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AWARDS AND HONOURS

Diseases of medicinal and aromatic plants: Insights in nematode biomanagement*

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SUMMARY

The cultivation of medicinal and aromatic plants (MAPs) has considerably increased in tropical and sub tropical countries of the world to meet the requirement of pharmaceutical, perfumery, cosmetic and food industries. Unfortunately, the major source of raw materials are highly susceptible to many diseases caused by variety of pest and pathogens viz. fungi, bacteria, viruses, phytoplasmas, insects and nematodes, which are responsible for severe loss in crop production/ yield and also affecting loss of major genetic resource of MAPs too. Therefore, the disease caused by such pest and pathogen is a major limiting factor for the successful cultivation of major medicinal and aromatic plants. Although, chemical control of plant diseases has proved effective but it cannot be recommended to the farmers due to its high cost and adverse impact on non target organism, human, animal and environmental health. Due to enormous use of medicinal plants in herbal medicines, maximum care is the need of the hours to manage diseases of MAPs. Some of the other alternatives for disease management are available in medicinal and aromatic plants like resistant germplasm, useful organic materials, effective biocontrol agents and other cultural/ physical method. Such resistant and tolerant germplasm could be exploited in future plant breeding programmes for developing resistant/ tolerant genotypes against major pest and pathogens. Various organic materials are available which have been proven useful to decrease disease incidence and enhanced MAPs yield and which could also be used in ongoing programmes for better and healthy plants. Large numbers of bio agents are available which could also be used on large scale to protect MAPs against various pest and pathogens. However, much attention is needed to study and develop a new strategy to mange major diseases in an ecofriendly way, which should be cost effective and environmentally friendly.

The availability of nutritious and healthy food, disease controlling food supplements and therapeutics are, among several factors, the determinants of quality of human life. In recent years, traditional medicines derived from plant sources are one of the important ways to support herbal medicine system for human health care. For example in China about 40% of total medicine consumption is attributed to traditional tribal medicine. The herbal medicine demand in Japan and other developed nations is very high. Similarly, aroma compounds from botanical sources are being increasingly used in cosmeceutical, nutraceutical, food and flavour industries due to the growing awareness in common masses about the risks involved in synthetic components in parallel products. The plant retail market including herbs and medicinal plants in the US are estimated to be approximately US$ 1.6 billion annually. The prima facie importance of MAPs can be figured out from the fact that the expected sale of herbal medicines is likely to increase up to US $ 3 trillion by 2020 (Schippmann *et al.,* 2002). In European countries about 400,000 ton of medicinal plant material is exported from Asia and Africa. The average market value of MAPs material is more than US$1 billion. Therefore, it is useful to say that the major raw materials used in pharmaceutical industries come from medicinal plants globally. Of late, farmers are increasingly motivated to cultivate medicinal and aromatic plants (people in tropical and subtropical countries cultivate these crops as industrial cash crop) because these crops can be incorporated in various cropping systems and also generate significant income. The cultivation, processing and trade through value addition of materials coming from MAPs are providing much needed avenues of self

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employment. The business opportunities in the sector of medicinal plants are enormous and are visible on the rise due to the diversified uses that plant inhabited important molecules are finding in pharmaceutical, cosmeceutical, nutraceutical and agri chemical industries. In well-developed industrialised nations plant derived drug prescriptions have become a major element in maintenance of human health. Therefore, MAPs have become an integral component of research in most of the pharmaceutical, perfumery, cosmetic and nutraceutical industries. It has also been estimated that Hong Kong, Germany, Japan and Singapore are the major importing countries in medicinal plant trade with estimated share of 17.3, 12.0, 10.2 and 8.4% respectively. In concrete it was found that Europe has become a huge reservoir of global herbal market, constituting about 45% of total market followed by North America (18.2%) and Asia (18.2%). With an increasing usage of such products, any attempt by researchers to enhance the production and yield of MAPs can be a great endeavour towards meeting the global demand.

The situation however, is not as smooth as it appears to be since MAPs production is hindered by various biotic and abiotic factors amongst which biotic constraints are more important. Till date, however, a considerable attention has been made to the diseases affecting the crop plants providing food to mankind but what has been largely ignored are the diseases affecting our own saviours MAPs (Reddy and Pandey, 2013). Studies further suggest that in the near future, threat hovers over the global food production, including MAPs as predictions expect pronounced affect on the growth and survival rates of pests and pathogens, along with the increased disease severity due to changing climatic conditions (Elad and Pertot, 2014; Pandey and Saikia, 2012). Apart from the changing climatic conditions, large scale cultivation of MAPs for meeting the huge demands of pharmaceutical and perfumery industries, in a manner has paved a way for the increased occurrence and severity of diseases. Furthermore, the cultivation of MAPs faces critical damage from diverse group of microbes (bacteria, fungi, viruses, phytoplasmas and nematodes), thereby posing serious threat to the yield, biomass, bioactive potential and future prospects of MAPs (Table 1). Overall, financial losses arising from plant diseases caused by phytopathogens not only reduces the yield of plant secondary metabolites but also the crop value which not only discourages consumers self-belief but also the prosperity of the producers. The present article specially focuses on the major diseases of MAPs, their effect on various metabolic processes of the host plants with insight consideration of plant parasitic nematodes especially root-knot nematode (*Meloidogyne* spp.) affecting the production and yield of MAPs and their ecofriendly biomanagement.

Fungal and bacterial diseases

Currently, commercial cultivation of MAPs has tremendously improved several folds due to increasing global demand in pharmaceutical, perfumery, cosmetic and food industries. These plants are often affected by a variety of diseases caused by fungi, bacteria, viruses and phytoplasmas of which fungal diseases are particularly important. A variety of fungi influence pathogenic invasions on MAPs and infect the aerial, foliage and underground plant parts. Amongst the various fungal diseases, powdery mildews primarily appear on the leaves and fresh stems, thereby covering the entire surface of the growing parts of plants. Similarly, rust is another airborne disease known to attack leaves, twigs, branches and fruits. They produce pustules on the upper and lower leaves surface. The other group belonging to fungal pathogens causes leaf spot and blight diseases where the symptoms appear on the leaves in the form of leaf spot followed by shrinking of the dead area and separation from the surrounding healthy tissues with varying lesion shapes (Bhandari *et al.,* 2014; Thaung, 2008). In case of blight, burnt appearance leading to sudden death of the plant or its conspicuous parts viz. leaves, twigs or blossoms occurs (Ramappa Parashurama and Shivanna, 2013). Several other diseases of MAPs such as root rot, wilt, damping off, anthracnose and die back affects crop badly caused by fungal and bacterial pathogens. They can generally be identified by decaying tissue which may be hard, dry, spongy, watery, mushy, or slimy in appearance.

Management

The major control measures available for all these different diseases are primarily the chemical control. Treatment of terminal cuttings with carbendazim solution (1g L^{-1}) before plantation is an effective protection from fungal pathogens. Streptocyclin application (300 ppm) around the roots of transplanted cuttings protects the crop from bacterial infection (www.indg.in). Similarly, the chemical emisan (0.2%) is effective for wilt disease treatment (Boby and Bagyaraj, 2003). Paramasivan *et al.* (2007) reported that the use of chemical fungicide (carbendazim) reduced the disease incidence by 18%. Although chemicals are effective for the control of all these diseases, yet their association with several harmful effects has led to the arousal of the need for alternative measures. Rhizospheric microorganisms prove to be a potential source of novel natural products for exploitation in agriculture and are recognized as a promising group in terms of diversity and pharmaceutical potential (Pliego *et al.,* 2011). The reduction of pathogen density or disease producing activities of a pathogen by one or more microorganisms, termed as biocontrol is achieved by competition, hyperparasitism, induced resistance etc. Several biocontrol agents have been successfully used and a large number of products are available in world market which are not only highly economical also ecofriendly with no adverse impact on human health.

Viruses and phytoplasma

Plant viruses and phytoplasma also cause various diseases which affects the biomass yield and production of MAPs worldwide. Large numbers of MAPs are reported to be infected by plant viruses *viz*. *Mentha* spp.,

Table 1. Major diseases on MAPs (Singh, Gupta and Pandey, 2016b)

Disease	Crops	Causal organism	Symptoms
Rust	*Mentha* spp.	*Puccinia menthae*	Rust pustules on lower surface of leaf
Downy mildew	*Papaver somniferum, Ocimum basilicum, Plantago ovata, Humulus lupulus, Capsicum annum*	*Peronospora arborescens, P. lamii, P. alta, Pseudoperonospora plantaginis, P. humuli, P. tabacina*	Chlorotic to light brown nectrotic lesions on the leaves and leaves curled and twisted
Powdery mildew	*M. arvensis, Rosa damascene, Anethum graveolens, Salvia officinalis, H. lupulus*	*Erysiphe cichoracearum, Sphaerotheca pannosa, E. heraclei, E. cichoracearun*	Crooked stems and curled leaves. Chlorotic spots appear on the surface and brownish discolorations appear in the form of the powdery mass
Alternaria/ Ascochyta leaf spot	*Mentha* spp., *Hyoscyamus* spp., *O. basilicum*	*Alternaria tenuis, A. alternata, Ascochyta kashmiriana*	Dark brown spherical spots spread over the infected leaves
Cercospora leaf spot	*Mentha* spp., *P. somniferum, Rauvolfia serpentine*	*Cercospora menthicola, C. papaveri, C. purpurea, C. rauwolfiae, C. serpentinae*	Necrotic spots with dark brown margin scattered on the leaves
Colletotrichum leaf spot	*Abelmoschus maschatus, Cymbopogan flexuosus*	*Colletotrichum graminicola, C. capsici*	Reddish brown spots, holes are formed due to detachment of infected tissue
Cornyespora leaf spot	*M. arvensis, R. serpentine, O. basilicum*	*C. cassiicola*	Yellowish to brown nectrotic spots with chlorotic halo over the surface of leaves
Curvalaria leaf spot	*C. flexuosus, R. serpentine*	*Curvalaria verruciformi, C. trifolii, C. lunata*	Small oval to elongated dark brown necrotic lesions
Diplocarpon black spot	*R. damascene*	*Diplocarpon rosae*	Brown to back spots with radiating dark purplish margin on the upper surface of leaves
Drechslera/ *Helminthosporium* leaf spot	*Costus speciosus, C. flexuosus*	*Drechslera victorie, D. holmii, D. sacchari, Helminthosporium leucostylum, D. rostrata*	Minute yellow, circular spots unevenly scattered over the infected leaves.
Macrophomina leaf spot	*Chlorophytum borivilianum*	*Macrophomina phaseolina*	Water soaked lesions surrounded with dark brown margin and measured 3 × 2 mm in size
Myrothecium leaf spot	*Withania somnifera*	*Myrothecium roridum*	Small, dull yellow to brown coloured water soaked spots on the leaves
Alternaria blight	*Pelargonium graveolens, Pogostemon cablin, Mentha* spp., *P. somniferum, W. somnifera, R. serpentine, Cassia angustifolia, P. ovata*	*A. alternata, A. phragmospora, A. tenuis, A. cassiae*	Brown necrotic irregular lesions on the infected leaves. Dark brown patched surrounded with chlorotic halo
Colletotrichum blight	*O. basilicum, C. borivilianum, R. serpentine*	*C. capsici, C. gloeosporiodes*	Small chlorotic spots on lower leaves. Spots enlarged rapidly, coalesced and turn to brown patches
Curvalaria leaf blight	*C. winterianus, C. martinii*	*Curvalaria andropogonis, C. eragrostides, C. trifolii*	Elongated reddish brown necrotic lesions on the leaves
Ellisiella blight	*C. martinii*	*Ellisiella caudata*	Minute dark brown necrotic lesions
Macrophomina blight	*R. serpentine*	*M. phaseolina*	Necrotic lesions predominatly at the apex and along the margins of infected leaves
Phytophthora blight	*C. speciosus, A.maschatus, Catharanthus roseus*	*Phytophthora nicotianae* var *nicotianae*, *P. parasitica*	Dark brown spots on the leaves. Spots enlarged and coalesce together forming irregular necrotic patches.
Rhizoctonia blight	*R. serpentine, C. forskohlii, Mentha* spp.	*Rhizoctonia solani*	Water soaked irregular lesions starting from the leaf margins spread inwards.
Xanthomonas blight	*Hyoscyamus muticus*	*Xanthomonas compestris* pv. *turf*	Water soaked necrotic lesion of unlimited growth.
Anthracnose	*P. graveolens, R. serpentine, M. piperita*	*C. acutatum, C. gleosporiodes, Sphaceloma menthae*	Numerous minutenecrotic spots on the leaves which enlarge to develop into typical anthracnose lesions

Contd...

Disease	Crops	Causal organism	Symptoms
Die- back	*C. roseus*	*C. dematium, Pythium butleri*	Withering of the terminal buds of the young branches followed by wilting and drying.
Collar rot	*P. somniferum, Trachyspermum ammi, C. borivilianum*	*R. solani, Sclerotinia sclerotiorum, Corticium rolfsii*	Chlorosis on the lower leaves with small brown necrotic lesion on the collar region
Inflorescence & fruit rot	*R. serpentine, C. forskohlii, Datura innoxia*	*R. stolonifer, A. alternate, Botrytis cinerea*	Water soaked lesions which later showed slimy wet rot
Leaf rot	*Hibiscus moschatus*	*P. butleri*	Water soaked spots on the leaves
Rhizome rot	*Zingiber officinale*	*Enterobacter cloacae, P. aphanidermatum*	Yellowish brown to brown discolored tissue of firm to spongy texture
Root rot	*M. arvensis, Stevia rebaudiana, C. forskohlii, Asparagus officinalis*	*R. bataticola, Sclerotinia rolfsii, S. sclerotiorum, Fusarium redolens*	Yellowing and dropping of leaves, with wilting of plants and white cottony mycelia growth at the collar region
Stem rot	*C. roseus, M. arvensis, Rosmarinus officinalis, A. officinalis, H. moschatus*	*Rhizopus stolonifer, Sclerotinia sclerotiorum, Botryodiplodia theobromae, Phomopsis aspargi, P. parasitica,*	Pale green water soaked lesions. The fleshy tissue becomes stingy and water exudes rapidly. The tissue turns brownish with mild odor.
Soft rot	*P. somniferum, C. borivilianum, H. muticus, Aloe vera, Z. officinale*	*Erwinia carotovora, P. aphanidermatum, Pseudomonas cichorii, E. chrysanthemi*	Black streaks on the stem. The pitch regions of the infected stems become sift, pulpy and often produce dirty white, foul smelling exudates.
Wilt	*P. graveolens, M. arvensis, R. serpentine, W. somnifera*	*Fusarium moniliformi, R. solani*	Withering and dropping of the plants, serve wilting and cottony growth appear around the main root.
Damping off	*P. somniferum*	*Fusarium, Rhizoctonia, Phytophthora, Sclerotinia, Pythium* spp.	Infected seedlings turn yellow and then collapse
Root knot nematode	*Mentha* spp., *P. cablin, O. basilicum, P. graveolens, Hyoscynamus* spp., *W. somnifera, Bacopa monnieri, C. borivilianum, Artemisia pallens*	*Meloidogyne incognita, M. javanica, M. hapla, M. arvensis, Pratylenchus brachyurus*	Galls are formed on infested root. Plants are stunted, reduced tillering, yellowing, premature drying of leaf tips and margins, narrowing of leaf blades, delay in flowering, immature fruit drop, excessive root branching
Leaf curl/ Golden yellow net	*M. viridis, Andrographis paniculata*	Begomovirus	Growth stunting and curling of apical and downward leaves.
Mosaic diseases	*H. muticus, C. roseus, R. serpentine, H. albus, P. somniferum, Mentha* spp., *A. paniculata*	Cucumber mosaic virus, Tobacco mosaic virus, Potato virus X, Tobacco rattle virus, Carlavirus, Strawberry latent ringspot virus, Catharanthus yellow mosaic virus	Formation of mottle crinkle, mosaic patches on the leaves, tiny leaves, stunting less number of flower and malformed seeds
Phytoplasma Diseases	*C. roseus, W. somnifera, Foeniculum vulgare, Phyllanthus amarus, Matricaria chamomilla, P. ovate, Portulaca grandiflora*	Aster yellows, Peanut witches' broom, Coconut lethal yellowing, Elm yellows, Clover proliferation, Ash yellows, Luffa witches' broom, Pigeon pea witches' broom, Bermuda while leaf, Stolbur group	Yellowing of leaves, general stunting, early flowering, phyllody, witches' broom, virescence, high levels of reproductive failure, proliferation of axillary shoots, leaves malformed, severe resetting and stunting

Andrographis paniculata, Hyoscyamus muticus, Catharanthus roseus, Rauvolfia serpentina, H. albus and *Papaver somniferum* (Khan *et al.,* 2015; Postman *et al.,* 2004). Plant viruses are the major pathogen of MAPs which produce a wide range of symptoms in plants, thereby causing huge losses in crop production all around the world. The symptoms expressed by the plant due to virus infection might be topical or systemic in nature and depend upon the strain of virus, plant variety and geo-cultural environment. The various kinds of symptoms include chlorosis, mosaic, discoloration of leaves and malformations (Tzanetakis *et al.,* 2010).

The major plant viruses influencing MAPs growth are nematode-transmitted viruses (Arabis mosaic virus, Strawberry latent ring spot virus and Tobacco ring spot virus), aphid-transmitted viruses (Alfalfa mosaic virus, Cucumber mosaic virus and Mint vein banding associated virus*),* vitiviruses (Mint virus-2 and Peppermint stunt virus), thrips-transmitted viruses (Tospoviruses: Impatiens necrotic spot virus and Tomato spotted wilt virus), whitefly-transmitted viruses (Tomato leaf curl Pakistan virus), viruses with unknown vectors (Tobacco mosaic virus and Lychnis ringspot virus-mint).

Like viruses, phytoplasmas are small (0.3-0.5 µM in size; 580-2,200 kb circular DNA genome), cell-wall-deficient obligate parasites, related to the gram positive bacteria (Hogenhout *et al.,* 2008). In the host plants, phytoplasma multiply and spread only in the phloem tissue of various organs. A number of studies have shown that in the phytoplasma-infected plant organs, the expression of genes concerned with primary and secondary metabolism, stress response, photosynthesis, cell growth, and development gets modified. This intervention in the host genome expression is primarily responsible for the phytoplasma disease symptoms. The most peculiar symptoms observed on these medicinal plants includes yellowing of leaves, general stunting, early flowering, phyllody (leaf-like flower organs), witches' broom (clustered branching), virescence (greening of flower petals), high levels of reproductive failure, proliferation of axillary shoots, leaves malformed, severe rosetting, stunting and death of entire plants (Bertaccini and Duduk, 2010; Christensen *et al.,* 2005).

Management

Integrated management techniques are usually the best control measures for viral and phytoplasma pathogens. Soil drenching with carbendazim (0.1%) or propiconazole (0.1%) or dipping stem cuttings from disease free plants with carbendazim solution (0.1%) is an effective treatment (Pandey, 2011; Reddy, 2014). Similarly, stem cuttings dipped in 0.1% *P. fluorescens* at the time of planting and growing is an effective treatment (Boby and Bagyaraj, 2003). An intercrop of *T. erecta* in between the rows of several MAPs has been also found to be beneficial in controlling root-knot nematode problem by 66.7% and also decreases the incidence of *Macrophomina phaseolina* root rot disease up to 50 per cent (D'Addabbo *et al.,* 2014) Further, drip irrigation should be used for minimizing the spread of pathogens from infected plants to healthy plants.

Phytonematodes

Plant parasitic nematodes constitute one of the most important groups of pathogenic organisms prevalent in and around the root playing a significant role in the plant growth and yield reductions. Undoubtedly, these nematodes are associated with most of the medicinal and aromatic plants and cause significant damage, but the magnitude of crop damage differ from plant to plants (Koshy *et al.,* 2005). Primarily three species of plant parasitic nematodes i.e. Root-knot nematodes (*Meloidogyne incognita* and *M. javanica*), root lesion nematode (Pratylenchus *thornei*) and stunt nematode (*Tylenchorhynchus vulgaris*) affect cultivation of major medicinal and aromatic plants. The major crops which suffer root-knot nematode infestation are: Menthol mint, Henbanes, Basil, Opium poppy, Aswagandha, Sarpgandha, Coleus, Kinghao, Brahmi and Safed musli (Pandey, 1999; Pandey *et al.,* 2016). Some models and techniques have been suggested to avoid the economic loss caused by plant parasitic nematode to medicinal and aromatic plants (Gupta *et al.,* 2016).

The effective management of plant parasitic nematode through chemical nematicides for field use may not be available in the future. Consequently, it has become inevitable to manage this pathogen through non-chemical methods. Though, several non-chemical management tactics like fallow, flooding, changes in time of sowing/planting material, tillage practices, crop rotations, use of antagonistic crop, trap crop/cover crop, use of nematode free planting materials or seeds, solarization, organic amendment and biological control are available, efforts are directed towards the use of microbes to minimize the phytonematode population and to make soil more suppressive to nematode diseases (Pandey *et al.,* 2016; Sikora, 1992). Different microbes have been exploited in this lab to reduce the population of phytonematodes below the economic threshold level (Reddy and Pandey, 2013) and could play a significant role either singly or can be integrated with other practices to develop integrated nematode management practices (INMP). Studies conducted at CSIR-CIMAP, Lucknow so far indicate that microbial agents may play a significant role in limiting phytonematode population (Saikia and Pandey, 2014). The results of the studies carried out on major medicinal plants like *Artemisia annua, Artemisia pallens, Bacopa monnieri, Chlorophytum borivillianum*, *Hyoscyamus* spp., *Lavandula officinalis, Mentha arvensis, Rauvolfia serpentina, Withania somnifera etc.* have proven the efficacy of microbial agents (*Paecilomyces lilacinus, Glomus aggregatum, Trichoderma harzianum, Glomus fasciculatum, Glomus mosseae, Pseudomonas florescens*, *Bacillus subtilis, B. megaterium* etc.) and organic farming in the management of nematodes and for sustainable growth and yield of medicinal and aromatic plants (Gupta *et al.,* 2015a, b; Pandey *et al.,* 1999; Singh *et al.,* 2016b). Here the occurrence of various phytoparasitic nematodes affecting only three crops *viz*. mint, patchouli and Ashwagandha have been described in detail.

Mint (*Mentha* spp.)

Among different medicinal and aromatic plants mints come in the front line not only because of its pharmaceutical importance but also due to its many fold uses for the farmers. The farmer in tropical countries can grow it as a bonus crop as it fits well in the cropping system with other crops like paddy, wheat, potato, sugar cane, maize, okra, carrot, onion, spinach, pigeon pea, cowpea etc. This crop also generates significant employment and earns lot of foreign exchange. Different types of mints, which are commercially cultivated in tropical and subtropical countries, are: Menthol mint (*M. arvensis*), Peppermint (*Mentha piperita),* Spearmint (*Mentha spicata*), Scotch spearmint *(M. cardiaca*), Bergamot mint (*Mentha citrata*) and Garden mint (*M. viridis*).

Nematodes of mints

Nematodes have been identified as major pests of several mint species. The important nematodes which are affecting the yield are: *Meloidogyne* sp., *Pratylenchus*

Table 2. Important phytonematodes affecting mint crops in India

Plants / cultivars name	Major Phytonematode affecting the yield
Mentha arvensis var. MAS-1, Himalaya, HY-77, Siwalik, Kosi, Gomti, Kalka	*Meloidogyne incognita, M. javanica, Pratylenchus thornei, Tylenchorhynchus vulgaris, Longidorus pisi*
Mentha piperita cv. Kukrail	*Pratylenchus thornei*
M. spicata cv. MSS-5, Arka, Neera, Neer, Kalka, MCAS-1	*Pratylenchus thornei,M. incognita*
M. cardiaca	*M. incognita*
M. viridis	*P. thornei , M.incognita*

Table 3. Loss in total alkaloids in healthy and *M. incognita* race-2 infested roots of *Withania somnifera*

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

sp. and *Tylenchorhynchus* sp (Pandey and Patra, 2001). Several other phytonematodes are found to be associated with different mint species (Table 2).

Root-knot nematodes attack major medicinal and aromatic plants and are cosmopolitan in nature. Only two species i.e. *Meloidogyne incognita* and *M. javanica* are globally important for the menthol mint damage but the occurrence of *M. incognita* is more than *M. javanica*. Maximum R&D work in nematodes of menthol mint has been carried out with *M. incognita* (Pandey, 1995, 2005; Pandey *et al.,* 2011b).

Symptoms of damage

The major aerial symptoms in the fields of mint are stunting and chlorosis, which occur in patches. Root-knot infested suckers/ roots bear several galls of various sizes and most of the times eggs are easily visible on the root system (Fig. 1). The life cycle of *M. incognita* in menthol mint is completed in 28-30 days and occurs in menthol mint up to four generation under favourable condition. The race was identified as *M. incognita* race-2, which is predominant in Lucknow, Uttar Pradesh, India. As per records, the *Meloidogyne* species attack number of medicinal and aromatic plants. *Meloidogyne* juveniles/ eggs survive in the storage root/ suckers and these could be easily disseminated through suckers/roots, which are the main transplanting materials. Adhered soils with suckers and alternate weed host are also main source of the root-knot nematode inoculum.

Management

Meloidogyne species multiply well in sandy soil. Generally soil types where menthol mint is being cultivated is sandy loam therefore, damage caused by root-knot nematode in this region is several fold than in other regions. In one of the studies it has been reported that the infestation of root-knot nematode was more prevalent in sandy soil than clayey, which is less suitable for nematode multiplication (Fig. 1). As menthol mint is transplanted in January and this time period (February to April) is best suited for nematode development in menthol mint growing areas where nematode can complete three to four generations and build up their population up to the economic threshold level. Root-knot nematode (*M. incognita* and *M. javanica*) caused 25-30% oil yield reduction in menthol mint. The quality of mint oil was also adversely affected due to nematode infection (Pandey, 2005). Management of phytonematodes is one of the most important prerequisite to minimize injury to crop plants. Nematode injury provides entry to a wide variety of plant-pathogenic fungi and bacteria, which may cause other serious diseases. These microbial infections may result in greater losses than the damage from nematodes alone. Preplant treatment for the nematode control is essentially important because once a plant is parasitized it is really difficult to cure. The most sustainable approach to nematode control involves the integration of several strategies, including the use of pesticides, organic materials, bio-agents, resistant/ tolerant plant varieties, cultural practices etc. To manage root-knot nematode in menthol mint through ecofriendly way is a difficult task because of endoparasitic nature of pathogen (Pandey *et al.,* 2015).

Several germplasm available with CSIR-CIMAP, Lucknow gene bank were screened for their resistance to *Meloidogyne incognita* (Pandey and Patra, 2001). Most of the 25 accessions screened for *M. incognita* infection,

Fig. 1. Menthol mint plant and its root-knot nematode (*Meloidogyne incognita*) infested suckers

showed susceptible reaction to nematode infection of varying degree. Highest root-knot infection was rated on Siwalik, SS-18 and Himalaya. Comparatively moderate reaction was found on SS-11, SS-27, Gomti, Kosi, *M. cardiaca* and MAH-1respectively. The lowest infection level was found on SS-5, SS-5-4, Kalka and SS-20. On the other hand moderate to high degree of resistance was noticed on SS-1-4, SS-2-7, SS-15, SS-26, SS-36, *Mentha piperita* cv. Kukrail, *M. spicata* cv. Neera, *M. spicata* cv. Arka, *M. citrata* cv. Kiran, *M. gracilis* and *M. viridis* respectively. These can be further exploited for future breeding programme for developing root-knot resistant mint genotypes.Experiments conducted in our experimental farm suggest that inclusion of some non host like mustard and wheat crop help to a great extent in reducing the population of *Meloidogyne* spp. and its occurrence and severity on menthol mint crop. The late transplanted mint technology developed at CSIR-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.

Patchouli (*Pogostemon cablin* syn. patchouli)

Root-knot nematode (*M. incognita*, *M. javanica*, *M. hapla*) has become a major constraint for the successful cultivation of patchouli in different parts of India.

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. Sometimes root galls are very small or the surrounding galls coalesce to form large one up to 2-5 cm large even more (Fig. 2). Infection of root-knot nematodes occurs when plants are in their early stage of development. Bhau *et al.* (2016) confirmed the destructive effects of *M. incognita* infestation as an initial population of juveniles per 1500 J2/plant was reported to inflict serious losses in Patchouli yields. Bhau *et al.* (2016) confirmed the destructive effects of *M. incognita* infestation as an initial population of juveniles per 1500 J2/plant was reported to inflict serious losses in Patchouli yields.

Fig. 2. Root-knot nematode infested field of patchouli and its root system with root-knots

Management

A large number of experiments were conducted to manage phytoparasitic nematode on patchouli. Krishnaprasad and Reddy (1979, 1984) 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, fphenamiphos to control root-knot nematode *M. incognita* on patchouli. Carbofuran was one of the most effective chemicals for *M. incognita* control. In another 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 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. Simarlarly large number of bioagents and pesticide tested for their positive impact on oil yield and root-knot development in patchouli (Pandey *et al.,* 2009).

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. *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 numbers of other phytoparasitic nematodes were found to be associated in root rhizosphere of Ashwagandha.

Symptoms of damage

The nematode infected plants typically show chlorosis, stunted growth, 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 *M. incognita* (Fig. 3). 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.

Management

Management studies were carried out (Pandey and Kalra, 2003) through the use of different organic materials and

Fig. 3. Root knot nematode (*M. incognita* race -2) infested plants and roots of *W. somnifera*

bioagent on growth/ yield of *W. somnifera* and nematode reproduction. In the experimentation neem compound, *Artemisia annua* marc, *Mentha* and *M. 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 *G. 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. Uses of essential oils were also found to be nematode inhibitory in Ashwagandha (Pandey *et al.,* 2011a). 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. Use of different bio-organics viz. farm yard manures (Fym), cow urine, neem cake, vermicompost, *T. harzianum, Paecilomyces lilacinus* separately and in dual combinations against root-knot disease of *W. somnifera* and successful management of root-knot nematode on this crop were achieved (Saikia *et al.,* 2013, Singh *et al.,* 2016a; Tiwari *et al.,* 2016; Gupta *et al.,* 2016). Similarly large number of medicinal and aromatic plants were also affected by variety of plant parasitic nematode and have severe impact on production of plant secondary metabolites (Gupta and Pandey, 2015; Singh *et al.,* 2016b; Gupta *et al.,* 2017a, b; Tiwari *et al.,* 2017). My lab has recently published a few research papers on MAPs which may be highly beneficial to future researchers in field of medicinal and aromatic plants (https://scholar.google.co.in/citations).

Future directions

Despite the exceptional progress in the production of synthetic compounds during the last two decades, plants continue to be the main source of important drugs. Biotic invasions on such "wonder plants" in the form of several pathogens however, are a major hindrance not only on total production but also on the quality of the produce. Further, with the changing climatic conditions resurgence of diseases is expected to shoot up. Diseases cannot be completely eradicated but development of new systems for detection, identification and monitoring can play a vital role in effective disease management in medicinal and aromatic plants. Also, disease management strategies should focus specifically on the eco-friendly and integrated disease management practices so as to protect our "treasure trove".

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