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Review Article

Important Fungal Diseases in Medicinal and Aromatic Plants and Their Control

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ABSTRACT

Aromatic plants constitute the main raw materials of the perfumery, food and cosmetics industry and in recent years with the increasing demand for therapeutic herbal medicines, interest in medicinal and aromatic plants has increased. Raw materials from medicinal and aromatic plants have recently begun to be used and spread in the food sector, especially in industrial sectors such as paint and perfumery. For this reason, growing healthy plant material is very important in terms of the protection of these crops. However, fungal diseases such as root rot, wilt, leaf spots, blight and anthracnose, which are problems during the cultivation of both medicinal and aromatic plants, negatively affect both the quantity and quality of these plants. For this reason, an integrated management practices including cultural measures, herbal products, biological control and, if necessary, chemical control methods with especially these fungal diseases are very important. In this review, 27 medicinal and aromatic plants, 37 fungal diseases, their chemical and biological control were included, and 161 references were used.

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RESEARCH ARTICLE

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INTRODUCTION

The term '*Herbal treatment'* has been used in many different countries with many names such as traditional therapy, complementary therapy, or natural therapy. The first records about herbal therapy were found in the Mesopotamian civilization in 5000 BC and it was determined that 250 herbal drugs; obtained from medicinal and aromatic plants as usually dried and sometimes fresh, whole, shredded or cut plant or plant parts were used (Demirezer, 2010). According to the World Health Organization (WHO), traditional medicine is used in the prevention of physical and mental diseases, diagnosis, healing, or treatment as well as maintaining good health. In addition, it is the whole of knowledge, skills and practices that can or cannot be explained based on theories, beliefs, and experiences specific to different cultures (WHO, 2017).

The therapeutic use of plants varies according to the development level of the countries. In developing countries, 80% of the population benefits from herbal products for therapeutic purposes. While this rate reaches up to 95% in some countries of Asia, Africa, and the Middle East, it is less in developed countries (40-50% in Germany, 42% in the USA, 48% in Australia, and 49% in France). However, the most important trade centres for medicinal plants are in Germany, USA, Japan, and England (Titz, 2004). World Health Organization predicts that the treatment with herbs will increase all over the world in the coming years.

According to the World Health Organization, 25% of the pharmaceutical drugs used today are manufactured from medicinal plants and 30% of drugs sold worldwide contain compounds derived from plant materials (FAO, 2005).

The use of herbal medicine in countries that apply traditional medical treatment varies according to the recommendations of the people practicing traditional/alternative medicine or their own experience. Also, in some countries, training is provided at universities related to complementary medicine. For example, in the universities of many countries in the Economic Community of West African States, such as Democratic Republic of Congo, South Africa and Tanzania there are complementary medicine courses in the curricula of pharmacy and medical studies (WHO, 2014). Complementary medicine is seen as a primary health care service in some African countries. For example, the ratio of traditional healers to the population in Africa is 1/40.000, while the ratio of medical doctors is 1/500 (Abdullahi, 2011).

Medicinal and aromatic plants are plants that have many uses such as food, medicine, cosmetics and spices and are known to have been used for similar purposes since the beginning of human history. While some of these plants are collected from nature, some of them have been cultivated and produced. However, most of the herbs used for therapeutic purposes are collected from nature. The most prominent and researched properties of medicinal and aromatic plants are their therapeutic uses (Kumar, 2014). Extracts of these plants in water or alcohol are also applied against pests and plant diseases due to their biological effects (Isman, 2000; Bakkali *et al.*, 2008). The aromatic parts of aromatic plants are used to extract therapeutic oils/essential oils containing allelochemical aroma of economic value (Nagpal and Karki, 2004).

More than 6 000 medicinal plant species have been identified from different tropical regions (Khare, 2008), more than 1 000 of them are classified as aromatic (Panda, 2015). Climate changes, intensive cultivation practices and market-oriented crop management have led to an increase in pests and diseases. These problems in medicinal and aromatic products have gradually increased (Sharma, 2013; Sharma *et al.*, 2014). Damages caused by pests or diseases can reduce their biomass and oil content (Gupta *et al.*, 2000; Zadotani and Ikegami, 2002). Besides changing climatic conditions, the indiscriminate and unplanned large-scale cultivation of medicinal and aromatic plants to meet the increasing demand of the pharmaceutical industries is leading to increased incidence and severity of diseases.

Losses caused by plant diseases not only reduce the yield of plant secondary metabolites but also reduce the quality of raw materials (Singh *et al.*, 2016).

In this review, fungal diseases causing an infection on medicinal and aromatic plants, grown or cultured spontaneously and reducing plant quality and yield and even causing death, their symptoms and methods of controlling them are included.

In this context, diseases and management of important medicinal and aromatic plants listed in Table 1 and reported from Turkey and the world were presented.

Lavandula spp. (Lavender), *Humulus lupulus* L. (Hops), *Papaver somniferum* L. (Poppy), *Rosa* spp. (Rose), *Salvia officinalis* L. (Sage), *Origanum* spp. (Oregano), *Carthamus tinctorius* L. (Safflower), *Dianthus caryophyllus* L. (Clove), *Sesamum indicum* Linn. (Sesame), *Pimpinella anisum* L. (Anise), *Asparagus* spp. (Asparagus fern), *Rosmarinus officinalis* L. (=*Salvia rosmarinus*) (Rosemary), *Mentha piperita* L. (Mint), *Aloe vera* L. Burm. (=*Aloe barbadensis* Mill.), *Withania somnifera* (L.) Dunal (Indian Ginseng-Poisonous Gooseberry-Winter Cherry), *Rauwolfia serpentina* (L.) Benth. ex Kurz (Snakeroot) (Serpentine/Sarpagandha), *Ocimum sanctum* L. (=*Ocimum tenuiflorum* L.) (Holy Basil, Tulsi), *Coleus forskohlii* Briq (Coleus flower, *Chlorophytum borivilianum* Santapau & Fernandez (Musli), *Hyoscyamus* spp. (Henbane), *Plantago ovata* Forssk. (Psyllium Blond), *Catharanthus roseus* (L.) G. Don (Pink periwinkle), *Pogostemon cablin* (Blanco) Benth. (Patchouli), *Zingiber officinale* Roscoe (Ginger), *Vetiveria zizanioides* (L.) Nash (Vetiver), *Santalum* spp. (Sandalwood) and *Cymbopogon citratus* Stapf. (Lemon grass). Fungal disease agents that cause leaf spots, blight, rust, powdery mildew, root rot, damping-off and dieback frequently occur in these medicinal and aromatic plants (Avan, 2021).

OCCURRENCE OF FUNGAL DISEASES

The cultivation of medicinal and aromatic plants has increased considerably in recent years due to their huge worldwide demands on plant-based medicines and aromatic compounds. These plants are affected by various diseases caused by fungi, bacteria, viruses and phytoplasmas. Among these diseases, especially fungal diseases are very important (Table 1).

Fungi infect leaves, stems and underground parts of medicinal and aromatic plants. Among these fungal diseases, Powdery mildew appears on the leaves and fresh stems, and as the disease progresses, it covers the entire developing surface of the plant. Rust diseases are airborne diseases that infect leaves, branches and fruits and cause pustules on leaves. Leaf spots and blights cause dead areas on the leaves with distinct spots over time, and in this way, they are separated from healthy tissues (Bhandari *et al.*, 2014). Blights appear on the leaves, twigs or blossoms of the plant and cause sudden death of the plant (Sattar *et al.*, 2006; Ramappa and Shivanna, 2013). Medicinal and aromatic plants are also highly affected by root rot, wilt, anthracnose and dieback caused by fungi and bacteria. These diseases manifest themselves with hard, dry, spongy, soft, watery or slimy-looking rotten tissues in plants (Singh *et al.*, 2016).

Table 1. Important fungal diseases of medicinal and aromatic plants.

DISEASES	PLANTS	CAUSAL ORGANISMS	SYMPTOMS
Rusts	*Aloe vera*	*Phakopsora pachyrhizi, Uromyces aloes*	Yellowish red spots appear on the lower surface of the leaf and rust pustules form in these spots (Jones, 1972; Koike *et al.*, 1998; Kalra *et al.*, 2005; Saber *et al.*, 2009; Soni *et al.*, 2011; Afshan *et al.*, 2012).
	Asparagus spp. (Asparagus fern)	*Puccinia asparagi*	
	Cymbopogon citratus (Lemon grass)	*Puccinia nakanishikii*	
	Mentha spp. (Mint)	*Puccinia menthae*	

	Pelargonium spp. (Geranium)	*Puccinia pelargonii-zonalis*	
	Pimpinella anisum (Anise)	*Puccinia pimpinellae*	
	Rosa spp. (Rose)	*Caeoma* spp.	
	Dianthus caryophyllus (Clove)	*Uromyces dianthi*	
	Origanum vulgare (Oregano)	*Puccinia menthae*	
Downy Mildews	*Coleus forskohlii* (Coleus flower)	*Peronospora belbahrii, P. lamii*	Yellow to light brown necrotic lesions, folds, and kinks occur on the leaves (Sain and Sharma, 1999; Garibaldi *et al.*, 2004; Landa *et al.*, 2005; Humphreys-Jones *et al.*, 2008; López-Guisa *et al.*, 2013).
	Ocimum sanctum (Holy Basil, Tulsi)	*Peronospora belbahrii*	
	Plantago ovata (Psyllium Blond)	*Peronospora plantaginis*	
	Humulus lupulus (Hops)	*Pseudoperonospora humuli*	
	Papaver somniferum (Poppy)	*Peronospora* spp.	
	Rosa spp. (Rose)	*Peronospora sparsa*	
	Rosmarinus officinalis (Rosemary)	*Peronospora lamii*	
Powdery Mildew	*Mentha* spp. (Mint)	*Erysiphe cichoracearum*	Chlorotic spots and brownish discolorations in the form of powder appear on the leaf surface. The disease causes the leaves to curl and the bend to stem (Valiyeva *et al.*, 2004; Kalra *et al.*, 2005; Humphreys-Jones *et al.*, 2008; Thines *et al.*, 2009; Baradaran *et al.*, 2012; Venegas-Portilla *et al.*, 2020).
	Cymbopogon citratus (Lemon grass)	*Erysiphe graminis*	
	Humulus lupulus (Hops)	*Podosphaera macularis*	
	Rosa damascena (Damask rose)	*Podosphaera pannosa*	
	Salvia officinalis (Sage)	*Golovinomyces neosalviae*	
		Peronospora lamii	
	Rosa spp. (Rose)	*Sphaerotheca pannosa* var. *rosae*	
***Alternaria* Leaf Spots**	*Aloe vera*	*Alternaria alternata A. brassicae*	Dark brown circular spots occur on infected leaves (Xiaoyin, 1982; Kumar et al., 1984; Kishore *et al.*, 1985; Kalra *et al.*, 2005; Taba *et al.*, 2009; Garibaldi *et al.*, 2011; Zimowska, 2015).
	Withania somnifera (Indian Ginseng)	*Alternaria alternata, A. tenuis*	
	Mentha spp. (Mint)	*Alternaria alternata*	
	Pelargonium spp. (Geranium)	*Alternaria alternata*	
	Salvia officinalis (Sage)	*Alternaria alternata*	
	Ocimum basilicum (Sweet Basil)	*Alternaria alternata*	
	Hyoscyamus spp. (Henbane)	*Alternaria alternata*	
	Carthamus tintorius (Safflower)	*Alternaria carthami*	
	Papaver somniferum (Poppy)	*Alternaria alternata*	
	Dianthus caryophyllus (Clove)	*Alternaria dianthi*	
	Origanum vulgare (Oregano)	*Alternaria alternata*	

Cercospora **Leaf Spots**	*Ocimum sanctum* (Holy Basil- Tulsi)	*Cercospora ocimicola*	Necrotic spots with dark brown edges are scattered on the leaves (Bubak, 1906; Enikuomehin, 2006; Bhandari *et al.*, 2014).
	Rauwolfia serpentina (Snakeroot)	*Cercospora rauvolfiae, Cercospora serpitinae*	
	Emblica officinalis (Indian Gooseberry)	*Cercospora* spp.	
	Sesamum indicum (Sesame)	*Cercospora sesami*	
	Pimpinella anisum (Anise)	*Cercospora malkoffii*	
Colletotrichum **Leaf Spots**	*Ocimum sanctum* (Holy Basil- Tulsi)	*Colleotrichum gleosporioides, C. capsica*	Reddish brown circular spots appear on the leaves first. Holes and premature drying occur in the leaves due to the rupture of the infected tissue (Tekade *et al.*, 2009; Gautam, 2014; Zimowska, 2015).
	Withania somnifera (Indian Ginseng)	*Colletotrichum gloeosporioides, C. dematium*	
	Pelargonium spp. (Geranium)	*C. gloeosporoides*	
	Origanum vulgare (Oregano)	*Colletotrichum fuscum*	
Corynespora **Leaf Spot**	*Coleus forskohlii* (Coleus flower)	*Corynespora cassiicola*	Yellowish-brown necrotic spots in the form of chlorotic halo occur on the leaves (Shukla *et al.*, 2000; Garibaldi *et al.*, 2007).
	Rauwolfia serpentina (Snakeroot)	*C. cassiicola*	
	Mentha arvensis (Menthol mint)	*C. cassiicola*	
	Ocimum basilicum (Sweet Basil)	*C. cassiicola*	
Curvularia **Leaf Spots**	*Cymbopogon citratus, C. flexuosus* (Lemon grass)	*Curvularia andropogonis,*	Small oval and long dark brown necrotic lesions appear on the leaves (Thaung, 2008; Bhagat *et al.*, 2014).
	Mentha spp. (Mint)	*C. lunata,*	
	Rauwolfia serpentina (Snakeroot)	*C. trifolii*	
Diplocarpon **Leaf Spot**	*Rosa chinensis* (China rose), *Rosa damascena* (Isparta rose)	*Diplocarpon rosae*	Brown to black spots with dark purplish margins occur on the upper surface of the leaves (Margina and Zheljazkov, 1995a).
Macrophomina **Leaf Spot**	*Chlorophytum borivilianum* (Musli)	*Macrophomina phaseolina*	Small water-soaked lesions are formed surrounded by a dark brown border on the leaves (Dadwal and Bhartiya, 2012).
Myrothecium **Leaf Spot**	*Withania somnifera* (Indian Ginseng)	*Myrothecium roridum*	Small, dull yellow, brown coloured water-soaked spots appear on the leaves (Shivanna *et al.*, 2014).
Stemphylum **Leaf Spots**	*Asparagus* spp. (Asparagus fern)	*Stemphylium vesicarium*	Light brown, large elliptical spots occur on the stem and branches, the lesions on the stems merge into large areas of infected tissue (Falloon and Tate, 1986; Zimowska, 2015).
	Origanum vulgare (Oregano)	*Stemphylium botryosum*	
Phoma **Leaf Spot**	*Origanum vulgare* (Oregano)	*Phoma herbarum*	The agent causes angular spots on the leaves. (Basavand *et al.*, 2020).
Alternaria **Leaf Blights**	*Chlorophytum borivilianum* (Musli)	*Alternaria alternata*	Brown necrotic irregular lesions and surrounding

	Rauwolfia serpentina (Snakeroot)	*Alternaria tenuis, A. alternata*	chlorotic halos occur on the leaves (Rai and Tetrawal, 2010; Thakur and Harsh, 2014).
	Mentha spp. (Mint)	*Alternaria alternata*	
	Pelargonium spp. (Geranium)	*Alternaria alternata*	
	Withania somnifera (Indian Ginseng)	*Alternaria tenuis, A. alternata*	
	Plantago ovata (Psyllium Blond)	*Alternaria alternata*	
Colletotrichum **Leaf Blights**	*Chlorophytum borivilianum* (Musli)	*Colletotrichum dematium, C. capsici*	Small chlorotic spots appear on the lower leaves, which rapidly expand and merge into brown spots (Sattar *et al.*, 2006; Ramappa and Shivanna, 2013).
	Rauwolfia serpentina (Snakeroot)	*Colletotrichum dematium, C. capsici*	
	Cymbopogon citratus (Lemon grass)	*Colletotrichum caudatum*	
Curvularia **Leaf Blights**	*Cymbopogon citratus* (Lemon grass)	*Curvularia trifolii*	Long, reddish-brown necrotic lesions occur on the leaves (Alam *et al.*, 1983; Sato and Ohkubo, 1990).
	Cymbopogon nardus (Lemon grass)	*Curvularia andropogonis*	
	Vetiveria zizanioides (Vetiver)	*Curvularia trifolii*	
Macrophomina **Leaf Blights**	*Chlorophytum borivilianum* (Musli)	*Macrophomina phaseolina*	Necrotic lesions appear on the edges and tips of infected leaves (Maiti and Geetha, 2013; Meena and Kadam, 2021).
	Rauwolfia serpentina (Snakeroot)	*Macrophomina phaseolina*	
Sclerotinia **Blights**	*Mentha* spp. (Nane)	*Sclerotinia sclerotiorum*	The first symptoms are necrosis of the stem, darkening and wilting of the leaves. Then cottony soft rots occur (Garibaldi *et al.*, 2013).
Rhizoctonia **Leaf Blights**	*Coleus forskohlii* (Coleus flower)	*Rhizoctonia solani*	Water-soaked irregular spots spreading inward from the leaf edge are formed (Mehrotra and Thapar, 1990; Shukla *et al.*, 1993; Kalra *et al.*, 2005; Sato *et al.*, 2010; Aktaruzzaman *et al.*, 2015).
	Mentha spp. (Mint)	*Rhizoctonia solani*	
	Rauwolfia serpentina (Snakeroot)	*Rhizoctonia solani*	
	Rosmarinus officinalis (Rosemary)	*Rhizoctonia solani*	
	Origanum vulgare (Oregano)	*Rhizoctonia solani*	
Botrytis **Leaf Blights**	*Pelargonium* spp. (Geranium)	*Botrytis cinerea*	Concentric ring lesions on leaves, wilting and drying of flowers appeared (Kalra *et al.*, 2008; Vinodkumar and Nakkeeran, 2017).
	Rosa chinensis, (China rose) *Rosa damascena* (Isparta rose)	*Botrytis cinerea*	
	Dianthus caryophyllus (Clove)	*Botrytis cinerea*	
Passalora **Blight**	*Pimpinella anisum* (Anise)	*Passalora malkoffii*	The disease causes lesions and drying on all above-ground parts of plants, including inflorescences (Erzurum *et al.*, 2005)
Phoma **Leaf Blight**	*Origanum vulgare* (Oregano)	*Phoma multirostrata var. macrospora*	Small, black spots are observed on the top and bottom of the infected leaves and on

			young shoots depending on the humidity (Garibaldi *et al.*, 2015b)
Anthracnoses	*Aloe vera*	*Colletotrichum gloeosporioides*	Small necrotic spots on the leaves turn into typical anthracnose lesions as the disease progresses (Sattar *et al.*, 2002; Singh *et al.*, 2004; Ayvar-Serna *et al.*, 2020)
	Rauwolfia serpentina (Snakeroot)	*Colletotrichum gleosporioides*	
	Emblica officinalis (Indian Gooseberry)	*Colletotrichum gloeosporioides*	
	Mentha spp. (Nane)	*Sphaceloma menthae*	
	Salvia officinalis (Sage)	*Colletotrichum dematium*	
	Origanum vulgare (Oregano)	*Colletotrichum tropicale*	
Diebacks	*Rauwolfia serpentina* (Snakeroot)	*Colletotrichum dematium*	Fading and drying appears in the tip buds of young branches. (Kulkarni and Ravindra, 1988; Kulkarni *et al.*, 1992).
	Catharanthus roseus (Pink Periwinkle)	*Pythium aphanidermatum*	
Collar Rots	*Cymbopogon citratus* (Lemon grass)	*Fusarium moniliforme*	Chlorosis on the lower leaves and small brown necrotic lesions in the collar area of the plant occurs (Singh *et al.*, 2001; Trivedi *et al.*, 2006).
	Mentha spp. (Mint)	*Sclerotium rolfsii*	
	Pogostemon cablin (Patchouli)	*Fusarium oxysporum, Rhizoctonia solani*	
	Chlorophytum borivilianum (Musli)	*Corticium rolfsii*	
Fruit Rots	*Rauwolfia serpentina* (Snakeroot)	*Rhizopus stolonifer*	Wet rots appear on the fruit (Shukla *et al.*, 2006; Singh *et al.*, 2011).
	Withania somnifera (Indian Ginseng)	*Myrothecium* sp.	
	Emblica officinalis (Indian Gooseberry)	*Phomopsis phyllanthi*	
Leaf Rots	*Aloe vera*	*Sclerotium rolfsii, Colletotrichum dematium, Phoma* sp., *Rhizoctonia bataticola*	Water-soaked spots occur on the leaves (Shukla *et al.*, 1981).
Rhizome Rot	*Zingiber officinale* (Ginger)	*Pythium aphanidermatum*	Hard or spongy yellowish brown to brown tissues formations appear (Stirling *et al.*, 2009).
Stolon Rots	*Mentha* spp. (Mint)	*Macrophomina phaseoli, Rhizoctonia solani, R. bataticola, Thielavia basicola*	The agent typically causes fading in the stolons and rot in later stages (Kalra *et al.*, 2008).
Root Rots	*Aloe vera*	*Fusarium oxysporum Phytophthora* spp., *Pythium* spp.	With the wilting of the plants, yellowing of the leaves, falling and white cotton-like mycelium growth in the collar area appear (Subbiah *et al.*, 1996; Boby and Bagyaraj, 2003; Kamalakannan *et al.*, 2006; Zimowska, 2008; Martini *et al.*, 2009; Govindappa *et al.*, 2010; Ziedan *et al.*, 2010; Zimowska, 2015; Ağaner and Cere, 2017).
	Asparagus spp. (Asparagus fern)	*Fusarium oxysporum* f.sp. *asparagi, F. proliferatum, F. moniliforme, F. solani, F. redolens, Phytophthora asparagi, Phytophthora megasperma* var. *sojae, Phytophthora* spp., *Rhizoctonia solani*	

	Origanum spp. (Oregano)	*R. solani*, *M. phaseolina*	
	Chlorophytum borivilianum (Musli)	*Rhizoctonia bataticola*, *Fusarium solani*	
	Coleus forskohlii (Coleus flower)	*Fusarium chlamydosporum*, *F. solani*, *Macrophomina phaseolina*, *Ralstonia solanacearum*	
	Ocimum sanctum (Holy Basil- Tulsi)	*Rhizoctonia solani*, *Pythium* spp.	
	Rauwolfia serpentina (Snakeroot)	*Macrophomina phaseolina*	
	Pelargonium spp. (Geranium)	*Rhizoctonia solani*, *Macrophomina phaseolina* *Pythium sp.*	
	Rosa chinensis (China rose), *Rosa damascena* (Isparta rose)	*Phytophthora* spp., *Alternaria* spp., *Rhizoctonia* spp., *Sclerotinia* spp., *Pythium* spp.	
	Salvia officinalis (Sage)	*Phytophthora cryptogea*, *Rhizoctonia solani*, *Fusarium spp.*, *Fusarium oxysporum*, *Phoma exigua* var. *exigua*	
	Lavandula spp. (Lavender)	*Phytophthora nicotianae*, *P. palmivora*, *P. cinnamomi*, *P. cactorum*	
	Carthamus tinctorius (Safflower)	*Macrophomina phaseolina*	
	Sesamum indicum (Sesame)	*Macrophomina phaseolina*	
	Origanum vulgare (Oregano)	*Phytophthora tentaculata*	
	Origanum dubium (Oregano)	*Boeremia exigua var. exigua*, *Rhizoctonia solani*, *Fusarium* spp.	
Stem Rots	*Asparagus* spp. (Asparagus fern)	*Fusarium oxysporum* f.sp. *asparagi*, *F. proliferatum*, *F. moniliforme*, *F. solani*, *F. redolens*	Pale green water-soaked lesions appear. The fleshy tissue becomes weak and the water in the tissue comes out quickly, a slight odor is felt and this part turns brown (Trujillo *et al.*, 1988; Burns and Benson, 2000; Elena, 2006; Oogi *et al.*, 2009; Martini *et al.*, 2009; Zimowska, 2015; Samouel *et al.*, 2016)
	Lavandula spp. (Lavender)	*Phytophthora nicotianae*, *P. palmivora*, *P. cinnamomi*, *P. cactorum*	
	Salvia officinalis (Sage)	*Phomopsis sclarea*	
	Rosmarinus officinalis (Rosemary)	*Sclerotinia sclerotiorum*	
	Dianthus caryophyllus (Clove)	*Rhizoctonia solani*	
	Origanum vulgare (Oregano)	*Phytophthora tentaculata*	

	Origanum dubium (Oregano)	*Boeremia exigua* var. *exigua*, *Rhizoctonia solani*, *Fusarium* spp.	
Crown Rots	*Asparagus* spp. (Asparagus fern)	*Phytophthora asparagi*, *Phytophthora megasperma* var. *sojae*, *Phytophthora spp.*	Infected crowns first turn yellowish orange and as the disease progresses, rots appear (Garibaldi *et al.*, 2015a; Mondal *et al.*, 2018).
	Rosa chinensis (China rose), *Rosa damascena* (Isparta rose)	*Phytophthora* spp., *Alternaria* spp., *Rhizoctonia* spp., *Sclerotina* spp., *Pythium* spp.	
	Papaver somniferum (Poppy)	*Pleospora papaveracea*	
	Salvia officinalis (Sage)	*Phytophthora cryptogea*	
Wilts	*Coleus forskohlii* (Coleus flower)	*Ralstonia solanacearum*	With the fading and falling of the plants, cottony growths appear around the main root. (Nelson *et al.*, 1960; Gupta *et al.*, 2004; Dung *et al.*, 2010; Ziedan *et al.*, 2010).
	Ocimum sanctum (Holy Basil- Tulsi)	*Fusarium oxysporum* f. sp. *basilicum*	
	Withania somnifera (Indian Ginseng)	*Fusarium solani*	
	Emblica officinalis (Indian Gooseberry)	*Fusarium* sp.	
	Vetiveria zizanioides (Vetiver)	*Fusarium* sp.	
	Plantago ovata (Psyllium Blond)	*Fusarium oxysporum*, *F. solani*	
	Mentha spp. (Mint)	*Verticillium alba-atrum* var. *menthae*	
	Pelargonium spp. (Geranium)	*Verticillium albo-atrum*, *Verticillium dahliae*	
	Humulus lupulus (Hops)	*Verticillium nonalfalfae*, *Verticillium albo-atrum*,	
	Lavandula spp. (Lavender)	*Fusarium sporotrichioides*, *F. oxysporum*, *F. solani*, *Sclerotinia sclerotiorum*, *Phytophthora palmivora*	
	Rosmarinus officinalis (Rosemary)	*Phytophthora citrophthora*, *Rhizoctonia solani*, *Fusarium oxysporum*, *Nigrospora oryzae*	
	Carthamus tinctorius (Safflower)	*Fusarium oxysporum* f. sp.*carthami*	
	Sesamum indicum (Sesame)	*Fusarium oxysporum* f. sp. *sesami*	
	Dianthus caryophyllus (Clove)	*Fusarium oxysporum* f.sp. *dianthi*	
Damping-off	*Withania somnifera* (Indian Ginseng)	*Rhizoctonia solani*	Infected seedlings first turn yellow and wilt, then the plant falls over and collapses (Kishore *et al.*, 1985; Alam *et al.*, 1996; Carkacı and Maden, 1998; Li *et al.*, 2008; Barguil *et al.*, 2009).
	Cymbopogon citratus (Lemon grass)	*Pythium aphanidermatum*	
	Rosa chinensis (China rose), *Rosa damascena* (Isparta rose)	*Phytophthora* spp., *Alternaria* spp., *Rhizoctonia* spp., *Sclerotinia* spp., *Pythium* spp.	

	Santalum spp. (Sandalwood)	*Fusarium* spp., *Phytophthora* spp., *Rhizopus* spp.	
	Lavandula spp. (Lavender)	*Rhizoctonia solani, Botrytis cinerea, Alternaria alternata, Colletotrichum* spp.	
	Papaver somniferum (Poppy)	*Fusarium solani*	
	Sesamum indicum (Sesame)	*Rhizoctonia solani, Fusarium* spp., *Alternaria tenuis*	
	Pimpinella anisum (Anise)	*Rhizoctonia solani, Fusarium* spp., *Alternaria tenuis*	
	Rosa spp. (Rose)	*Fusarium oxysporum*	
	Dianthus caryophyllus (Clove)	*Rhizoctonia solani*	
	Salvia officinalis (Sage)	*Fusarium oxysporum, F. solani, F. moniliforme, Rhizoctonia solani*	
Gray Mold	*Ocimum sanctum* (Holy Basil- Tulsi)	*Botrytis cinerea*	The agent causes dense gray-brown hairy growth on the stems and leaves, falling of leaves, damping-off of plants, severe lesions on the stem and death on the plant (Edney, 1967; Moreira *et al.*, 2015).
	Rosa chinensis, (China rose) *Rosa damascena* (Isparta rose)	*Botrytis cinerea*	
	Dianthus caryophyllus (Clove)	*Botrytis cinerea*	
Blue Mold	*Emblica officinalis* (Indian Gooseberry)	*Penicillium citrinum, P. islandicum*	Soft, wet and colourless-looking spots occurr on infected fruits. Blue green spores are appeared in these parts (Saini, 2017).
Wet Rots	*Withania somnifera* (Indian Ginseng)	*Choanephora cucurbitarum*	The infected area appears wet and these parts turn into signs of rot (Shukla *et al.*, 2006)
	Rauwolfia serpentina (Snakeroot)	*Rhizopus stolonifer*	

CONTROL OF FUNGAL DISEASES

Essential oils obtained from aromatic herbs are used in the perfume and food industry. Therefore, healthy plant material is very important for maintaining product quality. However, there are major problems in the cultivation of both medicinal and aromatic plants. The damages caused by fungal diseases cause negative effects on both the quality and quantity of the plant's biomass and the limitation of its successful cultivation in large areas and different places. Chemical applications are a form of management that is often used by producers. However, toxic pesticide residues in chemicals cause serious concerns as they pose serious dangers to human health. For this reason, cultural practices, products obtained from plants and biological control methods have been used along with chemical control (Table 2).

The methods of cultural control against fungal diseases on medicinal and aromatic plants include proper field cleaning and irrigation, use of resistant varieties, use of

compost, mulch and fertilizers that strengthen plant growth, avoiding close planting, pruning regularly, removing diseased plants and destroying them are especially recommended. Avoiding close planting, pruning regularly, removing diseased plant debris and destroying them are especially recommended. Various studies show that the management of diseases with biological control is more effective in controlling multiple diseases.

By reducing the chemicals used in agriculture, it seems possible to obtain quality products by preventing the yield loss in the soil with organic and biological solutions, which are alternative methods of control (Avan and Kotan, 2021).

Table 2. Chemical and biological control methods reported on fungal diseases of medicinal and aromatic plants.

Fungal Diseases in Medicinal and Aromatic Plants	Chemical Control	Biological Control
Rusts	- Sulfur, Copper oxychloride (Singh, 2006). - **Chlorothalonil**[1,2,6] (Douglas, 2003; Moorman, 2017) - Azoxystrobin, **Myclobutanil**[1,3], **Propiconazole**[1,2,3,4,7] (Mueller *et al.*, 2004) -**Tebuconazole**[5,7]+**Triadimenol**[2,7], **Triadimenol**[2,7], Flutriafol (Margina and Zheljazkov, 1995b) - **Trifloxystrobin**+ **Tebuconazole**[5,7], **Propiconazole**[1,2,3,4,7] (Mekonnen and Manahlie, 2018) - **Triadimefon**[2,7] (Tamuli *et al.*, 2012)	- *Bacillus subtilis* and *Trichoderma harizianum* (Saber *et al.*, 2009). - *Datura stramonium, Maesa lanceolata* ve *Milletia ferruginea* extracts (Mekonnen *et al.*, 2014). - *Vernonia amygdalina, Artemisia annua* (Mekonnen *et al.*, 2015)
Downy Mildews	- **Mancozeb**[1,2,3,6] (Jat *et al.*, 2015) - Metalaxyl (Yadav *et al.*, 2010) - Acibenzolar-S-methyl, Azoxystrobin, Cyazofamid, Mandipropamid (McGrath and LaMarsh, 2013, 2015) - Metalaxyl-M + **Copper hydroxide**[2], Mineral fertilizer "Alexin", Mandipropamid, Azoxystrobin, Glucohumates activator complex and Acibenzolar-S-methyl (Gilardi *et al.*, 2013)	- *Streptomyces lydicus*, *Bacillus amyloliquefaciens* strain D747, *Reynoutria sachalinensis* extract, neem oil, potassium bicarbonate and hydrogen dioxide (Wyenandt *et al.*, 2015)
Powdery Mildews	- Sodium bicarbonate (Salamone *et al.*, 2009). - Azoxystrobin, **Boscalid**[7]+Pyraclostrobin, Metalaxyl M+ Copper oxychloride, Mandipropamid and copper-based fungicides (Minuto *et al.*, 2012) - **Boscalid**[7], Monopotassium phosphate and vegetable oils (NTI 3404, NTI 3412) (Amoretti *et al.*, 2005)	- Thyme and clove essential oil (Salamone *et al.*, 2009).
***Alternaria* Leaf Spots**	- **Mancozeb**[1,2,3,6] (Sharma *et al.*, 2010a). - Bordeaux mixture (Smitha *et al.*, 2014). - **Propineb**[1,2] (Parashurama and Shivanna, 2013). - **Propiconazole**[1,2,3,7], **Difenoconazole**[7] (Chauhan and Ravi, 2020). - **Mancozeb**[1,2,3,6]+**Propiconazole**[1,2,3,4,7] (DMAPR, 2012). - Penconazole (Qazi *et al.*, 2006)	- *Trichoderma viride* (Chauhan and Ravi, 2020). - Garlic oil, ginger oil and tulsi oil, turmeric rhizome extract (Sharma *et al.*, 2010a) - Neem extract (Guleria and Kumar, 2006).

	- **Mancozeb**[1,2,3,6], **Propiconazole**[1,2,3,4,7], **Difenconazole**[7], Azoxystrobin (Sharma et al., 2010a). - **Benomyl**[1,2,7], **Mancozeb**[1,2,3,6], **Carbendazim**[2,7] (Singh, 2006)	
Cercospora **Leaf Spots**	- **Carbendazim**[2,7] (DMAPR, 2014) - **Chlorothalonil**[1,2,6], **Iprodione**[1,2,7], Copper oxychloride, **Maneb**[1,2,3,6], **Mancozeb**[1,2,3,6], **Thiophanate-methyl**[1,2,6], **Benomyl**[1,2,7] (Singh, 2006). - **Zineb**[1,2] (Mondal *et al.*, 2018)	- Soil application of neem cake + leaf waste of eucalyptus, *Millettia* (=*Pongamia*) *pinnata*+*Madhuca longifolia* cake; Neem oil or Neem seed extract+Neem cake and *Pseudomonas fluorescens* (Arumugam *et al.*, 2010).
Colletotrichum **Leaf Spots**	- **Tebuconazole**[5,7] (Sharma *et al.*, 2010a,b). - Dithane (DMAPR, 2014). - **Mancozeb**[1,2,3,6], Copper oxychloride (Mondal *et al.*, 2018)	- *Trichoderma viride, T. harzianum, T. koningii, T. virens, T. hamatum* (Musheer and Ashraf, 2017). - Gentisyl alcohol obtained from *Phoma herbarum* (Gupta *et al.*, 2016).
Corynespora **Leaf Spot**	- **Mancozeb**[1,2,3,6] (DMAPR, 2014).	- *Pseudomonas* sp.+Salicylic acid+ *Clerodendron inerme* leaf powder (DMAPR, 2014).
Curvularia **Leaf Spots**	- **Mancozeb**[1,2,3,6], Bordeaux mixture (Smitha *et al.*, 2014)	
Diplocarpon **Leaf Spot**	- **Trifloxystrobin+Tebuconazole**[5,7] (IIHR, 2016).	
Macrophomina **Leaf Spot**		- *T. viride* + *P. fluorescens* (Senthamarai *et al.*, 2008) - *T. viride* and neem based product (Kulkarni *et al.*, 2007)
Stemphylum **Leaf Spot**	- **Maneb**[1,2,3,6], **Mancozeb**[1,2,3,6], **Chlorothalonil**[1,2,6], **İprodione**[1,2,7] (Gindrat *et al.*, 1984). - **Mancozeb**[1,2,3,6], **Carbendazim**[2,7], **Propiconazole**[1,2,3,4,7] (Mondal *et al.*, 2018)	
Alternaria **Blights**	- **Mancozeb**[1,2,3,6] (Sharma *et al.*, 2010a; Jat *et al.*, 2015). - Bordeaux mixture (Smitha *et al.*, 2014). - Copper oxychloride, **Carbendazim**[2,7] (Singh, 2006) - **Mancozeb**[1,2,3,6]+**Propiconazole**[1,2,3,4,7] (DMAPR, 2012).	- *Ocimum sanctum*, *Zingiber officinale*, *A. sativum* or neem extracts and *Datura metel* or *Mentha spicata* extracts (Sharma *et al.*, 2010a). - *T. asperellum* (Gatak *et al.*, 2020)
Colletotrichum **Blights**	- **Mancozeb**[1,2,3,6], **Carbendazim**[2,7], Bordeaux mixture (Shukla *et al.*, 2010; Smitha *et al.*, 2014). - **Hexaconazole**[7], **Propiconazole**[1,2,3,4,7], Tricyclazole, **Thiophanate methyl**[1,2,6] and **Carbendazim**[2,7] + **Mancozeb**[1,2,3,6] (Kadam *et al.*, 2014).	
Curvularia **Leaf Blights**	- **Mancozeb**[1,2,3,6], Bordeaux mixture (Smitha *et al.*, 2014). - Copper oxychloride (Mondal *et al.*, 2018) - **Propineb**[1,2], **Hexaconazole**[7] and **Epoxiconazole**[1,2,6] (Lakpale, 2011).	- Neem oil, *Kalanchoe heterophylla*, *Curcuma amada* and *Adhatoda vasica* extracts, *T. viride* and *P. fluorescens* (Lakpale, 2011).
Macrophomina **Blight**	- Metalaxyl + **Mancozeb**[1,2,3,6] (Meena and Kadam, 2021)	- *Pseudomonas fluorescence* (Meena and Kadam, 2021)
Sclerotinia **Blight**	- **Tebuconazole**[5,7] (Sharma *et al.*, 2010a, b)	*Trichoderma harzianum, Gliocladium virens* (Mondal *et al.*, 2018)

***Rhizoctonia* Blight**	- **Mancozeb**[1,2,3,6], **Carbendazim**[2,7] (Mondal *et al.*, 2018)	- Trichoderma+ Organic fertilizer (Mondal *et al.*, 2018)
Anthracnose	- **Carbendazim**[2,7] (Prakash, 2012), - **Chlorothalonil**[1,2,6] (Parameswaran *et al.*, 2000). - **Mancozeb**[1,2,3,6], Bordeaux mixture (Mondal *et al.*, 2018)	
Collar Rot	- **Carbendazim**[2,7], **Thiophanate-methyl**[1,2,6] (TNAU, 2013) - **Mancozeb**[1,2,3,6] (Mondal *et al.*, 2018)	- *T. harzianum* (Singh and Singh, 2004).
Rhizome Rot	- Copper oxychloride, **Mancozeb**[1,2,3,6], **Carbendazim**[2,7] (Mondal *et al.*, 2018) - **Tebuconazole**[5,7] (Sharma *et al.*, 2010a,b).	
Stolon Rot	- **Mancozeb**[1,2,3,6], **Carbendazim** (Mondal *et al.*, 2018) - **Captan**[1,6] (Szezeponek and Mazur, 2006)	- *Trichoderma harzianum*, *Gliocladium virens* (Mondal *et al.*, 2018) - *T. viride, P. fluorescens* and *B. subtilis* (Kamalakannan *et al.*, 2003)
Root Rots	- **Mancozeb**[1,2,3,6], Copper oxychloride (Mondal *et al.*, 2018) - **Carbendazim**[2,7] (DMAPR, 2006) - **Carbendazim**[2,7]+**Mancozeb**[1,2,3,6] (Ingle *et al.*, 2014)	- *Trichoderma harzianum* (Govindappa *et al.*, 2010) - *T. viride*+*P. fluorescens* (Ingle *et al.*, 2014). - *T. viride* (DMAPR, 2006) - *P. fluorescens* (Govindappa *et al.*, 2010; Ingle *et al.*, 2014) - *Glomus fasciculatum, G. mosesae* (Mondal *et al.*, 2018). - *T. viride*, *P. fluorescens*, *Bacillus subtilis,* Neem cake and Mahua cake, *T. viride* + Neem cake (Gnanaprakash *et al.*, 2015). - *Allium schoenoprasum, Annona squamosa, A. indica, Calendula officinalis, Cinnamomum verum, Eucalyptus* sp., *Lawsonia inermis, O. sanctum, Piper nigrum, Z. officinale* aqueous extract sprays or extracts in 50% ethanol (Chathuri *et al.*, 2011) - *Bacillius subtilis* (Elewa *et al.*, 2011) - Neem seed powder+Carbofuran, Carbofuran+Carbendazim, Neem seed powder + Carbendazim (Kahkashan, 2003)
Stem Rot	- **Carbendazim**[2,7], **Mancozeb**[1,2,3,6] (Mondal *et al.*, 2018)	- *T. viride, P. fluorescens* and *B. subtilis* (Kamalakannan *et al.*, 2003) - *Trichoderma* spp., *Glomus fasciculatum* and *G. mosesae* (Mondal *et al.*, 2018)
Crown Rot	- **Carbendazim**[2,7], **Mancozeb**[1,2,3,6] (Mondal *et al.*, 2018)	- *Trichoderma* spp. (Mondal et al., 2018)
Wilts	- **Carbendazim**[2,7] (Singh, 2006; Bhat et al., 2014) - **Benomyl**[1,2,7] (Szezeponek and Mazur, 2006). - Copper oxychloride (Ramadevi *et al.*, 2005). - **Mancozeb**[1,2,3,6], **Carbendazim**[2,7] (Mondal *et al.*, 2018)	- *T. viride* + *P. fluorescens* (Senthamarai *et al.*, 2008) - *Glomus fasciculatus* + *P. fluorescens* (Singh *et al.*, 2009) - Mangiferin (Ghosal *et al.*, 1977) - *Bacillius subtilis* (Elewa *et al.*, 2011) - Vascular arbuscular mycorrhiza (Sahab *et al.*, 2001). - *Trichoderma viride, Pseudomonas fluorescens, Glomus fasciculatum, G. mosesae* (Mondal *et al.*, 2018)

Damping-off	- **Mancozeb**[1,2,3,6], Copper oxychloride (Mondal *et al.*, 2018) - Copper oxychloride, **Mancozeb**[1,2,3,6], **Carbendazim**[2,7] (Mondal *et al.*, 2018)	- *Trichoderma* spp. (Mondal *et al.*, 2018) - Azotobacter ve *Trichoderma* sp. (Bhat *et al.*, 2014)
Gray Mold	- **Mancozeb**[1,2,3,6], **Zineb**[1,2] (TNAU, 2013)	- *Aloe vera* cake, Cassava starch, gelatin and thyme oil, chitosan (Romero *et al.*, 2017)
Blue Mold	- Pre-storage - Sodium hypochlorite, Borax, During-storage – **Carbendazim**[2,7], **Thiophanate methyl**[1,2,6] (Prakash, 2012)	
Wet Rot	- **Mancozeb**[1,2,3,6], Copper oxychloride (Mondal *et al.*, 2018)	

[1]: PAN Bad Actor, [2]: Highyl Hazardous Pesticide, [3]: Development or Reproductive Toxin, [4]: Acute Toxicity, [5]: Acute Toxicity Moderate, [6]: Carcinogen, [7]: Carcinogen Possible (Pesticideinfo, 2021)

CONCLUSION

Since some of these chemicals listed in Table 2 are banned and/or restricted plant protection products in the world, including our country, extreme care should be taken in their use in medicinal and aromatic plant growing. Some environmental factors, climate changes, market-oriented crop production and management lead to an increase in the number of pests and diseases in particular. With the frequent use of synthetic pesticides in plant production, theirs damages to health, food and the environment have increased considerably. The use of chemicals can alter the qualitative and quantitative composition of the active ingredients in plants, which reduces their therapeutic value. For this reason, as a control method, the use of chemicals requires great care and expertise. People have become more interested in traditional and complementary medicine practices. With the reason that our country has a rich flora in terms of plant diversity, the production of medicinal and aromatic plants that can be an alternative to the use of chemical pesticides is supported. These plants, which are widely used in public health services, food and cosmetics sectors globally, continue to increase their agenda every year with the increase in market demand. Biopesticides and bioactive substances have been used instead of synthetic pesticides to prevent deterioration of the quality and increase the yield of the crop. Also, cultural practices and the use of durable varieties are preferred by the producers to reduce the application of synthetic pesticides. The most appropriate and effective control method plan should be combined with the integrated controls. The emergence of fungal diseases, which are frequently appeared in these medicinal and aromatic plants that grow spontaneously or are cultured, causes product and quality losses, creating a commercial and economic threat. For this reason, it is very important to identify, detect and control these diseases.

DECLARATION OF COMPETING INTEREST

The author declares that she has no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The author contributed 100% to the article.

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