned to a new genus and originally described as Rhabdionvirus oryctes. When the classification and nomenclature of insect viruses was completely revised by the International Committee on Taxonomy of Viruses (ICTV), the *Oryctes* virus became the type species of Subgroup C of the family Baculoviridae. Thus, for a long time it was cited in literature as 'baculovirus of Oryctes' or briefly as 'Oryctes baculovirus.' Recently, Evans and Shapiro (1997) have assigned the virus to a new *Oryctes* virus family. Release of *Oryctes rhinoceros* (OrV) virus infected adult beetles @ 10 -15 per ha.

Nematode: Another group of microorganisms that can control pests is the entomopathogenic nematodes, which control weevils, gnats, white grubs and various species. These fascinating organisms suppress insects in cryptic habitats (such as soil-borne pests and stem borers). Commonly used nematodes in pest management belong to the genera Steinernema and Heterorhabditis, which attack the hosts as infective juveniles (IJs). Entomopathogenic nematodes (EPN) can be mass-produced in vivo and in vitro in solid media or liquid fermentation.

Mode of action: IJs are free-living organisms, which enter the hosts through mouth, anus, spiracles or cuticle (Figure 2). They are able to release their bacterial symbionts in to the haemocoel of hosts, killing the host within 24–48 h. The nematodes can complete up to three generations within the host, after which the IJs leave the cadaver to find the new hosts.

Production and Development:

Some microbial biopesticides are easy to produce and develop and can be manufactured using simple and in-expensive technologies. The BVs and EPN can be produced i*n vivo* in insects and entomopathogenic fungi, such as *Hirsutella*, *Beauveria* and *Metarhizium,* are produced on grains. Such simple technologies are useful for developing countries where a substantial demand exists for local production and distribution at the farmers' level.

Conclusion: Entomopathogens can be important tools in IPM strategies in both organic and conventional production systems. Depending on the crop, pest, and environmental conditions, entomopathogens can be used alone or in combination with chemical, botanical pesticides or other entomopathogens.

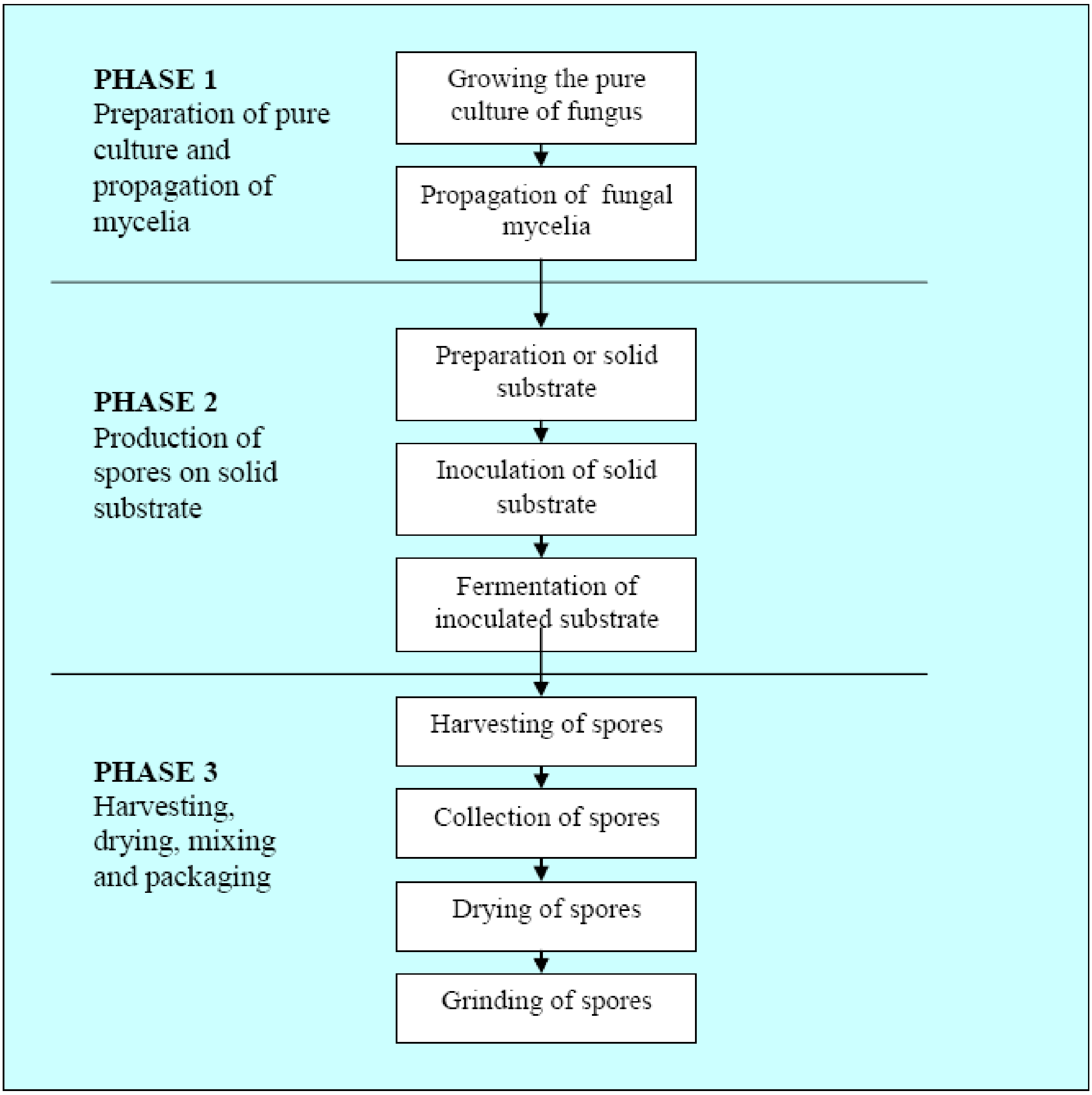


Figure 1: Chart showing the flow of the process involved to produce the spores of fungi

Pest and Disease Management in Coconut Nursery

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Pest management is an integral component of nursery operations for the successful production of quality coconut seedlings. This is equally as important as selection of healthy mother palms and as well as selection of quality seed nuts for production of vigorous seedlings. A healthy and vigorous coconut seedling maintained by good agricultural practice would therefore result in a hale and hearty palm capable of producing a sustained yield. Some of the nursery pests such as ash weevil, whiteflies, scale insects and mealy bugs affect the appearance of coconut seedlings. Though such seedlings may be vigourous, preference by farmers is lost due to damage symptoms on coconut seedlings. Since the nut production is by and large initiated after a period of at least three years for dwarf coconut cultivars and seven years for tall varieties, timely health management techniques hold the key for better output. A wide array of pests infesting coconut seedlings is enumerated hereunder with the characteristic symptoms and management strategies.

I INTERNAL BORERS

(i) Rhinoceros beetle, *Oryctes rhinoceros* Linn.

Adult beetle bores into the collar region of the coconut seedlings and brings forth dead heart-like symptoms. Irrecoverable loss is induced when central core of the spindle is severely affected and this is one of the new modes of entry by the pest. Extrusion of chewed up fibre at the bore hole is one of the characteristic symptoms for identification. In many cases, the growing point gets twisted, malformed and remarkable loss in vigour is observed. In certain pockets of Alappuzha and Kollam districts of Kerala incidence as high as 2-5% is reported. Presence of geometric V-shaped cuts on leaflets is quite common in juvenile palms.

Management

Nursery hygiene is very crucial for suppressing the damage by rhinoceros beetle as unhygienic practices attract beetles for oviposition and feeding. Integrated pest management involves disposal of breeding grounds, treating breeding sites of beetle with green muscardine fungus, *Metarhizium anisopliae* @ $5x10^{11}$ spores/m^3 as well as incorporation of weed plant, *Clerodendron infortunatum* and release of O*ryctes rhinoceros* nudivirus (OrNV) infected beetles @ 10-12 beetles/ha. Application of neem cake (10 g) or marotti cake (10 g) or pongamia cake (10 g) admixed with sand is recommended on the collar region of the seedlings. Placement of a botanical cake developed by ICAR-CPCRI on the topmost leaf axil was found to be effective in warding off beetle damage. Wherever possible, hooking of beetle is one of the best methods of management of black beetle.

(ii) Red palm weevil, *Rhynchophorus ferrugineus* (Oliv.)

Infestation by red palm weevil is noticed if aged seedlings are retained in the nurseries. Nurseries adjoining the root (wilt) diseased tracts have higher damage percentage by this weevil. Grubs of red palm weevil feed inside the growing point and results in death of the seedling especially the aged ones. Chlorosis of mid-whorls and toppling of the entire seedling are the key diagnostic features. All life stages of the pest are confined within the infested growing point. Seedlings of dwarf cultivars are relatively susceptible to red palm weevil infestation compared to the tall varieties.

Management

Ensure timely distribution of seedlings and avoid maintenance of aged seedlings in the nursery. Destroy infested dead palms in the immediate vicinity of the nursery. Skilled early detection and prophylactic filling of collar region with neem cake (10 g) or marotti cake (10 g) or pongamia cake (10 g) admixed with sand is recommended. Curative treatment with imidacloprid (0.025%) or spinosad (0.013%) is very effective.

II SUBTERRANEAN PESTS

(i) White grub, *Leucopholis coneophora* Burm.

White grubs feeding on the roots of coconut seedlings are predominantly noticed in sandy as well as sandy-clay soils in coastal districts,. Vigour of the seedlings is thus affected and initial establishment after transplantation is impaired.

Management

Raising nursery in white grub endemic zones is to be avoided. Summer ploughing and exposing grubs and pupae for predation are recommended. Mechanical collection and destruction of emerging beetles during May/June may also be done. Drenching soil with chlorpyriphos @ 2 kg ai / ha or bifenthrin @ 2 kg ai / ha after initial raking. Soil application of entomopathogenic nematode, *Steinernema carpocapsae* @ 11.5 lakh IJ/7.5 m^2 in endemic zones is found effective.

(ii) Termites, *Odontotermes obesus* Ramb

Termites generally attack seedlings specifically when the nursery is raised in laterite soils, preferring the husk of seed nuts. Invasion is either through the base of the seed nut or at the collar region. Wilting of the central shoot is usually the first visible symptom of attack followed by death of the seedlings. Infestation also continues in the transplanted field resulting in poor establishment.

Management

Wooden wastes, coconut petiole wastes and un-germinated seed nuts have to be removed and destroyed in advance prior to taking up of sowing of seed nuts. River sand is preferred as rooting media for innate selection of superior seedlings as well as reducing menace by termites. Soil application of nursery bed with Chlorpyrifos dust @ 5 g / nursery bed (7.5 m^2) or fipronil granules @ 5 g / nursery bed before sowing of seed nuts is also recommended. Curative spot treatment by soil drenching of chlorpyrifos (0.05%) or fipronil (0.05%) is very effective

(iii) Small red ant, *Dorylus orientalis* Westwood

These ants in gregarious forms feed on the growing tips as well as the haustoria by making tiny holes on the husk. Any injury to seed nuts would enhance the invasion by these ants. It feeds the inner contents and drains off the haustoria leading to the death of the seedlings. At times it attracts secondary infection by fungus accelerating rotting of seedlings. Sometimes infestation is continued in the main field also.

Management

Removal of un-germinated nuts at regular intervals, preferably at five months for tall varieties and at four months for dwarf cultivars is to be done. Reject damaged seed nuts during sowing. Soil application of Chlorpyrifos dust @ 5 g / nursery bed (7.5 m^2) before sowing of seed nuts in endemic tracts may be practiced.

(iv) Bandicoots, *Bandicota bengalensis* Gray

Bandicoots feed on the emerging sprouts and collar region causing severe damage to coconut seedlings in the nursery as well as immediately after transplantation into the main field. In most cases, the young seedlings collapse when invaded by bandicoots. Presence of burrow opening covered with mud in a discontinuous fashion is an indicator of its activity.

Management

Habitat management by reduction of field bund height and reconstruction is recommended. Monitor the nursery area critically for entrance holes of bandicoots and installation of bamboo traps / PVC traps along the route for trapping them.

III SAP FEEDERS

(1) Lace bug, *Stephanitis typica* Distant

Nymphs and adults feed from under surface of leaflets of coconut seedlings causing white speckles on the upper surface. Black stains of honey dews are quite prominent along with exuviae restricted to lower surface. Feeding damage by lace bugs induce an ugly look to seedlings. It is reported as one of the vectors of coconut root (wilt) disease.

Management

Encourage the population build up of the natural enemies. Spray fipronil 0.005% on the undersurface of leaflets during peak population period.

(ii) Palm aphid, *Cerataphis brasiliensis* (Hempel)

Dense aggregations of palm aphid colonies are found on spindle leaves as well as on younger leaves of coconut seedlings. Due to de-sapping and subsequent excretion of honey dews the lower whorls are covered with sooty mould fungus. Ant colonies are usually associated with the pest. Dwarf varieties especially Malayan Green Dwarf are highly susceptible.

Management

Conservation of lady beetles in the ecosystem for natural suppression of the pest before the arrival of phoretic ants. Two sprayings of imidacloprid @ 0.006% at fortnightly intervals was found to be effective in the management of the pest.

(iii) Mealybugs

a) Leaf mealybug, *Pseudococcus cryptus* Hempel,

b) Spindle mealybug, *Palmicultor palmarum* Ehrhorn

c) Root mealybug, *Nipaecoccus nipae* (Maskell)

Pseudococcus cryptus is confined on leaves of coconut seedlings, *P. palmarum* is restricted on spindle region and *N. nipae* is located only on the roots of coconut seedlings. Due to dense colonies and continuous desapping, the seedlings become weaker. Ants are normally associated except on root mealybugs.

Management

Destroy heavily infested plant parts and remove alternate weed hosts in the immediate vicinity of coconut nursery. Management strategies are to be initiated at the initial stages of infestation. Locate and destroy ant colonies during summer ploughing. Apply neem oil (0.5%) or imidacloprid @ 0.006% based on the severity of infestation. Conserve natural enemies identified against the pest.

(iv) Hard scales

a) Coconut scale *Aspidiotus destructor* Sign.,

b) Mussel scale *Lepidosaphes megregori* Banks

c) Needle scale, *Chionaspis* sp.

Aspidiotus destructor is found mainly on the undersurface of leaves. Entire leaves may turn yellow to brown and fall. The bright yellow colour of affected leaves is clearly visible from a great distance. Females of *L. megregori* are normally aggregated, typically boat shaped and feed continuously from undersurface of coconut leaflets. Mussel scales are mostly confined on coconut leaflets and no other plant parts are normally invaded. Honey dew production and ants are not associated with them. *Chionaspis* sp. is confined to undersurface as well as upper surface of coconut seedlings in large numbers and is densely congregated. Continuous feeding leads to chlorosis and drying of un-split leaves of the seedling.

(v) Soft scales

a) Wax scale *Ceroplastes* sp.

b) Stellate scale, *Vinsonia stellifera* Westwood

Wax scales (*Ceroplastes* sp.) are occasionally found on coconut leaflets and are easily recognized by thick wax coverings with characteristic mounds or projections. Stellate scale (*V. stellifera*) adversely affects the vigour of the seedlings by mass-feeding on leaflets. Abundant honey dew production is observed and ants are generally associated.

Management

Quarantine and restrict movement of planting materials across transcontinental borders. Adequate nutrition and well-drained soil reduces the pest attack. Heavily infested leaves are to be removed periodically. Conserve lady beetles and cybocephalids for natural suppression. Application of neem oil (0.5%) or fipronil 0.005% on need based situation is recommended.

(vi) Whiteflies

a) Areca whitefly, *Aleurocanthus arecae* David and Manjunatha

b) Spiralling whitefly, *Aleurodicus dispersus* Russell

Nymphs and adults of *A. arecae* insert the stylets on plant tissues, feed on the phloem sap and secrete honeydew. These sugar-rich excreta support sooty mould fungus interfering with photosynthesis. Eggs are laid in circular to spiral rings on the abaxial surface of leaves. The immature and adult stages of spiralling whitefly (*A. dispersus*) desap coconut foliage by direct feeding through the piercing and sucking mouth parts. Feeding damage is predominantly effected by the first three nymphal stages. Direct feeding even under heavy infestations is usually insufficient to kill seedlings.

Management

Lady beetles are found predaceous on adults and nymphs of *A. arecae.* Eggs of *A. arecae* are 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. Natural presence of *Encarsia dispersa* and *Encarsia guadeloupae* are identified as potential parasitoids against *A. dispersus* and brings out effective bio-suppression. In addition lady beetles and cybocephalids also reduce the population of whiteflies.

c) Rugose spiraling whitefly, *Aleurodicus rugiopperculatus* Martin

Rugose Spiralling Whitefly (RSW), *A. rugioperculatus* Martin is an invasive pest first reported on coconut from Belize, Central America during 2004. It was the latest non-exotic pest reported in India on coconut from Pollachi, Tamil Nadu and Palakkad, Kerala during July-August 2016. In a period of six months, it could be recorded from all districts of Kerala, Parts of Tamil Nadu, Parts of Andhra Pradesh and Parts of Karnataka mostly from coconut. The lateral spread of the pest in different places could be attributed mainly through the distribution of infested seedlings as well as transporting vehicles. The pest could establish and successfully complete the life stages on coconut and to limited extent on banana, however, egg laying had been recorded on a wide array of host without successful establishment.

Biological control

It cause heavy de-sapping, restricted from under surface of coconut leaflets. The presence of sooty mould on the upper surface of leaflets as well as on other intercrops is the characteristic diagnostic symptom for pest identification. Extensive de-sapping of RSW would induce stress on the palms due to removal of water and nutrients, but neither colour change nor necrosis of leaves is observed. The prevalence of the pest was noticed from the outer whorls and slowly progressing towards the inner whorls, whereas, the immature fronds were not infested. We could also observe that, more than 70% of the whitefly colonies were found parasitized by the aphelinid parasitoid, *Encarsia guadeloupae* Viggiani, indicating the natural buildup of the parasitoids. This is one of the classical biological control strategies and any disturbance in the buildup of *E. guadeloupae* would invariably affect the long term approach in pest bio-suppression. In a period of four to five months, parasitism rose to more than 70% in unsprayed coconut plantations in Kerala.

Of late, a Leiochrini beetle, *Leiochrinus nilgirianus* Kaszab 1946 (Tenebrionidae: Coleoptera) and its immature stages were found feeding on sooty mould developed over the honey dew excreted by RSW especially during early morning hours. Complete cleaning of the sooty mould laden palm leaflets could be accomplished in the experimental plots at Kayamkulam, Kerala.

Strategies

Being a new invasive whitefly species, the initial spread will be quite rampant. Since the natural enemy build up of *E. guadeloupae* has been initiated, RSW may not go beyond action threshold as expected. Therefore, awareness campaigns are to be followed in all epidemic zones to sensitize the farming community about the whitefly pest and the need for conserving the natural enemies and scavenging beetles to ward off the pest. Sensitization programme focusing on the natural build up of the parasitoid, *E. guadeloupae* in RSW endemic areas should be projected as a classical example of bio-control strategy in sustainable pest management in coconut system. Our approach should, therefore, be to encourage the niche survival of *E. guadeloupae* and habitat conservation of *L. nilgirianus* for effective bio-suppression of *A. rugioperculatus*. ICAR-CPCRI has conducted pest-alert campaign through mass media and sensitized about the invasive pest and the precautions to be handled to suppress the pest.

Integrated Pest Management Approaches

- ✓ Application of 1% starch solution on leaflets to flake out the sooty moulds.
- ✓ Installation of yellow sticky traps on the palm trunk to trap adult whiteflies.
- ✓ Encourage build up of parasitoids (*E. guadeloupae*) and re-introduce parasitized pupae to emerging zones of whitefly outbreak.
- ✓ In severe case, spray neem oil 0.5% and no insecticide is recommended.
- ✓ Complete destruction of RSW and immature stages on coconut seedlings by initial water spray as well as spraying imidacloprid 0.005% to avoid spread of the pest to new areas.
- ✓ Habitat conservation of sooty mould feeding scavenging beetles (*L. nilgirianus*) in the palm ecosystem.

(vii) Foliage mites- *Raoiella indica* Hirst., *Oligonychus iseilemae* Hirst., *Tetranychus ludeni* Z.

Mites live in webbed colonies on the undersurface of coconut leaflets and sucking the sap, resulting in yellowing and drying of affected parts. Higher mite population is observed during February to June.

Management

In case of severe infestation spraying with Spiromesifen (0.8 ml/litre) or wettable suphur (0.2%) can effectively control the pest. Phytoseiid predatory mites check the population of the pest in nature. Provide shade to the seedlings to reduce mite infestation.

IV DEFOLIATORS

(i) Ash weevils

a) Coconut ash weevil, *Myllocerus curvicornis* Fab.

b) Asian Grey Weevil, *Myllocerus undatus* Marshall

Adult weevils belonging to both species feed along the margin of leaves of coconut seedlings making a semi-circular cut leading to typical notching-like symptom. Such damaged seedlings have lesser consumer preference. At times nearly 40% of seedlings are infested by the weevil pest. Grubs feed on underground roots. All cultivars are equally susceptible to the pest attack.

Management

Rake soil during summer months and expose the grubs for predation. Soil application of entomopathogenic nematode suspension for infecting grubs. Application of contact insecticides is recommended only at higher level of pest infestation.

(ii) Skipper butterfly, *Gangara thyrsis* Moore and *Suastus gremius* Fab.

Typical tubes are constructed by the caterpillar of *G. thyrsis* uniting the edges of the leaflets with strong whitish silken threads and feeds on leaf lamina. Pupae have the habit of vibrating and striking against the inner surface of the fold when disturbed. It is minor pest in coconut nursery and juvenile palms.

Management

Avoid water stagnation in the coconut nursery. Mechanically collect and destruct the caterpillars and pupae of the pest. Need based application of any contact insecticides is recommended only when necessary.

(iii) Slug caterpillars, *Conthyla rotunda* H., *Latoia lepida* Cram. and *Macroplectra nararia* Moore

Early-instar caterpillar feeds from 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. During heavy infestation caterpillars feed on the entire leaflet sparing only the midrib. These caterpillars are covered with tiny spines that cause severe irritation on contact.

Management

Establishment of light traps in endemic tracts proved effective in monitoring the pest incidence well in advance. Mechanically remove the pest at initial stages of infestation. Cutting and burning infested leaflets prevent the spread of the pest. In case of severe damage, spray lower side of the leaves with *Bacillus thuringiensis* 20 g/litre

(iv) Bagworm, *Mentha albipes* M.

Caterpillars live inside a protective covering and hang from abaxial leaf surface. Feeding marks are seen as circular shot holes on the leaf.

Management

Cutting and burning heavily infested leaves prevent the spread of the pest.

(v) Leaf beetle, *Wallacea* sp. (Chrysomelidae: Coleoptera)

A close relative of the invasive pest, *Brontispa longissima viz., Wallacea* sp. feeding on the spindle region of coconut seedlings was recently recorded from South and Little Andaman. The pest was not located in the mainland so far. The feeding niche of *Wallecae* sp. confining on coconut spindle is a matter of concern, however, the pest was not observed from any adult palm. Though 80-90% of seedlings were infested by the pest, damaging about 40% of leaf area, there was no seedling mortality. Invasive nature of *Wallacea* sp. is under scrutiny, as a close relative, *Wallaceana* sp. was reported from Indonesia. Adult beetles are brownish with six rows of constrictions on each elytron and measured 4.72 mm long and 0.9 mm wide. They are active fliers may be for a short distance. Grubs possessed short-lateral spines on each body segments with prominent mandibles for active feeding and measured 5.75 mm long and 0.8 mm wide. Grubs and adults remain within the folds of the spindle leaves and feed from within. Typical feeding damage 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. Though a few feeding adult beetles were observed in between the leaf folds of emerged leaves, the grubs were mostly confined within the spindle region only. Pupae are located at the point of leaflet attachment to the main petiole. Pupae are exarate with exposed appendages and well-developed wing pads and are mostly located on the point of attachment of leaflet with the main petiole.

Management

Strengthening quarantine and ensure that planting material of coconut is brought to the mainland only with proper phytosanitary certificate. Tourists should be advised not to bring any coconut planting material to the mainland from Bay Islands.

(v) Nematode – Burrowing nematode *Radopholus similis* Thorne

R. similis has migratory endoparasitic habits and develops and reproduces inside the roots of coconut seedlings. Feeding by *R. similis* causes brown lesions on the infected roots impairing the nutrient uptake potential of the seedlings. Continuous feeding leads to the production of weaker seedlings in nursery. It is usually dispersed through root material and by poorly sanitized bare root propagative planting material.

Management

Remove old infected roots of coconut seedlings at the time of transplanting. Intercrops such as banana (most-preferred host) are not recommended near the nursery. Planting of marigold along the borders can act as trap crop and reduce the infestation. Apply neem cake (3 kg / nursery bed) at the time of preparation of coconut nursery bed. Changing the nursery site every year is recommended to avoid nematode build up and thereby to reduce damage by nematodes.

(vi) Disease- Grey leaf spot, *Pestalotiopsis palmarum*

Grey leaf spot caused by *Pestalotiopsis palmarum* is observed in nursery as well as in the main field. The disease is widespread in all the coconut growing regions in the tropics. It was first reported from British Guyana and later from Malaysia, New Hebrides, Sri Lanka, India, Trinidad, Nigeria *etc*. Generally the disease affects palms of all stages. The disease is characterized by the appearance of minute yellow spots with a grey brown margin. The spots may be oval in shape measuring up to 5 cm length (Menon and Pandalai, 1958). The centre of the spots becomes greyish white while the intensity of brown colour of the margin increases. Many spots coalesce to form large irregular necrotic patches. The leaves in advanced stage of infection present a blighted appearance and hence assumed the name as leaf blight.

Management

Restricted irrigation and farm hygiene is very crucial. Spraying of Bordeau Mixture 1% or carbendazim plus mancozeb 0.1% is very effective

Internal borers such as rhinoceros beetle, subterranean pests like termites, whitegrubs and bandicoots, sap feeders such as lace bugs, mealybugs and scale insects, defoliators like ash weevils and skippers, burrowing nematodes as well as grey leaf spot are the important nursery pests infesting the quality of coconut seedlings. Though other pests have been enumerated they emerge in severe proportions only in certain endemic tracts under favourable weather conditions. Skillful monitoring and correct identification of the pest would result in effective management of nursery pests at the appropriate time. In view of the prevalence of *Wallacea* sp. in Andaman, strict quarantine needs to be enforced in bringing the planting material from Island ecosystem. Tourists need to be properly advised about the impending danger in bringing coconut to the mainland. A holistic health management including quarantine measures holds the key for the success in planting material production in coconut.

Containing Palm Pests and diseases through Host Plant Resistance

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Introduction

Breeding for pest resistance is the most economically and environmentally safe method to reduce crop losses. Development of resistance is a continuous process. Development of pest and disease-resistant plants has been relatively successful with annual and biennial plants, but less so with perennials, primarily because of the longer time required to develop and test the progeny. During the past decades, the trend has been the release and cultivation of improved cultivars of crop species. These cultivars tended to be uniform as they are derived from a limited number of elite lines resulting in a narrow genetic base for the crop. This together with large scale cultivation of genetically uniform cultivars has increased the genetic vulnerability of major agricultural crop species, often with disastrous consequences. Hence it is necessary to broaden the genetic base of crop plants utilizing the large amount of genetic diversity available.

Detection and measurement of resistance

Many plant diseases have been successfully controlled by exploiting genetic resistance especially where differentiation in the pathogen with respect to resistance genes in the host is lacking. Resistance to disease can be detected by evaluating plants in the field under natural conditions of disease development or by subjecting the test plants, or plant parts, to artificial inoculation. Screening for resistance in the field under natural conditions is generally done when artificial methods of inoculation are not available or when disease is of minor importance and does not warrant the use of expensive and sophisticated methods.

Factors affecting expression and level of resistance

Plant disease is the result of interactions between the host, the pathogen, the environment and the time interval during which these three factors interact among themselves.

Effect of the host

The genotype of the host plant, its stage of development and its physiological condition influence its response to a given disease. The response of the plants to diseases may vary with age because the resistance genes may function at some stages of plant development but not at others.

Effect of the pathogen

Virulence, aggressiveness and inoculums density of the pathogen are among factors that influence the expression of resistance of a given host. Virulence is the ability of the pathogen to overcome resistance genes in the host. Therefore, host resistance is expressed only in the absence of relevant virulence genes in the pathogen. If screening for resistance is done with a less aggressive strain, then some loss of resistance is expected when a more aggressive strain gets selected in nature. Resistance may also decrease with increase in inoculum density.

Effect of the environment

Environment may affect the host and the pathogen differentially. Individual environmental factors may also affect disease development through effects on other environmental factors. Cultural conditions like the composition and pH of the medium, light intensity and temperature may affect the pathogenicity of the pathogen. If the effects of environmental factors are not taken into consideration in disease resistance studies, misclassification of resistance are possible.

SOURCES OF DISEASE RESISTANCE

Resistance may be found in locally adapted or exotic cultivars, or in related species. Locally adapted cultivars are good sources of resistance against disease which have assumed importance because susceptibility was unintentionally introduced while breeding for some other characters of economic valueResistance of locally adapted cultivars is preferable for two reasons. (i) such resistance may carry a smaller number of undesirable linkages than resistance in exotic material, and (2) resistance in exotic cultivars may be linked with susceptibility to some diseases or pests to which locally adapted cultivars are generally resistant. The use of exotic donors can lead to unintentional incorporation of such susceptibility which may later pose serious problems. Primary and secondary centres of origin of both host and the pathogen are considered to be good regions for locating resistance. Resistance can also be derived from distantly related species and genera. However, resistance from alien species or genera may be no more durable than resistance from close relatives. Resistance may also be obtained through induced mutations.

BREEDING PROCEDURES

The method of breeding for disease resistance is essentially the same as those for other agronomic characters. Commonly used procedures of breeding for disease resistance are backcross breeding, recurrent selection and interspecific hybridization. However, the following breeding methods have also been used 1) Introduction, 2) Selection, 3) Mutation, 4) Hybridization, 5) Somaclonal Variation, and 6) Genetic Engineering.

1. Introduction:

This is easy and rapid method of developing disease resistant variety. The resistant variety may be introduced and after testing, if found suitable, can be released in the disease prone area.

2. Selection:

When the source of resistance is a cultivated variety, mass selection and pure lines selection in self pollinated crops, mass and recurrent selection in cross pollinated species, and clonal selection in the vegetatively propagated crops will be ideal for isolating disease resistant plants. The resistant plants may be multiplied, screened for disease resistance and released a variety.

3. Hybridization:

Hybridization is used when resistant genes are available either in the germplasm or in wild species of crop plants. After hybridization, the hybrid material is handled either by pedigree method or by backcross method. The pedigree method is used when the resistance is governed by polygene and the resistant variety is an adapted one which also contributes some desirable agronomic traits. The backcross method is used when resistance to governed by oligogenes.

4. Mutation:

Induced mutations are also use for disease resistance. Many disease resistant varieties have been developed in various crops through induced mutations.

5. Somaclonal Variation:

Disease resistant soma clonal variants can be obtained in the following two ways, firstly, plants regenerated from cultured cells or their progeny are subjected to disease test and resistant plants are isolated. Secondly, cultured cells are selected for resistance to the toxin or culture filterate produced by the pathogen and plants are regenerated from the selected cell. In most cases, these plants are also resistant to the disease in question. Cell selection strategy is most likely to be successful in cases where the toxin is involved in disease development.

6. Genetic Engineering:

Genes expected to confer disease resistance are isolated, cloned and transferred into the crop in question. In case of viral pathogens, several transgenes have been evaluated, viz, virus coat protein gene, DNA copy of viral satellite RNA, defective viral genome, antisense constructs of critical viral genes, and ribozymes. Viral coat protein gene approach seems to be the most successful.

CLASSICAL RESISTANCE BREEDING WORK IN COCONUT

The coconut palm is affected by a number of maladies, some of them are lethal and others are of debilitating nature. The causes of these diseases were previously unknown and later the etiology of most of these diseases has been identified as phytoplasmas. At present the only efficient method to control phytoplasmal diseases is the use of resistant varieties. Since there is no method to transmit the disease experimentally, screening of coconut germplasm for phytoplasma resistance relies on performing field trials which may take several years. Though coconut is attacked by many pests, only few such as the eriophyid mite, red palm weevil and rhinoceros beetles cause major economic losses.

A. Resistance to Lethal yellowing

Lethal yellowing is a highly destructive, fast spreading disease of coconut and 35 other palm species. The first visual symptom of the disease in bearing coconut palms affected by lethal yellowing is the premature drop of most of the fruit regardless of their developmental stages. The next symptom to appear is the blackening of inflorescences. The first affected inflorescences usually show partial necrosis, but as the disease progresses, new inflorescences show more extensive necrosis. Long-term management recommendations have always included the planting of resistant coconut cultivars.

Resistance to lethal yellowing was first reported in Jamaica by Nutman and Roberts (1955) in fields of Malayan Red dwarfs that had survived despite continuous exposure to the disease. Later, green and yellow fruited Malayan dwarfs were found to be highly resistant. Many coconut ecotypes were introduced into Jamaica during the 1960s and subsequently screened for resistance. Three dwarf varieties from India and Sri Lanka, and the King Coconut have resistance that seems comparable to that of the Malayan Dwarfs. Other sources of resistance were subsequently observed in few existing plantings of Panama tall and in a population of the progeny of Malayan Dwarf x Fiji Dwarf (Niu Leka) F_1 hybrids (Whitehead, 1968).Observations on field resistance to lethal yellowing in twenty nine local and introduced varieties and twenty three hybrids indicated that Ceylon, Indian and Malayan dwarfs and the King Coconut appear to be highly resistant, while Bougainville, Cambodia, Karkar, Malayan, Panama, Peru, Rotuma, Sarawak, Thailand and Yap Talls and Fiji Dwarfs seems to be less resistant (Been, 1981). The highly susceptible group comprises Indian, Jamaican, and New Hybrides Talls and Rangiroa Dwarfs, the less susceptible being Ceylon, Fiji, Rangiroa, Rennel, Samoa, Solomon, Tahiti and Tonga Talls. Most of the hybrids had level of resistance intermediate between those of the parents but generally closer to that of the more resistant parent. However, Panama Tall X Solomon Tall showed much more resistant than either parent.

In the late 1970s, the results of resistance trials (Been, 1981) had led to encourage plantation of the Malayan Yellow Dwarf (MYD) and of the MYD x PNT hybrid or MAYPAN as a control measure against the disease. Malayan Dwarf and Maypan were replanted across the island because they were considered at that time as the most resistant varieties (Been, 1981). The MAYPAN was the best hybrid with 4 - 21% mortality and was considered as a good compromise between resistance level, yield and product quality. It was reported that at various locations along the coastal areas of the northern region, mortality levels among stands of MYD and Maypan were observed to be consistently higher than anticipated (Myrie, 2005). It was clear that LY re-emerged as the single most important plant disease affecting the coconut industry of Jamaica. In total, this new outbreak destroyed 1.3 million coconut trees.

In Tanzania, more than thirty ecotypes and hybrids have been screened, including those identified as highly resistant to LY in Jamaica. However, none showed acceptable resistance to lethal disease under conditions of high intensity (Schuling and Mpunami, 1992). The Sri Lanka Green Dwarf, Equatorial Green Dwarf and Malayan Yellow Dwarf and Vanuatu Tall which showed few losses to Cape St. Paul wilt in the two trials that have been affected by the disease. In contrast, the local West Africa Tall has been almost completely destroyed by the disease (Oropeza *et al*., 1995). Observations made in Jamaica and Ghana were similar which led to the conclusion that Malayan Yellow Dwarf, Malayan Red Dwarf and Sri Lanka Green Dwarf varieties are highly resistant to the LY type diseases. Tall populations from South-East Asia and from Pacific are less resistant. Wild type populations such as the Jamaica Tall, West Africa Tall, Vanuatu Tall and India Tall including their hybrid progeny are highly susceptible. In Tanzania, the dwarf varieties are not highly resistant and their resistance levels are similar to some less resistant tall ecotypes. The most promising source of resistance has been identified in an indigenous population of East African Tall.

B. Resistance to root (wilt) disease

Root (wilt) is a serious, non lethal, debilitating disease of coconut palm. It was first noticed in the erstwhile princely state of Travancore around 1874 and became very much evident after the flood of 1882 (Butler,1908). The disease was initially reported from Erattupetta, Kaviyoor, Kalloopara and Kayamkulam of Kerala and later spread to almost all states of Kerala and adjoining areas of Tamilnadu and Karnataka. The most obvious and diagnostic symptom is the abnormal inward bending of the leaflets termed ribbing or flaccidity. Foliar yellowing of the outer whorl of leaves and marginal necrosis are the associated symptoms (Radha and Lal, 1972). With the progress of the disease extensive rotting of roots is observed (Menon and Pandalai, 1958). In bearing trees, shedding of immature nuts are noticed in some cases and drying up of spathes and necrosis of spikelets from tip downward in unopened inflorescences. Radha *et al.*, (1962) reported reduction in yield of nuts upto 82% in palms in the advanced stage of the infection.

The search for resistance to root (wilt) disease started with Butler who suggested that there could be resistance to coconut root (wilt) disease in the local cultivars grown in the diseased tract. Varghese (1934) initiated search for root (wilt) resistance and surveyed about 10.5 sq. km in and around Kayamkulam. However, genotypes resistant to root (wilt) could not be located. Rawther and Pillai (1972) studies the root (wilt) disease incidence and average yield in Dwarf x Tall (Natural Cross Dwarf Hybrids), Tall x Dwarf, Dwarf Orange, Dwarf Green and WCT. They found that Dwarf x Tall (Natural Cross Dwarf hybrids) had lowest percentage of disease incidence (4.6%) and highest yield in both healthy and diseased palm. WCT had highest disease incidence (48.5%) and also the lowest yield. All other varieties and hybrid studied were superior to WCT in disease resistance and yield performance.

Ninan (1978) reported that among WCT, Chowghat Green Dwarf (CGD), Chowghat Dwarf Orange (COD) and their hybrids, CGD palms were most tolerant to root (wilt) with 92.2% palms free from the disease. Attempts to screen the available germplasm at CPCRI, Kasaragod were made as early as 1961 at CPCRI, Regional station, Kayamkulam. The cultivars tested were Andaman Ordinary, Andaman Giant, Cochin China, Ceylon Tall, Laccadive Dwarf, Laccadive Ordinary, New Guinea, Philippines, Strait Settlement Apricot, Strait Settlement Green, St. Vincent and Spicata. All these cultivars developed typical symptoms of root (wilt) disease (Menon *et al*., 1981). Mathai *et al*., (1991) studied the resistance/tolerance of ten exotic and geographically distinct cultivars of coconut to root (wilt) disease. The varieties tested were San Ramon, St. Vincent, Jamaica, British Solomon Islands, Kenya, Guam, Strait Settlement Green, Federated Malayan States, Java, Fiji and West Coast Tall. Among these, San Ramon and Guam varieties were most resistant whereas WCT was the most susceptible (Mathai *et al*., 1980; 1985; 1991).

Nair *et al*., (2004) screened ten varieties including Karkar, S.S.Apricot, Kappadam, CGD, Federated Malay States, Zanzibar, Philippines Lono, Fiji Rotuma and King Coconut with WCT as control. Observations on disease incidence revealed that CGD had the highest level of resistance (75%) followed by Philippines Lono and Zanzibar (70.8%) and King Coconut (8.3%) and Kappadam (33.7%) were the most susceptible. A comparative study of dwarf varieties viz., Malayan Green Dwarf, Malayan Yellow Dwarf, Malayan Orange Dwarf, Chowghat green Dwarf and Chowghat Orange Dwarf at Coconut Development Board farm, Neriamangalam indicated that the varieties MGD and CGD showed the lowest percentage of disease incidence (0 and 4.3% respectively). The disease index of the CGD and MGD varieties was 0 and 6.4% respectively (Nair *et al*., 2006).

C. Resistance to Eriophyid Mite *(Aceria guerreronis)*

Eriophyid mite develops in the meristematic regions of the immature nuts, which is covered by perianth (tepals). Their feeding causes scarring and distortions of the fruits, and may cause premature fruit drop. Based on laboratory observations, the tightness of the perianth to the nut was identified as a key factor in determining susceptibility or resistance to attack by *A. guerreronis.* Penetration tests showed that as the nuts grew, it became increasingly larger in proportion to the perianth. Tepal aestivation in female flowers, shape of the developing nut, growth rate and pattern of nut enlargement are some of the traits identified as contributing to a lesser mite attack. Biophysical traits of habitat of the mite in the plant provide selection indices for tolerance. However, a conclusive test to determine resistance is still elusive.

The entry of mites depends on the tightness of tepals to the fruits at the early stages of fruit development. Greater tightness is achieved in round rather than elongated and angled fruits (Moore 1986, Aratchige et al. 2007). Varadarajan and David (2002) measured the gap by estimating the ratio of length of nut to radius of tepal. A large gap could also allow the predatory mites and hence is not congenial for herbivorous mite. In Malayan Yellow Dwarf the space developed between the coconut surface and the perianth was large enough to allow mite to penetrate to the meristematic tissue (Howard and Rodriguez 1991). Differences for the gap in un infested nuts are significantly different among the three varieties, Sri Lankan Green Dwarf, Sri Lankan Tall and their hybrids. Sri Lankan Green Dwarf palms are susceptible to mites as the nuts of this variety are small with an elongated shape. The gap in the nuts of this variety before infestation is large enough for the eriophyid mite to enter, but too small for the predatory mites. However, this perianth-fruit rim gap in infested nuts does not differ significantly and hence accessible to predatory mites. Access of predatory mites long after the eriophyid mites reach a sufficient population is insufficient to keep the pest population below normal level. Hence, the gap between the fruit and tepal in uninfected nuts is important and needs breeders' attention.

Round and dark green fruits show better tolerance against the eriophyid mite than the elongated fruits and those of other colors, as reported by Moore and Alexander (1987). Drought is also a predisposing factor which makes coconut palms susceptible to mite attack, since the growth rate of nuts is slow because of lack of available soil moisture (Mariau 1986).

Thirty one varieties in India were evaluated in 1999 for eriophyid mite damage using a one to five scale. Under conditions of natural infestation, Laccadive Ordinary, Cochin China, Andaman Ordinary and Gangabondam recorded minimum nut damage whereas Seychelles, St. Vincent and Nigerian Tall were highly susceptible (Muthiah and Bhaskaran 1999). Screening of coconut varieties for tolerance to coconut mite resulted in identification of some accessions such as Kenthali (Ramaraju et al. 2000) and Chowghat Orange Dwarf (Nair, 2000) with lower incidence of mite.

Muthiah and Rajarathinam (2002) screened 33 coconut cultivars for eriophyid mite resistance for three years during 1999-2002. Chowghat Orange Dwarf, Siam, British Solomon Island (BSI), Ayiramkachi, Philippines Ordinary and Spicata were found to be moderately tolerant. The cultivars Seychelles and St. Vincent were found to be highly susceptible to mite attack. Among 34 coconut hybrids screened during 2001, four hybrids viz., Java Giant × East Coast Tall, Ayiramkachi × West Coast Tall, Cochin China × Philippines Ordinary and West Coast Tall × Chowghat Orange Dwarf were found to be moderately tolerant.

Levin and Mammooty (2003) reported that the spicata mutant showed a fair level of tolerance to eriophyid mite. They also reported that the genotype BSI recorded the highest percentage of nut damage by mites followed by Philippine Lono (81.1 per cent). Laksha Ganga (Lakshadweep Ordinaryx Gangabondam) recorded the minimum incidence (19.4 per cent) compared to the maximum mite damage (30.0 per cent) in Ananda Ganga. The cultivars Ayiramkachi (90.2 per cent) and Andaman Dwarf (85.3 per cent) were the most susceptible to mite damage among indigenous cultivars, whereas the genotypes Bombay (6.4 per cent), Laccadive Micro (7.4 per cent), Chowghat Orange Dwarf (8.8 per cent) and Spicata (9.5 per cent) were the least susceptible.

Muthiah and Natarajan (2004) conducted a field experiment in Tamil Nadu (India) during 1999-2001 to evaluate the resistance of 33 coconut cultivars and 34 hybrids to eriophyid mite (*Aceria guerreronis*). Four cultivars (BSI, Chowghat Orange Dwarf, Philippines Ordinary and Spicata) and two hybrids (Philippines Ordinary × San Blas and Cochin China × Philippines Ordinary) were moderately resistant, whereas all the other materials tested were moderately susceptible or highly susceptible to the pest.

The cross between Sri Lankan Yellow Dwarf X Sri Lankan Tall has been identified as tolerant to *Aceria* mite, in an evaluation of five commercially cultivated coconut cultivars in Sri Lanka in a severely mite affected area (Perera 2005, 2006). Sri Lankan Yellow Dwarf and

Gonthembili have also been identified as tolerant cultivars to coconut *Aceria* mite (Perera 2006).

Eleven coconut cultivars were screened against eriophyid mite in Andhra Pradesh (India) during September 2000 to January 2005 (Raju et al. 2006). None of the cultivars were resistant to *A. guerreronis*. However, Java Giant and Ceylon Green Tall were moderately resistant and the rest were susceptible. The maximum percentage of infested nuts was recorded by Fiji (83.65 per cent), followed by Chowghat Orange Dwarf (80.13 per cent).

Girisha and Nandhihalli (2009) screened ten coconut varieties *viz.* West Coast Tall, Arsikere Tall, Laccadive Ordinary, Gangabondam, Philippines, "Green Dwarf", Andaman Dwarf, Laccadive Dwarf, "Green Tall" and Spicata against eriophyid mite. Significantly less mite population was recorded in Gangabondam (28.96/28.28 mm^2 area of perianth) which was found significantly superior over other varieties followed by West Coast Tall where as varieties Laccadive, Green Dwarf, Arsikere Tall and Green Tall recorded more mite population. The superiority of Gangabondam might be due to the tight attachment of perianth to nut surface. Gangabondam also recorded least damage grade (1.40) and damaged nuts (16.00) with highest number of healthy nuts (78 nuts).

Sujatha et al. (2010) screened eight tall coconut varieties (45 year old) and 17 new hybrids (15 year old) for resistance against the mite for four years during 2004 to 2007 under natural conditions of coastal ecosystem of Andhra Pradesh (India). Out of the eight varieties; the lowest mite damage index was recorded in Laccadive Ordinary and the highest in Laccadive Micro. Among the 17 coconut hybrids screened, ECT × GB (Godavari Ganga) recorded the lowest mite damage whereas, LM × GB recorded the highest damage among various cross combinations.

Badge et al. (2016) screened coconut genotypes for their level of susceptibility to coconut eriophyid mite in India. Based on mean damage score, none of them were found to be resistant to eriophyid mite. Among the 26 coconut cultivars screened, minimum infestation was observed in the genotypes Jamaica, BSI, Philippines Lono, Guam and Orange Dwarf.

D. Resistance to Rhinoceros beetle *(Oryctes rhinoceros)*

Although all coconut cultivars are prone to damage by rhinoceros beetles, the hybrids developed with Chowghat Orange Dwarf as pollen parent was reported to be more susceptible (Nambiar 1988). Coconut varieties were screened in Tamil Nadu, India for reaction to rhinoceros beetle. Average leaf damage over three years recorded from different hybrid combinations and varieties revealed that Laccadive Ordinary X Cochin China and Gangabondam X East Coast Tall had significantly minimum damage. Among the 12 varieties evaluated, West Coast Tall (WCT) and East Coast Tall (ECT) recorded less damage. The damage was more in hybrids involving dwarf genotypes (Muthiah and Bhaskaran 2000).

E. Resistance to Red Palm weevil *(Rhynchophorus ferrugineus* Olive)

Red Palm weevil (RPW) is known to cause serious damage to the crop and has attained key pest status. A preliminary survey on the damage of coconut cultivars in different districts of Tamil Nadu (India) showed that Andaman Giant, Java Giant, East Coast Tall, West Coast Tall, Federated Malay States x Laccadive Ordinary, East Coast Tall x Malayan Green Dwarf, West Coast Tall x Gangabondam, Java Giant x San Blas and Laccadive Ordinary x Cochin China were more susceptible to red palm weevil attack (Sadakathulla and Ramachandran, 1993). Faleiro and Rangnekar (2001) studied the ovipositional preference of RPW to different coconut cultivars and reported that the highest cumulative egg lay was in CGD, COD and Benaulium, which recorded an average egg lay of 31.3, 30.9 and 27.4 eggs respectively.

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Bio-priming coconut seedlings for inducing resistance

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Introduction

The application of plant-beneficial microbes to plants during its initial growth stages such that a close contact is achieved between the microbes and plants for mutually beneficial interaction is termed as bio-priming. Microbes present in close proximity to plants in the rhizosphere (soil surrounding the root area), within the root, stem and leaf tissues (termed endophytes) and on the leaf surface (termed epiphyte) play a key role in maintaining good health of the soil and plant. Therefore, bio-priming technology aims at providing the target plant with agronomic opportunity to get associated with bacteria or fungi or actinomycetes proven for their growth promoting abilities. Bio-priming can be done to seeds, seedlings and even adult plants using different methods and one important service bio-priming offers is the ability to improve resistance to fungal pathogens *via* induction of resistance in the plants.

Resistance induction in plants

As in human beings vaccination is practiced to induce resistance against many important diseases, bio-priming with plant-beneficial microbes also induces resistance to ward off fungal pathogens and insect pests in agriculture. Induction of resistance in plants can occur by two methods: i) because of the limited infection caused by the known pathogen or non-virulent form of pathogens, certain chemicals etc. which is called systemic acquired resistance (SAR) resulting in accumulation of salicylic acid and pathogen related proteins in the plants that enhance the defense against the pathogens, and ii) by non-pathogenic rhizobacteria bacteria *via* production of siderophores, antibiotics and microbicidal enzymes such as chitinase and glucanase, which is termed induced systemic resistance (ISR). Plant growth promoting rhizobacteria (PGPR) such as *Bacillus* spp, *Pseudomonas* spp. *Enterobacter* spp and many others are able to offer ISR to plants.

Bio-priming methods

The aim of bio-priming is to quickly bring in contact high population of the beneficial bacteria with the growing roots of the plants. Following methods of application help in achieving bio-priming: i) coating seeds with bacterial solution, ii) dipping the roots of seedlings in bacterial solution, iii) pouring the bacterial solution into the root region of the plants etc. The bacteria thus applied immediately tries to colonize the growing root by biofilm formation and then is able to perform its activities which trigger or prime the defence mechanisms in the plants and make it prepared to ward of any eventual disease occurrence.

Bio-priming of coconut seedlings

Through meticulous studies more than hundreds of bacteria were isolated from rhizosphere soil and root samples of coconut collected from Kerala, Karnataka, Tamil Nadu, Andhra Pradesh, and Maharashtra for isolation of effective PGPRs. From these isolates, *Bacillus* and

Pseudomonas spp were consolidated and screened for several plant growth promotion properties including antibiotic, siderophore and microbicidal enzyme production. They were also tested for suppression of *Ganoderma applanatum* (causing basal stem rot) and *Thielaviopsis paradoxa* (causing stem bleeding), both soil based pathogens of coconut palm. The efficient ones were then evaluated for plant growth promotion of coconut seedlings. Bio-priming of the coconut seedlings was done by dipping the 6 month old coconut sprouts overnight in the bacterial solution containing a minimum of 1 x 10^8 cells/ml of the solution. The bio-primed seedlings were then transplanted to polybags and observed for their growth parameters. Bio-priming of the coconut seedlings was done by soil application in nursery beds too and was found to be effective. Biocontrol agents *viz*., *Bacillus subtilis* , *Pseudomonas fluorescence* both individually and in combination and *Trichoderma viride* were found to be useful for biopriming of coconut seednuts and developing seedlings with favorable growth. These biocontrol agents have been selected based on their antagonistic activities against root (wilt) disease pathogens, *Exserhilum rostratum* and *Colletotrichum gloeosporoides*

KeraProbio

Based on the results of the PGPR trials with coconut seedlings, *Bacillus megaterium,* one of most effective bacterium was selected and developed into talc-based bioformulation. The bioformulation was named '**Kera Probio'.** It is now being extensively supplied to farmers for bio-priming of the coconut seedlings before transplantation into main field.

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Climate change and pest outbreaks in Palms

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Global climate change, the current burning issue around the globe is the change in climate over time, either due to natural variability or as a result of human activity exerts multitude of threats to human life in various forms. Global average temperature increased by 0.6^{o}C in 20th century while CO_2 reached to 380 ppm till date. By the end of 21st century the global average temperature is projected to increase by 1.4-7.5^{o}C and CO_2 by 560 ppm, if the uncontrolled anthropogenic activities continue with the same speed to meet the demanding needs of growing population (IPCC, 2007). Climate change may disrupt not only pest dynamics in agriculture but also the dynamics of herbivores in stable ecosystem.

Changes in climate may trigger changes in geographical distribution, increased overwintering, changes in population growth rates, increases in the number of generations, extension of the development season, changes in crop-pest synchrony, changes in interspecific interactions, pest biotypes, activity and abundance of natural enemies, species extinction, increased risk of invasion by migrant pests and efficacy of crop protection technologies. Global warming will also reduce the effectiveness of host plant resistance, transgenic plants, natural enemies, biopesticides, and synthetic chemicals for pest management.

Many people believe that global warming as predicted would increase pressure from pests and diseases. Higher temperatures and longer growing seasons could result in increased pest population in temperate regions of Asia. In general, however, most pest species are favoured with warm and humid conditions. Pest infestations often coincide with changes in climatic conditions, such as early or late rains, drought, or increases in humidity, which can reduce yields. Climate change might have an influence on increased pesticide use due to presence of diseases and pests.

Effect of physical factors on insect pests

Insects remain active with in temperature range from 15 to 30-32^{o}C. Within the range of favourable temperature, an increase in temperature increased the rate of development thereby decreasing the developmental period. Distribution and frequency of rainfall may also affects the incidence of pests through changes in humidity levels as well as directly. Small insects such as aphids, jassids and whiteflies are washed away by heavy rains thereby reducing their incidence of crops.

Temperature thresholds for insect flight vary both among and within species with season and also with region. Climate warming would advance the time of year at which the flight thresholds are first reached and increase the possibility of early immigration. Likewise there are optimal and threshold temperatures for insect walking, an important factor in local redistribution. Below the optima, the climate warming would enhance movement but above it will be detrimental.

With rise in temperature, onset of hibernation may be delayed while it may be suspended earlier than usual in spring, thereby increasing period of activity of pests, which would result in more damage. Non-diapausing species of aphids such as *Myzus persicae*, which are able to over winter in their active stages showed increased survival in warm winters.

Rising temperature directly affect the biology and physiology of insect communities by shortening the life cycle and increasing number of generations which aggravate the pest problems. The feeding rate of the insect pests increases by 25% to meet their nutritional requirements in the form of aminoacids under elevated CO_2 (500 ppm). Global climate change also affects the migratory pattern and behaviour of insects like locusts, monarch butterflies and fruitflies.

For analyzing the impact of temperature rise on pest population, each species has to be studied separately in the light of its favourable range with respect to weather factors, current ambient conditions and quantum of temperature increase. If after the increase in temperature, the ambient temperature still remains within favourable range of the pest then more population may be expected because insect species will be able to complete their life cycles faster. However, if ambient temperature goes beyond the favourable range then pest population may be affected adversely.

The elevated CO_2 would produce increased plant size and canopy density with high nutritional quality foliage and microclimate more conducive to pests and diseases. Insect species richness has been shown to be strongly correlated with plant biomass and height as larger plants increased structural complexity and greater range of resources that herbivores can utilize. Under higher CO_2, there was an increase in C: N ratio, which increased feeding of herbivores in order to derive more amino acids.

At elevated $CO_{2,}$ there was an increased partitioning of assimilates to root crops and due to more carbon storage in roots, losses from soil borne pests may be diminished under climate change. Climatic warming would affect temperate annual and multivoltine species in different ways and to different degrees. In case of multivoltine species such as Aphididae and some Lepidoptera, higher temperatures would allow faster development rate probably allowing for additional generations within a year.

Global warming and climate changes will result in:

- Extension of geographical range of pests and pathogens.
- In cooler latitudes, global warming brings new species.
- Increased risk of invasion by migrant pests.
- Reduced effectiveness of crop protection technologies.
- A 2.4 to 2.7-fold increase in pesticide use by 2050.
- Increased probability of pests developing faster resistance to pesticides.
- Warmer winter temperatures would reduce winter kill, favouring the increase of pest populations. Rising temperatures extend the growing season.
- Overall temperature increases may influence crop pest interactions by speeding up pest growth rates which increases reproductive generations per crop cycle.

Assessment of Climate change impacts

Impact of climate change would depend upon on complex interactions of climatic and biological factors with technological and socioeconomic changes that are difficult to predict. Therefore, these interactions are not amenable to qualitative analyses. Hence, quantitative (modeling) approaches, which allow investigating multiple scenarios and interactions simultaneously, will become more important for impact assessment.

Approaches for studying Climate change impact

1. Experimental approach
2. Empirical approach
3. Simulation approach

Adaptation and Mitigation: Adaptation refers to an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects that moderate, harm or exploit beneficial opportunities.

- Biosecurity, quarantine, monitoring, and control measures can be strengthened to control the spread of pests and diseases under a warming climate.
- More resilient/adaptable crop genotypes needed,especially with durable resistance to pests.
- Adoption of environmental conserving pest controlling activities such as organic farming, biocontrol and integrated pest management.
- Application of natural mulches helps in suppression of harmful pests and diseases.
- A diverse fauna of natural enemy species can successfully suppress pests.
- Avoidance of excess use of nitrogen which can increase the severity of certain diseases and make a crop more susceptible to pests.
- The growers of the crops have to change pest management strategies by rescheduling the crop calendars in accordance with the projected changes in pest incidence and extent of crop losses in view of the changing climate.
- Pesticides with novel mode of actions such as neonicotinoid insecticides for controlling sucking pests which induces salicylic acid associated plant defense

responses. Such more compounds needs to be identified for use in future crop pest management.

Conclusion:

Pest outbreaks in Coconut:

Encouraged by favourable climatic factors and low population of the natural enemy fauna often ***epidemic outbreak*** of the pest devastates large areas of coconut plantations. The Eriophyid mite, *A. guerreronis* has become a serious problem in coconut plantations, causing heavy losses in coconut production. It was first recorded in 1965 in Guerrero state of Mexico (Keifer, 1965). The first report on occurrence of this exotic mite was made by Sathiamma et al. (1998) from Ernakulam district of Kerala. Rugose Spiralling Whitefly (RSW) (**Aleurodicus rugioperculatus** Martin) is an invasive pest on coconut reported from Polalchi, Tamil Nadu and Palakkad, Kerala during July-August 2016. Reported first from coconut during 2004 at Belize, the pest had threatened coconut palms in Florida during 2009. The change in weather pattern reflected as deficit monsoon was one of the primary reasons of immediate upsurge of spiraling whitefly. Increase in temperature over 2^{o}C during summer was found as another pre-disposing factor for the increase in pest population. Emergence of sucking pest as a victim of climate change, thus, warrants close scrutiny. Yet another pest, the coconut caterpillar, *Opisina arenosella* often causes locally serious outbreaks with severe defoliation to coconut palms and subsequent loss of yield.

Conclusion: Therefore, there is a need to generate information on the likely effects of climate change on pests to develop robust technologies that will be effective in future under global warming and climate change.