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INSECT PESTS AND DISEASES OF MEDICINAL AND AROMATIC PLANTS AND THEIR MANAGEMENT

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Medicinal and Aromatic Plants (MAPs) are the rich and major source for plant secondary metabolites. Huge world human population especially in developing nations mainly depend on traditional system of medicine for the treatment of various human ailments. At the moment traditional medicine derived from different MAPs have gained more importance and have become one of the useful ways to support herbal system of medicine in most of the countries like India, Japan, China, Indonesia, Pakistan, Bangladesh, Sri Lanka, Thailand, Malaysia etc. Similarly aroma compounds from botanical sources hold a promising field by being increasingly used in perfumery, nutraceuticals, food and flavour industries due to the growing awareness in common masses about the risks involved in synthetic components in parallel products. Accordingly, nearly more than one lakh such secondary metabolites are now known to occur in about 50,000 plant species and almost 4,000 new secondary metabolite are being discovered every year from a variety of plant species (Verpoorte et al. 1999; Gomez-Galera et al. 2007, Pandey, 2017). Since last several decades, these natural plant products have been utilized for human healthcare in the form of drugs, antioxidants, flavors, fragrances, dyes, pesticides, pheromones etc. During the last two decades, however, the use of synthetic drugs led to a decline in the use of plant-derived compounds, so that at one time it was believed that the synthetic drugs would perhaps completely replace the use of traditional plant-derived medicines. However, in recent years, a resurgence of the use of herbal drugs has once again been witnessed prominently, firstly because the synthetic drugs have been found to be hazardous in many cases, and secondly because there is growing awareness that the plant-derived medicines have negligible side effects that are so common in the case of synthetic drugs**.** During COVID-19 outbreak there is an intensive search for plant derived molecules in order to find a cure for this pandemic. In such a situation plant based anti-malaria drug Chloroquine is playing a significant role to cure this deadly disease. Consequently, the current global herbal drug market has reached a level of more than US $62 billion, which is expected to grow to US $5 trillion by the year 2050 (Joshi et al. 2004). The world market for herbal medicines including herbal products and raw materials is actually growing at an annual rate of 10–15%. This is an indication of a possible growing demand for plant-derived drugs in coming years. Despite this, although the area under cultivation of medicinal and aromatic plants have been slowly increasing due to increasing demand for herbal drugs. The use of medicinal plant species for human healthcare can not be avoided due to the following reasons: (1) low concentration of desired molecules in specific plant tissues; (2) medicinal crops being low priority crops; (3) technical difficulty in cultivation of these crops; (4) over-harvesting of naturally occurring herbal plants; (5) destructive collection techniques; and (6) conversion of habitats of medicinal plants to crop-based agriculture. The business of medicinal and aromatic plant industries could be enhanced by ensuring the disease free plants

Table 1. Insect pests of *Mentha* spp

Common name	Scientific name	Order	Family	Pest Status	References
Bihar hairy caterpillar	*Spilosoma obliqua*	Lepidoptera	Arctiidae	Major	Singh,1999
Soybean Semilooper	*Thysanoplusia orichalcea*	Lepidoptera	Noctuidae	Major	Sagar & Ramji, 1991
Tobacco caterpillar	*Spodoptera litura*	Lepidoptera	Noctuidae	Major	Kattimani, 2000
Variegated cutworm*	*Peridroma saucia*	Lepidoptera	Noctuidae	Major	Berry and Shields,1980
Black cutworm	*Agrotis ipsilon*	Lepidoptera	Noctuidae	Major	Singh,1999
Mentha leaf roller	*Syngamia abruptalis*	Lepidoptera	Pyralidae	Major	Kareem *et al.* 1960; Sagar and Reddy, 1987; Singh,1999
Mint root borer*	*Fumibotys fumalis*	Lepidoptera	Crambidae	Major	Morris, 2007
Cutworm	*Spodoptera exigua*	Lepidoptera	Noctuidae	Major	Morris, 2007; Singh,1999
Red pumpkin beetle	*Aulucophora fovecollis*	Coleoptera	Chrysomelidae	Major	Singh and Gupta,1970
Mint flea beetle*	*Longitarsus ferrugineus*	Coleoptera	Chrysomelidae	Major	Morris, 1990
Cotton whitefly	*Bemisia tabaci*	Hemiptera	Aleyrodidae	Major	Singh,1999
Green peach aphid	*Myzus persicae*	Hemiptera	Aphididae	Minor	Neubauer *et al.,* 1974
Aphids	*Aphis affinis*	Hemiptera	Aphididae	Major	Singh and Sagar, 1981; Singh,1999
Mint aphid	*Ovatus crataegarius*	Hemiptera	Aphididae	Major	Leonard, 1980
Citrus Mealybug	*Planococcus citri*	Hemiptera	Pseudococcidae	Minor	Ahmed and Abd-Rabou, 2010
Lace bug	*Cochlochila bullita*	Hemiptera	Tingidae	Minor	Samuel, 1939; Sharga, 1953; Singh,1999
Two-spotted spider mite	*Tetranychus urticae*	Trombidiformes	Tetranychidae	Major	Morris, 2007
Termites	*Odontotermes obesus*	Isoptera	Termitidae	Major	Singh,1999

***** Not present in India

and planting materials. Among the different plant pathogens, fungi, bacteria, viruses, phytoplasma, plant parasitic nematodes and large number of insects are the major are serious threat to the future prospects of medicinal and aromatic plants globally. The cultivation of various medicinal and aromatic plants has been severely affected by these pests and pathogens. Improvement of the yield and quality of plant secondary metabolites and products through disease management is one of the major tasks.

MINTS (*Mentha* spp): Mints are group of aromatic herb belonging to family Lamiaceae, which are considered to be the most important cash crop in Indo-Gangetic plains. Different types of mints, which are commercially cultivated in Indo-Gangetic plains, are: Menthol mint (*Mentha arvensis*), Peppermint (*Mentha piperita),* Spearmint (*Mentha spicata*), Scotch spearmint *(Mentha cardiaca*), Bergamot mint (*Mentha citrata*) and Garden mint (*Mentha viridis*). Among different medicinal and aromatic plants, mints come in the front line because Indian farmers grow it as a bonus crop and it also fits well in the cropping system with other crops like paddy, wheat, potato, sugar cane, etc. Now it is cultivated on an area of more than 1,50,000 ha of land.

Insect pests of *Mentha* spp. (Table 1)

Bihar Hairy Caterpillar, *Spilosoma obliqua* Walker, (Lepidoptera: Arctiidae):
Distribution: Occurrence of *S. obliqua* has been reported from Bangladesh, Sri Lanka, Pakistan, Philippines and Myanmar. In India the occurrence in Northern and North Eastern province is common.

Host plants: *Spilosoma obliqua* is a polyphagous pest damaging many crops including *Mentha* spp. sesamum, sunflower, cowpea, jute, sunnhemp and other pulse crops.

Identification and Biology: The adult moths are light brown in colour. The female moth lays

Figure1: *Spilosoma obliqua*

yellowish green eggs in clusters on the underside of leaves. The incubation period is 5-13 days. The larvae complete development in 4-8 weeks through 6-7 instars. The early three instars feed gregariously and later instars feed solitarily. The larvae are yellowish orange and covered with hairs (Fig.1). The full grown larvae spin a loose silken cocoon in which it pupates in plant debris or in the soil. The pupal duration of is 10–15 days. The adult moth longevity is 5-7 days. The total life cycle is completed in 6-12 weeks. The Bihar hairy caterpillar passes through three to four generations in a year.

Nature of Damage: The young larvae feed gregariously on the lower surface of leaves and apical the apical shoots. The damaged leaves by young caterpillars appear dusty white colour which can be easily recognized. Later the grownup larvae disperse to the entire field and start feeding voraciously on leaves. Under severe occurrence of the pest complete defoliation may occur.

Management

- Grow insect-tolerant cultivar "Sambhav" of *Mentha arvensis* (Khanuja *et al*. 2004).
- Hand collection and destruction of gregariously feeding larvae of the pest.
- Natural enemies, parasitoids (*Meteorus spilosomae* and *Protapantales obliquae*) and entomopathogens (*Bacillus thuringiensis, Entomophaga aulicae* and Nuclear Polyhedrosis Virus) play important role in the control of *Spilosoma obliqua* (Gotyal *et al.*, 2019; Senthil *et al.* 2011).
- Spray insecticides, like quinalphos 25EC (2ml/l) or cypermethrin 10EC (1.3ml/l).
- Install light traps (1trap/acre) in the field monitoring and attracting the moths of the pest.

Figure 2: Soybean semilooper, *Thysanoplusia orichalcea*

Soybean semilooper, *Thysanoplusia orichalcea* (Fabricius) (Lepidoptera: Noctuidae)

Distribution: *T. orichalcea* is widely distributed in the world. The pest is present in Sri Lanka, Africa, India, Europe, New Zealand and Australia.

Host plants: Soybean semilooper is polyphagous pest. The pest in addition to *Mentha* spp., feeds on plant belonging to families Chenopodiaceae, Cucurbitaceae, Compositae, Leguminosae, Cruciferae, and Linaceae (Singh and Rawat 1980; Sagar and Ramji 1991).

Identification and Biology

T. orichalcea moth is medium sized and brown in colour. The forewings of moth are brown with golden colour patch (Fig.2). The hindwings are grayish brown. The caterpillars are green in colour with white stripes on the body and full grown caterpillar measures about 45 mm in length. Caterpillars while moving form distinct looping action. Female moth lays 65-120 yellowish eggs on the lower surface of leaves singly. Incubation duration ranges

Figure 3: *Spodoptera litura*

between 3 to 4 days. The caterpillar passes through 6 larval instars and larval period ranges between 16-23 days. The full grown larva pupates in loose silken cocoon on the lower side of leaves. The pupal period varies from 6 to 9 days. Life cycle is completed in 30-35 days.

Nature of Damage: The freshly hatched larvae feed on the lower surface of leaves by scrapping the epidermal part of leaves. The grown up larvae feed voraciously on leaves and make holes. The pest is active during March to October (Sagar, 1985). Severe infestation affects the vegetative growth of the plant, thereby affecting the yield of *Mentha* spp.

Management

- Foliar application of *Bacillus thuringiensis* var. kurstaki, serotype H-39, 3B, Strain Z-52 (0.75–1.0 kg/ha) for the management semilooper.
- Install light traps in the field for monitoring and collection of adult moths.
- Conservation of natural enemies (*Apanteles ruficrus* and *A. glomeratus*) by minimizing use of broad spectrum pesticides (Sagar and Ramji, 1990).
- Foliar application of quinalphos 50EC (2ml/l) or monocrotophos 36SL (1.5ml/l) is effective for control of semilooper (Sagar, 1988; Tripathi, 2018).

Tobacco caterpillar, *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae)

Distribution

Tobacco caterpillar is one of the most important insect pests of agricultural crops in the tropical and temperate Asia, Australasia and the Pacific Islands (EPPO 2013).

Host plants: *Spodoptera litura* is a polyphagous pest damaging sunflower, cabbage, cotton, pulses, soybean, tobacco, castor, okra, groundnut etc. including *Mentha* spp.

Identification and Biology: The adult moth is medium sized dark brown with grayish white markings on forewings and hindwings are white in colour (Fig. 3). The female lays 300 spherical eggs in mass on the surface of leaves and covers them with scales. The incubation period ranges between 3 to 5 days. Full grown larvae are velvety black with yellow dorsal stripes and lateral white strips. Full grown larvae measures about 35-40 mm in length. The larva passes through 5 stages and the larval period is completed in 15-30 days. The full grown up larvae enter soil for pupation. The pupal duration lasts for 7-15 days. Life cycle is completed within 32-60 days. The pest completes 8 generations in a year.

Nature of Damage: Freshly emerged caterpillars feed gregariously on the leaves from the low surface by scrapping the leaf lamina. Later on the larvae feed voraciously on leaves by making irregular holes in solitary phase. The larvae remain hidden in cracks, crevices and plant debris in soil during daytime.

Management

- Hand collection and destruction of egg

masses and gregariously feeding larvae of *S. litura.*

- Castor or sunflower plants can be grown as trap crops with main crop to attract female moths of *S. litura* for egg laying.
- Foliar application of SlNPV (*Spodoptera litura* nuclear polyhedrosis virus) at 250 LE/ha for *S. litura*.
- Foliar application of *Bacillus thuringiensis* var. kurstaki, serotype H-39, 3B, Strain Z-52 (0.75–1.0 kg/ha) to control larvae of *S. litura.*
- Spray 5% neem seed kernel extract (NSKE) during the early stages of crop.
- Foliar application of chlorpyrifos 50EC + cypermethrin 5EC (1ml/litre) or quinalphos 25EC (2ml/l).
- Release of egg parasitoids *Trichogramma chilonis* and *Telenomus remus* four times at 50,000/ha at weekly interval against *S. litura*.
- Use pheromone traps (5 traps/ha) for monitoring of the pest.

Black cutworm, *Agrotis ipsilon* (Hufn.) (Lepidoptera: Noctuidae)

Distribution : *Agrotis ipsilon* is well distributed in Asia, North Africa, Europe, America and Oceania.

Host plants: A part from *Mentha* spp. the pest are also known to feed on the other crops such as potato, barley, oats, pulses, peas, beetroot, cabbage, tobacco and many other cultivated crops (Khan, 1976).

Identification and Biology : The moth is stout and has wavy lines and spots on brownish forewings whereas; hindwings of adults are off-white with dark veins (Fig.4). The larva is dark brown in colour (50 mm long) with a distinct yellow dot on each segment down the centre of back. The female lays about 300 eggs in groups of 30 on the under surface of leaves or moist soil. The egg, larval and pupal periods is respectively 2-13, 10-30 and 10-30 days. Larva moults six times to become pupa. The total life cycle lasts from 30 to 68 depending on weather conditions. The pest completes four generations in a year.

Figure 4: Black cutworm, *Agrotis ipsilon*

Nature of Damage: Larvae remain hidden during day time in cracks in the soil, become active at dusk, feed on leaves and also cut the tender, stems of young and growing plants and thus cause retardation in growth and reduction in yield.

Management

- Deep ploughing exposes the larval and pupal stages to predators.
- Collect and destroy larvae mechanically as they may be curled near the base of young plants.
- Install bird perches to increase the activity of birds in the field.
- Use poison baits (2 g malathion 5% dust with 1 kg of wheat bran) or *Bt* mixed bait (2 g of *Bacillus thuringiensis* formulation with 1 kg of wheat bran) @ 10kg bait/ha in field one week before planting.
- Keep piles of weeds in the crop field as the larvae hide inside weeds to remain protected from day light. Collect and destroy the hidden larvae during morning hours.
- Soil application of granular phorate10G (1.5 kg a.i. ha) before planting reduces cutworm damage (Szezeponek and Mazur, 2006; Rita and Animesh, 2011) or Before planting broadcast chlorpyriphos 50EC treated sand (3 litre per 10 kg sand) @ 10 kg treated sand /ha in the field.
- Release egg parasitiods, *Trichogramma* sp. at weekly interval to parasitize cutworm eggs.
- Release entomopathogenic nematodes in moist soil which kills the cutworms living underground (Yuksel *et al.* 2018).

Cutworm, *Spodoptera exigua* (Hbn.)

Figure 5: Cutworm, *Spodoptera exigua*

(Lepidoptera: Noctuidae)
Distribution
Spodoptera exigua is native to Southeast Asia and currently found in Africa, Southern Europe, North America, Japan and Australia.

Host plants: *S. exigua* has a wide host range, occurring as a serious pest of asparagus, cabbage, pepper, tomato, lettuce, celery, strawberry, eggplant, sugar beet, alfalfa, *Mentha* spp. and cotton

Identification and Biology: The adult moths' are medium sized, with wing span measuring 25-30 mm. The forewings are grayish brown with irregular banding pattern and a light yellow coloured spot (Fig.5). Hind wings are grayish white colour. The early instars larvae are pale green in colour. The later instar larvae are brownish green with yellowish white stripe laterally and yellowish pink colour ventrally. The larvae hide in soil during day time and feed on leaves at night and become full grown in 10-16 days. The full grown larvae pupate in the soil in earthen cocoons and emerge as adults in 7 to 11 days. The female moth lays cluster of eggs on the lower portions of young plants.

Nature of Damage: Larvae feed on the foliage of the mint plants. Young caterpillars feed gregariously and skeletonize the foliage. As they mature, caterpillars become solitary and eat large irregular holes in foliage.

Figure 6.*Syngamia abruptalis*

Management: Described under *Agrotis ipsilon.*

Mentha leaf roller, *Syngamia abruptalis* Walker (Lepidoptera: Pyralidae)
Distribution
It occurs in the tropics of the Old World from Africa to Australia.

Host plants:*S. abruptalis* has a host range restricted to *Mentha* spp. and *Ocimum sanctum* (Sagar and Reddy 1985).

Identification and Biology: The adult moths are light yellowish brown in colour with small size. The female moth lays 12-74 eggs on the lower surface of leaves singly. The incubation period varies 3 to 5 days. Larval duration ranges between 18 to 25 days with five larval instars. Pupal period lasts 5-7 days and 6-10 adult longevity.

Nature of Damage : Early instar larvae feeds on the undersurface of leaves and removes the parenchyma making very small patches of injury without forming webbing of leaves (Fig.6). The later growth stages of larvae forms webbing by joining the edges of upper and lower leaves with silken threads. Due to webbing the growth of plant is hindered (Kareem *et al.* 1960; Sandhu and Bhala 1975; Sagar and Reddy 1987).

Management
- Cypermethrin (50 gm a.i./ha) and Quinalphos

Figure 7. Cotton whitefly, *Bemisia tabaci*

(0.05%) found effective in controlling the *Syngamia abruptalis* (Sagar, 1983,1984).

Cotton whitefly, *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae)

Distribution: The whitefly, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) is a devastating pest of different crops throughout the tropical and subtropical regions of the world (Oliveira *et al.* 2001).

Host plants: *B. tabaci* has been recorded from more than 900 different plant species (Attique *et al.* 2003; Greathead 1986, GISD, 2005).

Identification and Biology: Adults are winged, they are 1.0-1.5 mm long and their yellowish bodies are slightly dusted with white waxy powder (Fig.7). They have two pairs of pure white wings and have prominent long hind wings. The wings are held over the body like a tent. The adult males are slightly smaller in size than the females. The nymphs are flattened, oval-shaped, and greenish-yellow in color. The first instar nymphs are mobile and have antennae, eyes, and three pairs of well developed legs. The legs and antennae are atrophied during the next three instars and they are immobile during the remaining nymphal stages. The last nymphal stage has red eyes. This stage is sometimes referred to puparium. The females lay stalked eggs singly on the underside of the leaves, with a range between 80-110 eggs per female. The incubation period is 3-5 days. The nymphs feed on cell sap and grow into three stages to form the pupae within 14-28 days. In 2-8 days, the pupae change into whiteflies. The total lifecycle completed in 14-100 days depending on weather conditions.

Nature of Damage: Nymphs and adult whiteflies suck the cell sap from the lower side leaves, thus lowering the vitality of the plants. The whiteflies excretes honeydew on which growth of sooty mould takes place, which results in blackening of leaves, consequently affecting photosynthesis. In case of very high incidence, there is total blackening of crop resulting in drying of leaves and ultimately total failure of the crop. Whiteflies are also a vector of number of viral diseases.

Management

- Grow resistant cultivars of *Mentha arvensis* (MA-92-194 and Kosi), *M. piperita* (MPS-1), *M. cardiaca* (MCAS-2 and MCAM-19), *M. citrata* (Kiran and Arka) and *M. spicata* (Neerkalka and MSS-5) which suffer less infestation of whiteflies (Singh *et al.,* 2004).
- Removal the weed plants in and around the mint cultivated fields may in decreasing the pest population.
- Yellow sticky traps are effective for monitoring and managing the whiteflies.
- Conserve the naturally occurring natural enemies, namely, predators: *Serangium parcesetosum, Cheilomenes sexmaculata, Coccinella septempunctata, Brumoides suturalis,* chrysopid *Chrysoperla zastrowi sillemi* and parasitiod, *Encarsia lutea* play important role in controlling *B. tabaci* (Kedar *et al.* 2014; Kedar *et al.* 2017).
- Grow sorghum or maize as barrier crop in may be planted to reduce the pest population (Hilje *et al.* 2001).
- During initial stages foliar application based on neem oil, castor oil, cotton seed oil etc. must be followed.
- Foliar application of entomopathogenic fungus, *Verticillium lecanii* (10gms/lit) against *B. tabaci*.

Aphids, *Aphis affinis* Del Guercio (Hemiptera: Aphididae)

Distribution

Aphid, *Aphis affinis* is found in Southern Europe, Russia, the Middle East, India and Pakistan.

Host plants: This pest is monophagous feeds on plant belonging to **Lamiaceae family** (*Mentha viridis* and *Ocimum basilicum*).

Identification and Biology: They are small to medium sized soft-bodied insects, dark grey-green to almost black in colour. These aphids are dusted with light wax powder with clear intersegmental lines. The adult female multiplies parthenogenetically and viviparously.

Nature of Damage: The nymphs and adults are usually clustered on stem apices and tender shoots and upper leaves of *Mentha* spp. Nymphs and adults suck the plant sap due to which the growth of the plants is affected. Such stressed plants are more susceptible to other pests. Aphids excrete honey dew on which growth of sooty mould fungus takes place, which results in blackening of leaves consequently affecting the photosynthesis process. Aphids are also vector of viral diseases which can be more damaging than the feeding aphids (Singh and Sagar 1981).

Management

- Use of yellow sticky traps for monitoring and mass trapping of aphids.
- Conservation of natural enemies by minimizing use of broad spectrum insecticides.
- *Coccinella septempunctata, Coccinella transversalis, Cheilomenes sexmaculata, Brumoides suturalis* and *Propylea dissecta* reported biocontrol agents of *A. affinis* infesting Japanese mint (Singh and Bali, 1993).
- Foliar application of oxydemeton-methyl 25EC (2ml/l) or dimethoate 30EC (1.5ml/l) can be used for control *A. affinis* (Sagar and Singh, 1981).

Red Pumpkin Beetle, *Aulacophora foveicollis* (Lucas), (Coleoptera: Chrysomelidae)

Distribution: Red Pumpkin Beetle is widely distributed in Asia, Africa, Australia and South Europe. In India, it occurs throughout the country.

Host plants: *Aulacophora foveicollis* is a major pest of cucurbitaceous crops. Damage of this pest was also reported on *Mentha arvensis* (Singh and Gupta 1970).

Identification and Biology; The adult beetle is oblong in shape deep orange and ventral side is black in colour (Fig.8). The adult beetle measures about 5-8 mm in length and 3.5-3.75 mm in width. Adult female beetle lays brownish elongate eggs singly or in batches of 8 to 9 in the moist soil near the base of host plant. A beetle may lay 150 to 300 eggs. The incubation period is 5 to 8 days. The grubs become full grown in 13-25 days and pupate in soil. The pupal period ranges from 7 to 17 days. In a year there may be 5 to 8 generations of the insect. The adult beetles hibernate in soil or in dry weeds during November to February.

Nature of Damage: The adult beetle feeds on the leaves. The beetle bite holes on the leaves, causing death or retardation of growth. Damage during seedling stage is often devastating. The grubs of this pest feed on the

Figure 8: Red Pumpkin Beetle, *Aulacophora foveicollis*


Figure 9: Termite, *Odontotermes obesus*

roots and sometimes on stem also (Singh and Gupta 1970).

Management

- Hand collection and destruction of adult beetles.
- Foliar application of 0.1% malathion 50EC (Singh and Gupta, 1970) or trichlorfon* 50EC (500ml/ha) or trichlorfon* 5% dust (500gm/ha) or diclorvos* 76EC (1.25ml/l) is effective against this pest. (*The use these insecticides is completely banned with effect from 31st December 2020).

White ants/Termites, *Odontotermes obesus* (Ramb.) (Isoptera: Termitidae)

Distribution: *Odontotermes obesus* is a widespread species in India, Bangladesh and Pakistan.

Identification: Termites are social insects; live in termitaria, in distinct castes, workers, soldiers, kings and queen. Worker caste causes damage to plants. Workers are small and have soft, white body and brown head.

Nature of Damage: Termites damage plants soon after transplanting and continue till late growing stage. Termites bore in to root and stem. The leaves of the damaged plant droop down (Fig.9). Such plants, if pulled, are easily uprooted and termite cuts or galleries are seen. The incidence of termite is common during drought period.

Management

- Field application of oil cakes of *Azadirachta indica*, *Mahua longifolia* and *Ricinus communis* is effective for termite management.
- Soil application of chlorpyriphos 20EC is very effective.
- Avoid use of partially decomposed farm yard manure (FYM).
- Irrigating field at short period of intervals also reduces termite infestation.
- Destroy the termitaria around field and kill the termite queen.
- Spot application of granular insecticides (phorate 10G) if termite infestation is in patches.
- Entomopathogenic nematodes effective against termites (Rathour *et al*. 2014).

Fungal diseases of mints (Table 2)

Rust: Rust is an important disease which is caused by *Puccinia menthae* Pers. (Shukla et al. 1999). This fungus infest leaves and twigs of *Mentha* species and produces postules on upper and lower leaf surface, are in redish brown and yellow orange in colour

Host range: *Mentha arvensis* and *M. spicata* are the major host.

Figure 10. Rust of *Mentha arvensis* caused by *Puccinia menthae*

Diseases occurrence and distribution: Due to infection of rust fungi the defoliation in mints occurred and caused severe economic loss due to reduction in oil yield. This disease is prevalent in all mint growing area of India (Ganguli and Pandotra, 1962; Shukla et al. 1999) whereas the fungus *Puccinia menthae* has also been reported from Indiana, USA (Stone and Green, 1967). In tarai region of Uttar Pradesh the dual infection of *P. menthae* and *Alternaria alternate* have been reported (Shukla *et al.* 1999). The young shoots infected by rust fungi are usually twisted and most of the times broken off at the infection site (Fig. 10).

Diagnostic symptoms: In menthol mint typical symptoms of rust pustules develop on lower surface of leaves between April and June. In general, there are three types of pustules found on the infected area. First types of postules are circular, yellowish brown in colour whereas second is orange in colour and third type of pustules are of variable shape and size, dotted tan in colour.

Disease cycle: These fungi generally persist in the form of ureidospores on runner and plant debris of the host plant. The rust postules possess enough ureidospores which under favourable condition infect the host plant. The rust fungi also formed telia at later stage which is thick walled teliospores and survives in adverse conditions.

Management

Use of disease free materials is the major preventive measures of this disease. Treatment of planting materials with hot water and use of resistant variety is common method of this disease management. Elimination of old mint rust infected mint plant also help to prevent the disease spreading and also reduce the rust inoculum. Application of few fungicides like mancozeb, propiconazole, Diclobutazol and nickel chloride offer reliable protection against rust disease (Krall 1977, Margina and Zheljazkov 1994). Suab and Nagy (1972) also reported that application of denitroamine and Krezonit-E (DNOC) help to decrease the disease incidence. Shukla *et al.* (2008) screened different varieties/genotypes for multiple disease resistance of menthol mint, himalaya, kalka and Damroo were found to be

Table 2. Major fungal diseases of *Mentha* spp.

Sr. No.	Disease	Causal Organism	References
1	Alternaria leaf spot	*Alternaria tenuis* *A.alternata*	Ganguli and Pandotra, 1962 Srivastava and Srivastava, 1971
2	Cercospora leaf spot	*Cercospora menthicola*	Shukla et al. 1988
3	Corynespora leaf spot	*Corynespora cassicola*	Sattar et al. 1981
4	Curvularia laef spot	*Curvularia verruciformis, C.trifoli*	Thakur et al. 1974
5	Alternaria blight	*Alternaria alternata.*	Shukla et al. 2000
6	Rhizoctonia blight	*Rhizoctonia solani*	Sharma and Munjal , 1978
7	Anthracnose disease	*Sphaceloma menthae*	Bains, 1938
8	Root rot	*Thielavia basicola* *Rhizoctonia bataticola* *Sclerotinia roffsii* *Rhizoctonia solani* *Sclerotinia sclerotiorum*	Sattar and Husain, 1976 Husain and Janardhnan, 1965 Pandotra and Shastry, 1968 Singh, 1991
9	Stem rot	*Botryodiplodia theobromae*	Shukla et al. 2001
10	Wilt	*Fusarium oxysporum*	Sattar and Husain, 1980

resistant to rust fungi whereas genotypes MAH-3, S-10-11-45 and S-13-2-125 were moderately resistant to rust, The variety Kalka was resistant to rust, leaf spot and leaf blight, but was found susceptible to powdery mildew, and stem blackening and rot.

Viral diseases of mints: Viruses are obligate parasites; that is, they require a living host in order to grow and multiply.Therefore they are considered intracellular (inside cells) pathogenic particles that infect other living organisms. In general the virus particles are very small and can be seen only with the help of an electron microscope. Most of the plant viruses are either rod or isometric (polyhedral) in shape. Generally TMV, potato virus Y (PVY) as well as cucumber mosaic virus (CMV) are very good examples of a short rigid rod-shaped, a long flexuous rod-shaped, and an isometric virus, respectively. For viral infection there are need of injury for their entrance in plant cell and injury may occur naturally in plants like lateral branching. The transmission of plant viruses may be through agronomic or horticultural practices, or fungal, nematode, insects etc.

Several viruses belonging to more than twelve genera have been reported to cause diseases in various species of *Mentha* spp. World-wide, the important genera include: *Alfamovirus, Begomovirus, Cheravirus, Closterovirus, Cucumovirus, Cytorhabdovirus, Hordeivirus,*, *Nepovirus, Potexvirus, Tobamovirus, Tospovirus, Vitivirus, etc*. However, there are only few reports of viral diseases on mints from India which may be attributed that this crop has come in regular and mass cultivation here, lately.

Figure 11: Mosaic on leaves of *M. gracilis*

A mosaic disease of *M. arvensis* was suspected to be caused by virus, was reported as early as in 1965 in India, but the causal virus could not be characterized (Nene *et al.* 1965). The genus *Begomovirus* belongs to the family *Geminiviridae.* A light yellow mosaic disease has been reported from Lucknow on *Mentha spicata* cv. viridis (Samad *et al.* 2009). The symptoms include mosaic, yellowing, leaf curling, crinkling, and retarded growth that induced drastic reduction in herb yield. An isolate of *Tomato leaf curl Pakistan virus (Begomovirus)* was identified from infected plants.

Tobacco mosaic virus belongs to genus

Table 3. Major viral diseases of mints in India

Sr. No	Name of Virus/Diseases	Genus	Host plant	Transmission	Place	References
1.	Mosaic Disease of *M. arvensis*	--	*M. arvensis*	--	India	Nene *et al*.1965
2.	Tobacco mosaic virus	*Tobamovirus*	*M. cardiaca*	Mechanical	India	Samad *et al*.1994
3.	Tobacco mosaic virus	*Tobamovirus*	*M.gracillis*	Mechanical	India	Samad e*t al*.2000
4.	Tomato leaf curl Pakistan virus	Begomovirus	*M.spicata*	whitefly	India	Samad *et al*.2009
5.	Mosaic and leaf deformation disease virus	--	*M.piperita*	--	India	Zaim (2011, unpublished)

Tobamovirus. The virus was first reported in Scotch spearmint (*M. cardiaca* Baker) in 1994 in India (Samad et.al.1994)). Subsequently an isolate of TMV was isolated from Scotch spearmint (*M. gracilis* Sole) (Samad *et al.* 2000). The disease symptoms included green mosaic with vein banding, deformation of leaves, and retarded growth (Fig. 11). The virus particles were rod shaped 300x18 nm in size. Mol. Mass of capsid protein was found to be 17000 ± 500 Daltons. The virus showed close serological relationship with TMV-UI and Brinjal necrotic mosaic virus

Another mild mosaic symptom has been recorded on peppermint (*M. piperita* L.). Initially terminal leaves of the diseased plant showed mottling, curling and finally mild mosaic symptom which spread in whole plant giving sick appearance, associated with heavy stunting and occasional necrosis of the leaves. Flowering was delayed with small size flower. The DNA from the diseased leaves amplified and identified as the causal virus could be a member of family Geminiviridae (Zaim 2011 unpublished).

Nematode diseases of mints

Menthol mint (*Mentha arvensis* L.): Menthol mint (*Mentha arvensis* L.), an important aromatic herb, is widely cultivated for its essential oil, which is a potential source of natural menthol, menthyl acetate, menthone and terpenes. Different constituents of menthol mint oil are extensively used in pharmaceutical, perfumery, food and cosmetic industries all over the world. In India the commercial cultivation of menthol mint suffers a great yield loss due to root-knot disease caused by *Meloidogyne* spp. Both the species of root knot nematode (*Meloidogyne incognita & M. javanica)* occur together but the frequency of *M. incognita* is greater than *M. javanica* (Pandey *et al.* 1992). In the root rhizosphere other plant parasitic nematodes viz. *Tylenchus sp., Tylenchorhynchus vulgaris, Hoplolaimus indicus, Helicotylenchus dihystera, Pratylenchus thornei, Rotylenchulus reniformis, Aphelenchoides* sp., *Longidorus pisi,* and *Xiphinema* sp. were reported (Pandey *et al.* 1992, Pandey 1997a). In 1938, Buhrer for the first time reported that *M. arvensis* as host of *Meloidogyne* species. For the first time Pandey (1989) reported the root-knot disease of menthol mint (*Mentha arvensis*) and Bergamot mint (*M. citrata*). Two major nematode species viz. *M. incognita* and *M. javanica* were found to be associated with menthol mint. Introduction of *M. arvensis* as a commercial crop into sandy loam soil in India showed that a threat was posed by the root-knot nematode, *Meloidogyne incognita* (Kofoid *et* White) Chitw. (Haseeb and Pandey 1989). As this species is sedentary endoparasitic, its spread is facilitated by infected suckers/roots that are used in the vegetative propagation of the crop (Pandey 1998a, b).

Distribution: Root-knot disease was first observed in Lucknow and subsequently found in Pantnagar, Rampur, Moradabad, Badaun, Bareilly, Saharanpur. The incidence of disease varied from cultivar to cultivar and location to location. The most severe infestation was found in Lucknow, Barabanki, and Moradabad whereas least infestation was recorded at Pantnagar (Pandey, 1989).

Symptoms: Whole roots and suckers are invaded by root-knot nematode. Small to medium size of galls were noticed on *M. incognita* infested roots. Secondary roots of suckers are also highly infested with *M. incognita* and most of the times whitish colour egg masses of *M. incognita* were seen on the root system. Heavily root knot infested menthol mints plants are stunted poorly tillered and have chlorotic leaves. Infested suckers serve as major source of infection and means of dissemination. Root knot nematode continue to develop after the crop has matured and been harvested.

Other host: Several weeds, which are present

in menthol mint growing areas, are also major source of root-knot nematodes

Host-parasite relationship: Experiments have been carried out to determine the pathogenic potentiality of different plant parasitic nematodes on menthol mint (*Mentha arvensis* L.). The pathogenic potentiality of *M. incognita* was observed on all cultivars of *Mentha arvensis*. With an increase in load of inoculum there had been a significant decrease in oil yield, fresh and dry weight of plant and rate of photosynthesis. The reduction in different growth parameters was found to be directly correlated with inoculum load of nematode. Root-knot nematode (*M. incognita*) caused 25-30% oil yield reduction in menthol mint. The quality of mint oil was also adversely affected due to nematode infection (Pandey *et al.* 1992).

MANAGEMENT

To manage plant parasitic nematodes in different medicinal and aromatic plants through ecofriendly way is one of the difficult tasks because of different nature of parasitism. Studies conducted by Pandey *et al.* (1997, 1998) on interaction between *M. incognita* and AM fungi indicated that root-knot nematode, *M. incognita* multiplies well in absence of AM fungi and significantly reduced plant growth/ yield. Root-knot nematode infection was drastically impaired when plants were inoculated with three AM fungi simultaneously as compared to their alone inoculation. It was concluded with this experiment that AM fungi besides improving plant growth biomass could effectively inhibit nematode infection (Pandey *et al.* 1998).

Successful control of root-knot disease has been achieved with carbofuran (@ 3kg a.i. /ha (Pandey1995). Addition of neem cake (@500kg/ha) was also found encouraging. Significant success both in pots as well as in fields with regard to management of *M. incognita* with bio-agents, organic matter and integration of both has also been obtained (Pandey, 2000). Pandey and Patra (2001) screened large number of mint accessions against root-knot nematode, *M. incognita* and reported moderate to high degree of resistance in 11 accessions of mint species. Development of some varieties, which could be propagated through seeds, would also help in breaking the disease cycle by avoidance of infested suckers. Management of the nematode by integration of various means would probably be the best method in fighting nematode problems. Current research is directed towards this goal. Pandey (2005) conducted field trial to determine the efficacy of *Trichoderma harzianum* isolate U, *Glomus aggregatum*, oil seed cakes of neem (*Azadirachta indica*), and mustard (*Brassica compestris*) in the management of *Meloidogyne incognita* and their impact on yield of menthol mint (*Mentha arvensis*) cv. Kosi. Significant reductions in nematode populations and root-knot indices were noticed in plots receiving oil seed cakes and bio agents, whose effects were equal to that of carbofuran. Application of oil seed cakes and *T. harzianum* significantly enhanced crop yield. The late transplanted mint technology developed at Central Institute of Medicinal and Aromatic Plants Lucknow, which allows farmers to have non-host crop like wheat, mustard etc. has greatly benefited the farmer in fighting root-knot nematode menace to some extent. Further the higher temperature prevailing during the transplanted cropping season (April-July) also checks the nematode population buildup and infection of menthol mint crop.

STRATEGIES TO PREVENT SPREAD OF MINT NEMATODES

Most plant-parasitic nematodes, which affect the crop yield, occur in the soil or plant roots. Prevention of spreading of phytonematodes from nematode infested field to noninfested field is an important part as the nematodes

which damage mints are generally endoparasitic in nature and they can easily spread through suckers / runners (propagating materials) from infested planting sites to noninfested planting sites. Therefore it is essential and utmost important to check their spread in new areas/ fields. We should take following prevention measures:

- Use of certified suckers as planting material
- Use of nematode free soil for suckers multiplication
- Cleaning soil from equipment before moving between fields
- Prevention of animal movement from infested to uninfected fields
- Eliminating important weed and alternate hosts of phytonematodes

Peppermint (*Mentha piperita* L.) :Peppermint (*Mentha piperita* L.) Belonging to family Lamiaceae is also known as black mint, candy mint or "Mitcham" yielded peppermint oil by the steam distillation of herbs. The major oil component of peppermint oil is menthol, menthone, isomenthone, menthyl acetate and neomenthol. Oil of these mint species is used in pharmaceutical, flavour and food industries. The oil possesses antibacterial, antiviral, antiparasitic, antifungal as well as nematicidal properties. Peppermint is commercially cultivated in USA, Russia, Bulgaria, Italy, Morocco and India. In India it is cultivated on 4300 ha of land and oil production is about 830 tonnes annually. The world requirement is approximate 8000 tonnes per year and USA is the largest producer and user of peppermint oil. In India the major cultivated states are, Uttar Pradesh, Himachal Pradesh, and Uttarakhand. Buhrer (1938) reported *M. piperita* as host of *Meloidogyne* species. Horner and Jenson (1954) reported in western Oregon, USA the occurrence of *M. hapla* on different mint species. Species of root lesion nematode, *Pratylenchus* like *P. minyus, P. penetrans* and *P. thornei* associated with, *M. piperita* var. Mitcham (Skotland and Menzies, 1957; Pandey, 1997b). The name "root lesion" nematode has been derived from the characteristic symptoms produced due to this nematode infection in roots. De Man described the first species of *Pratylenchus* in 1880 under the name of *Tylenchus pratensis*. Filipjev established the genus *Pratylenchus* in 1936. and more than 50 species of *Pratylenchus* have been reported all over the world.

Major causal organism: *Pratylenchus thornei, P. penetrans, P. scribeneri, P. minyus*

Symptoms: This mint species is highly susceptible to *Pratylenchus thornei, P. penetrans, P. scribeneri, P. minyus* (Skotland and Menzies, 1957; Faulkner, 1962; 1964 Pandey, 1997c). *Pratylenchus* species is migratory endoparasitic nematode and attack the root cortex. Roots develop dark lesions and an overall brown color. The lesions first develop on younger roots but may be found anywhere on the roots. The lesions enlarge, coalesce and ultimately girdle whole root which appear constricted this follows secondary attack by fungi and bacteria. The affected area may be sloughed off and the overall root system is reduced. Loss of the epidermis and cortex decreased root growth nutrient and water uptake. Under stress, plants are yellow, become stunted, and have reduced yields. The extent of damage depends on the phenolic content of the cells. The oxidation of these phenols causes the characteristic browning of the lesions. The aerial symptoms always resembled like due to malnutrition or water or deficiency. In the initial stages, the infestation can be noticed as small patches of stunted growth of mint and yellowing of leaves. These stunting increases every year and may formed a large patch. Leaves may become yellowish brown and wilt during April-May. The root system of mint species become very poor when severely infested with *P. thornei* and can be pulled out from the field very easily (Pandey, 1997b).

Host parasite relationship: The root lesion

nematode is second most important pest of medicinal and aromatic crops. *Pratylenchus* gain importance due to its ubiquitous distribution, although certain species have climatic preferences, wide host range render the host more vulnerable to secondary attack by other pathogens due to extensive necrosis. The nematode migration is both inter and intra cellular and feeding is restricted to cortical region. Bergeson and Green (1979) reported that all cultivars of peppermint grown in Indiana are highly susceptible to *P. penetrans*.

The damage becomes many folds when *Pratylenchus* species interact with plant pathogenic fungi in peppermint and spearmint. Interactive effect of *P. penetrans* and *Verticillium albo atrum* on yield of peppermint was established by Bergeson (1963). Similar result was reported by Faulkner (1965) with *P. minyus* and *V. dahliae* (kleb) f. *menthae*. Presence of nematode species increases both incidence and severity of disease. Faulkner and Bolander (1969) have studied the disease severity of peppermint at different temperature when inoculated peppermint plant with *V.dahliae* f.sp. *menthae* and *Pratylenchus minyus.* The 27^0C temperature favours the disease development whereas optimum wilting occurs at 24^0C temperature, higher temperature did not favour the nematode multiplication as least nematode reproduction was reported at 30^0C. Faulkner *et al.* (1970) reported that *P. minyus* not only help to the *V.dahliae* for infection but also alter the physiology and biochemistry of *M. piperita* plant. Esmenjaud *et al.* (1990) found that three-peppermint cultivar proved to be good host of *Pratylenchoides lauticauda.* Studies carried out in CIMAP reveals that the population of *P. thornei* was very high in roots and the root rhizosphere of rhizospheric stunted peppermint plants. Pathogenicity of *P. thornei* was established on this mint species (Pandey 1997b). P*ratylenchus* spp. frequently caused wounds in roots through which other pathogenic organism such as fungi and bacteria enter the root tissues. The interaction of these agents results in the formation of lesions that finally destroy the whole root tissues.

Management

Information pertaining to the management studies of root-lesion nematode on *M. piperita* is very meager. Pinkerton *et al.* (1988) successfully managed the population of *P. penetrans* on peppermint through the use of oxamyl, aldicarb and carbofuran. Marrifield and Ingham (1992) used ethoprop@6.6kg a.i./ha for the control of *P. penetrans* in *Mentha piperita*, whereas Ingham (1992) applied same nematicide @6.6, 13.2 or 26.4 kg a.i./ha for the management of lesion nematode in peppermint. They concluded their findings and reported that ethoprop @6.6kg a.i/ha is very effective to reduce the root lesion nematode population in soil at significant level. *O*n control aspect several experiment were carried out with herbicides, pesticides, and cultural methods with variety of plant parasitic nematodes on peppermint (Faulkner and Skotland 1963,, Jatala and Jenson 1974, Gokte and Mathur 1980, Pinkerton and Jensen 1983, Jensen and Horner 1959, Pandey 1993). The non-chemical methods are getting more importance nowadays due to hazardous effect of chemical pesticides. In general the management strategies can be concluded as follows

I.The use of resistant crops and varieties provides the best option for farmers to control *Pratylenchus* as these crops will limit multiplication of the nematode and reduce losses to following crops.

II. Some crops and varieties vary in their resistance/susceptibility and tolerance to either *P. penetrans* or *P. thornei*.

III. To limit yield losses from *Pratylenchus*, soil assays to identify the species and nematode levels present are highly recommended. With this information, the likely risks can be assessed, and management decisions made, especially for variety resistance and tolerance of crops to be used in rotations.

IV. Good soil nutrition (particularly nitrogen, phosphorus and zinc) can reduce the effects of

Pratylenchus on infested peppermint plant.

Spearmint (*Mentha spicata* Huds.)

Distillation of spearmint herbs yielded spearmint oil, which is major source of carvone and limonene**.** Oil is mainly used in flavouring industries. Species of root lesion nematode, *Pratylenchus* like *P. minyus, P. penetrans* and *P. thornei* associated with *M. spicata* var. native (Skotland and Menzies, 1957).

Causal Organism: *Pratylenchus thornei, P. penetrans, P. scribeneri,*

Host parasite relationship: Bergeson (1963) for the first time established the pathogenicity of *P. penetrans on M. spicata* and reported a reduction of foliage and root/ stolon growth up to 34 and 66% respectively. The population of *P. penetrans* increases from 30X to 80X after 8 months. Bergeson and Green (1979) showed the herb reduction of spearmint in Indiana due to *P. penetrans.* Further they reported that all cultivars of spearmint grown in Indiana are highly susceptible to *P. penetrans*. Rhoades (1983) isolated the population of Belanolaimus longicaudatus, *Dolichodorus heterocephalus*, *Pratylenchus* scribeneri and *Paratrichodorus christie* from the stunted plant rhizosphere of *M. spicata* and pathogenic potentiality of these nematode has also been tested. Similarly Inserra and Rhoades (1989) reported damage potential of *Belonolaimus longicaudatus*, *Dolichodorus heterocephalus, Pratylenchus* scribeneri and *Paratrichodorus christie* on *M. spicata* and suggested the use of non-volatile nematicide for lowering the population of these nematodes and increasing yield of the plant. Studies carried out in CIMAP reveals that the population of *P. thornei* was high in the root and rhizosphere of chlorotic spearmint plant (Pandey 1997b). Pathogenicity of *P. thornei* was established on spearmint (Pandey 1997b). The damage becomes several folds when *Pratylenchus* species interact with plant pathogenic fungi in spearmint crops.

Management: Least experiment has been carried out on the management aspect of lesion nematode in spearmint. Rhoades (1984) studied the effect of carbofuran, fenamiphos and oxamyl @5.6 and 11.2 kg/ha and terbufos@11.2kg/ha for the control of *P. scribeneri* infesting *M. spicata*. The nematode population decreased significantly but turbefos best followed the affectivity of fenamiphos. Similarly Ingham *et al*. (1992) used ethoprop@6.6, 13.2,26.4 kg a.i./ha in their experimentation for the control of *P. penetrans* in *M. spicata*. They reported ethoprop @6.6kg a.i/ha was highly effective to reduce the population of *P.penetrans* in spearmint field. Some of the experiments on control aspect were also carried out with herbicides, pesticides, and cultural methods with variety of plant parasitic nematodes on spearmint (Jatala and Jenson 1974;,Lisetskaya 1985, Emenjaud *et al.* 1989, Gokte and Mathur 1980, Pandey 1993**).**

Nematodes associated with Scotch spearmint, Bergamot mint and Gardenmint

Scotsch spearmint (*Mentha cardiaca* (GF Gray) baker, Bergamot mint (*Mentha citrata* Ehrh.) and Gardenmint (*M. viridis* L.) are affected by various plant parasitic nematodes. Large number of plant parasitic nematodes is associated with different mint species other than root knot and root lesion nematodes. Horner and Jenson (1954) reported the association of *M. hapla*, *Pratylenchus* species, *Aphelenchoides* sp. and *Longidorus* sp. with these three mint species and established pathogenicity of *M. hapla* on *M. cardiaca*. *Aphelenchoides olesistus* and *A. ritzemabosi* associated with *M. piperita* and *M. spicata* (Goodey, 1940**).** Skotland and Menzies (1957) reported the association of *Tylenchorhynchus capitates*, *Trichodorus* sp. with *M. cardiaca* var. native in the Yakima valley and in Columbia basin. They further reported the population of *P. hamatus* was associated with *M. cardiaca* var. Scotch, *M. piperita* var. mitcham and *M. spicata* var. native. Population

of *Longidorus elongatus* (de man) Thorne & Swanger associated with peppermint cultivation in USA (Horner and Jenson, 1954). The population of *L. elongatus* was controlled with the use of oxamyl on peppermint (Jatala and Jenson, 1974).

In India the most important nematode pathogen of Scotch spearmint and Garden mint is *M. incognita* while bergamot mint is affected by *P. thornei* (Pandey, 1997b). Among these three mint species *M. cardiaca* and *M. viridis* are most susceptible while *M. citrata* is considered to be tolerant to *M. incognita* and *M. javanica* (Pandey, 1998a). Most plant-parasitic nematodes, which affect the crop yield, occur in the soil or plant roots. Prevention of spreading of plant parasitic nematodes from nematode infested field to non-infested field is an important part as the nematodes which damage mints are generally endoparasitic in nature and they can easily spread through suckers (propagating materials) from infested

Table 4. Insect pests of Patchouli

Common name	Scientific name	Order	Family	Pest Status	References
Weevil	*Blosyrus* sp.	Coleoptera	Curculionidae	Major	Triveni, 2017
Ash weevil	*Myllocerus viridanus*	Coleoptera	Curculionidae	Major	Triveni, 2017
Weevil	*Apion* sp.	Coleoptera	Curculionidae	Minor	Triveni, 2017
Scarab beetle	*Maladera* sp.	Coleoptera	Scarabaeidae	Minor	Triveni, 2017
Beetle	*Longitarsus* sp.	Coleoptera	Chrysomelidae	Minor	Triveni, 2017
Bug	*Aspilocoryphus dixnoni*	Hemiptera	Lygaeidae	Minor	Triveni, 2017
Leaf hopper	*Neodartus acocephaloides*	Hemiptera	Cicadellidae	Minor	Triveni, 2017
	Kolla ceylonica	Hemiptera	Cicadellidae	Minor	Triveni, 2017
	Nirvana pallida	Hemiptera	Cicadellidae	Minor	Triveni, 2017
Aphid	*Aphis gossypii*	Hemiptera	Aphididae	Major	Triveni, 2017
Bug	*Pachypeltis* sp.	Hemiptera	Miridae	Major	Ramani and Bhumannavar, 1990
Yellow scale of cotton	*Cerococcus hibisci*	Hemiptera	Cerococcidae	Minor	Umesha *et al*., 1998
Thrips	*Bathrips melanicornis*	Thysanoptera	Thripidae	Minor	Sanjta and Chauhan, 2018
	Thrips carthami	Thysanoptera	Thripidae	Minor	Sanjta and Chauhan, 2018
	Anaphothrips sudanensis	Thysanoptera	Thripidae	Minor	Sanjta and Chauhan, 2018
	Aeolothrips sp.	Thysanoptera	Aeolothripidae	Minor	Sanjta and Chauhan, 2018
	Haplothrips sp.	Thysanoptera	Phlaeothripidae	Minor	Sanjta and Chauhan, 2018
Soybean leaf folder	*Nacoleia vulgaris*	Lepidoptera	Pyralidae	Minor	Triveni, 2017
Leaf webber	*Pronomis profusalis*	Lepidoptera	Pyralidae	Minor	Ramani and Bhumannavar, 1990
Leaf roller	*Psara stultalis*	Lepidoptera	Pyralidae	Minor	Ramani and Bhumannavar, 1990
Semilooper	*Thysanoplusia orichalcea*	Lepidoptera	Noctuidae	Minor	Triveni, 2017
Grasshopper	*Attractomorpha* sp.	Orthoptera	Acrididae	Major	Triveni, 2017
	Acrida exaltata	Orthoptera	Acrididae	Major	Triveni, 2017
	Cantantops innotabilis	Orthoptera	Acrididae	Major	Triveni, 2017
Mite	*Tetranychus* spp.	Trombidiformes	Tetranychidae	Major	Triveni, 2017
	Brevipalpus phoenicoides	Trombidiformes	Tenuipalpidae	Minor	Ramani and Bhumannavar, 1990

Fig.12. *Attractomorpha* sp

planting sites to no infested planting sites. Therefore it is essential and utmost important to use of nematode free planting material would check the spread of pathogen.

Patchouli (*Pogostemon patchouli* Pellet.), (Syn. *P. cablin* Benth.): Patchouli is an important aromatic plant, belonging to family Lamiaceae is the major source of commercial patchouli oil. In the perfumery industries still there is no synthetic chemical which could replace the patchouli oil. It is native of the Phillipines and cultivated mainly in Malaysia, Jawa, Brazil, West Indies, Singapore, Indonesia, China and India. It is a perennial aromatic herb that yields fragrant leaves containing very sweet smelling oil, attains a height of about 1m – 1.2 meter. The chemical components of patchouli oil are b-patchoulene, a-guaiene, caryophyllene, a-patchoulene, seychellene, a-bulnesene, norpatchoulenol, patchouli alcohol and pogostol. It is propagated by stem cuttings. The commercial oil of patchouli is obtained by steam distillation of the shade dried herbage. The oil of patchouli has a strong fixative property, which helps to prevent the rapid evaporation of perfume and thereby promotes tenacity. The oil is generally blended with other essential oils. It is used in a wide range of toilet soaps, scents, body lotions, etc. At very low concentration, the oil is extensively used to add flavour to major food products including alcoholic and non alcoholic

Figure 13. *Aphis gossypii*

beverages, frozen dairy desserts, candy etc. It also posses medicinal properties like helpful in relieving from all forms of depression, anxiety and stress related conditions. The other therapeutic properties of patchouli oil are antiseptic, aphrodisiac, astringent, deodorant, diuretic, febrifuge, fungicide, sedative and also used in several other pharmaceutical preparation. It is used as general tonic and a stimulant and helps the digestive system (Sarwar *et al.* 1982). In India this plant is cultivated in state of Assam, Madhya Pradesh, Tamil Nadu, Kerala and Karnataka. This crop suffers from fungal, viral and nematode diseases.

Insect pests of Patchouli: Triveni (2017) documented 16 species of pest species on patchouli (*Pogostemon cablin*) which included 10 species of defoliators belonging to Coleoptera, Lepidoptera and Orthoptera orders and 6 species of sucking pests (Hemiptera, Acarina) (Table 3). Among the different species of pests observed, *Attractomorpha* sp. (Fig.12), *Cantantops innotabilis, Acrida exaltata, Blosyrus* sp., *Myllocerus viridanus*, *Aphis gossypii* and *Tetranychus* spp. were major pests of patchouli. Both the nymphs and adults of grass hoppers, namely, *Attractomorpha* sp., *C. innotabilis* and *A. exaltata* act as defoliators, which feeds on the leaves of patchouli and showing nibbling

Fig. 14. Alternaria Blight of *Pogostemon cablin*

symptoms (Triveni 2017). Adult weevils, *Blosyrus* sp., and *M. viridanus* feeds on the leaf margin of patchouli (Triveni, 2017). Sanjta and Chauhan (2018) recorded infestation of five species of thrips, viz. *Bathrips melanicornis*, *Thrips carthami, Anaphothrips sudanensis, Aeolothrips* sp. and *Haplothrips* sp. on patchouli.

Cotton aphid, *Aphis gossypii* Glover (Hemiptera: Aphididae) has a worldwide distribution. The nymphs and adults are yellowish in colour (Fig.13). The alate as well as apterous females multiply parthenogenetically and viviparously. The female give birth to 8-22 nymphs which becomes adults in 7-9 days. Nymphs and adults of *A. gossypii* infest the tender shoots and the under surface of leaves in very large numbers and suck the sap. Severe infestation results in downward curling of leaves. Black sooty mould develops on the honey dew of the aphids which falls on leaves (Triveni, 2017).

Wilt disease: It is most important disease of several medicinal and aromatic plants but in patchouli is very serious disease caused by *Fusarium solani*.

Symptoms: The prevalence of this disease is mainly during kharif season. The infected plants are characterized by gradual yellowing and drying of leaves followed by premature death. The plants show discoloration of roots and collar regions of fully grown plants. Severe disintegration of secondary roots surface is also observed. Singh and Angadi (1990) reported that *Fusarium solani* wilted plants of Patchouli symptoms were characterized by blackening of roots at collar regions of fully grown plants. Severe disintegration of secondary roots surface was also observed. Similarly yellowing of leaves were found in Alternaria blight of patchouli (Fig.14).

Host range: Leath and Kendall (1978) conducted experiments on host range of *F. solani* and showed the susceptibility of white clover and *Lotus corniculatus* to root rot pathogen. Cock foot and *Coronilla varia* were the most resistant while lucerne, red clover, subterranean clover and *Coronilla globosa* showed moderate reaction. Nielson and Mayer (1979) used *F. solani* causing root rot of stored sweet potatoes for studying the reaction with other crops. The results revealed that roots of the Cv. Jewel were more susceptible than those of jersey orange, georgia red, continental, nugget, fruits of apple, cucumber, egg plant, squash, tomato and potato which were susceptible. Moubasher *et al.* (1984) observed that *F. solani* and *F. oxysporum* were most common species infecting cotton, pea, wheat and tomato. Out of 16 different hosts treated for determining the host range of *F. solani,* black gram, green gram, bengal gram, tomato, brinjal, ladies finger, potato and guava were found to be susceptible. However, maize, peanut, linseed, sunflower, pigeonpea, soybean and safflower were free from infection (Kore and Patil, 1985). Patel (1991) reported considerable variation among 13 isolates of *F. solani*. Sharma and Agnihotri (1972) recorded morphological and pathogenic variation among three isolates of *F. orthocerus* App. & Wr.

Management

Essential oils of *Thymus vulgaris* L., *Lavandula angutifolia, Mentha piperita*, Neem oil, *Allium sativum* were tested in the

laboratory against *F. solani. T. vulgaris* was effective from a minimum concentration of 50 ppm. Mint and Lavender oils were only effective at higher concentrations (400-800 ppm). In the field, neem oil gave good protection against *F. solani* (Aulerio and Zambonelli 1997). Shivapuri *et al.* (1997) investigated that fungitoxic properties of different plant extracts against *F. solani* and other pathogenic fungi. Ethanol extract of *Allium cepa* L., *Allium sativum, Lantana camara* L., *Polyalthia longifolia* Benth and Hook, *Tagetus erecta* L., *Vinca rosea* L. and *Withania somnifera* showed fungitoxic effect against *F. solani*. The inhibitory effects of essential oils extracted from the genus Eucalyptus, *O.basilicum, Prosopis cineraria* and *Pongamia pinnata* were evaluated against *F. solani.* Among these oils extracted from the Eucalyptus species markedly inhibited fungal growth (Rai *et al.*1999). The effects of aqueous leaf extract of 5 medicinal plants *(Strychnos nux-vomica, Calotropis procera, Azadiracta indica,* A. Juss, *Ocimum sanctum and Allium sativum)* on the spore germination of five species of *Fusarium* viz. *F. solani, F. moniliformae, F. equiseti, F. acuminatum* and *F. oxysporum* were examined. Spore germination of all the fungi tested was completely inhibited by 100% aqueous extract of *A. indica* while only 20% of germination of spores was observed with treatment of 100% aqueous extract of *A. sativum* (Tripathi *et al.*1999). Leaf extracts of *L. camara* followed by *A. indica,* and *Acalypha indica* were found to be equally effective in inhibiting the growth of *F. solani in vitro*. Leaf extracts of *L. camara* has been reported to exhibit maximum toxicity against spore germination of *F. solani* (Mamatha and Ravishankar Rai 2004).

Sarhan (1989) observed that an isolate of *B. subtilis* antagonistic to *F. solani* in culture was found effective against root rot of Fabae beans in green house studies. Bacterium applied as a seed treatment significantly reduced seed colonization and root rot. *Bacillus subtilis* inhibited the growth of *F. solani* on potato dextrose agar and resulted in significant spore reduction due to production of toxic metabolites. Patel (1991) found that *T. harzianum* initially showed two mm inhibition zone of *Fusarium* sp. and later it overgrew the colony of pathogen. Fluorescent Pseudomonads (FPs) have received much attention in the last few years for their ability to suppress plant diseases especially those caused by soil-borne plant pathogens (Thomashow and Weller, 1990). Fluorescent Pseudomonads with potential antagonistic activity and *Trichoderma harzianum* strain THA were found to be highly effective and inhibited the growth of *F. solani* in dual culture (Zapata *et al.* 2001). Twelve isolates of *Trichoderma* obtained during survey from soils in dry root-rot affected acid lime gardens of Andhra Pradesh were evaluated for their variation in phenotypic characters, growth rate and antagonistic potential against *F. solani.* Out of 12 isolates, only two isolates (T2 and T4) showed very fast growth rates and the antagonistic potential (Kavitha *et al.* 2004).

Several techniques for evaluating fungicides have been described from time to time. Poisoned food technique is the most commonly practiced method for evaluating fungicides under laboratory conditions (Flack 1907). Six fungicides were evaluated in laboratory against mycelial growth and conidial germination of *Fusarium solani the* cause of decay in colocasia and yam. carbendazim was found to be the best fungicide among the tested, in disease control (Mishra and Rath 1987). Kapoor and Kumar (1991) reported that carbendazim and benomyl (500 mg a.i. /ml) were found to be most toxic to *Fusarium solani*. Etebarian (1992) found that iprodione and carbendazim totally inhibited fungal growth of *F. solani* at 10 ppm and 100 ppm concentrations. Wahid *et al.* (1995) concluded that Derosol (carbendazim) and benlate (benomyl) at 10 ppm completely

Table 5. Major fungal diseases of *Pogostemon cablin*

Disease	Causal Organism	References
Alternaria blight	*A.alternata*	Parameshwaran *et al.* 1987
Leaf spot	*Corynespora cassiicola*	Chen *et al.* 2010

inhibited the growth of *F. solani* which was isolated from soybean seed. Topsin-M and vitavax gave 100 percent inhibition at 50 ppm.

Integration of biological and chemical control seems to be a promising way of controlling many pathogens with minimum interference in the biological equilibrium in soil (Papavizas, 1973). Integration of chemicals and bioagents (*Trichoderma* Sp.) has been the subject of intense research during recent years (Chet, 1991).

Certain strains of *Trichoderma hamatum* and *T. pseudokoingii* are reported to be adapted to excess soil moisture, whereas *T. viride* and *T. polysporum* are restricted to low temperature conditions. *T. harzianum* is most commonly distributed in warm climate region, whereas *T. harmatum T. koningii* are reported to be distributed under diverse environmental conditions. Species of *Trichoderma* have been shown to be effective against wide range of plant pathogens, such as *Botrytis* sp., *Fusarium* sp., *R.solani*, *Scloritium rolfisii,* etc. Various mechanism of parasitism by *Trichoderma* sp. on different plant pathogenic fungi are reported to be varied such as inhibition by contact action, parasitism, hyphal interaction, coiling, penetration and lysis of hyphal cell, antibiosis and production of toxic metabolites etc. (Hriday 1991). Hartman and Fletcher (1991) reported *Trichoderma harzianum* to be efficient against *Fusarium* root rot of tomato.

Figure15. Yellow mosaic symptoms on *Pogostemon*

Viral Diseases (Table 6)

Patchouli is known to be infected by a number of viruses such as *Patchouli mosaic virus* (PaMV), *Tobacco necrosis virus* (TNV), *Patchouli mild mosaic virus* (PaMMV), *Patchouli mottle virus* (PaMoV), *Patchouli yellow mosaic virus* (PaYMV) and *Peanut stripe virus (*PStV) distributed all over world belonging different genera of the viruses.

Mosaic disease of *P. cablin* (Blanco) Benth. is widespread In India and has been reported by different workers. However the causal virus (es) was not fully characterized. A yellow mosaic disease has been reported on *P. cablin* (Blanco) Benth. From Lucknow (Zaim et. al 1999). The typical yellow mosaic appears when temperature is high during April to June

Table 5. Major viral diseases on *Pogostemon cablin* (Blanco) Benth. in India

S. No.	Viral Diseases	Genus	Transmission	References
1.	Yellow mosaic	--	Whitefly	Sastry and Vasentha kumar, 1981
2.	Patchouli mosaic	Potyvirus	Aphid & Mechanical	Subba Rao 1986
3.	Mixed infection of Patchouli	Potyvirus and Tobamovirus	Mechanical	Zaim *et al.*1999
4.	Peanut stripe virus (PstV)	Potyvirus	--	Singh *etal.*2009

(Fig. 15). These symptoms generally are masked during winter season. The Lucknow isolate of virus which is tentatively designated as patchouli yellow mosaic virus (PaYMV) was transmitted by sap and aphids. Host range was found to be restricted. The virus incited typical line pattern on the leaves of *Nicotiana benthamiana*, which is diagnostic host for this virus. Purified virus preparation showed flexuous rod shaped virus particles about 805 nm in length. The virus was detected by RT-PCR using potyvirus specific degenerate primers.

Nematode diseases : Root-knot nematode (*Meloidogyne incognita*, *M. javanica*, *M. hapla*) become most important constraint for the successful cultivation of patchouli in India.

Symptoms: Root-knot infested plants are weak and grow slowly. Heavy galling on root system with root knot nematode on patchouli results in stunting, wilting, defoliation and chlorosis of the plant. Sometimes root galls are very small or the surrounding galls coalesce to form large one up to 2-5 cm large even more. Infection of root-knot nematodes occurs when plants are in their early stage of development.

Causal organism and Host Parasite relationship:Root-knot diseases of patchouli caused by *Meloidogyne incognita*, *M. javanica*, *M. hapla.* Krishna Prasad and Reddy (1979, 1984) carried out the pathogenicity experiment and reported the threashold level of *M.incognita* on *P.cablin* was 4 larvae/g soil. They reported 46.7 and 52% loss in fresh and dry weight pf patchouli by *M.incognita*. They further reported that the multiplication of *M. incognita* was more in sandy soil on patchouli than clay soil. Dijwanti and Momota (1991) reported the association of *M. incognita*, *M. hapla*, and *Pratylenchus* brachyurus with *P. cablin* in West Jawa.

Symptoms of damage: Root knot infested plants are weak and grow slowly. Heavy galling on root system with root knot nematode on patchouli results in stunting, wilting, defoliation and chlorosis of the plant (Fig. 16). Sometimes root galls are very small or the surrounding galls coalesce to form large one up to 2-5 cm large even more. Infection of root-knot nematodes occurs when plants are in their early stage of development.

Figure 16. Root-knot nematode infested field of patchouli

Disease Management:
A large number of experiments were conducted to manage phytoparasitic nematode on patchouli. Krishnaprasad (1978) used aldicarb-sulfone, aldicarb-fensulphothion, carbofuran, cyerolan AC-92 and AC-100 @3.6 and 10kg a.i./ ha as pre and post inoculation treatment. Good control of *M. incognita* on patchouli was obtained by these chemicals. Sarwar *et al.* (1982) also conducted some experiment with fensulphothion, carbofuran, aldicarb, nemagon, metham sodium, fenamiphos to control root-knot nematode *M. incognita* on patchouli. Carbofuran was one of the most effective chemicals for *M. incognita* control. In other experiment effect of different oil seed cakes such as neem, pongamia and castor cake on plant growth and nematode population development was studied. Neem oil seed cake @4 tonnes / ha proved better than other oil seed


Eggs


Grub


Pupa


Adult

cakes for increasing growth and yield of the crop and reducing the *M. incognita* population. *Mucuna purita* as rotational crop with patchouli was found to be effective for reducing root-knot nematode population. Summer fallowing also proved to be a good method for reducing *M. incognita* population below threshold level. Kumar and Nanjan (1984) applied aldicarb, carbofuran or phorate @2-3 kg a.i. / ha to manage the *Helicotylenchus dihystera* on *P. patchouli.* Significant control of spiral nematode on this crop was observed and increase yield of crop was detected in all the treatment.

Ashwagandha (*Withania somnifera* (L.) Dunal): Ashwagandha (*Withania somnifera* L. Dunal), also known as Indian ginseng, belongs to the family Solanaceae, is an important ancient medicinal plant, used in the Indian traditional systems of medicine, ayurveda and unani. It is a widespread species having distributed from the southern mediterranean area to the different parts of Africa, India, Isreal, Jordan, Egypt, Sudan, Iran, Afghanistan and Pakistan. It grows in dry parts in sub-tropical regions. In India it is commercially cultivated in the states of Rajasthan, Punjab, Haryana, Uttar Pradesh, ujarat, Maharashtra, Tamil Nadu and Madhya Pradesh. The estimated annual production of ashwagandha roots in India is more than 2000 tonnes, against annual requirement of about 7000 tonnes (Patra *et al*. 2004).Ashwagandha is regarded as the treasure of biochemical constituents serving as remedy for many health problems. Roots contain several pyrazole alkoloids like withasomnine, withaferin A, withanolides, withaninol and steroidal lactones, starch and reducing sugars. Withaferin is the chief constituent (0.13 to 0.31%) havi
ng bacteriostatic and antitumerous properties. It is considered to be one of the best rejuvenating agents in Ayurveda (Farooqi *et al.* 2003). Its roots, seeds and leaves are used in ayurvedic and unani medicines. Roots are used for treatment of rheumatic pain, inflammation of joints, nervous disorders and epilepsy, and also used as tonic for hiccup, cold, cough and female disorders. The leaves are also useful for carbuncles, inflammation, swellings and conjunctivitis.

Insect pests of Ashwagandha, *Withania somnifera* (Table 7)

Spotted leaf eating beetle/Hadda beetle, *Henosepilachna vigintiotopunctata* (Fabricius) (Coleoptera: Coccinellidae)

Distribution: *Henosepilachna vigintioctopunctata* (Synonym: *Epilachna vigintioctopunctata* L.) is widely distributed in Southeast Asian countries, Korea, Australia, Sri Lanka, China, Japan including India (Kapur 1950, Richards 1983).

Host plants : The spotted leaf beetle is considered is a polyphagous pest and is considered as voracious foliage feeder of various cultivated and wild plants belonging to the families solanaceae (potato, brinjal, tomato, tobacco, *Datura* spp., *Physalis* spp., *Solanum nigrum*) and cucurbitaceae (melon, gourds, cucumber etc.) in different parts of India (Mohanasundaram and Uthamaswamy, 1973; Ghosh and Senapati 2001, Venkatesh 2006; Varma and Anandhi 2008). Spotted leaf beetle has been recorded as one of the major

Table 7. Insect pests of Ashwagandha, *Withania somnifera*

Common name	Scientific name	Order	Family	Pest Status	References
Epilachna beetle	*Henosepilachna vigintioctopunctata*	Coleoptera	Coccinellidae	Major	Mathur and Srivastava, 1964; Kumar *et al.* 2009; Chaudhary, 2013; Nirmal *et al.,* 2015; Rehaman *et al.,* 2018; Kumar *et al.,* 2009 b
Fruit borer	*Helicoverpa armigera*	Lepidoptera	Noctuidae	Major	Hanumanthaswamy *et al.,* 1994; Kumar *et al.* 2009 a; Kumar *et al.,* 2009 b; Chaudhary, 2013; Nirmal *et al.,* 2015; Rehaman *et al.,* 2018
Oleander hawk-moth	*Deilephila nerii*	Lepidoptera	Sphingidae	Minor	Hanumanthaswamy *et al.,* 1994; Nirmal *et al.,* 2015; Rehaman *et al.,* 2018
Metallic blue	*Corynodes peregrines*	Coleoptera	Chrysomelidae	Minor	Chaudhary, 2013
Snout beetle	*Cyrtozemia dispar*	Coleoptera	Curculionidae	Minor	Chaudhary, 2013
Weevils	*Myllocerus viridanus*	Coleoptera	Curculionidae	Minor	Hanumanthaswamy *et al.*1994
	Myllocerus discolor	Coleoptera	Curculionidae	Minor	Ramanna *et al.,* 2010
	Blosyrus inaqualis	Coleoptera	Curculionidae	Minor	Hanumanthaswamy *et al.,* 1994
Semi looper	*Hyposidra successaria*	Lepidoptera	Geometridae	Minor	Chaudhary, 2013
Til hawk moth	*Acherontia styx*	Lepidoptera	Sphingidae	Minor	Manjoo, 2006
Grass hopper	*Crotogonus trachypterus Acrida exaltata*	Orthoptera	Acrididae	Minor	Chaudhary, 2013
	Trilophida annulata	Orthoptera	Acrididae	Minor	Hanumanthaswamy *et al.,* 1994
	Phenoroptera gracilis	Orthoptera	Tettigonidae	Minor	Hanumanthaswamy *et al.,* 1994
Solenopsis mealybug	*Phenacoccus solenopsis*	Hemiptera	Pseudococcidae	Major	Chaudhary, 2013; Sharma and Pati, 2013; Kedar and Saini; 2015
Eggplant mealybug	*Coccidohystrix insolitus*	Hemiptera	Pseudococcidae	Major	Hanumanthaswamy *et al.,* 1994
Striped mealybug	*Ferrisia virgata*	Hemiptera	Pseudococcidae	Minor	Ramanna *et al.,* 2010
Citrus mealybug,	*Planococcus citri*	Hemiptera	Pseudococcidae	Minor	Attia and Awadallah, 2016
Mango mealybug	*Drosicha mangiferae*	Hemiptera	Margarodidae	Major	Sharma *et al.,* 2014 Bhagat, 2004; Kumar *et al.,* 2009 b
Aphids	*Myzus persicae*	Hemiptera	Aphididae	Major	Kumar *et al.,* 2009a; Kumar *et al.,* 2010
	Aphis gossypii	Hemiptera	Aphididae	Minor	Chaudhary, 2013; Rohini *et al.,* 2018
Tree hopper	*Oxyrachis tarandus*	Hemiptera	Membracidae	Minor	Ramanna *et al.,* 2010; Sharma and Pati, 2011
	Tricentrus bicolor	Hemiptera	Membracidae	Major	Kumar *et al.* 2009; Kumar *et al.,* 2010
	Tricentrus congestus	Hemiptera	Membracidae	Minor	Mitra and Biswas, 2002
	Otinotus oneratus	Hemiptera	Membracidae	Minor	Mitra and Biswas, 2002; Chaudhary, 2013
	Leptocentrus taurus	Hemiptera	Membracidae	Minor	Chaudhary, 2013;
	Leptocentrus substitutus	Hemiptera	Membracidae	Minor	Mitra and Biswas, 2002; Rehaman *et al.,* 2018;
	Gargara mixta	Hemiptera	Membracidae	Minor	Hanumanthaswamy *et al.,* 1994
Lantana bug	*Orthezia insignis*	Hemiptera	Orthezidae	Minor	Hanumanthaswamy *et al.,* 1994
Jassids	*Amrasca biguttula biguttula*	Hemiptera	Cicadellidae	Minor	Chaudhary, 2013
	Aconurella prolix	Hemiptera	Cicadellidae	Minor	Chaudhary, 2013
	Nephotettix virescens	Hemiptera	Cicadellidae	Minor	Chaudhary, 2013
	Balclutha incise	Hemiptera	Cicadellidae	Minor	Chaudhary, 2013
	Balclutha saltuella	Hemiptera	Cicadellidae	Minor	Chaudhary, 2013
	Penthimia sp.	Hemiptera	Cicadellidae	Minor	Hanumanthaswamy *et al.,* 1994
Spittle bug	*Poophilus costalis*	Hemiptera	Aphrophoridae	Minor	Mitra and Biswas, 2002
Lygaeid bugs	*Graptostethus servus*	Hemiptera	Lygaeidae	Minor	Chaudhary, 2013
Seed bug	*Spilostethus pandurus*	Hemiptera	Lygaeidae	Minor	Chaudhary, 2013
Seed bug	*Spilostethus hospes*	Hemiptera	Lygaeidae	Minor	Mitra and Biswas, 2002; Manjoo,2006; Rehaman *et al.,* 2018
Stink bug	*Aspongopus janus*	Hemiptera	Pentatomidae	Minor	Chaudhary, 2013;
	Nezara viridula	Hemiptera	Pentatomidae	Minor	Chaudhary, 2013; Nirmal *et al.,* 2015; Mitra and Biswas, 2002; Kumar *et al.,* 2009 b
	Plautia fimbriata	Hemiptera	Pentatomidae	Minor	Mitra and Biswas, 2002; Kumar *et al.,* 2009 b
	Agonoscelis nubila	Hemiptera	Pentatomidae	Minor	Mitra and Biswas, 2002
	Acrosternum gramineum	Hemiptera	Pentatomidae	Minor	Rehaman *et al.,* 2018

Black shield bug	*Dolicoris indicus*	Hemiptera	Pentatomidae	Minor	Rehaman *et al,* 2018
Red cotton bug	*Dysdercus cingulatus*	Hemiptera	Pyrhocoridae	Minor	Sharma *et al.,* 2014
Coreid bug	*Acanthocoris sordidu*	Hemiptera	Coreidae	Minor	Manjoo, 2006
Greenhouse whitefly	*Trialeurodes vaporariorum*	Hemiptera	Aleyrodidae	Minor	Kumar *et al.,* 2009 b
Whitegrub	*Holotrichia serrata*	Coleoptera	Scarabaeidae	Major	Meshram, 2005
Pea nut Trash bug	*Elasmolomus pallens*	Hemiptera	Rhyparochromidae	Minor	Rehaman *et al.,* 2018
Red Spider mite	*Tetranychu urticae*	Trombidiformes	Tetranychidae	Major	Gupta and Karmakar, 2011; Chaudhary, 2013; Sharma and Pati, 2012; Rehaman *et al.,* 2018
Mite	*Tetranychus macfarlanei*	Trombidiformes	Tetranychidae	Major	Gupta and Karmakar, 2011
Oriental red mite	*Eutetranychus orientalis*	Trombidiformes	Tetranychidae	Major	Gupta and Karmakar, 2011
Broad mite	*Polyphagotarsonemus latus*	Trombidiformes	Tarsonemidae	Major	Gupta and Karmakar, 2011
Mite	*Brevipalpus phoenicis*	Trombidiformes	Tenuipalpidae	Major	Gupta and Karmakar, 2011

pest of *Withania somnifera* causing severe foliage damage to crop (Mathur and Srivastava, 1964; and Ramanna *et al.* 2010).

Identification and Biology: The brownish hemispherical beetle has 28 lack spots on elytra (Fig. 17). The female lays elongate, spindle-shaped yellowish eggs in groups of 10 to 20 on the under surface of leaves (Fig.17). The gravid females lay 562–1500 eggs in several batches during the ovipositional period. The incubation period is 2-5days. The yellowish spiny grubs become full grown in 10-30 days and pupate on the leaf or stem. The grub passes through four instars (Venkatesha, 2006). The first instars feed gregariously on the foliage. The pupa is yellowish with spines on the posterior part, the anterior portion being devoid of spines. The pupal period is about 5-9 days under optimal conditions. The total life cylce is completed in 17 to 50 days depending on weather conditions. Male and female longevity has been recorded as 27–108 days and 37–108 days, respectively (Venkatesha 2006).

Nature of Damage: The grubs scrape the epidermal layer of leaves and in severe infestation the epidermis is entirely removed (Mathur and Srivastava, 1964). The nature damage by adult beetle is same as of grubs.

Gram pod borer, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae)

Distribution: *Helicoverpa armigera* is an important polyphagous pest widely distributed in the tropics, subtropics and warmer temperate regions of the world including India (CABI, 2020). This species is a well known important pest of pulses and cotton in India.

Host Plants:*Helicoverpa armigera* is polyphagous in nature and feeds on various agricultural crops. The important host plants of *H. armigera* are gram, pigeon pea, tomato, maize, cotton, okra etc. The pest also feeds on many weed species during off season.

Identification and Biology: The moth is medium sized and with 30-38 mm wing span, V-shaped speck on the light brownish forewings and a dark border on the hindwings (Fig. 18). Sexual dimorphism is distinct, male moth is light brown and female is dark brown. The female moth lays 600-1000 spherical yellowish white eggs singly on the tender parts of plants. Incubation period varies from 3-10 days depending on the weather conditions. Caterpillar has six growth stages (instars) takes 18-25 days to fully develop. The full grown caterpillar measures about 35-45 mm in length and is greenish with dark grey lines laterally on the body. The egg, larval and pupal periods is 2-4, 18-25 and 6-21 days, respectively. The caterpillar passes through five to six instars.

Fig. 18. *Helicoverpa armigera*

Under optimal conditions the pest completes 11 generations in a year.

Nature of damage: The larvae feed on tender foliage, flowers and later instars damage the berries. They bore circular holes in berries of *Withania somnifera* keeping the head portion inside the hole to eat the inner content (Rehaman *et al.* 2018).

Solenopsis mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae)

Distribution: *Phenacoccus solenopsis* was originally described from USA in 1898 (Tinsley 1898). *P. solenopsis* is distributed over a wide range of agro-ecological zones in more than 24 countries worldwide including India (Fand and Suroshe 2015).

Host plants:*P. solenopsis* is highly polyphagous in nature damaging over 202 plant species of 55 families across the globe comprising field crops, vegetables, ornamentals, fruit trees, medicinal and weeds. Most of the host plants belonging to plant families Malvaceae, Solanaceae, Asteraceae, Euphorbiaceae, Amaranthaceae and Cucurbitaceae. The pest causes severe damage to cotton followed by okra, brinjal, tomato, sesame, sunflower and China rose. The wild host plants supports carryover of the pest from one season to other season (Fand and Suroshe, 2015, Kedar and Saini 2015). The incidence of *P. solenopsis* as major pest on *Withania somnifera* has been recorded by several workers in India (Vennilla *et al.* 2011; Sharma and Pati 2013, Kedar *et al.* 2013; Sahu *et al.* 2017).

Identification and Biology: The mealybug is cottony in appearance, small, oval, soft-bodied covered with white mealy wax (Fig.19). Adult females are wingless, 2.5-4.0 mm long with 9 segmented antennae and long flagellate dorsal setae. Short filaments around the body and dark stripes on the dorsal side are present. The anal filaments are about one fourth the length of the body. Females produce egg mass in an ovisac.

Figure 19. Solenopsis mealybug, *Phenacoccus solenopsis*

Males have one pair of wings, long antennae and absence of mouth parts with white wax filaments projecting posteriorly (Kedar *et al.,* 2013). The developmental period of first, second and third instars are 3-4, 5-8 and 4-5 days, respectively. Males have an additional pupal stage of 5-7 days. The total developmental period is 13-15 days for female and 18-19 days for male. Reproduction is parthenogenetic and ovoviviparous (Kedar *et al.* 2013). A female may produce 120-800 crawlers and duration of reproduction varies from 10 to 47 days. Life cylce of female mealybug is completed in 25-38 days and male mealybug in 17-27 days (Kedar *et al.* 2011). The mealybug completes 15 generations per year.

Nature of Damage:*P. solenopsis* nymphs and adults suck the sap and once established on a plant often remains there till the attacked parts get dried up, causing even death of the whole plant. When the attack is in the vegetative phase, the plants remain stunted; the attacked parts gradually dry up; and the plants bear few or no fruiting bodies. The pest secretes large amounts of honey dew which fall on the underlying plant parts and sooty mould develops on them causing their blackening. The development of sooty mould reduces the photosynthetic ability of the plants.

Eggplant mealybug, ***Coccidohystrix insolitus*** (Green)**, (Homoptera: Pseudococcidae)**

Distribution : The eggplant mealybug, *Coccidohystrix insolita* (Green) is broadly distributed in the tropics and subtropics and well known as a agricultural and horticultural pest (Lit *et al.* 1998, Williams 2004, Williams and Watson 1988).

Host plants:*Coccidohystrix insolitus* is polyphagous and recorded on host plants belonging to families *Solanaceae, Fabaceae, Malvaceae, Amaranthaceae, Cucurbitaceae,*

Figure20. Eggplant mealybug, *Coccidohystrix insolitus*

Acanthaceae, etc. (Ben-Dov 2020).

Nature of Damage: Nymphs and adults of mealybugs suck sap from the under surface of leaves and tender shoots (Fig.20). The attack results in yellowing and sometimes dying of plants. A heavy black sooty mould may develop on the honeydew like droplets secreted by mealybugs.

Red spider mite, ***Tetranychus urticae*** **Koch (Trombidiformes: Tetranychidae)**

Distribution : Red spider mite emerged as a serious pest of eggplant, tomato, French bean, okra, cucumber, rose and other field crops in South Asia, Southeast Asia, Africa, Europe, and Mediterranean countries. On *Withania somnifera* the damage of *T. urticae* has been reported by several workers from different states of India (Gupta and Karmakar 2011; Chaudhary 2013, Sharma and Pati 2012; Rehaman *et al.* 2018).

Identification and Biology: They are minute in size, and vary in color (green, greenish yellow, brown, or orange red) with two dark spots on the body (Fig. 21). Reddish spherical eggs are laid on an average 100 eggs by a female. After hatching it passes through a larval stage and two nymphal stages (protonymph and deutonymph) before becoming adult. Newly hatched larva is pale

Figure 21. *Tetranychus urticae* a) adult; b) nymphs; c) egg

white. At the deutonymph sex can be distinguished, males being smaller and females larger with darker colour. Life cycle is completed in 5 to 12 days and in a year about 40 generations are completed.

Nature of Damage: The incidence of mites is observed during the warm and dry periods of the season. It is generally found on the under surface of the leaves but, in heavy infestations, it may be found all over the leaf surface. Nymph and adult mites punctures the leaf tissue and oozing plant sap is sucked. The removal of plant sap with chlorophyll and other plants pigments results in the characteristic blotching of leaves. The affected leaves become mottled. Mite infested plants can be diagnosed from distance by characteristic mottling symptoms produced on the upper surface of the leaves. Under severe infestation, the mites move to the tip of the leaves or top of the plant and congregate using strands of silk to form a ball like mass, which will be blown by winds to new leaves or plants, in a process known as "ballooning".

Green peach aphid, *Myzus persicae* (Sulzer) (Hemiptera: Aphididae)

Distribution : *Myzus persicae* is of Asian origin distributed over Africa, America, the Caribbean, Europe, Ocenaia, Aurtralia, Fiji, New Zealand etc. It occurs everywhere in the world except where there are extremes of temperature or humidity

Host plants :*Myzus persicae* is highly polyphagous on summer host plants. Infestation of green peach aphids has been reported hundreds of host plants in over 40 plant families including *Withania somnifera* (Blackman and Eastop 2007, Kumar *et al.* 2009).

Identification and Biology;Green peach aphid adults are about 2 mm long, greenish-yellow or pink, with red eyes. Adults may be winged or wingless (Fig.22). Winged aphids have a black head and thorax and a yellowish green abdomen with a large dark patch dorsally. The nymphs are similar to the wingless adult, except in size. Eggs are initially yellow or green but soon turn black. Nymphs are initially greenish but soon turn yellowish, greatly resembling viviparous (parthenogenetic, nymph-producing) adults (Margaritopoulos *et al.* 2002). In tropical countries, male do not exist. Females reproduce parthenogenetically. The life cycle is completed in about 12-18 days. There are about 20 generations of the pest per year.

Nature of Damage;Nymphs and adults of aphids feed on the young foliage of *W. somnifera* and stems during December to March in North Indian conditions (Kumar et al. 2009). They suck the cell sap from tender

Figure 22. *Myzus persicae*

shoots which often results in drying out shoots, causing wilts and distortion. Aphids produce honeydew which falls onto foliage and which leads to black sooty mould fungi development. The development of sooty mould reduces the photosynthetic ability of the plants. *M. persicae* is most important aphid virus vector. More than 100 plant viruses have been reported to be transmitted by *M. persicae.*

Management of insect pests of *Withania somnifera:* Ayyar (1984) suggested hand collection and destruction of egg masses, larval and adult stages of epilachna beetle in the field could be useful for control the pest population effectively. Venkatesha (2006) reported 51.91 per cent population of *H. vigintioctopunctata* was naturally controlled by a larval parasitoid *Pediobius foveolatus* in Karnataka province of India. Chandrananth and Katti (2010) evaluated six insecticides under field conditions for management of epilachna beetle, and recommended dimethoate 30EC (1 ml/litre), fenvalerate 20EC (0.5 ml/litre) and quinalphos 25EC (2 ml/litre); whereas less effective insecticides included chlorpyriphos 20EC (2 ml/litre), endosulphan 35EC (2 ml/litre) and neem seed kernel extract 5% (NSKE 5%). They reported least epilachna beetle population (4.3 beetles/plant) in treated plot compared to 14.9 beetles/plant in untreated plot of *Withania somnifera*, with highest root yield of 4.60 q/ha (3.20 q/ha in the untreated control plot).

To check the fruit damage from feeding of *Helicoverpa armigera* on *Withania somnifera* Rehaman and Pradeep (2016) evaluated organic insecticides in a field trial and found highest per cent reduction of *H. armigera* infestation with Ha NPV (250 LE), which was on par with nimbicidine (3 ml/L) followed by NSKE (5 %) and neem oil (5 ml/L).

Ravikumar *et al.* (2008) reported soil application of NO (3%) in a mixture of farm yard manure (12.5 t/ha) and a commercial biofertilizer Azophos (containing a mixture of azospirillum and phosphobacteria) at 2 kg/ha resulted in significant reduction in damage caused by mealybug, *C. insolitus* and epilachna beetle, *H. vigintioctopunctata*.

Mealybug, *Phenacoccus solenopsis* management primarily depends on the use of chemical insecticides. Commonly used insecticides for managing mealybug infestations included profenophos, monocrotophos, malathion, quinalphos, methyl demeton, triazophos, dichlorvos, acephate, acetamiprid, imidacloprid, thiamethoxam, alphamethrin, buprofezin, cypermethrin, deltamethrin, endosulfan and chlorpyriphos (Nagrare *et al*. 2011, Kumar *et al*. 2012). Biocontrol agents are successful means of suppressing invasive mealybugs providing a non-toxic, self-perpetuating control method. Several predators and parasitiods have been reported that feed on *P. solenopsis* (Fand *et al.* 2010; Kedar *et al*. 2011; Suroshe *et al*. 2013). Over 88 per cent natural parasitization of *P. solenopsis* population by solitary endoparasitoid *Aenasius arizonensis* (=*Aenasius bambawalei*) has been reported from different agroecosystems by several workers (Ram *et al.* 2009, Dhawan *et al*.,2011, Kedar *et al*. 2012). For suppression of the *P. solenopsis* several findings revealed conservation of parasitoid, *A. arizonensis* prior to applying chemical insecticides (Ram *et al.* 2009). Nagarare *et al.* (2011) reported 45-60 per cent mortality of *P. solenopsis* caused by entomopathogenic fungi viz., *Verticilium lecanii* (Zimm.), *Beauveria bassiana* (Bals.) and *Metarhizium anisoplae* (Metchnikoff) under laboratory conditions.

Hirekurubar *et al.* (2018) evaluated the bio efficacy of different insecticides and acaricides viz., acetamiprid 20SP, thiamethoxam 25WG, spiromesifen 240SC, difenthiuron 50WP, azadirachtin 1500 ppm, NSKE 5 per cent, dimethoate 30 EC and dicofol 18.5EC against red spider mite, *Tetranychus urticae* infesting *Withania somnifera*. Significant reduction in red spider mite population was noticed in plots sprayed with acaricide spiromesifen 240SC (1

ml/l) followed by difenthiuron 50WP (0.75 g/l) and dicofol 18.5 EC @ 2.50 ml/l. Spiromesifen sprayed treatment registered maximum root and seed yield.

Myzus persicae (Hemiptera: Aphididae) is a major pest of young shoots (Kumar *et al.,* 2009). Meena *et al.* (2016) evaluated bio-efficacy of some botanical products against mixed population of aphids (*Myzus persicae*, *Hyadaphis coriandri* and *Aphis craccivora*) on coriander. The highest reduction in aphid population was recorded in the plots treated with organic salt (bio-product 5ml/l) followed by karel extract 10ml/l and tumba fruit extract 10ml/l.

Fungal diseases: Root-rot and wilt is one of the most important disease of this crop in the nurseries and commercial field ashwagandha growing areas of Uttar Pradesh. The diseases occur during April-May and caused 30-50% mortality of plants (Gupta *et al.* 2004). The disease is caused by *Fusarium solani*.

Diagnosis: Many fungi can cause root rots. Often, it is possible to identify which fungus is responsible either by observing the structure of the fungus in the roots using a microscope or by placing infected roots on artificial media or baits (apple, carrot, or potato pieces) and allowing the fungus to grow out where it can be detected and then identified.

Symptoms: The major symptoms of the disease is withering and drooping of plants whereas at advance stage it causes severe wilting leading to decomposing and death of underground parts. The cottony growth appeared around the infected roots under moist condition. The infected roots become soft and brown in colour.In addition to killing plants and thereby reducing the quantity of saleable crop, root rots can also slow or stop plant growth and thus suppress plant quality. Root-rotted plants are usually smaller, less vigorous, produce fewer and/or small leaves, flowers, and fruit than healthy plants of equal age. Flowering may be delayed when the plant's roots are rotted. As a result, the crop quality is very uneven. Root rots must be managed early in the disease if the losses are to be avoided.

Symptoms of Root Rot

- Growth of infected plants slows as compared to healthy plants.
- Older leaves yellow and fall.
- Margins of leaves die.
- Roots appear dark brown or black and few or no white roots or root tips can be found when the root ball is washed free of soil
- Roots are limp and not brittle and crisp as is found in healthy plants of all types.
- When plants are pulled from the potting mix, the outer layer of cells strips off the roots leaving only the central strand of water conducting tissue.

Management

Many effective pesticides have been tested against soil borne pathogens but not considered as long term solution because of concerns about exposure risks, health and environmental hazards, expensiveness, residue persistence, development of resistance to pesticides and elimination of natural enemies. The disease root rot and wilt complex of ashwagandha is caused by soil borne pathogens. In nature, plants are rarely exposed to the influence of single pathogen. Fawcett (1931) recognized that “nature does not work with pure cultures' and that many plant diseases are influenced by associated organisms. Before any action is taken, a diagnosis must be made of the actual cause of the symptoms. If the damage is due to the activity of fungi, chemicals are sometimes available which can check the fungus and allow the plant to grow. The dead roots do not recover. New roots must grow. The fungus is usually not completely eradicated (killed) by chemicals. Some fungus usually remains alive although its growth is greatly slowed as long as the fungicide is in high enough concentration. Therefore, repeated applications of fungicides

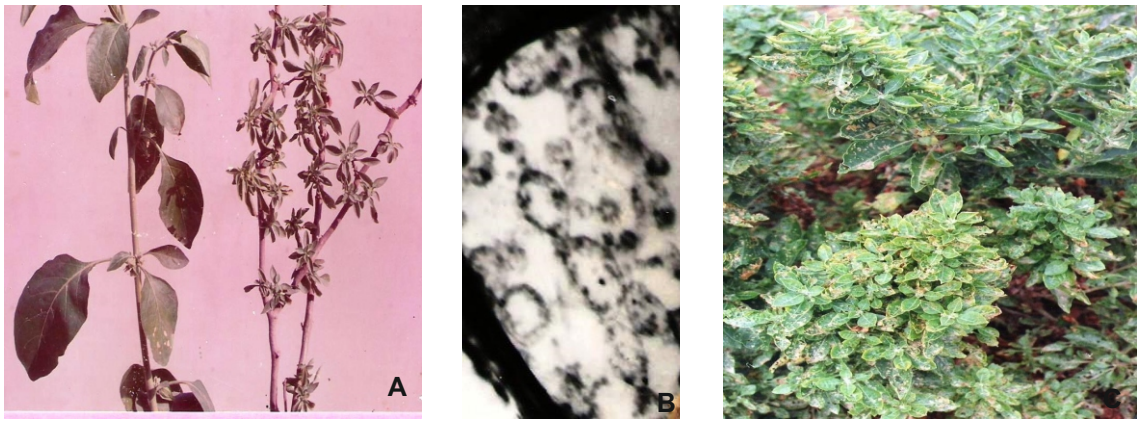

Fig.23. Phytoplasma infected plant along with healty (**A**), electron microscopy of Phytoplasma infected *W. somnifera* (**B**), and field view of naturally infected plants (**C**).

are necessary.

Phytoplasma disease: In CIMAP, Lucknow the Witches broom disease was first observed in 1988 and more than 30% plants were affected by this disease.

Symptoms: This disease was reported for the first time from Lucknow (Zaim and Samad 1995). The succession of symptoms appearance include, little leaf, phyllody, dense clusters of highly proliferating branches with shortened internodes resulting witches'-broom and bushy appearance of infected plants (Fig 23 –A, B & C).

Causal organism: In subsequent studies *Withania* phytoplasma was found to be PCR amplified using universal primers, designed from the 16S rDNA sequences of phytoplasmas and sequenced. Nucleotide sequence data and phylogenetic studies suggested that the *Withania* phytoplasma be assigned to the Aster yellows group (Khan *et al.* 2006). In another studies the *Withania* phytoplasma was detected by PCR using by universal phytoplasma primers P1/P6. Upon sequencing, the PCR product showed highest similarity with several isolates of the 16SrVI group of phytoplasmas and classified as a member of Clover proliferation group (16SrVI) (Samad *et al.* 2006). Other viral and phytoplasma diseases of *Withania somnifera* have been given in table 8.

Table 8. Major viral & phytoplasma Diseases on *Withania somnifera* (L.) Dunal in India

S. No	Name of Diseases	Causal agent	Host	References
1.	Witches-broom disease	Phytoplasma	*W. somnifera*	Zaim and Samad 1995
2.	Little leaf disease	*Phytoplasma*-Aster yellows group/Genus	*W. somnifera*	Khan *et.al* 2006
3.	Witches-broom disease	Phytoplasma-Clover proliferation group	*W. somnifera*	Samad *et.al.*2006
4.	Tobacco leaf curl virus	--	*W. somnifera*	Pathak and Raychou-dhuri , 1967
5.	A yellow mosaic disease	*Begomovirus*	*W. somnifera*	Baghel *et al.* 2010

Nematodes of Ashwagandha:

Root-knot disease of ashwagandha caused by the root-knot nematode *Meloidogyne incognita* (Kofoid and White) Chitwood, is very widespread affecting more than 80% plants in India (table 8). *R*ace identification was done using host differential test and was identified as race-2 (Pandey and Kalra 2003). Nematodes were multiplied on roots of tomato and pathogenicity of *M. incognita* was confirmed on 10-day-old potted plant of *W. somnifera*. Large number of other phytoparasitic nematodes were found to be

Table 9. Loss in total alkaloids in healthy and root-knot infested roots of *Withania somnifera* *

Treatments	Alkaloids (%)
Healthy root	0.32
M. incognita severely infested roots	0.11

associated in root rhizosphere of ashwagandha.

Symptoms of damage: The nematode infected plants typically show chlorotic, stunted, less branched with fewer and smaller leaves and poor response to fertilizer and irrigation. Such symptoms usually are not noticeable until severe damage to root system has been done by the nematodes. Roots of such plant were severely galled. When stem touches the soil it was also found to be infested with root-knot nematode *Meloidogyne incognita*. It was also noticed that root-knot nematode infected plants are more likely to be killed early with adverse effect of environment than healthy noninfested plants.

Control measures: Management studies were carried out (Pandey and Kalra, 2003) through the use of different organic materials and bioagent on growth/ yield of *W. somnifera* and nematode reproduction. In the experimentation neem compound, *Artemisia annua* marc, *Mentha* and *Murraya koenigii* distillates were found highly useful to suppress the root-knot development and *M. incognita* population on *W. somnifera*. Bio-agents however were found less effective as compared to organic materials on *W. somnifera*; may be due to host reactions towards the bio-agents. Integration of Vermicompost with *Trichoderma harzianum* and *Mentha* distillates with *Glomus aggregatum* were found nematode suppressive and enhanced the growth of *W. somnifera* significantly. It was concluded that neem compound, *A. annua* marc, vermicompost and their integration with bio-agents can be an important way for nematode management, which could pave the way in future for integrated nematode management programme on agricultural and commercial crops.

Use of bio-organics (organic materials, bioagent) is a potential alternative to the environment detrimental chemical nematicides, which are generally used to restrict nematode infestation in agricultural crops. Pandey and Kalra (2011, In press) used different bio-organics viz. farm yard manures (Fym), cow urine, neem cake, vermicompost, *Trichoderma harzianum* separately and in dual combinations against root-knot disease of *Withania somnifera* and successful management of root-knot nematode on this crop were achieved.

Henbanes (*Hyoscyamus* species)

Henbanes (*Hyoscyamus muticus*, *H. niger* & *H. albus*) are important tropane alkaloid bearing plants belonging to family Solanaceae and one of the chief source of tropane alkaloids viz. hyoscine or scopolamine, hyoscyamine and atropine which are obtained from the dried leaves and other plant parts (Table 7). The hyoscine and its derivatives are used in pharmaceutical preparations, since they have

Table 10. Insect pests of Henbane

Common name	Scientific name	Order	Family	Pest Status	References
Henbane Flea Beetle	*Psylliodes hyoscyami*	Coleoptera	Chrysomelidae	Major	Parfentjev, 1921; Newton, 1934
Colorado potato beetle	*Leptinotarsa decemlineata*	Coleoptera	Chrysomelidae	Minor	Hsiao, 1978; Hubert, 1950
Three-lined potato beetle	*Lema trilineata daturaphila*	Coleoptera	Chrysomelidae	Minor	Kogan and Goeden, 1970
Bordered straw moth	*Heliothis peltigera*	Lepidoptera	Noctuidae	Minor	Zacher, 1921; Shchegolev, 1929; Printz, 1925
Green peach Aphid	*Myzus persicae*	Hemiptera	Aphididae	Major	Singh *et al.,* 1988
Potato psyllid	*Bactericera cockerelli*	Hemiptera	Triozidae	Minor	Knowlton and Thomas, 1934
Belladonna leaf-miner	*Pegomyia hyoscyami*	Diptera	Anthomyiidae	Minor	Cameron, 1914

anticholinergic, antiphasmodic and mydriatic properties. Leaves, seed and flowering tops of the plant are used in respiratory diseases and old cough. These plants originated in Egypt and spread to rest of the tropics. The two species of henbane i.e. black henbane (*H. niger*) and Egyptian henbane (*H. muticus*) are widely cultivated for pharmaceutical purposes.

Insect pests of Henbane

Incidence of insect pests in *Hyoscyamus* spp. is not as severe as in other medicinal and aromatic crops. However, a number of insect pests have been observed to damage the crop growth to variable level depending on climatic conditions and crop management practices (Table 9).

Henbane Flea Beetle, *Psylliodes hyoscyami* Linn. (Coleoptera: Chrysomelidae)

Distribution : Palaearctic, including the Middle East and North Africa. Widely scattered in England, South Wales and Scotland (West Lothian).

Host plants:*Hyoscyamus niger*, *Atropa Belladonm* (Van Emden 1924).

Identification and Biology: Adult is 2.9-3.5mm in length, blackish with blue-green or dark bronze reflection; may appear metallic green or bronze, sometimes coppery or blue-green. The egg is oval, yellowish white in colour with a deeper yellow equatorial band in the later stages. The full-fed larva is of the same general appearance and elongate form as other flea-beetle larvae. The body colour is white with the head dark brown, prothoracic shield, anal shield and legs light brown. The pupa is of the typical flea-beetle form. It is white in colour. The female lays eggs in the soil which hatch about in 2 weeks. The larval stages passed within the plant leaf-stalks mines. The prepupa constructs the usual earthen cell, lining the inside surface with a cementing secretion. The majority of the pupae lie between 5 and 7.5 cm. deep. Pest is active during May to November (Newton 1934). Adults hibernating in the grass bordering the field during the winter. Generally, only one generation completed per year

Table 11. Major fungal and bacterial diseases of *Henbane* sp.

Disease	Causal Organism	References
Alternaria leaf spot	*Alternari alternata*	Pandey and Nigam, 1985
Myrothecium leaf spot	*Myrothecium roridum*	Maharshi 1986
Soft rot	*Pseudomonas cichorii*	Sattar et al. 1981
Wilt	*Fusarium solani*	Thakur et al. 1974
Xanthomonas blight	*Xanthomonas compestris pv. turf*	Sattar and Alam, 1996

Nature of Damage : Adults feed on leaves, larvae mine leaf-stalks (petioles) and leaf-blades. The central pith of the main stem is also invaded and some larvae also infest the tap root. In severe infestation the stem is completely hollowed out

Management

- Crop rotation
- Early harvesting in June month.

Fungal diseases (Table 11)

Leaf spot : This is an important disease and first time reported in the state of Jammu and Kashmir caused by *Ascochyta kashmiriana* (Ganguli and Pandotra, 1962) Leaf spot also caused by *Alternaria alternata* on Egyptian henbane (Kumar *et al.* 1984). This disease appeared during cultivation in the month of January, February and March.

Symptoms: On infected leaves several irregular brownish spots occurs and later on these spots enlarges in size and become big spots. The infected leaves generally defoliated prematurely and consist of spores. These spores are the major source of perpetuation of the disease.

Management: Spraying of Dithane M-45 (0.3%) or Kavach (0.2%0 at an interval of 15 days minimizes the disease severity and incidence.

Viral Diseases: Diseases caused by different isolates of viruses on henbane belong very diverse genera. Among the first viruses reported to cause diseases on hebane are Hyoscamus virus II, Hyoscamus virus III and Hyoscamus virus I, (Hamilton, 1932). Later number of diseases had been reported to caused by viruses belonging to genus; *Tobamovirus, Cucumovirus, Tospovirus, Potexvirus, Tobravirus* etc. (Table 11).

A cucumber mosaic virus isolate was found to be associated with green mosaic disease of *H. niger* L. Based on host range, symptomatology, mode of transmission, biological properties, electron microscopy and serology, it was found to be an isolate of cucumber mosaic virus. The disease still is prevalent. The virus was transmitted by aphid, *Myzus persicae* Sulz, the virus was isometric, 27 nm in diameter and it reacted with the antiserum of CMV9ATCC, PVAS-30)

Tomato spotted wilt virus (TSWV) belong to genus *Taspoviruses*. TSWV had been found to cause a mild mosaic disease in *Hyoscyamus muticus* L (Zaim, 1999). It had diagnostic host as Vigna unguiculata CV.152 which produced Chlorotic spots on inoculated leaves. Biological properties and electron microscopy of ultrathin sections of infected *H. muticus* leaves exhibited the typical Tospoviruses sorounded by endoplasmic reticulum inside cytoplasm. Purified virus preparation spherical virus particles about 87 nm in diameter.

A cucumber mosaic virus isolate was found to be associated with mottle crinkle and severe mosaic disease of Egyptian henbane (*Hyoscyamus muticus* L.). The virus has been characterized as an Indian isolate of cucumber mosaic virus (CMV) based on non-persistent transmission by aphid, presence of 28-nm isometric particles, capsid protein of 26 K and single-stranded tripartite RNA genome with a subgenomic RNA (RNA 4). There was no evidence of satellite RNA genome. The isolate showed a strong serological relationship with S and A strains of CMV (CMV-S and CMV-A) in double diffusion test. A band of the 26 K capsid protein was also detected by Western blot analysis using antibodies specific to CMV-S.

Nematodes of Henbane:

Large number of plant parasitic nematodes viz. *Tylenchorhynchus vulgaris, Pratylenchus thornei, Hoplolaimus indicus, Longidorus pisi* and *Meloidogyne* sp. have been reported to be associated with different species of henbane but the nematode which has been reported to cause serious damage to the crop is root-knot nematode (*Meloidogyne* spp.). Root-knot nematode causes poor growth of the seedling establishment and leads to significant decrease of the herbage yield of the plant (Figure 24).

Root-knot nematodes of henbane: The different species of *Hyoscyamus* are found to be heavily infested with root-knot nematode, *M. incognita* & *M. javanica*, which cause significant damage to the crop (Pandey, 1990).

Symptoms of damage: In the field the root-knot infested plants of *Hyoscyamus muticus*, *H. niger* & *H. albus* show chlorosis, stunted plant growth, a patchy appearance fewer smaller leaves and flowers. The roots of infested plants depict severe galling of various degrees. Experiments carried out in CIMAP indicate that even 3-4 larvae/g soil cause significant damage to the crop (Haseeb and Pandey 1989).

Control measures:

In the control programme of root-knot nematode the major attention has been paid to protect the young seedlings. Reduction of nematode population in soil prior to sowing is very important to avoid the poor plant growth. Pre-sowing measures to suppress root-knot nematode population include rotation with non host crops, fallowing, green manuring, organic amendments and application of some nematode antagonistic organisms.

Growing of non host crop such as *Cymbopogon flexuosus, C. winterianus,* and *C.*

martinii can reduce the incidence of damage caused by root-knot nematode. Marigold (*Tagetes spp*) are one of the most highly studied crops for its ability to suppress nematode population with antagonistic phytochemical in root exudates i.e. polythienyls. Therefore prior to sowing henbanes, it is very important to grow *Tagetes minuta* at the distance of 30 X 30 cm which drastically reduced the phytonematode population (Pandey 2011 Unpublished).Removal of weed host of root-knot nematode from the field is an integral part to avoid the infestation of root-knot nematode as the susceptible weed hosts may serve as a reservoir for root-knot nematode inoculum. Avoiding the general practice of irrigation of noninfested field with water from infested field, will help to restrict *Meloidogyne* sp. population spreading from one field to another.

Certain crops resistant to root-knot nematodes could be used in rotation with henbanes to reduce the root-knot nematode population. However population explosion renders the practice of fallowing not possible due to increased economic pressure on agricultural land. Experiment has been carried out at Central Institute of Medicinal and Aromatic Plants, Lucknow and its resource canters to screen large number of tetraploid henbane species but none was found to be resistant to root-knot nematodes. Chemicals such as carbofuran (@2kg a.i./ha soil)and monocrotophos (@0.1% SS) have been used to prevent root-knot nematode infestation to henbane. Monocrotophos can be used for seed soaking whereas carbofuran is preferred prior to sowing the seeds of the crop. It helps up to some extent to eliminate the root knot nematode infestation.The harvesting period of this winter crop is only four months, sowing daicha as green manuring crop can be used which decreases nematode population below the economic damage levels.

Biological control: Some ecofriendly approaches have also been made to manage this important pest on these plants. In one of the experiment Pandey *et al.* (1999) observed that the plants with inoculum of different mycorrhizal fungi showed better growth in comparison to untreated - *M. incognita i*noculated and untreated-uninoculated one.

The best results were obtained with *Glomus aggregatum* for increasing growth/ biomass of plants and reduction in root-knot nematode population. For example in *Hyoscyamus niger* the nematode population was observed maximum in nematode alone inoculated plants than plants inoculated in combination of nematode and bio-inoculants resulting significant reduction of *M. incognita* (Mi) population especially in combined treatment followed by *Pseudomonas florescens* (Pf) or *G. aggregatum* (Ga) inoculated treatments. Thus, the degree of losses in biomass

Figure 24. Healthy & root-knot infested plant and roots of Egyptian henbane (*H. muticus*)

production caused by Mi in combination with the bio inoculants were significantly reduced over the losses observed with Mi alone. Among the four combined inoculations, a combination of all the four with Mi appeared to be the best followed by GA or Pf. Root colonization and spore population of VAM-fungi was observed 16 weeks after inoculation. Maximum spore population and percent root colonization was observed in combined treatment, which was followed by GA, Gm and Gf. It is worth mentioning here that root colonization was found directly proportional to spore population and biomass yield from the crop. Experimental findings indicated that application of bio-inoculants have not only enhanced the total biomass yield of *H. niger* but it have also significantly decreased the multiplication of nematode, however, a significantly higher reduction was recorded in the treatment where all bio-inoculants are combined . This may be attributed to the fact that these bio-agents may be secreting potent chemicals which are either non favorable for multiplication of Mi or inducing tolerance in the plant against the attack of root knot nematodes. Nematode reproduction was higher in plants inoculated with nematode alone than in plants with combined inoculation of nematodes with bio-inoculants. Thus, experimental evidences indicated that mixed inoculation of rhizobacterium with VAM fungi could be considered as biological management instead of nematicides for reducing the deleterious effect of root knot disease in black henbane. Similar results were also obtained with different bio-agents in *H. muticus* plants (Pandety 1997c, Pandey *et al.* 2000c).

Essential oils were also used in another experiment to manage root-knot nematode population in *H. niger* (Pandey *et al.* 2000a). It was observed that oils of *Cymbopogon martinii, C. wintrianus, Ocimum basilicum* and *Mentha arvensis* were quite effective in reducing *M. incognita* population and improving the growth of plant; the oil of *C. martinii* (@2ml/pot) being most effective.

Summary

The cultivation of medicinal and aromatic plants has considerably increased in tropical and sub tropical countries of the world to meet the requirement of pharmaceutical and perfumery industries. The disease caused by variety of pest and pathogen is a major limiting factor for its production. Although chemical control of pest and pathogen has proved effective, but it can not be recommended to the farmers because of cost, harmful effect on human and animal health and its percolation in ground water resources. Other alternatives are available in medicinal plants like resistant germplasms, useful organic materials, effective biocontrol agents and other cultural/physical methods of disease management. Such resistant and tolerant germplasms could be exploited in future plant breeding programmes for developing resistant/ tolerant genotypes against major pest and pathogens. Various organic materials are available which has been proven useful to decrease disease incidence and enhanced medicinal and aromatic plant yield could be used in ongoing programmes for better healthy plants. Large number of bio agents is available which could be used on large scale to save medicinal and aromatic plants against various pest and pathogens. Based on the contribution added to the science of mycology, virology and nematology in relation to medicinal and aromatic plants, CIMAP plant pathology, virology and nematology labs have been placed in national and international records. However much attention also is needed to study and develop some new strategy to mange major diseases in ecofriendly way, which should be cost effective and environmentally friendly

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REFERENCES:

Ahmed NH and Abd-Rabou SM 2010 Host plants, geographical distribution, natural enemies and biological studies of the citrus mealybug, *Planococcus citri* (Risso) (Hemiptera:Pseudococcidae). *Egypt. Acad. J. biolog. Sci*. 3(1) 39- 47.

Álvarez A, Virla EG, Pera LM and Baigor MD 2009 Characterization of native *Bacillus thuringiensis* strains and selection of an isolate active against *Spodoptera frugiperda* and *Peridroma saucia. Biotechnol. Lett* **31** 1899-1903.

Attia AR and Awadallah KT 2016 Parasitoids and Predators of the Citrus Mealybug, *Planococcus citri* (Risso) (Hemiptera: Pseudococcidae) Infesting the Herb, Withania somnifera, a New Host Plant in Egypt. *Egyptian Journal of Biological Pest Control* 26(2) 245-248.

Attique MR, Rafiq M, Gaffar A, Ahmad Z and Mahyuddin AI 2003 Hosts of *Bemisia tabaci* (Genn.) (Homoptera: Aleyrodidae) in cotton areas of Punjab, Pakistan. *Crop Protection,* **22** 715-720.

Aulerio AZ and Zambonelli A 1997 Fungal diseases of officinal plants: Spread, effects and defence. *Informatore-Agrario*. **53** 91-93.

Ayyar TVR 1984 Hand of book of economic entomology for South India. 528pp. International Books & Periodicals Supply Service, New Delhi.

Baghel G, Jahan T, Afreen B, Naqvi QA, Snehi SK and Raj SK 2010 Detection of a begomovirus associated with yellow mosaic disease of Ashwagandha (*Withania somnifera* L.) and its impact on biomass yield. Medicinal Plants - *International Journal of Phytomedicines and Related Industries* **2(3)** 219- 22)

Bains RC 1938 Mint anthracnose. *Phytopathology* **28**103-113.

Beery RE and Shields J 1980 Variegated cutworm: Leaf consumption and economic loss in peppermint. *Journal of Economic Entomology* **73** 607-608.

Ben-Dov Y 2020 ScaleNet. *Coccidohystrix insolita*. Accessed 26 April 2020. http://scalenet.info/catalogue/Coccidohystrix%20insolita/.

Bergeson G B 1963 Influence of *Pratylenchus penetrans* alone and in combination with *Verticillium albo-atrum* on growth of peppermint. *Phytopathology* **53** 1164-1166.

Bergeson G B and Green Jr R J 1979 Damage to cultivars of peppermint, *Mentha piperita* by the lesion nematode *Pratylenchus penetrans* in Indiana. *J. Nematol*. **7** 654.

Bhagat KC 2004 Mango mealybug, *Drosicha mangiferae* (Green) (Margarodidae: Hemiptera) on Ashwagandha a medicinal plant. *Insect Environment* **10(1)** 14.

Blackman RL and Eastop VF 2007 Taxonomic issues. In: Aphids as crop Pests, (HF van Emden and R Harrington, Eds.), CABI, UK pp. 1–29.

Buhrer E M 1938 Addition to the list of plants attacked by root-knot nematode (*Heterodera marioni*). *Plant Dis. Reptr*. **22** 216-234.

CABI 2020 https://www.cabi.org/isc/datasheet/26757.

Cameron AB 1914 A contribution to a knowledge of the belladonna leaf-miner, *Pegomyia hyoscyami*, Panz., its life-history and biology *Annals of Applied Biology* **1(1)** 43-76.

Chandranath HT and Katti P 2010 Management of epilachna beetle on ashwagandha. *Karnataka Journal of Agricultural Sciences* **23(1)** 171.

Chandranath HT and Katti P 2010 Management of epilachna beetle on ashwagandha. *Karnataka J Agric Sci* 23 171.

Chaudhary V 2013 Arthropods associated with ashwagandha, *(Withania somnifera* Dunal) in semi arid region of Gujarat. *Karnataka J. Agric. Sci.* **26(3)** 433-435.

Chen X Y, Sui C, Gan BC, Wei JH and Zhou YK 2010 First Report of Corynespora Leaf Spot on Patchouli Caused by *Corynespora cassiicola* in China. Plant Disease **94** (12) :1508.

Chet I 1991Biological control of soil borne plant pathogens with fungal antagonists in combination with soil treatments, In: *Biological Control of Soil Borne Plant Pathogens* (ed. Hornby, D.), CAB International, London, pp.479.

Dhawan AK, Singh K, Saini S, Aneja A and Singh J 2011 Parasitizing potential of parasitoid (*Aenasius bambawalei*) on mealybug (*Phenacoccus solenopsis*) in cotton (*Gossypium* spp) and weed plants. *Indian Journal of Agricultural Sciences* **81(1)** 97–9

Digwanti SR and MomotaY 1991 Parasitic nematode associated with patchouli disease in West Jawa. Industrial *Crop research Journal* **3(2)** 31-34.

Emden FV 1924 Bericht uber die entomologische Uberwachung der Speicher und Kulturen der Firma Caesar und Loretz, A.-G. im Jahre 1923.Jahresbericht 1924, von Caesar and Loretz 167-232.

Emenjaud D, Minot J C, Voisin R and Guiran G de 1990 *Pratylenchoides laticauda* on pepper mint in Southern Alps, host range, population densities in different crop relations and host suitability of three mint subspecies. *Meded Van de Facult Land Rijksun Gent* 55(2b): 779-786.

EPPO 2013 PQR database: European and Mediterranean plant protection organization, Paris, France. Retrieved November 19, 2016 from http://www.eppo.int/DATABASES/pqr/pqr.htm

Etebarian HR 1992 Studies on *Fusarium* wilt of tomato and its chemical control in Varamin area. *Iranian J. Agric. Sci.* **23** 1-14.

Fand BB and Suroshe SS 2015 The invasive mealybug *Phenacoccus solenopsis* Tinsley, a threat to tropical and subtropical agricultural and horticultural production systems -A review. *Crop Protection* **69** 34–43.

Fand BB, Gautam RD and Suroshe SS 2010 Comparative biology of four coccinellid predators of solenopsis mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae). *J. Biol. Control* **24(1)** 35-41.

Farooqi AA, Iqbal A, Aquil F and Ahmad L 2003 Broad-spectrum antibacterial and antifungal properties of certain traditionally used Indian medicinal plants. *World J.Microbiol. and Biotech.,* **19** 653-657.

Faulkner L R, Bolander W J and Skotland CB 1970 Interactions of *Verticillium dahliae* and *Pratylenchus minyus* in Verticillium wilt of peppermint: influence of nematode as determined by a double root technique. *Phytopathology* **60**100-103.

Faulkner LR and Bolander WJ 1969 Interactions of *Verticillium dahliae* and *Pratylenchus minyus* in Verticillium wilt of peppermint: effect of soil temperature. *Phytopathology* **59**868-870.

Faulkner LR 1962 Pathogenecity and population dynamics of *Paratylenchus hamatus* Thorne and Allen on *Mentha* species. *Phytopathology* 52 (8): 731.

Faulkner LR 1964 Pathogenicity and population dynamics of *Paratylenchus hamatus* on *Mentha* species. *Phytopathology* **54** 344-348.

Faulkner LR 1965 Interactions of *Verticillium dahliae* and *Pratylenchus minyus* in Verticillium wilt of peppermint. *Phytopathology* **55** 583-586.

Faulkner LR and Skotland CB 1963 Control of Verticillium wilt of mint and plant parasitic nematodes associated with mint by soil fumigant. *Plant Disease Reporter* **47** 662-665.

Flack 1907 Wachstumgectze wachstufakoren and temperature holzerstorenden. *Myceliero.***1** 53 – 154.

Ganguli D and Pandotra VR 1962 Some of the important commonly occurring diseases of important medicinal and aromatic plants in Jammu and Kashmir. *Indian Phytopath*. **15** 50-54.

Ghosh SK and Senapati SK 2001 Biology and seasonal fluctuation of *Henosepilachna vigintioctopunctata* Fab. On brinjal under Terai region of West Bengal. *Indian Journal of Agricultural Research* **3** 149-154.

Ghosh SK and Senapati SK 2001 Biology and seasonal fluctuations of *Henosepilachna vigintioctopunctata* Fabr. on brinjal under teraj region of Wes Bengal. *Indian J Agric Res* **35** 149-154.

Global Invasive Species Database (GISD). 2005. *Bemisia tabaci*. Available from:http://www.issg.org/database/species/ecology.asp?si=106&fr=1&sts=sss & lang=EN.

Gokte N and Mathur VK 1990 Thermal therapy for the eradication of Mentha spicata roots infected with Meloidogyne incognita. *FAO Plant Protect. Bull*. **8(4)** 213-215.

Gomez-Galera S, Pelacho A M, Gene A, Capell T and Christou P 2007 The genetic manipulation of medicinal and aromatic plants. *Plant Cell Rep.* **26**1689–1715.

Goodey T 1940 The nematode parasites of plants catalogued under their hosts. Imp. Bur. Agric. Parasit. (Helminth.) St. Albans, England 80

Gotyal BS, Babu VR, Satpathy S and Selvaraj K 2019 Biological control of key pest of jute, *Spilosoma obliqua* Walker (Lepidoptera: Arctiidae)-A case study *Journal of Biological Control* **33**(3) 222-224.

Govier, D.A. and Plumb, R.T.(1972). Henbane mosaic virus CMI/AAB. *Description of Plant viruses*, 95.

Greathead AH 1986 Host plants. In: Cock, M.J.W. (Ed.), *Bemisia tabaci*. A Literature Survey on the Cotton Whitefly with an Annotated Bibliography. CAB International, UK 17–25.

Gupta SK and Karmakar K 2011 Diversity of mites (Acari) on medicinal and aromatic plants in India. *Zoosymposia* **6** 56–61.

Gupta ML, Mishra HO, Kalra A and Khanuja SPS 2004 Root-rot and wilt: a new disease of ashwagandha (*Withania somnifera*) caused by *Fusarium solani*. *Journal of medicinal and Aromatic plants Sciences* **26** 285-287.

Hamilton MA 1932 On three new virus diseases of *Hyoscyamus niger. Ann. Appl. Biol.* **19** 550-557

Hanumanthaswamy BC, Rajagopal D, Farooqi AA and Chakravarthy AK 1994 Insect Pests of

Ashwagandha (*Withania somnifera* Dual). *The Lal-Baugh-Journal of the Mysore Horticultural Society* **36(1&2)** 19-21.

Hartman J R and Fletcher J T 1991 *Fusarium* crown rot and root rot of tomatoes in the UK. *Pl. Pathol.* **40** 85-92.

Haseeb, A. and Pandey, R. (1989). Observation on *Meloidogyne* spp. infesting Japanese mint - New disease records. *Nematropica* 19: 93-97.

Hilje L, Costa HS and Stansly PA 2001 Cultural practices for managing *Bemisia tabaci* and associated viral diseases. *Crop Prot.* **20** 801–812.

Hirekurubar RB, Patil S, Jayappa J, Tatagar MH and Masuthi DA 2018 Evaluation of new insecticides and Acaricides against red spider mite (*Tetranychus urticae* Koch) In Ashwagandha (Withania somnifera Dunal) *Journal of Pharmacognosy and Phytochemistry* **SP3** 319-322.

Horner C E and Jensen JJ 1954 Nematode associated with mints in Oregon. *Plant Disease Reporter* **38(1)** 39-41.

Horner C E 1952 Root and rhizome rot of peppermint. (Abstr.). *Phytopathology***. 41** 514.

Hriday S Chaube and Singh US 1991 Plant disease management principles and practice*s,* CRC Press, Boston, 319 pp.

Hsiao TH 1978 Host plant adaptations among geographic populations of the Colorado potato beetle (Proceedings 4th Insect/Host Plant Symposium) *Ent exp & appl.* **24** 237-247.

Hubert K 1950 Henbane, another host for Colorado beetle. *Nachrichtenblatt des Deutschen Pflanzenschutzdienstes* **4** 136.

Husain A and Janardhanan K K 1965 Stolon rot of Japanese mint. *Current Science* **34** 156-157.

Ingham, R. E. (1992). Biology and control of nematodes in peppermint. Oregon Mint Commission Progress Reports for 1991-1992. 28 pp.

Ingham R E, Newcomb G B and Morris M A 1988 Spring nematicide application for control of root lesion and pin nematodes of pepper mint, 1987. *Fungicide and Nematicide Test* 43 170p.

Inserra R N and Rhode H L 1989 Some nematode problems of spearmint in Florida. Nematology Circular (Gainesville, U.S.A.) no. **167**:3p.

Ireneo LLJr, Merdelyn CL, Calilung VJ 1998 The mealybugs (Pseudococcidae, Coccoidea, Hemiptera) of egglant (*Solanum melongena* Linn.) in the Philippines. *Philippine Entomologist*. **12(1)** 29–41.

Jatala P and Jensen H J 1974 Oxamyl controls Longidorus elongates on peppermint in greenhouse experiment. *Plant Disease Reptr*. **58** 591-593.

Jensen HJ and Horner CE 1959 Peppermint decline caused by *Longidorus sylphus* can be controlled by soil fumigation. *Phytopathology* **47**18.

Jenson HJ and Horner CE 1956 A decline of peppermint caused by an ectoparasitic nematodes Longidorus sylphus. *Phytopathology* **46** 637.

Joshi K, Chavan P, Warude D and Patwardhan B 2004 Molecular markers in herbal drug technology. *Curr Sci* **87**159–165.

Kapoor AP 1950 Biology and external morphology of larvae of Epilachininae (Coleoptera: Coccinellidae). *Bull. Entomol. Res*. **41** 161-208.

Kapoor IJ and Kumar B 1991 Relative efficacy of systemic and non-systemic fungicides against *Fusarium oxysporum* and *Fusarium solani* affecting tomato. *Indian Phytopath.,* **44 (1)** 87-93.

Kareem AA, Jayraj S and Vasudevamenon PP 1960 *Syngamia abruptalis* Walker (Pyralidae: Lepidoptera) a pest of *Mentha viridis* Linn. (mint) in south India. *J Bombay Nat Hist Soc* **57** 681–683

Kattimani KN and Patil BV 2000 Record of *Spodoptera* feeding on field mint, *Mentha arvensis*, L *Insect Environment* **6(1)**: 30.

Kavitha M, Gopal K, Anandam RJ and Prasad Babu G 2004 Evaluation of native isolates of *Trichoderma* in the control of dry root-rot in Acid Lime. *J. Mycol. Pl. Pathol.* **34** 384-386.

Kedar SC and Saini RK 2015 Seasonal occurrence of solenopsis mealybug, *Phenacoccus solenopsis* Tinsley on different host plants in cotton based agro-ecosystem. *Journal of Cotton Research and Development* **29(2)** 297-300.

Kedar SC, Saini RK and Kumaranag KM 2017 Seasonal abundance and predatory potential of *Serangium parcesetosum* Sicard (Coleoptera: Coccinellidae) against whitefly, *Bemisia tabaci* on cotton. *Journal of Entomological Research* **41(1)** 63-68.

Kedar SC, Saini RK and Ram P 2011 Biology of *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) on potato sprouts. *Journal of Insect Science* **24** 30-34.

Kedar SC, Saini RK and Ram P 2011 Record of coccinellid predators of solenopsis mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) in Haryana, India. *Journal of Entomological Research* **35(3)** 245-246.

Kedar SC, Saini RK and Ram P 2012 Survival of solenopsis mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) on cotton in relation to abiotic and biotic factors. *Journal of Entomological Research* **36(4)** 315-319.

Kedar SC, Saini RK and Ram P 2013 Bionomics of solenopsis mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae), on cotton in Haryana. *Journal of Cotton Research and Development* **27(1)** 99-103.

Kedar SC, Saini RK and Ram P 2013 Relative population density of *Phenacoccus solenopsis* Tinsley on some host plants. *Bioinfolet,* **10(2)** 586.

Kedar SC, Saini RK, Kumaranag KM and Sharma SS 2014 Record of natural enemies of whitefly, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) in some cultivated crops in Haryana. *Journal of Biopesticides*, **7(1)** 57-59.

Khan SM 1976 Biology and control of *Agrotis* spp. M.Sc. Thesis, submitted to the Department of Entomology, Faculty of Agriculture, University of Peshawar. pp 60.

Khan JA, Srivastava P and Singh SK 2006 Sensitive detection of a phytoplasma associated with little leaf symptoms in *Withania Somnifera*. *European Journal of Plant Pathology* **115** 401–408

Khanuja SPS, Shasany AK, Dhawan S, Darokar MP, Satapathy S, Santha Kumar TR, Saikia D,Patra NK, Bahl JR, Tripathy AK and Sushil K 2004 Mint plant named 'Sambhav'. US PP14538P2.

Khanuja SPS 2004 Agrotechnologies of Ashwagandha (*Withania somnifera*), *J. Medicinal Arom. Pl. Sci.,* **26** 332-335

Knowlton GF and Thomas WL 1934 Host plants of the potato psyllid. *Journal of Economic Entomology* **27** 547

Kogan M and Goeden RD 1970 The Host-Plant Range of *Lema trilineata daturaphila* (Coleoptera: Chrysomelidae). *Annals of The Entomological Society of America* **63(4)** 1175-1180.

Kore SS and Patil DS 1985 Dry rot disease of mango seedling caused by *Fusarium solani*. *Indian J. Mycol. Pl. Pathol.,* **15** 287-288.

Krall J 1977 Protection of peppermint against mint rust. *Agril. Lit. Czechoslovakia* **2** 291.

Krishna Prasad PR and Reddy, DDR (1979). Study on the root-knot nematode infecting patchouli (*Pogostemon cablin* Benth.). *Maysore J. Agric. Sci*. 13 (3): 367-368.

Krishna Prasad PR and Reddy DDR 1984 Pathogenicity and analysis of crop losses in patchouli due to *Meloidogyne incognita*. Ind. *J. Nematol.* **14(4)** 36-38.

Krishna Prasad PR 1978 Studies on root-knot nematode infesting patchouli (*Pogostemon cablin* benth,). Thesis Abs. :99pp.

Kumar A, Kumari S and Singh CP 2010 Incidence of *Myzus persicae* Sulzer and *Tricentrus bicolor* Distant on *ashwagandha*, *Withania somnifera*. *Journal of Insect Science* **23** (4) 359-363.

Kumar A, Sharma PC and Mehta PK 2009b Insect pests on Ashwagandha, *Withania somnifera* Dunal in Himachal Pradesh. *Journal of Insect Science* **22(2)** 210-211.

Kumar A, Singh CP and Pandey R 2009a Insect pests of Ashwagandha, *Withania somnifera* Linn. in tarai region of Uttarakhand. *Entomon* **34(2)** 115-118

Kumar R, Nitharwal M, Chauhan R, Pal V and Kranthi KR 2012. Evaluation of Ecofriendly Control Methods for Management of Mealybug, *Phenacoccus solenopsis* Tinsley in Cotton. *Journal of Entomology* **9** 32-40.

Kumar S and Nanjan K 1981 Control of spiral nematode in patchouli. *Fungicide & Nematicide* Tests. 39: 93.

Leath KT and Kendall WA 1978 *Fusarium* root rot of forage species, pathogenicity and host range. *Phytopath.* **68** 826-831.

Leonard MD 1980 The distribution and habits of the mint aphid, *Ovatus crataegarius* (Walker). *Proc. Ent. Soc. Wash.* **65** 55-62.

Lisetskaya LF 1985 The effect of herbicides on the number of *Paratylenchus hamatus* in the hizosphere of pippermint. *Ekologiya prakticheskoe Znachenie Zoo-I Fitoparazitcheskikh Organizmov* 48-51.

Luc M, Sikora R A and Bridge J 2005 Plant Parasitic Nematodes in Subtropical and Tropical Agriculture 2nd Edition CABI,Bioscience, Egham, Surrey, U.K.)

Maharshi RP 1986 *Withania somnifera*_ a new host for *Myrothecium roridum. Indian Journal of Mycology and Plant Pathology* **16**109.

Mamatha T and Ravishankar Rai V 2004 Evaluation of fungicides and plant extracts against *Fusarium solani* leaf blight in *Terminalia catappa. J. Mycol. Pl. Path.* **34** 306-307

Manjoo S 2006 Bio-ecology of major insect pests of ashwagandha (*Withania somnifera* (L.) Dunal] and their management. M.Sc. (Ag) Thesis, Maharana Pratap University of Agriculture and Technology, Udaipur, p 55.

Margaritopoulos JT, Tsitsipis JA, Goudoudaki

S and Blackman RL 2002 Life cycle variation of *Myzus persicae* (Hemiptera: Aphididae) in Greece. *Bull Entomol Res* **92** 309–319.

Margina, A. and Zhelijazkov, V. (1994). Control of mint rust (*Puccinia menthae* Pers.) on mint with fungicides and their effect on essential oil content. *Journal of Essential Oil Research* 6: 607-615.

Mathur AC and Srivastava JB 1964 *Epilachna vigintioctopunctata* as a defoliator of some solanaceous medicinal plants. *Indian Journal of Entomology* **26** 246.

Meena NK, Singh B, Lal G, Kant K and Meena RD 2016 Sustainable management of aphid in coriander (*Coriandrum sativum* L.) through botanicals and bio-pesticides. *International J. Seed Spices* **6(1)** 25-31.

Merrifield, K. J., and Ingham, R. E. (1996). Population Dynamics of *Pratylenchus penetrans*, *Paratylenchus* sp. and *Criconemella xenoplax* on western Oregon peppermint. *Journal of Nematology* 28:557-564.

Meshram PB 2005 New reports of defoliator, *Psilogramma menephron* on *Rauwolfia serpentine* and whitegrub, *Holotrichia serrata* on *Withania somnifera*. *Indian Forester* **13(7)** 969-970.

Mitra B and Biswas B 2002 Insects of Aswagandha in South 24 Paraganas, West Bengal. *Insect Environment* **8(3)** 122.

Mohanasundaram M and Uthamaswamy S 1973 A note on the *Epilachna* spp. commonly found in Tamil Nadu with observation on the host range and distribution. *Science and Culture* **39** 305-306.

Moris MA 1989 Sampling, biology and management of mint flea beetle in Central Oregon peppermint. MS thesis, Oregon State University, Corvallis. pp 87.

Morris MA 2007 Mint, the genus *Mentha*, pp. 87–136. *In* B. W. Lawrence (ed.), *Commercial mint species grown in the United States.* CRC, Boca Raton, FL.

Moubasher AH, Mazen MB and Abdel-Hafez AII 1984 Studies on the genus *Fusarium* in Egypt III.Seasonal fluctuations of *Fusarium* in the rhizoplane of five plants. *Mycopathologica,* **85** 161-165.

Nene YL, Gulati BC and Duhan SPS 1965 Suspected viral disease of *Mentha arvrnsis* L. (Japanese mint) and its effect on yield and quality of oil. *Indian Oil Soap J.* **30** 297-299.

Munroe EG 1973 Pyraloidea, p. 70. *In The moths of America North of Mexico.* Classey Ltd. and The Wedge Entomological Research Foundation, London, United Kingdom

Nagrare VS, Kranthi S, Kumar R, DharaJothi B, Amutha M, Deshmukh AJ, Bisane KD and Kranthi KR 2011 Compendium of Cotton Mealybugs. Central Institute for Cotton Research, Nagpur, India, 42 pp.

Neubauer S, Kral J and Klimes K 1974 Insect pests of peppermint. *Nase Liecive Rastliny* **11**(2) 38-4.

Newton HCF 1934 On the Biology of *Psylliodes hyoxcyami* Linn. (Chrysomelidae, Coleoptera), The Henbane Flea-Beetle, with Descriptions of the Larval Stages. *Annals of Applied Biology* **21**(1) 153-161.

Nielson LW and Mayer JW 1979 A Fusarium root rot of sweet potatoes. *Plant Dis.Reptr.*, **63** 400 404.

Nirmal A, Jayaram CS, Ganguli JL and Tirkey A 2015 Scenario of insect pests on Ashwagandha (*Withania somnifera*) in the

plains of Chhattisgarh. *Insect Environment* **20(4)** 142-143.

Oliveira MRV, Henneberry TJ and Anderson PK 2001 History, current status and collaborative research projects for *Bemisia tabaci*. *Crop Protection* **20** 709-723.

Pandey GN and Nigam KB 1985 *Diseases of Ashwagandha*. Biannual Workshop Bangalore.

Pandey R 2005 Field application of bio-organics in the management of *Meloidogyne incognita* in *Mentha arvensis* . *Nematologia Medit.* **33 (1)** 51-54.

Pandey R 1989 Studies of root-knot nematode, *Meloidogyne incognita* infesting Japanese mint (*Mentha arvensis*) Linn Subsp. *haplocalyx* Briquet var. *piperascens* Holmes) and its control. Ph.D, Thesis, Kanpur University Kanpur, India: 163pp.

Pandey R 1990 Pathogenicity and reproduction of *Meloidogyne incognita* on *Hyoscyamus albus* and rhizospheric association of other phytoparasitic nematodes. *International Nematology Network Newsletter* **7 (4)** 34-37.

Pandey R 1993 Conceptual models for the management of root-knot and lesion nematodes in important medicinal and aromatic plants. *Afro-Asian Journal of Nematology* **3(1)** 103-106

Pandey R 1994 Bionomic of Phytonematodes in relation to medicinal and Aromatic Plants. *Indian J. Plant Pathology* **12(1&2)**19-23.

Pandey R 1995 Application of oil seed cake, pesticides and dry leaf matter on the reproduction potential of *Meloidogyne incognita* and yield of Japanese mint. *Indian J. of Nematol.* **25(1)** 12-13.

Pandey R 1997a Seasonal variation in population of phytonematodes associated with peppermint (*Mentha piperita* L.) and spearmint (*Mentha spicata* L.). *Journal of Aromatic & Spices Crops* **6 (2)** 149-151.

Pandey R 1997b Comparative potentiality of *Pratylenchus thornei* on different mint species. *Indian Journal of Plant Pathology* **15(1&2)** 24-30.

Pandey R 1997c Ecofriendly approaches for the management of root-knot nematode on black henbane. *Indian J. Nematol*. **27(2)**: 175-178.

Pandey R 1998a Phytopathological impact of root-knot nematode on some medicinal and aromatic plants-*Journal of Medicinal And Aromatic Crop Sciences* **20** 67-84.

Pandey R 1998b Nematode Pests of Medicinal and Aromatic Plants and their management in Phytonematology- Aspects And Prospects (Edited By Dr. P.C.Trivedi, Department of Botany, University of Rajasthan, Jaipur): 177-216.

Pandey R 1999 Spatial and temporal dynamics of phytonematodes in arable soil planted with Japanese mint. *Journal of Mycology and Plant Pathol*. **29(2):** 232-235.

Pandey R 2000 Additive effect of three organic materials and pesticides on the reproduction of *Meloidogyne incognita* and yield of *Mentha arvensis. Nematropica* **30:** 155-160.

Pandey R 2009 Nematode disease of medicinal and aromatic plants: Indian scenario and ecofriendly management In Proc. national seminar on Environment Degradation and Biodiversity: Problem & Prospects" on 29-30th November 2009 : 9-20.

Pandey, R. 2017. Diseases of medicinal and

aromatic plants: Insights in nematode biomanagement. Indian Phytopathology: **70 (1)** 12-21.

Pandey R and Kalra A 2003 Root-knot disease of Ashwagandha, *Withania somnifera* and its ecofriendly and cost effective management. *Journal of Mycology and Plant Pathology* **33 (2)** 240-245.

Pandey R and Kalra A 2010 Inhibitory effects of vermicompost produced from agro-waste of medicinal and aromatic plants on egg hatching in *Meloidogyne incognita* (Kofoid and White) Chitwood. *Curr. Sci.* **98** 833-835

Pandey R and Patra NK 2001 Screening mint (*Mentha* spp.) accessions against root-knot nematode infection. *Journal of Spices and Aromatic Crops* **10(1)** 55-56.

Pandey R, Kalra A and Kumar S 2000a Efficacy of various essential oils in the management of root-knot disease in black henbane. In Proc. of Centennial Conf. On Spices and Aromatic plants, 20-23 September 2000, at IISR, Calicut: 263-266.

Pandey R, Gupta ML, Singh H B and Kumar S 1999 Interaction potentialities of Vesicular-arbuscular mycorrhizal fungi with root knot nematode, *Meloidogyne incognita* on black henbane. *Bio resource Technol*. **69** 275-278.

Pandey R, Gupta ML, Singh HB, Singh HN and Kumar S 2000b Disease management potentiality of VAM fungi to *Meloidogyne incognita* on *Hyoscyamus muticus* In Proc. of International conference on "Integrated plant disease management for sustainable agriculture", IARI, New Delhi pp. 1239-1240.

Pandey R, Haseeb A and Husain A 1992 Distribution, Pathogenicity and Management of *Meloidogyne incognita* on *Mentha arvensis* cv. MAS-1. *Afro-Asian Journal of Nematology* **2(1)** 27-34.

Pandey R, Singh HB and Gupta ML 1997 Antagonistic impact of Vesicular-arbuscular (VAM) on *Meloidogyne incognita* population development in Japanese mint. *Int. J. Tropical Plant Disease* **15** 237-245.

Pandey R, Singh HB, Gupta ML, Singh HN, Sharma S and Kumar S 1998 Efficacy of VAM fungi, green manure, organic materials and pesticides in the management of root-knot nematode in menthol mint. Proceedings of national Symposium on rational approaches in nematode management for sustainable agriculture at GAU, Anand (Eds. S.C.Dhawan & K.K.Kaushal): 47-50.

Pandotra VR and Shastry KSM 1968 Studies on Sclerotium rots of mints. Proc. *Indian Acad. Sci. Sect. B*. **68** 9-10.

Papavizas Gc 1973 Status of applied biological control of soil borne plant pathogens. *Soil Biol. Biochem.,* **5** 709.

Parameshwaran TN, Ravindra NS and Sarwar M 1987 *Alternaria* blight a new disease of patchouli. *Curr. Sci.* **56 (9)** 408-409.

Parfentjev I 1921 Insect pests of medicinal plants in the Crimea *Bulletin de la Société de Pathologie Exotique* **14(3)** 164-167.

Patel S T 1991 Studies on some aspects of wilt of chickpea. *Ph.D. Thesis,* Uni. Of Agric.Sci. Dharwad (India).

Pathak HC and Raychoudhuri SP 1967 *Withania somnifera* -an additional host of tobacco leaf curl virus. *Sci. Cul.* **33** 234–235.

Patra DD, Singh K, Misra HO, Gupta AK, Singh J, Singh SC and Peng TL, Sajap AS, Jeen LH, Hua LS and Chen LW 2014 Occurrence of *Cochlochila Bullita* Stal in Malaysia *Serangga*

19(2) 67-76.

Pinkerton JN 1984 Relationship of *Pratylenchus penetrans* (Cobb, 1917) population density and yield of pepper mint, *Mentha piperita* L. *Dissertation Abstract Int. B. (Science & Engineering)* **44 (12)** 3593b.

Printz YA I 1925 The biology of *Heliothis obsoleta* F. and its control. Notes *App. Sci. Dept. Tiflis Bot. Gdns.* Part **2**, separate 54.

Proctor C H 1944 A virus disease of Henbane in New Zealands. *New Zeal. J. Sci. Technol*. **26**83-87

Rai SN and Singh 1997 Population trend in *Brevipalpus phoenicis* Geij. on Ashwagandha in relation to weather factors in Varanasi. *Pestology* **12** 38-43.

Rai MK, Qureshi S and Pandey AK 1999 *In vitro* susceptibility of opportunistic *Fusarium* spp. to essential oils. *Mycoses* **42** 97-101.

Ram P, Saini RK, Vijaya 2009 Preliminary studies on field parasitization and biology of solenopsis mealybug parasitoid, *Aenasius bambawalei* Hay at (Encyrtidae: Hymenoptera). *Journal of Cotton Research and Development* **23(2)** 313-315.

Ramani S and Bhumannavar BS 1990 Pests of patchouli (*Pogostemon patchouli* Pellet) and reaction of some cultivars to the bug *Pachypeltis* sp. (Hemiptera: Miridae) *Indian Perfumer* **34(4)** 269-273.

Ramanna D 2009 Investigations on pest complex of medicinal plants and their management with special reference to ashwagandha, *Withania somnifera* (Linn.). M.Sc. (Ag) Thesis, University of Agricultural Sciences, Dharwad, p 88

Ramanna D, Prasad K and Basavanagoud K 2010 Pest complex of Medicinal Plants. *Karnataka Journal of Agricultural Sciences* **23** 197-199.

Rathour KS, Ganguly S, Das T, Singh P, Kumar A, Somvamshi VS 2014 Biological management of subterranean termites (*Odontotermes obesus*) infesting wheat and pearl millet crops by entomopathogenic nematodes. *Indian J Nematol* **44** 97-100.

Ravikumar A, Rajendran R, Chinniah C, Irulandi S, Pandi RJ 2008 Induction of resistance through organic amendments for the management of spotted leaf beetle, *Epilachna vigintioctopunctata* Fab. on ashwagandha. *Journal of Biopesticides* **1** 23-27.

Rehaman SK and Pradeep S 2016 Effect of biopesticides on management of *Helicoverpa armigera* in Ashwagandha (*Withania somnifera* Linn.). *Pest Management in Horticultural Ecosystems* **22(1)** 99-102.

Rehaman SK, Pradeep S and Dhanapal R 2018 Incidence of Fruit Borer *Helicoverpa armigera* (Hubner) on Ashwagandha in Shivamogga. *International Journal of Current Microbiology and Applied Sciences* **7(3)** 1060-1066.

Rehaman SK, Pradeep S, Dhanapal R and Chandrashekara GV 2018 Survey studies on insect-pests associated with important medicinal plants in Shivamogga, Karnataka. *Journal of Entomology and Zoology Studies* **6(1)** 848-857.

Rhode HL 1983Effect of *Belonolaimus longicaudatus , Dolichodorus heterocephalus* and *Pratylenchus scribeneri* on growth of peppermint. *Phytopathology* **53** 1164-1166.

Rhode HL 1984 Control of *Pratylenchus scribneri* on spear mint, *Mentha spicata* with nonfumigant nematicides. *Nematropica* **14 (1)** *85-89.*

Richards AM 1983 The *Epilachna vigintioctopunctata* complex (Coleoptera: Coccinellidae). *International Journal of Entomology* **25** 11-41.

Rita P and Animesh K 2011 An updated overview on peppermint (*Mentha piperita* L.). *International Research Journal of Pharmacy* **2(8)** 1 –10.

Rita P, Animesh K 2011 An updated overview on peppermint (*Mentha piperita* L.). *International Research Journal of Pharmacy* **2**(8) 1 –10.

Rohini BS, Suchithra Kumari MH and Rashmi S 2018 The diversity of aphids on medicinal and aromatic plants of Chikkamagulru district. *Journal of Pharmacognosy and Phytochemistry*. **SP3** 453-456.

Sagar P 1983 Comparative efficacy of some organophosphorus and synthetic pyrethroid insecticides against *Syngamia abruptalis* Walker infesting Japanese mint. *Indian J. Agril. Sci.* **53(8)** 742-744.

Sagar P 1984 Comparative efficacy of some insecticides against leaf webber, *Syngamia abruptalis* Walker infesting Japanese mint in the Punjab; *Inter. Pest Control*. **26(4)** 97-105.

Sagar P 1985 Note on outbreak of the cabbage semilooper, *Thysanoplusia orichalcea* (Fab.) = (*Plusia orichalcea*) on Japanese mint, *Mentha arvensis* Linn. In Punjab. *Indian Perfumer* **29** 167–168.

Sagar P 1988 Efficacy of some synthetic pyrethroids and other insecticides against infestation of Japanese mint in Punjab *Indian Perfumer* **32(3)** 186-189.

Sagar P and Ramji 1990 Natural enemies of cabbage semilooper on Japanese mint crop at Ludhiana. *Indian Perfumer* **34(1)** 44-46.

Sagar P and Ramji 1991 A study on the host range of cabbage semilooper, *Thysanoplusia orichalcea* (Fab.) in Punjab. *Indian Perfumer* **35(1)** 61–62.

Sagar P and Reddy RO 1985 Host range and preference of mentha leaf webber, *Syngamia abruptalis* (Lepidoptera: Pyralidae) in Punjab (India) *Journal of Research Punjab Agricultural University* **22**(3) 488-492.

Sagar P and Reddy VO 1987 Nature and extent of damage of mentha leaf webber, *Syngamia abruptalis* Walker, a pest of Japanese mint in the Punjab *Indian Perfumer* **31**(4): 379-382.

Sagar P and Singh DP 1981 Chemical control of the aphid, *Aphis affinis* (Homoptera: Aphididae) a pest of Japanese mint *Mentha arvensis* in the Punjab India. *Entomon* **6(1)** 73-80.

Sahu C, Ganguli JL and Joshi S 2017 Seasonal incidence of the mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) on ashwagandha in Raipur (Chhattisgarh). *International Journal of Plant Protection* **10(2)** 270-274.

Samad A, Shasany AK, Gupta AK, Gupta S, Ajayakumar PV, Darokar MP and Khanuja SPS 2006 First report of a 16SrVI group phytoplasma associated with witches broom disease of *Withania somnifera*. *Plant Disease* **90** 248.

Samad A, Gupta MK, Shasany AK, Ajayakumar PV and Alam M 2009 Begomovirus related to *Tomato leaf curl Pakistan virus* newly reported in *Mentha* crops in India, *Plant Pathology,* **58** *404*

Samad A, Zaim M and Ajayakumar PV 1999 White Mosaic: A New Virus Disease on Egyptian Henbane in India. *Ind. J. Virol.*, **15**39-42.

Samad A, Zaim M, Ajayakumar P V and Garg I D 2000 Isolation and characterization of a TMV isolate infecting scotch spearmint (*Mentha gracilis* Sole) in India. *J. Plant Dis.Prot.* **107** 649-657.
]
Samad A, Zaim M and Ajayakumar P V 1994 An outbreak of mosaic disease on mint (*Mentha cardiaca* Baker) in India. *Indian J. Plant Pathol.* **12**1-4.

Samad A, Raj SK, Srivastava A, Chandar G, Ajyakumar PV, Zaim M and Singh BP 2000 Characterization of an Indian isolate of cucumber mosaic virus infecting Egyptian Henbane (*Hyoscyamus muticus* L.) *Acta Virologica* **44** 131-36

Samuel CK 1939 Oviposition of the tinged *Monanthia globulifera* Wlk. *Indian Journal of Entomology* **1** 89-99.

Sandhu GS, Singh B and Bhalla JS 1975 Insect pests of Japanese mint (*Mentha arvensis* L) in India *Indian Perfumer* **19** 13–18.

Sanjta S and Chauhan U 2018 Incidence and diversity of thrips and its associated natural enemies in medicinal plants. *Journal of Medicinal Plant Studies* **6(1)** 1-2.

Sarhan ART 1989 Biological control of *Fusarium* root rot of broad bean. *Acta Phytopathologica*, **24** 271-275.

Sarwar M, Parameswaren T N, Shanamugham C and Narayana MR 1982 Appraisal of patchouli in India, root-knot problem and control. *Indian Perfumer* **26** 117-121.

Sastry KSM 1969 Investigation and control of some important medicinal plants. *Indian Phytopath*.**42** 140-142.

Sastry KSM and Vasanthakumar T 1981 Yellow mosaic virus of Patcouli (*P. patchouli*) in India. *Cur. Sci.* **50** 767-768

Sattar A and Alam M 1996 Bacterial leaf blight disease of Egyptian henbane caused by *Xanthomonas compestris* pv. Turf. In proc. Of 9th Int. Conf. on Plant Pathogenic Bacteria (Eds. A. mahadevan, Udayam offset Publisher, Chennai : 404-406.

Sattar A and Husain A 1976 Stolon and root-rot of Japanese mint in uttar Pradesh. *Indian Phytopath* **29** 441-444.

Sattar A and Husain A 1980 Fusarium wilt of Japanese mint. *New Botanist* **7** 69-71.

Sattar A, Alam M, Janardhanan KK and Husain A 1981 A new leaf spot disease of Japanese mint caused by *Corynespora cassicola*. *Indian Phytopath*. **34** 404.

Senthil Kumar CM, Jeyaram K and Singh HB 2011 First record of the entomopathogenic fungus *Entomophaga aulicae* on the Bihar hairy caterpillar *Spilarctia obliqua* in Manipur, India. *Phytoparasitica* **39** 67–71.

Sharga US 1953 Bionomics of *Monanthia globulifera* Wlk. (Hemiptera- Heteroptera: Tingidae). *Journal of the Bombay Natural History Society* **51** 885-889.

Sharma A and Pati PK 2011 First report of *Withania somnifera* (L.) Dunal, as a New Host of Cowbug (*Oxyrachis tarandus,* Fab.) In Plains of Punjab, Northern India. *World Applied Sciences Journal* **14(9)** 1344-1346.

Sharma A and Pati PK 2012 First Record of the Carmine Spider Mite, *Tetranychus urticae*, Infesting *Withania somnifera* in India. *Journal of Insect Science* **12** 50

Sharma A and Pati PK 2013 First record of Ashwagandha as a new host to the invasive mealybug (*Phenacoccus solenopsis* Tinsley) in India. *Entomological News* **123(1)** 59-62.

Sharma PC, Kumar PK and Singh R 2014.

Survey studies on insect-pests associated with important medicinal plants in Himachal Pradesh. *Ind. J. Sci. Res. and Tech*. **2(4)** 2-7.

Sharma A D and Munjal RL 1978 Blight of some commercial species of mentha in Himachal Pradesh. *Indian Forester* **104**238-239.

Sharma RC and Agnihotri JP 1972 Pathogenicity and variability of lentil wilt *Fusarium*.*Indian J. Mycol. Pl. Path.*, **2** 170.

Shchegolev VN 1929 The Lepidoptera of the genus *Heliothis* as insect pests of oil plants and medicinal cultures and fodder plants in the North Caucasian region. *Byull. Sev. Kavkazek. Kraev. sel. khoz. opuitn. Sta.* 2112 48.

Shivapuri A, Sharma OP and Jhamaria SL (1997). Fungitoxic properties of plant extracts against pathogenic fungi. *J. Mycol. Pl. Pathl.,* **27** 29-31.

Shukla RS, Alam M, Singh V P and Kumar B 2008 Multiple disease resistance in menthol mint genotypes. *Curr. Sci.* **95 (7)** 836-838.

Shukla RS, Chauhan SS, Gupta ML, Singh V P, Naqvi AA and Patra NK 2000 Foliar diseases of *Mentha arvensis*: Their impact on yield and major constituents of oil. *Journal of Medicinal and Aromatic Plant Sciences* **22** 453-455.

Shukla RS, Gupta ML and Singh HN 2001 *Botryodiplodia theobromae* on *mentha arvensis*-causing stem blackening and rot, a new disease from India. *Journal of Mycology and Plant Pathology* **31**395-396.

Shukla RS, Singh HB and Kumar S 1998 Pathogenic response of *Cercospora menthicola* on different cultivated mint species. *Indian Journal of Plant Pathology* **16**76-77.

Shukla RS, Singh HB, Kalra A, Singh VP and Kumar S 1999 Occurrence of dual infection by *Puccinia menthae* and *Alternaria alternate* on *Mentha arvensis* in Tarai region of Uttar Pradesh. *Journal of Medicinal and Aromatic Plant Sciences* **21** 311-315.

Singh D 1999. Major insect pests of important medicinal and aromatic plants in Northern India. *Insect Environment* 5(3) 139-140.

Singh D and Bali R 1993 New record of coccinellid predators on aphids (*Aphis affinis* and *Myzus persicae*) in Japanese mint (*Mentha arvensis* subsp. *haplocalyx* var *piperascens*) and Egyptian henbane (*Hyoscyamus muticus*). *Indian Journal of Agricultural Science* 63(5) 313-314.

Singh D Tripathi AK and Rao SM 1988 Phenology and chemical control of aphid, *Myzus persicae* on henbane *Hyoscyamus niger* and *H.muticus. Indian J. Agric. Sci.,* **58** 292-296.

Singh D, Singh DK, Bahl JK and Tiwari RK 2004 Evaluation of different genotypes of *Mentha* species for resistance potential to sweetpotato whitefly *(Bemisia tabaci) Indian J. Genet.,* **64(3)** 253-254.

Singh DP and Sagar P 1981 Biology of the aphid (*Aphis affinis* Del Guercio; Homoptera, Aphididae) on the Japanese mint in the Punjab. *Indian perfumer* **25(1)** 105-109.

Singh JP and Gupta P 1970 The red pumpkin beetle *Raphidopalpa foveicollis* (Lucas), as a pest of the Japanese mint. *Journal of the Bombay Natural History Society* **67(1)** 123-44.

Singh OP and Rawat RR 1980 Alternative food-plants of the soybean looper *Plusia orichalcea* F. (Lepidoptera: Noctuidae) in Jabalpur, India. *Anzeiger fur Schadingskunde pflnzenschutz Umweltschutz* **53(2)** 25.

Singh R and Angadi SP 1990 Wilt of patchouli (*Pogostemon patchouli* Pellet) and reaction of

some patchouli strains to the disease. *Indian Perf.,*, **32 (2)** 81-82.

Singh MK, Chandel V,Hallan V, Ram Rand Zaidi AA 2009 Occurrence of *Peanut stripe virus* on patchouli and raising of virus-free patchouli plants by meristem tip culture. Journal of Plant Diseases and Protection, **116 (1)**2–6

Singh R 1991 Stolon rot of *Mentha arvensis. Indian Perfumer* **35**192.

Skotland CB and Menzies J P 1957 Two pepper mint diseases found in Yakima valley of Washington. *Plant Disease Report*. **41** 494.

Smith KH 1945A further note on the viruses affecting *Atropa belladonna* and a description of the virus complex attacking *H. niger*. *Parasitology*.**36** 209-210

Srivastava AK and Srivastava R 1971 *Mentha piperita* L.-a new host of *Alternaria tenuis* Auct. *Indian Forester* **97**34.

Stone W J H and Green R J Jr 1967 The epidemiology of spearmint rust in Indiana. *Mycopathol. Mycol. Appl*. **31**17-26

Suab J and Nagy F 1972 Results of mint rust control experiments. *Mycopathol. Mycol. Appl*. **31**66-67.

Subba Rao BL 1986 Patchouli (*Pogostemon patchouli*) mosaic caused by a potyvirus in India. Phytopathology **76** 1109.

Suroshe SS, Gautam RD and Fand BB 2013 Natural enemy complex associated with the mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) infesting different host plants in India. *J. Biol. Control* **27** 204-210.

Szezeponek A and Mazur S 2006 Occurrence of fungal diseases on lemon balm (*Mentha officinalis* L.) and peppermint (*Mentha piperita* L.) in the region of Malopolska. *Communications in Agricultural and Applied Biological Sciences* 71(3) 1109 –1118.

Thakur RN, Singh KP and Husain A 1974 *Curvularia* leaf spot of Japanese mint in India. *Journal of Mycology and Plant Pathology* **4**199.

Thomashow LS and Weller DM 1990 Role of antibiotics and siderophores in biocontrol of take all disease of wheat. *Plant Soil,* **129** 93-99.

Tinsley JD 1898 Notes on Coccidae, with descriptions of new species. *Can. Entomologist* **30** 317–320.

Tollerup KE, Marcum D, Wilson R and Godfrey L 2013 Biology of Mint Root Borer (Lepidoptera: Crambidae) and Control Options on California Pepper mint. *J. Integ. Pest Mngmt.* **4(3)** 1-4.

Tripathi AK 2018 Pests of Medicinal and Aromatic Plants. In: *Pests and Their Management, eds.* Omkar Springer Nature Singapore Pte Ltd. 719-822.

Tripathi MN, Shukla DN and Dwivedi BK 1999 Effect of aqueous extracts of leaves of some medicinal plants on spore germination of *Fusarium* spp. *Bioved.* **10** 43-44.

Triveni B 2017 Bio-ecology and eco-friendly management of insect pests of patchouli, tulsi, and mint (Family: Lamiaceae). M.Sc. (Ag) Thesis, University of Agricultural Sciences, Bangalore, 284.

Unesha K, Thyagaraj NE and Chandrappa HM 1998 New record of the yellow scale of cotton, *Cerococcus hibisci* (Homoptera: Cerococcidae) on patchouli *Pogostemon cablin* (Blanco) Benth. *Pest Management in Horticultural Ecosystems* **4(1)** 51.

Varma S and Anandhi P 2008 Seasonal incidence of brinjal hadda beetle *Henosepilachna vigintioctopunctata* (Fab.) and its natural enemies. *Indian Journal of Entomology* **70** 31-39.

Venkatesh MG 2006 Seasonal occurrence of *Henosepilachna vigintioctopunctata* (F) (Coleoptera: Coccinellidae) and its parasitoids on ashwagandha in India. *Journal of Asia and Pacific Entomology* **9** 265-268.

Venkatesha MG 2006 Seasonal occurrence of (*Henosepilachna vigintioctopunctata* (F.) (Coleoptera: Coccinellidae) and its parasitoid on ashwagandha in India. *Journal of Asia Pacific Entomology* **9(3)** 1-4.

Vennila S, Prasad YG, Prabhakar M, Kumar R, Nagrare V, Amutha M, Dharajyothi, Agarwal M, Sreedevi, G, Venkateswarlu B, Kranthi KR, Bambawale OM, 2011. Spatio-temporal Distribution of Host Plants of Cotton Mealybug, *Phenacoccus solenopsis* Tinsley in India. Technical Bulletin No. 26. National Centre for Integrated Pest Management, New Delhi, India, 50 pp.

Verpoorte R, Van der Heijden R, Ten Hoopen H. JG and Memelink J 1999 Metabolic engineering of plant secondary metabolic pathways for the production of fine chemicals. *Biotechnol Lett* **21**467–479

Wahid A, Jawed MS and Idress M 1995 Chemical control of *Fusarium* root rot, wilt and collar rot of soybean. *Pakistan J. Phytopathol.*, **7** 21-24.

Williams DJ and Watson GW 1988 The scale insects of the tropical South Pacific region. Part 2. The mealybugs (Pseudococcidae) CAB International; Wallingford. 260. English.

Williams DJ 2004 Mealybugs of southern Asia. Southdene SDN. BHD.; Kuala Lumpur. 896. English.

Yuksel E, Taskesen YE, Erarslan D and Canhilal R 2018 Effectiveness of different entomopathogenic nematode species against the variegated cutworm, *Peridroma saucia* (Hubner) (Lepidoptera: Noctuidae). *Egyptian Journal of Biological Pest Control* **28** 8.

Zacher F 1921 Animal pests of curative and poisonous plants and their importance in the cultivation of medicinal plants. *Ber. Deutschen pharmazeut. Gea.* **31(2)** 53-65.

Zaim M and Samad A 1995 Association of phytoplasmas with a witches-broom disease of *Withania somnifera* (L.) Dunal in India. *Plant Science* **109** 225–229.

Zaim M 1999 Studies on transmission, purification and some properties of virus strain causing mosaic disease in *Hyoscyamus muticus* L. and its effect on alkaloid production. Phytopathological Society, Zonal Meeting, Gorakhpur University, Gorakhpur, p.78.

Zaim M and Samad A 1995 Cytopathic effects of tomato spotted wilt virus (TSWV) in *Hyoscyamus muticus* L. National Symposium on Viral Disease of Socio-economic Importance relevant to India, 16-18 January at Trivandrum, Abstract PV 37

Zaim M, Joseph J, Samad A, Khaliq A and Savithri HS 1999 Mixed viral infection in Patchouli (*Pogostemon cablin* (Blanco) benth.). "National Symposium on Changing & Prospects of Plants Pathology in coming millennium" December 9-11, NBRI Lucknow.

Zapata RL, Palmucci HE and Blanco Murray V 2001 *Fusarium solani*, causal agent of wilt and root rot of Eggplant (*Solanum melongena*) in Argentina. *Fitopat*. **36** 15-18.