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Management of Fusarium Wilt of *Pisum sativum*: A Review

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A B S T R A C T

Pisum sativum is an important legume crop belongs to family fabaceae and it is commonaly known as garden pea or green pea. It provides a good source of protein, carbohydrates, vitamins, phosphorus minerals, and bioactive compounds. The young seeds can also be used in soup, canned, fozen, and dried peas are commonly used during the off-season. Peas are cultivated in almost all country around the world and regarded as an essential part of the human diet. The young pods and immature pods of this crop are cultivated as vegetables, while the mature dried pods are consumed as legumes. Peas have soil- improving and conditioning properties. The diseases affects the field pea production including fungal diseases such Ascochyta blight, powdery, downy mildew, Fusarium wilt, and rust. These diseases can be controlled by use of plant extracts. The present paper is a review of management of Fusarium wilt of *Pisum sativum*.

Introduction

Peas grow best in regions where there is a slow transition from cold to warm weather. Seeds can germinate at a minimum of 5°C. In the Southern parts of the country, it is sown in plains from October to December; On the hills it is sown from March to May and as a second crop in autmn. The main crop field pea sown in September – November in the plains. There are early, medium and late maturing types and best method obtaining a succession of peas is to sow all of them early at about the same time. Early sowing is said to be of greater importance for the late maturing types than for quick maturing ones and generally late sowing yields losses. The average yield of garden pea grown for green pods has been estimated to range from 2750 – 5050 Kg/ha. While in some selected types yield, as high as 15140 Kg/ha. have been recorded. When field pea was grown for fodder in admixture with oats, it gave yield of 19000-28000 Kg/ha (Anonymous, 1969). The young green seeds of peas are eaten raw or after cooking. The seeds are also used as pulse and they are good source of proteins, vitamins (B_1, B_{12} and Vit. K), Potassium and Phosphorus. Peas are consumed both in the fresh form as vegetable and in the dried form as pulse.

Diseases in Pea

The major obstacles in the way of increased pulse production are the diseases which are responsible for the reduction and uncertainty in pulse yields (Grewal, 1983; Grewal *et al.,* 1988). So it is essential that we understand the relative importance of diseases and device (ways) to tackle them in effective manner (Grewal, 1988). The yield in pea, besides other factors is greatly affected by the diseases caused by fungi such as wilt, stem rot, root rot and mildew.

Pea wilt caused by *Fusarium oxysporum* f. sp. *pisi* (Linford) Race I (Sunyder and Hansen) is said to be common fungal pathogen, causing serious damage to garden peas (Anonymous, 1969). *Fusarium oxysporum* f. sp. *pisi* (Apparently race 1) was isolated from wilted plants in Sao Paulo State (Teranishi and Namekta, 1972).

Fusarium oxysporum f. sp. *pisi* race-1 was found associated with seed, field plants with a race-1 susceptible pea variety in 1972, the first report in the field of this race in Eastern Washington for nearly 40 yrs (Kraft *et al.,* 1974). They reported that 25% of the plant showed symptoms of this disease.

A new race (*Fusarium oxysporum* f. sp. *pisi* race 6) was isolated by Haglund and Kraft (1979) from commercial pea growing areas in Western Washington. Nyvall and Haglund (1976) reported that severity is dependent on the age of plant at infection and length of time of root and fungus contact. Aerial photography for detection and identification of *Fusarium* wilt of pea in forest steppe and woodland of Ukraine was studied by Kirik and Steblyuk (1975) caused by *Fusarium oxysporum* and *F. solani*. They reported that the soil is main source of infection.

In Poland, Czyzyweska (1984) examined 1534 plant sample from 247 localities in 1969-74 and reported 71% of pea crops were infected by *Fusarium* spp. Further he examined 261 seed samples (1966-76) and found that 67% of infestation ranged from 0.1 to 30% most often 0.6-5.5%. *Fusarium avenaceum* (*Gibberella avenacea*), *F. culmorum*, *F. equiseti*, *F. oxysporum, F. sambucinum, F. sporotrichioides* and *F. solani* were isolated from infected plants and seeds. *Fusarium* root rot and wilt of garden peas in Taiwan was studied by Lin *et al.,* (1984). They reported that pea crops in Taiwan were severely damaged by pea 'likubin' diseases in 1981-83, showing root rot, vascular root rot, vascular discoloration and wilt. *Fusarium oxysporum* f. sp. *pisi* (FOP) and *F. solani* f. sp. *pisi* (FSP) were isolated. Some other Indian workers studied on wilt disease of pulses from time to time (Vasudeva and Srinivasan, 1952; Chauhan, 1963; Chattopadhyay *et al.,* 1967; Khare and Sharma, 1970; Singh and Singh, 1970; Khare *et al.,* 1974)

Cultural Practices

Several attempts have been made by the scientists to reduce wilt through various cultural practices. Shehta *et al.,* (1976) reported the inoculation technique for simultaneous evaluation of peas for resistance to *Fusarium oxysporum* f. sp. *pisi*. Several other reports are also available on the same kind of work by various workers (Guy and Baker, 1977; Furgal-Wegrzycka, 1984; Saxena and Khare, 1988; Gaur and Sharma, 1989; Yan' Kov, 1989; Tu, 1991; Orlikowski and Wolski, 2000 and Reddy *et al.,* 2000)

Although the use of cultural practices are useful to reduce the wilt disease to certain extent, but considering the various climatic zones in our country and limited research work carried out so far to certain zones, only the recommendation made could not be utilized properly in several areas, this practice has not gained popularity amongst the farmers and growers of pea.

Use of chemicals has also become an integral part of modern crop protection technology and served the cheapest and direct control method (Neergaard, 1977). Although very little information is available on the chemical control of the disease.

Side effects of chemicals

In addition, due to induction of new physiological races of pathogens, many of the synthetic fungicides are gradually becoming ineffective (Wellman, 1977; Dekkar, 1984; Shephard, 1987 and Staub, 1991). Seed treatment and soil amendment are the usual practices to control soil-borne diseases. Most of the seed dressing fungicides are non-biodegradable, phytotoxic and produce adverse effect on soil microorganisms, including rhizosphere and mycorrhizal population (Gruzdyev *et al.,* 1983). According to Rangaswami (1981) the excessive use to synthetic fungicides possess potential health hazards not only to human being but also to liverstock, wildlife, fishes, birds and other animals. Gupta (1983) emphasized that the use of many chemicals involves toxicity to operators, unwanted residues in food and environmental pollution.

Antifungal or antimicrobial compounds in pea

Previously the presence of antifungal compounds in some higher plants has long been recognized as an important factor of disease resistance (Fawcett and Spencer, 1970). It is noteworthy that Pyrethrum (Casida, 1973) of plant origin holds a leading place amongst the insecticides and there is not a single chemical yet developed of such potency. Agrawal (1992) in one of his Presidential address pointed out the need of development of antifungal drugs from indegeneously available plants besides chemicals and antibiotics because such drugs may prove more safe, effective and economical. During last eight decades, a number of higher plants have been found to exhibit strong antimicrobial activity against various phytopathogenic fungi (Reynold, 1930; Fisher, 1935; Little and Grubaugh, 1946; Valle, 1957; Anselme, 1959; Masilungon *et al.,* 1963; Dixit *et al.,* 1976; Russell and Musa, 1977; Tripathi *et al.,* 1978; Renu *et al.,* 1980; Bhargava *et al.,* 1981; Srivastava *et al.,* 1982; Dixit *et al.,* 1984; Mishra *et al.,* 1988; Mishra and Tripathi, 1989; Miah *et al.,* 1990; Hussain Shah *et al.,* 1992; Gourinath and Manoharachary, 1993; Singh *et al.,* 1994; Arumugasamy and Udaiyan, 1995; Mahasneh *et al.,* 1996; Ali *et al.,* 1998; Deraniyagala *et al.,* 1998; Freixa *et al.,* 1998; Cavin *et al.,* 1999; Madhumathi *et al.,* 2000; Agnese *et al.,* 2001; Kariba *et al.,* 2001; Setzer *et al.,* 2001).

Plant parts and their constituents have recently proved their fruitfulness in providing less phytotoxic, more systemic, easily brodegradable and host metabolism stimulatory pesticides (Blair, 1943; Neergaard, 1958; Papescu, 1960; Tokin, 1960; Gera *et al.,* 1963; Kovacs, 1964; Thapliyal and Nene, 1967; Papavizaz and Lewis, 1977; Russell and Musa, 1977; Bosshard *et al.,* 1987; Kumar and Tripathi, 1990; Goswami and Jitendra Mohan, 1998).

Why use green plants for control of diseases?

Green plants because of their vast diversities contain a wide spectrum of plant defence chemicals most of which make a vital contribution of the list of medicines for human beings today. Farnsworth and Bingel (1977) emphasized the exploitation of higher plants for the control of various plant diseases. Neem products have been tested for versatile use in agricultural management as insecticide, nematicide. An American based multinational company has purchased a U.S. patent on the pesticidal properties of the Indian Neem seed and it has been recognized as "green gold".

The grain legumes have special significance in the nutritional dietary in semi-arid tropics particularly for India where major dependence for protein is through food from vegetable origin.

A large number of pathogens are known for causing various diseases in plants and human beings. Major emphasis for control of diseases in plants remained through physical, chemical and biological methods. In recent years higher plants proved their antifungal activity and their antifungal compounds could be used for the control of various plant diseases.

The presence of antifungal compounds in higher plants have been recognized as important factor of disease control. It can be grouped under the following heads:

I-Fungitoxicity of crudes of higher plants
II-Fungal disease control by higher plants and their products.

Fungitoxicity of crudes of higher plants

The extracts have been tested for their antifungal activity, results showed that these are fungitoxic in nature. The chief findings on fungitoxic activity of plant extracts are presented in chronological order in Table – 1.

Fungal disease control by higher plants and their products

Several plants have been reported to possess fungitoxic properties and they have been tested for fungitoxic activity during *in-vitro* studies. They were also tested for their *in-vivo* efficacy against field and soil infections. However, large scale trials in this directions are still lacking. Investigations on the application of plant crudes and their products in control of field and soil infictions as well as in induction of disease resistance by various investigations are presented in Table – 2.

Green plants contain a wide spectrum of plant defence chemicals most of which make a vital contribution to the list of medicines for human being even today. The presence of antimicrobial factors in herbal tissues is well known since longback. Such naturally occurring compounds have been considered responsible for disease resistance in plants (Farkas and Kiraly, 1962; Fawcett and Spencer, 1970; Mahadevan, 1978; Dubey *et al.,* 1982; Furgal-Wegrzycka, 1984; Kraft, 1986; Yadava, 1989; Baker and Ahmed, 1990; Kaur and Sharma, 1993; Raghuwanshi and Patil, 1999).

Table.1 Fungitoxic activity of Crudes (extracts) of higher plants

Plant(s) tested	Fungi	Results	Investi-gator(s)
1	2	3	4
Varieties of *Lycopersicum esculentum* (Different parts)	*Fusarium bulbiginum* and *F. lycopersici*	Extract showed fungistatic activity against both pathogens	Irving *et al.,* (1945)
Zea mays and *Lycopersicum* sp. (leaf and stem extract)	*Fusarium* sp.	Fungitoxic activity against test fungus	Little and Grubaugh (1946)
915 plant spp.	*Venturia inaequalis*	Four plant extracts showed fungistatic and nine plants showed fungicidal activity	Gilliver (1947)
11 plant spp.	*Monilia fructicola* and *Rhodoturula glutinis*	Some plant extracts fungitoxic against both fungi	Sproston *et al.,* (1948)
Catalpa spinora	Some fungi	Aqueous and alcohlic extract showed strong antifungal activity	Mc Gray and Mc Donough (1954)
Varieties of *Hordeum vulagare* and *Triticum* spp.	Some fungi	Aqueous and ethanolic extracts showed antifungal activity against a number of fungi	Ark and Thompson (1958)
Gossypium sp.	*Verticillium albo-atrum*	Extract inhibited the mycelial growth completely	Garber and Houston (1959)
Sinapsis alba and *Brassica juncea*	*Aspergillus niger*	Extracts of both plants showed fungitoxic activity against test fungus	Slavens (1959)
Abies pectinata (rhizome), *Allium cepa* (bulb), *A. sativum* (bulb), *Citrus* sp. and *Prunus* sp. (leaf)	*Phytophthora infestans*	All the plant extracts exhibited fungicidal activity	Tokin (1960)
Several plant spp.	*Fusarium sxysporum, F. vasinfectum* sp. and *Verticillium dahliae*	Extract of some plant species exhibited antifungal activity	Mozes and Pall (1961)
Abies balsamea (wood extract)	*Stereum sanquinolentum*	The extract of heart wood showed higher fungitoxic activity than sap wood	Etheridge (1962)
13 plant spp.	*Colletotrichum falcatum* and *Pyricularia oryzae*	Extract of all the plants showed antifungal activity agains tboth fungi	Janardhanan *et al.,* (1963)
Allium sativum	*Aspergilus niger*	Extract of both plants showed	Kovacs
Anagallis arvensis (leaf)	Several fungi	Completely inhibited the growth of all the fungi except *A. niger*	Nene and Thapliyal (1965)
Erigeron linfolicus	*Helminthosporium* spp.	Extracts inhibited, the mycelial growth of all the species of *Helminthosporium* tested	Nene and Kumar (1966)

88 plant spp.	*Helminthosporium turcicum*	The extract of 14 plant spp. Inhibited the growth of test fungus completely	Nene *et al.,* (1968)
4 plant spp.	*Diploidia notolansic*	*Datura strumarium* showed strong fungitoxicity against test fungus	Jain and Pathak (1970)
5 plant spp. (seed)	Some fungi	Extract of all the plants showed fungitoxicity against test fungi	Srivastava and Misra (1971)
14 plant spp.	*Alternaria alternata*	Leaf extract of *Azadirachta indica, Piper betel* and root extract of *Croton bonplandianum, Sida rhombifolia* inhibited spore germination of test fungus	Khanna and Chandra (1972)
36 Plant spp.	*Alternaria tenuis, Curvularia lunata, Fusarium moniliforme, Helminthosporium sativum, H. speciferum* and *Rhizoctonia bataticola*	Extract of root and bark of *Plumbago zeylanica* were strongly active	Bambode and Shukla (1973)
4 plant spp.	Some fungi	Plants of different ages were tested against a number of fungi. Roots were more active than stems	El-Hissey (1974)
29 plant spp.	*Cephalosporium sacchari* and *Fusarium nivale*	Extracts of four plant species were strongly fungistatic, 6 other were partially active against fungi	Dixit and Tripathi (1975)
Lawsonia alba	Some fungi	Water soluble fraction of leaves inhibited growth of some pathogenic fungi, inhibitory action was enhanced by autoclaving	Sharma and Kulkarni (1975)
155 Plant spp.	*Fusarium nivale*	Extracts inhibited spore germination and mycelial growth of test fungus	Dixit *et al.,* (1976)
Some plant spp. (leaf, root and inflorescence)	Three fungi	Extracts of leaves of *Lawsonia alba,* roots of *Datura strumarium* and inflorescence of *Mentha piperata* showed antifungal activity	Ahmad and Agnihotri (1977)
Vinca rosea (leaf, root, stem and flower)	6 fungi	Extract of different parts showed fungitoxic effect against all the test fungi	Narain and Satapathy (1977)
Some plant spp.	*Alternaria alternata, Crynospora coasseicda, Drechslera rostrata* and *Fusarium oxysporum*	Aqueous extract of *Allium cepa, A. sativum, Gossypium* sp., *Kalnchoe* sp., *Parhonium* sp. and *Phaseolus autropur-pureus* inhibited the spore germination	Kumar *et al.,* (1979)
93 plant spp.	*Pyricularia oryzae*	Extract of 19 plants species inhibited the fungal growth	Lapis and Dumancas (1979)
Some plant spp. (leaf)	*Rhizoctonia solani*	Extract of *Cestrum diurnum,* showed fungitoxic activity	Renu *et al.,* (1980)
32 plant spp. (leaf)	*Alternaria alternata* and	Extract of six plant species	Pandey *et al.,*

	Aspergillus niger	showed marked activity against *A. niger*	(1981)
Several plant spp.	*Drechslera turcica*	Extract of 10 plant species inhibited the fungal growth completely	Bhowmik and Vardhan (1982)
40 spp. of higher plants	*Aspergillus flavus* and *A. versicolor*	Extract of *Cetrus medica* and *Erigeron bonariensis* exhibited absolute toxicity	Dubey *et al.,* (1982)
49 plant spp.	*Alternaria alternata*	Only *Iberis amara* and *Ipomea fistulosa* showed antifungal activity	Srivastava *et al.,* (1982)
Iberis amara (different growth stages)	*Helminthosporium oryzae*	Seedling stage exhibited maximum activity	Tripathi *et al.,* (1983)
Parthenium hysterophorus (different parts)	4 spp. of *Aspergillus*	Leaves, stem and inflorescence showed more efficacy than the root against all the fungi tested	Srivastava *et al.,* (1984)
40 plant spp.	Nine fungi	Extract of several plants showed good antifungal activity	Guerin and Reveillere (1985)
Artabotrys hexapetalous	*Drechslera oryzae*	Extract inhibited the mycelial growth of test fungus	Grainge and Alverer (1987)
Several plant spp.	5 fungi	Extract of some plants reduced the growth of fungi	Nanir and Kadu (1987)
Butea monosperma	Some fungi	Extract showed fungicidal activity	Powal *et al.,* (1988)
Annona squamosa	Some fungi	Extract exhibited antifungal activity	Annapurna *et al.,* (1989)
Citrus medica and *Cleome viscosa* (leaves)	*Aspergillus flavus* and *Penicillium oxalicum*	Extract showed strong fungitoxicity against both fungi	Tiwari *et al.,* (1990)
13 plant spp.(leaf)	*Curvularia tuberculata*	Extracts of *Eucalyptus globulus* and *Catharantus roseus* were absolutely active	Upadhyay and Rai (1990)
Adhatoda vasica, Allium sativum, Cassia fistula and *Prosopis juliflora* (leaf)	Some fungi	Chloroform and ethanolic extracts showed fungitoxic effect against test fungi	Malik *et al.,* (1991)
191 plant spp.	*Fusarium oxysporum* f. sp. *ceceri*	*Clematis gouriana* and *Xanthium strumarium* showed absolute toxicity against test organism	Mishra (1991)
Artemisia scoparia (flower)	7 fungi	Extract was active against all the fungi	Naquvi *et al.,* (1991)
40 plant spp. (leaves)	*Fusarium oxysporum* f. sp. *lentis*	Extracts of *Adenocalyma allicea* and *Artabotrys hexapetalous* showed complete mycelial inhibition	Singh and Tripathi (1992)
Eucalyptus lanceolatus (different parts)	*Curvularia lunata, Cylindrocarpon licheni, Fusarium solani* and	Extract showed antifungal activity at different concentrations	Gourinath and Manohara-chary (1993)

	Myrothecium leucotrichum		
Euporbia geniculata	Some fungi	Methanolic extract of *E. hirta* showed more activity than *E. geniculata*	Soni and Chauhan (1993)
40 plant spp.	*Fusarium oxysporum* f. sp. *lentis*	Leaf extract os *Mentha spicata* inhibited the growth of test fungus completely	Singh *et al.,* (1994)
Aegle marmelos (leaf)	*Sclerotium rolfsii*	Extract inhibited the mycelial growth and number of sclerotia of test fungus	Prithiviraj *et al.,* (1995)
Capparis spinosa, Prosopis farcta, Salzola villosa and *Suaeda kermiculata* (whole aerial parts)	*Fusarium oxysporum*	The Petriteum ether extract of *S. vermiculata* and butanol extract of *S. villosa* showed higher antifungal activity	Mahasneh *et al.,* (1996)
Bauhinia variegate (leaf)	*Aspergillus fumigatus* and *A. niger*	Methanolic extract showed antifungal activity against both fungi	Sharma and Saxena (1996)
Ficus racemosa (leaf)	*Alternaria* spp., *Colletotrichum gloeosporioides, Corynespora cassiicola, Curvularia* spp. and *Fusarium* spp.	Extract were found to be fungitoxic to all the test fungi	Deraniyagala *et al.,* (1998)
19 plant spp.	Several fungi	Dichloromethane and methanol extract of plants showed antifungal activity	Freixa *et al.,* (1998)
Cassia alata (leaf)	Some fungi	The various organic extracts of plant showed high antifungal activity against all test fungi	Sakharkar and Patil (1998)
Screened 204 crude extacts of 77 plant spp.	*Cladosporium cusumerinum*	Extract of 20 plant species found to be active against test fungus	Cavin *et al.,* (1999)
Azadirachta indica (cake, leaves and seed extract)	*Plasmapara viticola* and *Sphaerotheca fulignea*	The plant extract was fungitoxic to both fungi	Steinhaver (1999)
Six fabaceae plant species	*Aspergillus niger*	Extracts of two plant showed antifungal activity to inhibit the mycelial growth	Rosado-Vallado *et al.,* (2000)
Scchizozygia coffaeoides (leaf)	*Cladosporium cucumerinum*	Showed antifungal activity	Kariba *et al.,* (2001)
Allium sativum bulb extract	*Fusarium oxysporum*	Showed antifungal activity	Chand and Singh (2005)
20 botanical extracts	*Fusarium oxysporum*	*Artocarpus heterophyllus. Azadirachta indica* showed the highest inhibition, with 90.7% inhibition in spore germination and 67.7% in mycelial growth	Manmohan and Govindaiah (2012)
Extract of Turmeric,	*Fusarium* sp.	Reduced the mycelial growth of	Shukla and Dwivedi

Garlic and Black pepper		test fungi	(2012)
Six plant extracts	Some fungi	*Allium sativum* at a 5% concentration and *Zingiber officinalis* at a 15% concentration significantly reduced the incidence of seed-borne fungi.	Saroja (2012)
Azadirachta indica leaf extract	*F. oxysporum* f. sp.*ciceri*	Showed 50.19% inhibition of the radial growth of test fungus	Hossain *et al.,* (2013)
11 weed extracts	*Fusarium oxysporum*	*Cannabis sativa, Ageratum conyzoides* and *Argemone maxicana* were found to be the most effective in inhibiting the fungi.	Pal and Kumar (2013)
53 Plants	Several fungi	The extract of *Piper methysticum* was found to be 1:35 (w/v) and it was fungicidal at 1:30 w/v.	Rao (2014)
11 Phytoextracts	*Fusarium* sp.	The onion bulb extracts at 10% displayed the maximum growth inhibition (63.52%), followed by garlic bulb extract (62.05%) and ginger rhizome extract (59.70%).	Sandipan (2014)
Five medicinal plants	*Fusarium oxysporum* f.sp. *ciceri*	Aqueous extract showed antifungal activity	Dwivedi and Sangeeta (2015)
Several plant extracts	*Fusarium oxysporum* f.sp. *ciceri*	*Azadirachta indica* exhibited the highest inhibition at 52.59% when used at a 10% concentration, followed by *Lantana camara* at 44.23%.	Patra and Biswas (2017)
Some plant extracts	*Fusarium oxysporum* f.sp. *ciceri*	Inhibit mycelial growth	Jamil and Ashraf (2021)
Some plant extracts	*Fusarium* sp.	Showed antifungal activity	Muche and Yamala (2022)
8 plant extracts	*Fusarium oxysporum* f.sp. *ciceri*	Showed mycelial inhibition of test fungus	Navneet and Rao (2024)
Hyptis suaveolens	*Fusarium oxysporum* f.sp. *ciceri*	Showed complete (100%) mycelial inhibition of test fungus	Tripathi and Rao (2025)

Table.2 Efficacy of plant crudes and their product to control fungal diseases

Plant(s) tested	Fungi	Results	Investigator(s)
1	**2**	**3**	**4**
Dry grass alfa-alfa or wheat straw (Soil amendment)	*Rhizoctonia solani*	Controlled the fungus	Blair (1943)
Pulsatilla pratensis (seed treatment)	*Ustilago paniciliareae*	5 – 25% distillate of the plant reduced the infictions on *Panicum* seeds	Degis (1958)
Sap of *Capsium annum,* Onion horse radish and radish (seed treatment)	*Psorosporium holci-sorghi*	Reduced the disease caused by fungus in maize seed	Papescu (1960)
Garlic extract (seed treatment)	*Fusarium solani* f. sp. *Phaseoli* (root rot of *Phaseolus vylgaris*)	Control the disease	Russell and Musa (1977)
Lawsonia inermis extract (spraying)	*Drechslera oryzae* (rice leaves)	Control the disease effectively	Natrajan and Lalithakumari (1987)
Ecalyptus rostrata (soil amendment)	*Sclerotium capivorm* (white rot disease of onion)	Controlled the disease effectively	Salama *et al.,* (1988)
Residucs of wheat, oat, chickpea, pea and lentil (soil amendment)	*Rhizoctonia batalicola*	Population of the fungus reduced by oat and wheat	Singh and Nem (1988)
Chenopodium ambrosioides (soil amendment)	*Rhizoctonia solani* (Damping off of *Phaseolus aureus*)	Controlled the disease upto 70%	Kishore *et al.,* (1989)
Eupatorium cannabinum (seed treatment)	*Fusarium oxysporum* (Damping off of pea)	Successfully inhibited the disease	Kumar and Tripathi (1990)
Burberis vulgaris, Juglens nigra and *Rhus typhina* (spraying)	*Cotoneaster salicifolius* var. *floccosus*	Controlled the fungal incidence upto 53%	Mosch *et al.,* (1990)
Poeonia suffruticosa (soil amendment)	*Pythium ultimum* (Damping off of sesame)	Good control of the disease	Paik and Oh (1990)
Mustard, groundnut, margosa and saw dust cakes (soil amendment)	*Fusarium* sp. (wilt of muskmelon)	Reduced disease upto 45 to 80%	Chakraborty and Sen (1991)
Clematis gouriana and *Xanthium strumarium* (soil amendment)	Wilt disease	Controlled the disease upto 50 – 62.75 per cent and 87.50 – 100 per cent respectively	Mishra (1991)
Azadirachta indica (seed treatment)	Seed mycoflora of wheat	Extract showed marked reduction in seed mycoflora as well as enhancement of seed germination	Khan and Shah (1992)
Agava americana (soil treatment)	*Fusarium oxysporum* (root rot of ginger)	85% control of the dosease	Pandey (1992)

Azadirachta indica, Brassica compertris var. sarson, *Arachis hypogea* and *Ricinus communis* (soil amendment)	*Sclerotium rolfsii* (foot rot of bartey)	Reduced the disease upto 85%	Singh and Dwivedi (1992)
Azadirachta indica (soil amentment/ spray)	Cowpea thrip disease	3 per cent aqueous extract of neem seed extract (NSE) sprayed twice or thrice reduced the disease and yield in plots sprayed with 3 per cent NSE was higher than in control (water spray)	Saxena (1993)
Azadirachta indica (soil amendment)	*Pythium aphanidermatum* (Damping – off in tabacco)	Controlled the disease	Shenoi *et al.,* (1993)
Artabotrys haxapetalous and *Ranunculus sceleratus* (soil amentment)	*Fusarium oxysporum* f. sp. *Lentis* (wilt disease in lentil)	Controlled the disease upto 82 – 98 per cent and 62 – 86 per cent respectively	Singh (1993)
Garlic clove extract	*Onion wilt and bulb rot*	Reduced the disease syndrome and used to increase the onion bulb yield	Alice and Sivaprakasam (1996)
Adenocallyma alliaceum (soil amendment)	*Fusarium udum*	Controlled the disease upto 100% when unsterilized and sterilized soils were amended by 4 and 2% powder	Singh and Rai (2000)

Table.3 Maximum Dilution for Absolute Inhibition (MDAI) of various plants and their products (Crude extracts) against different fungi

Investigator(s)	**Plant(s)**	**MDAI (w/v)**	**Test organism**
1	**2**	**3**	**4**
Misra (1975)	*Pepromea pellucida*	1: 50	*Fusarium nivale*
Chaturvedi (1979)	*Adenocalyma allicea*	1: 200	*Helmenthosporium oryzae*
Kishore *et al.,* (1982)	*Xanthium strumarium*	1: 15	*Fusarium moniliforme*
Mishra (1991)	*Xanthium strumarium*	1: 10; 1: 20; 1: 30	*Fusarium oxysporum* f. sp. *ciceri*
Grourinath and Mansharachary (1993)	*Eucalyptus lancolatus*	1: 80	*Curularia lunata, Cylindrocarpon licheni, Fusarium solani, Myrothecium leucotrichum*
Singh *et al.,* (1994)	*Mentha spicata*	1: 2	*Fusarium oxysporum* f. sp. *lentis*
Raja and Kurucheve (1999)	*Callistemon lanceolatus*	10%	Tomato wilt pathogen
Singh and Rai (2000)	*Adenocalyma alliaceum*	1: 9	*Fusarium* sp.

Application of crudes (extracts) of higher plants for control of fungi has been demonstrated by various workers (Irving *et al.,* 1945; Gilliver, 1947; Sproston *et al.,* 1948; Ark and Thompson, 1958; Tokin, 1960; Mozes and Pall, 1961; Etheridge, 1962; Janardhanan *et al.,* 1963; Masilungan *et al.,* 1963; Kovacs, 1964; Nene and Thapliyal, 1965; Nene *et al.,* 1968; Srivastava and Misra, 1971; Khanna and Chandra, 1972; Bambode and Shukla, 1973; Crison and Hodison, 1975; Narain and Satapathy, 1977; Tripathi *et. al.,* 1978; Lapis and Dumancas, 1979; Bhargava *et al.,* 1981; Pandey *et al.,* 1981; Bhowmik and Vardhan, 1982; Dubey *et al.,* 1982; Tripathi *et al.,* 1983; Guerin and Reveinllere, 1985; Mishra *et al.,* 1987; Annapurna *et al.,* 1989; Miah *et al.,* 1990; Malik, 1991; Mishra, 1991).

Further, the crude extracts of higher plants have been reported to control the diseases in field by some workers (Blair, 1943; Degis, 1958; Neergaard, 1958; Ark and Thompson, 1958; Vysots Kyi, 1962; Gera *et al.,* 1963; Thapliyal and Nene, 1967; Papavizas and Lewis, 1977; Russell and Musa, 1977; Smith and Mankg, 1983; Natrajan and LalithaKumari, 1987; Salama *et al.,* 1988; Singh and Nem, 1988; Kishore *et al.,* 1989; Mosch *et al.,* 1990; Chakraborty and Sen, 1991; Khan and Shah, 1992; Pandey, 1992; Shenoi *et al.,* 1993; Alice and Sivaprakaram, 1996; Gupta *et al.,* 1996; Tripathi *et al.,* 1999; Singh and Rai, 2000 and Kumudini *et al.,* 2001).

Tequniues for screening of plant extracts

Screening of higher plants have been made against various fungi by different techniques such as "Hanging drop technique" of Hoffmann (1960), "Slide germination technique" as recommended by American Phytopathological Society (Anonymous, 1943), "Inverted Petri plate method" of Bocher (1938). "Modified paper disc technique" of Sharvelle and Pelletier (1956) and "Poisoned food technique" of Grover and Moore (1962). The first two techniques i.e., hanging drop and Slide germination techniques have been followed for the screening of plants strictly against spore germination of fungi while the Inverted Petri plate technique had proved useful for testing of antifungal activity of volatile – constituents of plants. The rest of the two techniques, i.e. Modified paper disc and Poisoned food could not demarcate the volatile as well as non volatile activity of the plants so these two techniques can be used for inhibition of mycelial growth as well as spore germination of fungi.

Fungitoxicity of higher plants or their constituents is generally assessed through inhibition of spore germination or mycelial growth of test fungi. According to Mahadevan (1978) spore germination assay cannot be considered par excellance because some micro organisms either do not sporulate or it is difficult to induce sporulation. As such several recent workers viz., Singh and Tripathi (1992); Singh *et al.,* 1994; Prithiviraj *et al.,* 1995; Alice and Sivaprakasam, 1996; Freixa *et al.,* 1998; Cavin *et al.,* 1999; Singh and Rai, 2000 and Kariba *et al.,* 2001 and used inhibition of mycelial growth for evaluation of fungitoxicity of plant species.

For biological activity of plants most commonly the crude extract has been used. Some workers have used organic solvents for extraction (Malik *et al.,* 1991; Soni and Chauhan, 1993; Mahasneh *et al.,* 1996; Freixa *et al.,* 1998; Agnese *et al,* 2001; while others used expressed juices or aqueous extract of plant parts to evaluate their fungitoxicity (Irving *et al.,* 1945, Ark and Thompson, 1958; Schonback, 1968; Jain and Pathak, 1970; Ahmad and Agnihotri, 1977; Charya *et al.,* 1979; Mishra *et al.,* 1988; Singh *et al.,* 1994; Cavin *et al.,* 1999; Rosado-Vallado *et al.,* 2000; Setzer *et al.,* 2001).

Potent fungitoxicity of leaf

Several workers have reported potent fungitoxicity in leaves (*Anagallis arvensis,* Nene and Thapliyal, 1965; *Chenopodium ambrisoides*, Kishore, 1985; *Adhatoda vesica*, Malik *et al.,* 1991; *Argemone mexicana*, Hussain Sah *et al.,* 1992; *Mentha spicata*, Singh *et al.,* 1994; *Bauhinia variegata*, Sharma and Sexena, 1996; *Callistemon lanceolatus* and *Euphorba hirta*, Raja and Kurucheve, 1999; *Jatropha gossipifolia*, Madhumathi *et al.,* 2000; *Schizozygia coffaeoids*, Kariba *et al.,* 2001). Table-3

A perusal of Table – 3 shows that the maximum dilution for absolute inhibition (MDAI) varies from plant to plant. This variation may be due to various/different test fungi or different techniques adopted by different workers.

Control of diseases by fungitoxic plant

Some publications clearly indicate the fruitfulness of plant crudes as their products in the control of various field infections. Dagis (1958) observed reduction of infection of *Ustilago panecilliareae* on seeds of *Panium* by the use of 5-25% distillate of *Pulsatilla paratensis*. Anonymous (1959) reported 90-100% control of wheat rust by the use of extract of *Carperium abortinoids*. The use of 1-20% aqueous extract of garlic powder provided good results for control of downy mildew of cucumber, downy mildew of radish, bean rust and brown rot of stone fruits (Ark and Thompson, 1959). Papescu (1960) inoculated maize seeds with chlamydospores of *Psorosporium holci-sorghi* and treated the infected seeds for 30 minutes with the sap of *Capsicum annuum*, onion, horse radish and radish and noted a considerable reduction of disease when such seeds sown in the field. Vysots Kyi (1962) reported that phytoncides of *Cannabis sativa* gave the best control of *Fusarium* in pine seedlings when the seeds were treated three months before sowing with a mixture of *Cannabis sativa* and glume chaff at 1 Kg/10 Kg seeds. Thapliyal and Nene (1967) used the shoot extracts (1:10 and 1:100 w/v) of *Anagallis arvensis* for the control of brown rust of wheat and leaf blight of maize. The seeds of *Phaseolus vulgaris* treated with the extract of garlic provided good control of foot rot caused by *Fusarium solani* f. sp. *phaseoli* (Russell and Musa, 1977). Natrajan and Lalithakumari (1987) found that the leaf extract of *Lawsonia inermis* sprayed on rice leaves infected by *Dreshlera oryzae* gave promising results for its control. Ghewande (1989) treated groundnut seeds with the extracts of several plants and found that the extract of *Azadirachta indica* and *Lawsonia inermis* were most effective in controlling diseases caused by *Phaseoisaripsis personata* and *Puccinia arachidis*. Mosch and Zeller (1989) controlled the fire blight caused by *Erwinia amylovara* by spraying the extract of *Allium sativum, Berberis vulgaris, Mahonia aquefolium, Rhus typhina,* the extracts significantly reduced infection levels, giving 25.6-52.2% control. Mishra (1991) recorded significant control of wilt disease in chickpea by the seed treatment with the extracts of *Clematis gouriana* and *Xanthium strumarium*. Pandey (1992) reported the effective reduction in root rot incidence of ginger when the rhizomes were dip in the extract of *Agave americana* before showing. Alice and Sivaprakasam (1996) used garlic clove extract for the cosntrol of onion wilt.

Goswami and Jitendra Mohan (1998) reported the leaf extracts of *Atropa belladonna*, *Azadirachta indica, Eclipta alba* and *Phyllanthus niruri* to reduce a disease complex on tomato. Tripathi *et al.,* (1999) used the aqueous extracts of leaves of *Allium sativum* and *Azadirachta indica* to control the wilt disease of guava at seedling stage Singh and Tripathi (2000) reported that the leaf extract of *Artabotrys hexapetalous* reduce the wilt incidence in lentil.

The advantage of seed treatment or soil amendment with various plant crudes and their products have been reported by various workers from time to time Neergaard (1958) reported the use of *Pulsatilla conforata* for the control of *Pythium debaryanum* by soil treatment. The extract of *Acanthopanax gracilisylis* was found to reduce wilt disease of cotton without exhibiting any phytotoxicity (Anonymous, 1959). Besides the extracts of *Lycoris radiata* and *Oryze japonica* controlled the infections caused by *Phytophthara infestens* and provided similar results to those achieved with copper sulphate preparations.

Kovacs (1964) controlled the *Fusarium lini* infection of flax seed and *Rhizoctonia solani* infection of lettuce seeds by use of onion extracts to the infested soil.

Further different plants parts have been used in amending soil for the control of soil borne diseases by various investigators (Blair 1943, Papavizas and Lewis, 1977; Smith and Mankg, 1983; Salama *et al.,* 1988; Singh and Nem, 1988; Chakraborty and Sen (1991); Singh and Dwivedi, 1992; Shenoi *et al.,* 1993; Singh and Rai, 2000; Singh and Tripathi, 2000).

In conclusion, several plants and some of their extracts have been found to exhibit antifungal, antimicrobial, and strong bactericidal properties, require a short time to kill pathogens, withstanding high inoculation densities, being heat-resistant, having a long shelf-life, exhibiting no phytotoxicity, and effectively controlling wilt disease. Therefore, these plants (plant exracts) can be recommended as control agents for pea wilt and other soil-borne diseases, and represent an economical resource for disease management.

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Jeetendra Kumar Rao: Conceived the original idea and designed the model the computational framework and wrote the manuscript.

Declarations

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