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Root mealybugs and their management in horticultural crops in India

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ABSTRACT: Root mealybugs feed on root, basal stem touching the soil and root hairs of plants. As many as 16 species of mealybugs are known to attack horticultural crops like banana, black pepper, betelvine, coffee, sweet potato and elephant foot yam. Infested plants are associated with ant colonies in the rhizosphere by which mealybug infestation could be easily recognised. The species belonging to genera *Geococcus, Rhizoecus* and *Formicoccus* are widely known to cause damage to pot & greenhouse plants and also field crops in India. They are colonized in junction of lateral roots with the main root, and suck the sap resulting in drying of such roots; general weakening of the plants, yellowing and narrowing of leaves and finally reduction in yield. Higher population of root mealybugs was observed in cooler months (November-January, and lowest in rainy months (June-July). Six ant species were associated with root mealybugs infestingblack pepper. Natural enemy complex is very poor on root mealybugs. However the Lycaenid *Spalgis epeus* Westwood and the coccinellids *Scymnus* sp. and *Horniolus* spp. were found feeding on mealybugs infesting basal stem touching the soil. Among the fungal pathogens screened, *Lecanicillium lecanii* Zimmerman was found better in causing mortality of root mealybug *F. polysperes*. Aqueous suspension of Entomopathogenic nematode *Heterorhabditis* was more efficient with 70% control efficiency against coffee root mealybug. There was 50 % reduction in the banana root mealybug population by soil drenching with Nimbicidine (1%) and neem seed kernel extract (5 %). Application of Sodium silicate and calcium oxide at the time of planting effectively reduced the mealybug *Geococcus* spp. in banana. Among the chemicals, soil drenching with imidacloprid 0.0125%, chlorpyriphos 0.075%, acetamiprid 0.0125% and carbosulfan 0.075 % were highly effective against the root mealybugs in black pepper and banana.

Keywords : Root mealybug, *Geococcus, Rhizoecus, Xenococcus*, management

INTRODUCTION

Root mealybugs are found below the soil surface, and feed on root, basal stem touching the soil and root hairs of plants. They are also called as soil mealybugs / subterranean mealybugs/hypogeic mealybugs. Infestations frequently are not detected easily when the root mealybugs occur in the soil. Careful examination of infested plant roots will reveal white, cotton-like masses. These white masses contain both mature females and eggs of root mealybugs. Infested plants are found associated with ant colonies in the rhizosphere by which mealybug infestation could be easily recognized. Because they are white or light gray in color, they often resemble small grains of rice. They are often confused with fungal infection on the plant roots. Root mealybugs pose serious problem to potted and greenhouse plants and also field crops.

ROOT MEALYBUG SPECIES

The species of genera *Geococcus, Rhizoecus, Xenococcus, Formicoccus. Planococcodoides, Pseudococcus* and *Phenacoccus* are known to roots of the plants while that of *Ferrisia, Planococcus* etc are known to attack basal stem touching the soil. *Dysmicoccus brevipes* is known to infect roots in the soil and basal stem touching the soil (Table 1).

Among the root mealybugs *Geococcus coffeae* and *G. citrinus* are known to cause wide spread damage to banana. *Rhizoecus amorphophalli* was found causing serious damage to roots of elephant foot yam. *Dysmicoccus brevipes* is common on the roots of pineapple, and large colonies develop on the stems just above ground level in black pepper. *Formicoccus polysperes* is found to colonise on roots and below ground stem region of black pepper vines. It is widely distributed in pepper growing areas of Kerala.

BIOLOGY

Geococcus spp.

G. coffeae can be easily be distinguished by the pair of stout dorsal spines situated on the head (Green, 1933). *Geococcus citrinus* is a bisexual species. Females lay eggs in chain like fashions. Eggs are pearly white, translucent, elongate oval. The average incubation period is 12.2 days. A single female is known to lay eggs up to 130 eggs. There are three nymphal instars for the females. Nymphs are elongate oval, white in colour and cluster together on the roots, and feed on them. The period lasts for an average of 7.3, 5.6 and 5.8 days respectively, for the first, second and third instars nymphs. The size of the nymphs increases with instars in males. In males, pupal stage lasts for 5 days. Adult female mealybugs were creamy-white in colour; elongate - oval in shape; devoid of wax filaments on the sides of their body; body segmentation clearly visible; antennae short but well developed and six segmented; presence of two anal lobes each terminating in a sclerotised hook. Adult female mealybug measured 2.13 mm in length and 1.16 mm in width. Females live for about 15 days. Adult males are light brown in colour and winged, with only one pair of narrow elongated opaque wings with round outer margin. Males live for a maximum of five days. Unlike other mealybugs, here the nymphs and adults do not produce honey dew; hence usually these are not associated with ants. The total life cycle of *G. citrinus* and *Geococcus coffeae* is completed in 29 days and 34 days respectively. The ratio of male: female was 1:22.5 (Smitha, 2007; Maicykutty Mathew *et al.*2011c).

Formicoccus polysperes

Formicoccus polysperes is widely distributed in pepper growing areas of Kerala (Najitha 2016). Adult females are oval shaped and pink in colour. Waxy filaments surrounding the body margin were short and thick. Female exhibits ovoviparity mode of reproduction with pre larviposition, larviposition and post larviposition period of 24, 10 and 4days respectively. An adult female deposits an average of 135 eggs but it goes up to 350. They are found to colonise on roots and below ground stem region of black pepper vines. Life cycle of females consists of three nymphal instars and adult and that of males had two nymphal, a prepupal, pupal and adult. Average duration of I andII instaris 8.4 and 6.5 days respectively Male and female are distinguished from third instar on wads with a finesilken waxy thread formed by males at the end of second instar. Duration of third female instar is 8.5 days and that of pre-pupa and pupa of male is 1.4 and 7.15 days respectively. Life cycle is of male is competed in about 25 days but female took about 60 days to its complete life cycle Males are winged with a pair of long waxycaudal filaments. Males are short lived with an average span of 1.8 days and females live for 37.4 days (Najitha, 2016).

Dysmicoccus spp.

Two species of pineapple mealybugs are known to occur *ie.* the pink strain (*D. brevipes*) and the grey strain (*D. neobrevipes*). Pink strain is mostly found on the root, crown and lower stem of pineapple plants and reproduces parthenogenetically. The grey strain, on the other hand, mostly seen on upper parts of the plant, such as leaf whorls and the developing fruits and reproduces sexually. *Dysmicoccus neobrevipes* Beardsley is known to attack severely the roots of tube rose in Bangalore North. India. *Dysmicoccus brevipes* reproduces through a process called parthenogenesis in which female mealybug gives birth to young ones without fertilization by males. The first, second and third instars last for 10 -26 days, 6 - 22 days and 7 - 24 days respectively. Thus, the total nymphal period varies from 26 to 55 days; averaging about 34 days .Adult females are plump and convex in body shape and pinkish in body color. Lateral wax filaments are usually less than one fourth as long as the breadth of the body, and those towards the back of the insect are one-half as long as the body. Fecundity of female goes up to 650 nymphs/ovisac. The pineapple mealybug has 8 antennal segments; has short clavate setae on its body and appendages (Mani and Shivaraju,2016).

Rhizoecus amorphophalli

Adult female mealybug lays ovoid, pale white eggs in clusters inside the egg sac. Eggs turn into light brown on hatching. After eclosion, the first instar larvae (crawlers) move out of their ovisac actively searching for suitable feeding site on the tubers. Crawlers are oval, semi-translucent with three pairs of legs and paired eyes.. Crawlers prefer to hide out in crevices or depressions of the tubers, and on settlement they produce mealy substance to waxy filaments over their body. The first instar lasts for 4-7 days. The second instar larva lasts for an average of 4.82 days and before undergoing next moulting they settle either on the previous site or on another suitable site on the tuber and covered themselves with mealy filaments. The third instar is relatively bigger. Duration of this instar is 4-6 days, and the sex differentiation is obvious at the end of this stadium

Female nymph moults normally, but male instar produces a cottony puparium around its body and form a pupal stage with protected mealy cocoon. Pupal stage lasts for an average of 2.50 days, and the male transforms to winged adult form. Male undergoes a radical change during its life cycle, the wingless nymphs transforms to a winged adult.Adult female is oval, whitish, wingless and sparsely covered with white mealy substance. Proceeding mating, adult female secretes an ovisac of white waxy substance in about 7-14 hours, and egg laying starts 3-7 hours after this process. Eggs are laid in a bead shaped pattern, but later these are found in a disarrayed and scattered manner under mealy covering. Oviposition is completed in about 3-8 hours with a maximum fecundity of 79 eggs. At 32-35°C and humidity 55-65%, all the eggs hatch out in about 6-9 days of incubation (Sreerag *et al.* 2014;Mani and Shivaraju,2016).

Rhizoecus cocois

Adult female is subglobular, cream coloured and enclosed within a loose jacket of pure white cottony felt. Groups of mealybugs were seen on thin fibrous roots. Eggs are laid in continuous chain which may emerge out of the felt covering through an opening which is present near the genital pore. The egg chain subsequently breaks distributing the eggs among the sand particles around the roots. Eggs are also deposited within the felt covering of the mealybug, and the mealybug shrinks after laying the eggs. Female lays about 70 eggs. The egg is white, smooth and oval in shape. Crawlers are white(Nair et al. 1980).

DISTRIBUTION OF ROOT MEALYBUGS

Geococcus coffeae was known to infest sweet potato *Ipomoea batatas* in Tamil Nadu, India (Williams, 1985) and also several other plants *Theobroma cacao, Coffea* spp., ornamentals, pine apple, palms etc (Ben-Dov,1994). *Geococcus citrinus* is a ground mealybug that lives in the soil and damages the roots of betel vine from Tamil Nadu (Muthukrishnan *et al.*1958). This species became an important pest of Nendran variety of banana in Kerala. A total of 28 collateral hosts were recorded for *Geococcus citrinus*in banana ecosystem (Abraham *et al.* 2000; Smitha *et al.* 2005). *Geococcus citrinus* was found to damage the banana roots in Ernakulam, Palakkad and Thrissur districts of Kerala in 2000 (Abraham *et al.* 2000).The root mealybugs *G. coffeae* and *G.citrinus* were wide spread in Keralain 12 districts (Macykutty Mathew *et al.* 2011b).The highest per cent incidence of root mealybug was observed in Waynad district (34.62%) followed by Malappuram, Palakkad and Idukki, and the lowest mealybug population was recorded in Kozhikkode (3.99%) (Smitha, 2007). *Geococcus citrinus* was found to cause serious damage to the banana roots in reclaimed paddy fields. *G. coffeae* is also associated with banana grown in uplands (Smitha and Macykutty Mathew, 2010b). The maximum population of *Geococcus* spp. was colonised within 20-40 cm radius followed by 40-60 cm. In the case of vertical distribution, more mealybugs were collected within 20 cm depth. *Dysmicoccus brevipes* was found colonizing at the base of roots and in cracks and crevices on the rhizome made by the banana rhizome weevil (Smitha et al 2005).

Dysmicoccus brevipes is common on the roots of pineapple, and large colonies develop on the stems just above ground level in Kerala. It lives in colonies underground, and few may be seen on foliage. Mealybugs have become increasing threat to tube rose cultivation in India. *Dysmicoccus neobrevipes* Beardsley is known to attack severely the roots of tube rose in Bangalore North, India

According to Devasahayam *et al.* (2010), infestation by the pepper mealybugs *Planococcus* sp., *Planococcus citri*, *Planococcus lilacinus*, *Ferrisia virgata* and *Dysmicoccus brevipes* were confined to certain parts of Kerala and Karnataka states. In Kerala, root mealybug infestations on black pepper were observed in all the taluks surveyed in Wayanad (Kerala). The root mealybug infestation was also observed in Udumbanchola (Idukki District), Kozhikode (Kozhikode District) and Taliparamba (Kannur District) taluks in Kerala. The pest infestation was higher in Wayanad (8.0%–21.1%) and lower in Idukki (0%–3%). Stray infestations of the mealybugs were also observed in Kozhikode and Kannur districts in Kerala. Among the taluks in Kerala, the percentage of vines infested by root mealybugs was higher in Vythiri (21.1%) taluk. In Karnataka state, mealybug infestation was confined to Kodagu and Hasan districts (Alur and Saklespur). Mealybug infestation was higher in Kodagu (1.7%–15.1%) district and lower in Hassan (0%–4.4%) district. Among the taluks in Kodugu district, the percentage of vines infested by root mealybugs was higher in Virajpet (15.1%) taluk. A highly significant and positive correlation (r=0.451**) was observed between root mealybug infestation and altitude of the location. A mean of 0.1% of vines were infested at lower altitudes (0–250 m above MSL) when compared to 8.9% at higher altitudes (751–1000 m above MSL).

Table 1 List of root mealybugs reported on horticultural crops in India

Mealybug species	Crop	State	Reference
Dysmicoccus brevipes (Cockerell)	Black pepper	Kerala	Koya *et al.* (1996); Devasahayam *et al* (2010); Najitha (2016)
	Coffee	Kerala	Najitha (2016)
	Pineapple		Manichellappan (2016)
Dysmicoccus neobrevipes Beardsley.	Tube rose	Karnataka	Krishnamoorthy (2016)
Dysmicoccus subterreus sp.n.	Black pepper	Kerala	Williams (2004)
Ferrisia virgata (Ckll.)	Black pepper	Kerala	Koya *et al.*(1996); Prasad Kumar *et al.*(1998); Williams (2004); Devasahayam *et al* (2010)
	Ginger	Kerala	Williams (2004)
Formicoccus polysperes Williams	Black pepper	Kerala	Williams (2004)
	Ginger & Elephant foot yam	Kerala	Devasahayam *et al* (2010); Najitha (2016)
	Betel vine	Madhya Pradesh, Uttar Pradesh, West Bengal & Maharashtra	Williams (2004)
Geococcus citrinus Kuwana	Banana	Kerala	Ben-Dov (1994); Maicykutty Mathew *et al.* (2011a,b,c); Smitha *etal.* (2005)
Geococcus coffeae Green	Betel vine	Tamil Nadu	Muthukrishnan *et al.* (1958)
	Coffee	Tamil Nadu	Rao *et al.* (1974)
	Banana	Kerala	Maicykutty Mathew*et al.* (2011 b); Smitha *et al.*(2005)
Planococcus citri (Risso)	Sweet potato	Tamil Nadu	Williams (1985)
	Black pepper	Kerala	Koya *et al.*(1996); Devasahayam *et al.* (2010)
Planococcus lilacinus (Cockerell)	Black pepper	Kerala	Koya *et al.*(1996); Devasahayam *et al.* (2010)
Planococcus sp.	Black pepper	Kerala	Devasahayam (2006) ; Narasimham (1987); Koya *et al.*(1996)
Planococcodoides robustus Ezzat and Mc Connell	Mango	Karnataka	Puttarudriah & Eswaramurhty (1976)
Rhizoecus amorphophalli Betrem	*Amorphophallus* sp.	Kerala	Williams (1985); Sreerag *et al.* (2014)
	Zingiber officinale		Williams (1985)
	Dioscorea elephantipes	Goa	Williams (1985)
	Curcuma domestica	Maharashtra	Williams (1985)
Rhizoecus cocois Williams	Coconut	Kerala	Nair *et al.* (1980); Williams (1985)
Xenococcus annandalei Silvestri	Grapevine	Karnataka	Rajagopal *et al.*(1997)
Phenacoccus parvus Morrison	China aster	Karnataka	Sridhar *et al.* (2012)
Pseudococcus sp.	Black pepper	Kerala	Najitha (2016)

The pepper root mealybug *Formicoccus polysperes* was the dominant species found wide spread in Wayanad and Idukki districts in Kerala. *D.brevipes* was collected in Manathavady Panchayat in Wayanad district. The third species *Pseudococcus* sp. was found infesting in Nedumkandam panchayat of Idukki district and Kaniambeta of Wayanad district (Najitha, 2016).

Rhizoecus amorphophalli was recorded on roots of elephant foot yam, *Amorphophallus* sp. from Thiruvananthapuram, Kerala, ginger *Zingiber officinale* from Calicut, *Dioscorea elephantipes* from Goa and rhizomes of *Curcuma domestica* from Kohlapur, Maharashtra (Williams, 1985).

DAMAGE

There are several generations of the root mealybugs throughout the year, and numbers can multiply under favourable conditions. With severe infestations, root mealybugs can be found on the soil surface at the stem base. It is very difficult to detect symptoms of root mealybugs on the plant. White, cottony-like masses containing egg-laying females and/or eggs are normally visible on the outside of the root mass when an infested plant is lifted. Slow plant growth and leaf deterioration are the symptoms of mealybug infestation. Root-bound or under environmental or nutritional stress, the plants are more susceptible to attack. Once established in the greenhouse, root mealybugs spread as crawlers from plant to plant as the water moves out of the drainage holes to nearby plants and in plant debris. In case of heavy infestations, crawlers are observed on the soil surface. The mealybugs are found particularly the new feeder roots in the upper layer of the soil. The resulting damage stifles the ability of roots to absorb water and nutrients. The only outward sign of root mealybug feeding may be a decline in the health of infested plants. When plants are removed from the pot, the whitish mealybugs feeding on the roots are then observed.

The adults and nymphs of *Geococcus* suck sap from the lateral roots of banana colonizing at the junction of laterals with main root resulting in drying up of such roots. Such roots cannot absorb water and nutrients from soil. Yellowing and narrowing of leaves, and also burnt appearance, general weakening of the plant, reduction in bunch weight etc. are the observed symptoms. In severe cases, the plants will be toppled down in wind due to the destruction of anchor roots (Smitha *et al.* 2005).

Mealybugs (*Planococcus* sp., *P. citri*, *P. lilacinus*, *Dysmicoccus brevipes* and *Ferrisia virgata*) were found infesting the roots and basal region of stem of black pepper vines. Infested plants show slow or poor growth. Leaves wilt, become pale or turn yellow or grey. Wax deposit is seen around the roots, on the soil or on the side of the pots. The infestation is generally severe during the post monsoon. The root mealybug affects the aerial parts of the black pepper vines such as the tender shoots, leaves and berries (Devasahayam *et al.* 2010).

Formicoccus polysperes iscolonised on roots and basal stem regions of black pepper. The runner roots that touch the soil were found colonized with root mealybugs. In severe cases of infestation the root mealybugs were found on the adventurous roots at nodes with which they are attached to the standards. The leaf colour was pale green in case of minor infestation whereas the leaves turned yellow in the severe case of infestation. In some cases, a gall like thickening was observed on runner roots with root mealybug colonies. The mealybug infested plants show stunted growth (Najitha, 2016).

Rhizoecus cocois was reported from Kazhakkoottam, Kerala infesting coconut palms. Infested young palms show yellowing and loss of vigour and discolouration of the roots at the point of feeding resulting in the drying up of such roots. In severe cases of infestation, an average of 8.5 colonies were noted per 10 cm length of the root, and the young plants which were infested thus showed yellowing and loss of vigour (Nair *et al.* 1980).

Rhizoecus amorphophalli is a soft-bodied insect, infesting the corms both in storage and in the field. It was found together and suck the cell contents of the tubers (Palaniswami, 1999).The field infestation goes up to 45 %. Mealybugs multiplied during high temperature and humidity. They cover tuber surface with powdery mealy substances. Severely infested tubers shriveled affecting the quality and marketability.

Dysmicoccus brevipes is common on the roots of pineapple and large colonies develop on the stems just above ground level. The mealybugs may spread upwards to feed in the floral cavities, on both small and mature fruit, and on the crown leaves. The leaves turn bright pink with some degree of flaccidity. The leaf tips turn brown, curl downward and the leaf margins show a light inward curving. Later, these symptoms become more pronounced. Ultimately, the plant wilts and dries with downward browning due to necrosis on leaf tips. Finally, the leaf tips dry up completely, and the bright pink turns

completely dull. Correspondingly, the roots cease to elongate and collapse. Often, new roots appear above the old ones, and, concurrently, the renewed aerial growth associated. Sometimes, infected plants recover from the ailment, and normal new leaves come out at the centre. Mealybugs attack in basal portion and in fruit as well the plants exhibit stunted appearance, and size of fruits are reduced. Mealybugs cause pineapple growers problems because they have impact the size of pineapple fruit due to withdrawal of plant nutrients; they produce large volumes of the sweet liquid called "honeydew" that makes the pineapple fruit sticky and black colored from an associated fungus called sooty mold (Mandal 2009).

Planococcoides robustus was found infesting roots of mango, grapes and the weed plant *Coniza ambigua* in the Kolar district of Karnataka, India. Ants were observed to carry the mealybugs. The affected plants showing desiccation and leaf fall survived (Puttarudriah and Eswaramurthy, 1976).

The grape root mealybug *Xenococcus annandalei* is known to cause damage occasionally by sucking the sap from roots and the affected vines show reduced vigour, shortening of fruit bearing canes and reduction in size of fruit bunches and yields (Rajagopal *et al.* 1997).

Phenacoccus parvus was recorded feeding mainly on collar region and subterranean plant parts of the ornamental China asterin India. About 25 % of the plants were infested making the plant stunted without bearing flowers (Sridhar *et al.* 2012).

VARIETAL SUSCEPTIBILITY

Pepper cultivar Panniyur 2 issusceptible to *Formicoccus polysperes* followed by Panniyur1. Karimunda supports lower population of root mealybugs (Najitha, 2016). The susceptibility of six commonly cultivated varieties of banana, *viz.*, Palayankodan, Njalipoovan, Poovan (Rasthali), Robusta, Kodappanilla-kunnan and Nendran, to root mealybug, evaluated in farmers' field, revealed that Palayankodan and Kodappanillakunnan were free from root mealybug infestation. Nendran was the most susceptible one with highest number of root mealybug colonies (4.38) followed by Njalipóovan (2.55) (Smitha. 2007: Smitha and Maicykutty Mathew 2010a).

SEASONAL DEVELOPMENT

Banana root mealybugs: The intensity of *Geococcus* spp. was severe in the rainy season than in the dry season and the population build-up was observed during pre-monsoon showers. The population increased with the commencement of southwest monsoon in June and reached a peak in July, followed by a decline in September, reaching a lower level in January (Smitha and Maicykutty, 2010c). Severe root mealybug infestation was also recorded in March –April (Smitha and Maicykutty, 2005). A strong positive correlation was observed between soil moisture content and root mealybug population while a negative correlation with maximum and minimum soil temperature (Smitha, 2007).

Pepper root mealybugs: The infestation by the pepper mealybugs *Planococcus* sp., *Planococcus citri*, *Planococcus lilacinus, Ferrisia virgata* and *Dysmicoccus brevipes* is generally greater during the post monsoon season and lesser during summer months (Devasahayam *et al.* (2009).The population of pepper root mealybug *Formicoccus polysperes* was found to be higher in cooler months i.e. December (13.3/15cm root length), January (10.2) and November (9.9). The lowest root mealybug population was recorded in rainy months i.e. June (2.8 mealybugs) and July (2.4).In the caseof vine infestation, highest percent of infested vines was observed during September –January ranging from21.7 to26.7 %), and lowest in June (10.0). A significant correlation was observed between root mealybug population and soil temperature (Najitha,2016).

MODE OF SPREAD

Infestations often begin with the purchase of infested plant material. Under moist conditions, young root mealybugs or crawlers are active. They move short distances to adjacent plants. They may crawl from pot to pot via drainage holes. They are slow moving in irrigation water thereby facilitating the spread. Ants are also responsible for the spread of root mealybugs (Smitha *et al.* 2005).

ANT ASSOCIATION

Six ant species were associated with root mealybugs in black pepper. They are responsible for the spread of root mealybugs. Najitha (2016) reported four ant species were found associated with colonies of root mealybugs *Formicoccus polysperes* and *Dysmicoccus brevipes* in black pepper. They are *Anopolepis gracilipes* Smith, *Cremaster rogenoferi* Mayr, *Lephomyrmex quadrispinsus* Jerdon and *Paratrechina* sp. Devasahayam *et al.* (2010) also reported the presence of *Anopolepis* sp. and *Technomyrmex* sp. in the root zone of mealybug infested

vines. Mealybug control often focuses on the control of caretaking ants that are essential for the proper development of pineapple mealybugs. They provide the mealybugs for shelter, protection from predators and parasitoids, and keep them clean from detritus that may accumulate in the secreted honeydew and be deleterious to the colony. Because of the essential role of the ants, management practices often include the control of tending ant species.

NATURAL ENEMIES

There is poor natural enemy complex particularly natural predators or parasitoids on root mealybugs (Maicykutty Mathew and Mani, 2016). The coccinellid *Scymnus* sp. was found feeding on *G.citrinus* infesting banana (Smitha and Maicykutty Mathew, 2010a). Maicykutty Mathew *et al.* (2011a) reported the fungal pathogen, *Paecilomyces lilacinus* Thomon *Geococccus* spp. It was pathogenic to both *Geococcus coffeae* and *G. citrinus*. *Hirsutella* sp. was also isolated from G. *citrinus* (Smitha, 2007; Smitha and Maicykutty Mathew (2011). The larvae of *Spalgisepeus* Westwood were observed to predate on pepper root mealybug colonies (*Planococcus* sp., *Pl. citri*, *Pl. lilacinus*, *Dysmicoccus brevipes* and *Ferrisia virgata*) (Devasahayam *et al.* 2010; Ventataramaiah and Rehman, 1989).

MANAGEMENT OF ROOT MEALYBUGS

Cultural

Since root mealybugs are very difficult to detect and control, effort should be made to prevent their spread and establishment. Use of clean planting material; Removal of alternate host plants; Irrigation water not allowed from infested areas; Disposal of the infested plant debris; Dipping of infested plat materials in hot water at 49°C for 10 seconds - All will help to eliminate the mealybugs from the roots.A total of 16 weeds were recorded as host plants for *G.citrinus* (Smitha, 2007; Maicykutty Mathew 2011b) and seven weeds as host plants for *Formicoccus polysperes* (Najitha, 2016). Ploughing the interspaces in black pepper gardens and removal of weeds also help in lowering the level of root mealybug population. Various intercrops (coconut, areca nut, coffee, banana, colocasia, cardamom and turmeric) grown in black pepper gardens are found infested with root mealybugs. Root mealybug infestations are also observed on black pepper vines trailed on all standards (support trees like silver oak, *Erythrina* spp. and jackfruit) (Devasahayam *et al.* 2010; Najitha, 2016). Continuous infestation without proper management leads to gradual decline and death of the pepper vine. Since banana suckers are suspected to be the possible source of infestation, spread of the root mealybug is to be checked by prevention of use of suckers from the mealybug infested areas within and outside the state. Farmers should not transplant infested nursery plants in the field and mild infestations should be controlled in the nursery itself.

Biological control

The entomopathogenic fungus, *Lecanicillium* (*Cephalosporium) lecanii* Zimmerman was found better against banana root mealybug *Geococcus citrinus*. At five months after planting, *L. lecanii* treatment recorded 1.95 mealybug colonies per 15 cm^3 soil followed by *Hirsutella* sp. (2.25 / 15 cm^3 soil), and the number in the control was 5.70 per 15 cm^3 soil (Smitha, 2007; Smitha and Maicykutty Mathew, 2010b). The pathogen *Hirsutella* sp. was known to cause a nymphal mortality of 90 % at a concentration of 10^8spores ml^{-1} on *G. citrinus* (Smitha, 2007). The white halo fungus *L. lacanii* $2x10^8$ was found effective against pepper root mealybug *Formicoccus polysperes* in both laboratory and pot culture experiments. It was found causing 57% mortality of mealybugs under laboratory conditions but 28% mortality in potexperiment. Entomopathogenic nematode, *Steinernema glaseri* is also known to cause mealybug mortality under laboratory conditions. Entomopathogenic nematodes (EPNs) have potential for biological pest control, and have been successfully used in several countries in soil and cryptic pests control, as for example the coffee root mealybug *Dysmicoccus texensis* (Tinsley). Aqueous suspension of *Heterorhabditis* on was more efficient with 70% control efficiency comparable with thiamethoxam (Alves *et al.* 2009).Approximately 2 to 3 numbers of *C. montrouzieri* are required for each infested tubers to control mealybug *Rhizoecus amorphophali* (Misra *et al.* 2013).

Natural products

Soil drenching with botanicals helps to bring down the population of root mealybugs. Citronella oil at 5% performed better towards controlling the root mealybugs followed by 5% neem oil and 5% neem leaf extract (Anonymous, 2011).There was about 50 % reduction in the root mealybug population by soil drenching with Nimbicidine (1%) and neem seed kernel extract (NSKE 5%.) (IISR,2006). Smitha and Maicykutty Mathew (2010b) also observed that drenching of roots with

NSKE 3% at monthly intervals was superior to neemcake, neemoil and pongamia oil in reducing the population of *Geococcus* spp. in banana. Among the combinations, without synthetic insecticides, sodium silicate alone and its combination with Neem seed kernel extract (NSKE) and *Lecanicillium lecanii* Zimm, were effective in reducing the mealybug population at sixth and seventh month of the crop (Smitha and Maicykutty Mathew, 2010b). In pepper, alcoholic extracts (3%) of *Azadirachta indica* and *Vitex negundo*, tobacco extract (3%); custard apple seed extract (2%) and agro spray oil (3%) are known to cause up to 75% reduction in root mealybug population at 30th day of treatment. Among the neem products, Nimbicidine (0.5%) was the most effective resulting in 60% reduction in population of root mealybugs, 30 days after treatment (Devasahayam, 2010). Common salt is used in treating the corms of elephant foot yamto check the damage caused by *Rhizoecus amorphophalli* prior to storage (Nedunchezhiyan *et al.* 2011).

Chemicals

Soil drenching with imidacloprid 0.0125%, chlorpyriphos 0.075%, acetamiprid 0.0125% and carbosulfan 0.075 % were effective against the root mealybugs in black pepper (IISR, 2006). There was 98 % reduction in the mealybug population *Formicoccus polysperes* with imdicloprid drenching at 25g a.i/ha at one week after drenching whereas chlorpyriphos at 300 g a.i /ha caused 80% reduction (Najitha, 2016).If the infestation persists, then drenching may have to be repeated after 20 - 30 days. Adequate care should be taken to ensure that the insecticide solution percolates down to the roots while drenching the vines. Farmers should not transplant infested nursery plants in the field and mild infestations should be controlled in the nursery itself (IISR, 2006).

Out of four soil ameliorants, application of sodium silicate and calcium oxide at the time of planting were better in reducing the population of banana root mealybug *G. citrinus* to 0.63 / 15 cm^3 soil and 1.00 / 15 cm^3 soil respectively, at 5thmonth after planting compared to control (3.88 / 15 cm^3 soil).The treatment sodium silicate alone offered the highest benefit cost ratio 2.30:1(Smitha, 2007; Smitha and Maicykutty Mathew, 2010b)

Drenching of the chemical insecticides, chlorpyriphos at 0.05% at monthly intervals, are known to reduce the banana root mealybug population. Application of chlorpyriphos alone produced the highest bunch weight (11.43kg), and was significantly superior to all other treatments. The treatment chlorpyriphos alone offered the highest benefit cost ratio of 2.46Ó1 (Smitha, 2007; Smitha and Maicykutty Mathew, 2010b).

Dipping the basal portion of the planting material in chlorpyriphos 0.05% as a prophylactic measure and application of phorate 10G @ 1.75 kg ai ha^{-1} and neem cake ground application at 100 days after planting (DAP) and 180 DAP can effectively control pineapple mealybug (Mandal, 2007).

In mango orchards, *Planococcoides robustus* was controlled with the application of disulfoton granules at monthly intervals and watering weekly. The affected plants showing desiccation and leaf fall had survived (Puttarudriah and Eswaramurthy, 1976).

In general, soil drenching with the chemicals chlorpyriphos, imidacloprid, thiamethoxam and thioclopridat monthly intervals is recommended for controlling the root mealybugs in the field.

Pot culture plants

- Infestations usually begin with new plant material. Inspect roots of newly purchased plants by removing them from their pots.
- Inspect roots of suspected plants, especially slow growing ones.
- Avoid pot-bound plants by re-potting when necessary.
- Use pots with inner coatings of copper hydroxide which prevents root matting and thereby minimizes root mealybug infestations Separate pots from the ground on raised benches or with plastic film over the soil. Palm roots in the pot not treated with copper hydroxide (right) are more compacted and infested with mealybugs (Hara *et al.*2001).
- Do not allow water from infested areas to run onto clean areas.
- Remove alternate host plants from around the greenhouse, or control mealybugs on them.
- Use clean pots and soil; if infested, wash pots with soap and water.
- Keep the growing area clean of plant debris.
- First, isolate the affected plants, especially if they share a common watering tray with other, healthy

plants. Although soil mealybugs do not spread easily, they will travel over moist surfaces.

- Root mealybugs can be spread by irrigation water, re-use of previously infested pots, re-use of contaminated media, and crawlers moving from infested plants to other plants.

- Infestation of greenhouse bench plants by root mealybugs can occur by introducing nursery stock that was already infested when purchased or from crawlers that move in from host plants near the greenhouse.

- For root mealybug in pots- Remove all soil and destroy it. Wash the roots thoroughly and treat (eventually immersing the whole plant) with the above mentioned insecticide, letting the roots dry after treatment and before replanting in completely fresh, sterilized soil. Always cleanse and sterilize frames and all other items used when replanting. Regular applications (weekly for several weeks) of insecticide watered into the soil are also effective; it's also possible to immerse the plant pot up to the top of the soil in a bucket of insecticide.

- A promising alternative to chemical treatments has been found in the use of Diatomaceous Earth, a fully inert, non-volatile substance that has proven effective in eradicating certain insect pests. Strictly speaking, Diatomaceous Earth is not an insecticide. It is made from the skeletal remains of diatoms, a microscopic form of algae. When processed into Diatomaceous Earth, these skeletal remains form razor-sharp particles which cut into the bodies of small insects. While eradicating the insects, Diatomaceous Earth does not harm African Violets. To treat for soil mealybugs, repot the African violet in a soil that has been mixed with Diatomaceous Earth. Use about 1 tablespoon per one litre of soil. Pasteurize soil before re-potting. To make soil uninhabitable for future mealybug infestations, mix about 1/4 tablespoon of Diatomaceous Earth with every litre of soil.

- Hot-water dips are as effective as insecticides against mealybugs. Submerging the potted palms in water held at 120°F (49°C) until the internal root ball temperature reached 115°F (46°C) was 100 percent effective in killing root mealybugs. Drenching potted palm roots in hot water at 120°F for 15 minutes will not only control mealybugs but will also eliminate burrowing nematodes. If an infestation is found (*Rhizoecus hibisci*), hot water treatment of root balls is very effective (Hu *et al.*1996).

- Chemical control of root mealybugs requires saturation of the root ball and potting medium to a degree that allows the pesticide to penetrate the pests' white, waxy secretion dipping or drenching with liquid insecticide is more effective than applying a granular formulation. Chlorpyriphos, applied twice as a drench or dip at two-week intervals controls coffee root mealybug; however, it may take four to six months before the cottony, waxy secretions deteriorate completely. In the dip method, submerging the plant's entire root ballwithoutthe pot in a diluted chlorpyriphos solution (1 pint per 100 gallons) for about 30 seconds with slight agitation is nearly twice as effective as dipping the plant while still in its pot. Imidacloprid, applied only as a drench and can be incorporated with a surfactant or wetting agent to ensure thorough distribution of solution in the potting medium, can also significantly reduce the number of individuals in an infestation (Hata *et al.* 1996).

- Moth ball: As a preventative measure, moth balls (paradichlorobenzene), added to the potting mix, seem to discourage infestation by root mealybug, and probably discourages other insects. However, the chemicals in the moth balls can cause damage to plastic plant pots and are best used with clay pots

- Traditionally, the only effective treatment for soil mealybugs (*Rhizoecus amercanus*) has been to spray the soil with acephate (as directed on the label) or with malathion (1 teaspoon of malathion 50 per 4 liters of lukewarm water). While this treatment does work, it usually takes several applications over a period of days. Moreover, there is usually some risk to plants when using any chemical treatment.

- Under green house and farmers field conditions: Diazinon application was superior in the pot and dipping treatments (Tadesse *et al.* 2010). Phyrinex 48% EC and Phostoxin tablet had provided better control of root mealybug (*Paraputo* sp.)

Phytosanitary risk

Consignments of containerized host species from areas where *Rhizoecus hibisci* occurs should have containers removed and the roots inspected. Montanucci (2010) described a safe and inexpensive procedure for

elimination root mealybugs (genus *Rhizoecus*) from a small cactus collection. The procedure prevents re-infestation by taking advantage of the fact that the root mealybug females and nymphs are wingless and must crawl to potted plants to become established. The procedure is expected to permanently eradicate rather than simply control these mealybugs.

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