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Cumin wilt management – a review

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Abstract

Cumin (*Cuminum cyminum* L.) is one of the oldest seed spice and an important production constraint is wilt caused by *Fusarium oxysporum* f. sp. *cumini* Prasad and Patel (*Foc*) and crop losses could be up to 60%. Maximum population of *Foc* was estimated at 0-5 cm soil depth in the presence of crop, but the population density tended to decline progressively with distance from the surface. Resting structures of the *Foc*, the chlamydospores, survive in the soil for more than 10 years. The inoculum density in the soil increases with each year of cumin cultivation and is directly proportional to disease incidence in the field. In this review, an effort has been made to compile research findings generated during past four decades on symptomatology, ecology and management strategies. In the absence of resistant sources against *Foc*, to reduce population of pathogen below the economic threshold level, integration of cultural, chemical and biological control measures is the only effective way to manage this diesease.

Keywords: *Aspergillus versicolor*, *Brassicas*, compost, *Fusarium oxysporum* f. sp. *cumini*, *Trichoderma harzianum*

Introduction

Cumin (*Cuminum cyminum* L.), one of the oldest seed spice, is believed to be a native from the east Mediterranean to east India. Seeds excavated at the Syrian site Tell ed- Der, have been dated to the second millennium BC. Originally cultivated in Iran and Mediterranean region, today it is mostly grown in Iran, Uzbekistan, Tazikistan, Turkey, Morocco, Egypt, India, Syria, Mexico, Bulgaria, Cyprus and Chile. It is the second most popular spice in the world after black pepper. Cumin seeds are used as spice for their distinct aroma, traditionally added to chilli, curries and other food preparations. India is the largest producer and consumer of cumin seed in the world. Cumin seeds contain 2.5-4.0% volatile oil and aldehydes or cuminol, which attributes for the aroma and special medicinal properties (Agarwal 1996 & 1950).The essential oil of the seeds contain cumin aldehyde (*p*-isopropyl-benzaldehyde, 25% to 35%), perilla aldehyde, cumin alcohol, α- and β-pinene (21%), dipentene, *p*-cymene and β-phellandrene. In traditional medicine, it is used to treat jaundice,

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dyspepsia and diarrhoea and seeds have stomachic, diuretic, carminative, stimulant, and astringent and abortifacient properties. The diseases like wilt, powdery mildew and blight along with improper nutrient management are the major reasons for its low productivity (Dange *et al*. 1992). Among diseases, maximum losses are caused by wilt. Low organic matter, low microbial population and poor moisture retention capacity along with repeated cultivation of susceptible genotypes have made the soils conducive to wilt pathogen. This review discusses the extent of damage, symptomatology and effective management strategies developed during past four decades in different cumin growing countries in order to facilitate research workers to intensify their efforts to develop more effective management strategies against wilt and to disseminate these to cumin growers for making cumin cultivation profitable.

Extent of damage

Wilt is the most destructive disease of the cumin crop. Gaur (1949) first reported the existence of a wilt disease caused by a species of *Fusarium* from the Rajasthan state of India. Patel *et al*. (1957) identified the pathogen and established the pathogenicity of the fungus. Since then the disease has also been reported from many other countries like Argentina (Gaetan & Madia 1993), Iran (Omer *et al*. 1997), Egypt (Arafa 1985), Greece (Pappas & Elena 1997), Syria, Afghanistan, Pakistan and Turkey and has become a regular problem in limiting the production of cumin worldwide (Alawi 1969; Champawat & Singh 2008). Surveys revealed losses of about 5-60% in the cumin growing regions of India (Patel *et al*. 1957; Patel & Prasad 1963). However, infection may vary from 25-40% and can be as high as 70% in some cases (Gaur 1949). In the Indian arid regions, where cumin is extensively cultivated during winter, approximately 40% yield loss was recorded (Lodha *et al*. 1986). Frequently, growers are left with no alternative except to abandon its cultivation after a few successive years of cropping in the arid region.

Symptoms

The plants are affected at all growth stages, but the severity of wilt increases with the plant age. Generally, when the crop is about one month old, the disease appears in the field. When plants attain a height of 2.5-5.0 cm, they wilt and die. In older plants, color of leaves changes from green to yellow, beginning from the oldest leaves and extending upward to younger leaves. In the severe stages, the tips of the plant and leaves wither dropdown leading to total mortality of the plants. Such plants can be easily pulled out of soil. The roots of diseased plants bear dark browning marks. Sometimes, only partial wilting is observed. If the plants are infected at flowering stage, they remain sterile (Mathur & Prasad 1964). Seeds if formed are thin, small and shriveled. Seed is often contaminated during harvesting and the pathogen spreads to newer areas. In partially wilted plants, growth is arrested and the leaves become pinkish yellow in color.

Pathogen

The pathogen *Fusarium oxysporum* f. sp. *cumini* Prasad and Patel (*Foc*) is soil as well as seed-borne in nature. Patel (1968) studied sources of perennation of the pathogen and emphasized the possibility of the fungus to be internally seed borne. Subsequently, the role of internally seed borne inoculum was established (Singh *et al*. 1972). The fungus produces abundant, white mycelium in culture. Microconidia are scattered freely on the mycelium measuring 4.8-12.8 μM. Macroconidia constitute about 90% of the conidia produced, mostly 2-3 septate 34.44 × 3.28 μM. The chlamydospores are terminal or intercalary, spherical, smooth and measuring 8.2 μM in diameter on an average and survive in the soil for more than 10 years. In respect of toxins and toxic metabolites, *Foc* filtrate delays symptom production (Mathur & Mathur 1965). *Fusarium* metabolites are also non- host specific (Mathur & Mathur 1967). Extracellular enzymes produced by *Foc* have role in pathogenesis. The virulence of isolates varied with the ability of production of pectinolytic enzymes (Champawat *et al*. 1977). Variation in mycelial growth and pathogenicity has been reported in nine isolates of *Foc* (Champawat & Pathak 1989). Wide range of variability in pathogenicity was shown by Arafa (1985) for isolates from infested fields (Assiut & EL-mina) in the Egypt. The chlamydospores of *Foc* were severely affected with increase in temperature and duration of exposure. After 45°C, with every increment of 5°C, the time required for complete killing of chlamydospores reduced considerably. Similarly, the time taken under moistened conditions was significantly less than that estimated under dry conditions. Thus, LD_{90} values calculated for 45°C, 50°C, 55°C and 60°C were 207, 64, and 43 and 19 minutes, respectively under moist conditions and for 60°C and 62°C, LD_{90} values were 31 minutes and 10 sec, respectively under dry conditions (Israel 2002). Survival of *Foc* propagules even up to 62°C in dry soils is clear evidence about the heat tolerant nature of chlamydospores. Reduction in LD_{90} under moist condition indicated increased thermal sensitivity of chlamydospores to moisture.

Ecology

Knowledge of population dynamics of *Foc* is required to understand the suppressiveness of soils and to isolate specific antagonists from these soils as bio-control agents. Studies conducted on the arid soils revealed that in the presence of crop, maximum population of *Foc* was estimated at 0-5 cm depth, but the population density tended to decline progressively with distance from the surface (Israel & Lodha 2004).

Highest population observed in top soil (0-5 cm) and its positive correlations with maximum soil temperature and total bacterial population indicated that lesser competition due to actinomycetes and total fungi supported greater survival of *Foc* propagules at this depth. An initial population of 2.3×10^3 CFU g^{-1} gradually increased in the presence of cumin crop and reached 8.6×10^3 CFU g^{-1} after harvest of the crop in April. After second cumin crop, population of *Foc* further increased and reached 15×10^3 CFU g^{-1} soil at the end of the season. Thus, a six-fold increase in the population was estimated after two successive cumin crops in the top soil layer. A 2.5-fold increase in population of *Foc* after one crop and 3.7-fold increase after the second crop explains why the disease intensity increases in the field with increased years of cultivation of a susceptible crop (Mawar & Lodha 2002).

Positive correlation of maximum as well as minimum soil temperature at 6-15 cm soil depth in the presence of crop was in close agreement with the earlier findings that wilt incidence was maximum between third week of January and first week of February (Mathur & Mathur 1966). The rate of increase in *Foc* population at 16-25 cm was relatively slower than that estimated at 0-15 cm soil depth.

Population of *Foc* decreased with increasing depth even in the absence of crop. However, in general, these population ranges were considerably lower than that observed in the presence of crop. The population remained almost stationary throughout the experimental period at 0-15 cm soil depth. In general, a stationary population maintained by *Foc* in the absence of wilt susceptible cumin crop is the clear indication that arid soils are deficient in adequate quantity of antagonists making it conducive for the occurrence of wilt in severe form. Such studies are needed in other major cumin growing countries in order to understand factors influencing survival of *Foc* in different agro-climatic regions.

Management

Incidentally, there are limited resistant sources against wilt pathogen in the available germ-plasm throughout the world. Therefore, disease can be managed by cultural, biological and chemical means. Management strategies have been developed to reduce wilt incidence in the field; integration of cost effective and practical strategies in a particular agro-climatic zone can make the cumin cultivation profitable.

Cultural method

Sowing time and rotation with non-host crops have been found to be the most effective ways of managing wilt in the field because the pathogen is host specific (Mathur *et al.* 1967). In the Indian arid region, rotating cumin fields with mustard and pearl millet in winter and rainy season, respectively has been found to keep incidence of wilt under check. Summer ploughing decreased disease incidence significantly (Champawat & Pathak 1990). Significant reduction in wilt incidence and improvement in seed yield was recorded with three compared to one summer ploughing. This method is especially effective where ample solar radiation and high soil temperatures are available during summer months. However, in the regions where high wind blows during summer, this practice may not be advisable because the wind may blow away the fertile soil.

Soil solarization has been found to be an effective technique in reducing soil population density of the plant pathogens and induced diseases in the field, where ample solar radiation and the soil temperatures are available during crop free period (Katan 1981). In hot arid regions of India such situation exists during April to June. In the field tests carried out to examine efficacy of soil solarization in conjunction with urea (20 kg N ha^{-1}) and farmyard manure (10 t ha^{-1}), elevated temperature coupled with amendments greatly reduced *Foc* population amounting to a net reduction of 94.7%. Reductions in *Foc* propagules at the 15 cm and 30 cm depth were 92.5% and 74.0% (wet mulched), respectively. The *Foc* population remained suppressed in solarized plots despite the cultivation of susceptible cumin crops. After the harvest of the second crop of cumin, *Foc* population remained significantly lower only in wet amended plots compared to dry mulched plots. This combination greatly reduced the plant mortality due to wilt and increased the yield of cumin in both the seasons.

Use of organic amendments like oil-cakes, residues and composts has shown excellent results in managing wilt of cumin in many countries. These amendments increased microbial population and activity in the soil, besides enhancing population of antagonists against *Foc*. Higher plants contain and release an enormous variety of biologically active compounds, some of which have been exploited as potential pesticides against *Foc*.

In the laboratory, among three levels of residues of pearl millet (PMR) equivalent to 20, 40 and 60 kg N ha^{-1}, maximum reduction (96.3%) in *Foc* propagules was estimated in N + PMR equivalent to 40 kg N ha^{-1} after 60 days. Reduction in the pathogenic propagules of *Foc* was attributed to combined effects of volatiles and enhanced microbial activity including antagonism. In a subsequent test, when N + PMR, was evaluated along with oil-cakes of mustard and castor (1%), the *Foc* population reduced by 100% in mustard oil-cake amended soil within 30 days (Sharma *et al*. 1995).

Crucifer plant residues incorporation in the soil was shown to reduce the population of soil-borne plant pathogens and the effect was mainly attributed to the release of toxic volatiles such as mercaptan, methyl sulphide and isothiocyanate (Gamliel & Stapleton 1993). The improvement in populations of actinomycetes antagonistic to *Foc* was recorded in amended soil, which might have also contributed in reducing the pathogenic population.

Efficiency of cruciferous residues in controlling wilt indicated that amending soil with mustard residues or oil- cake during hot summer days with one irrigation or at the time of rainy season led to significant reduction in wilt incidence on cumin (Mawar & Lodha 2002). The reduction in wilt incidence was significantly improved when amendments were applied during summer compared to their application in rainy season, which may be a cumulative effect of bio- toxic volatiles released during decomposition of residues at high soil temperatures (38-42°C) and subsequent microbial antagonism. Allyl- glucosinolate is one of the predominant glucosinolate in *Brassica* spp. and is generally converted to allyl-isothiocyanate (ATIC). The concentration of the ATIC was found to be directly related to heating of the soil up to 45°C (Gamliel & Stapleton 1993). However, isothiocyantes were not detected at low temperatures (Lewis & Papavizas 1971). Despite proven efficiency of soil solarization or amending soil with mustard oil-cake (2.5 t ha^{-1}), these approaches did not find acceptance by the resource deficient farming community of the Indian arid region because of high cost of polyethylene film or mustard oil cake. Thus, a need was felt to improve the efficiency of mustard pod residue by integrating with other easily available, cost-effective practical management strategies. Therefore, effects of soil solarization, residue incorporation, summer irrigation and biocontrol agents alone or in combination on survival of *Foc* were ascertained (Israel *et al.* 2005). Combining amendments and soil solarization elevated the soil temperatures by 0.5-5.0°C and 2.5-13.0°C compared to non-amended solarized and non-solarized plots, respectively. Combining mustard pod residues with soil solarization almost eliminated viable propagules of *Foc* at 0-30 cm soil depth. However, a combination of mustard pod residues and oil-cake (2.5 + 0.5 t ha^{-1}) with summer irrigation also caused pronounced reduction in pathogenic propagules, which was equal to that recorded in non-amended solarized plots. Significant reductions in wilt incidence were recorded in residue amended plots with or without polyethylene mulching compared to non-amended control. The least wilt incidence was recorded in amended solarized plots. However, the disease indices in the plots having a combination of mustard residues and oil-cake amendment with summer irrigation were equal to that achieved in the treatment having polyethylene mulching. Thus, in hot arid regions use of *Brassica* residues can be a practical and feasible substitute for polyethylene mulching in managing wilt.

Efficiency of *Brassica* amendments was further improved when *Foc*- infested fields were continuously exposed to dry summer heat for 60 days before application of amendments and irrigation (Mawar & Lodha 2009). This improvement in control was attributed to interactive effects of sub- lethal heating achieved by prolonged exposure to natural heat in dry soil exerting a weakening effect on *Foc* propagules, *Brassica* amendments and summer irrigation. The weakening effect depends on temperature level exposure time and the environment into which the pre heated propagules are introduced. In all, 10-14% reduction in viable propagules was evident merely by increasing exposure time. Since a part of the oil cake is consumed as a supplemental feed for live stock, other inexpensive and readily available on farm wastes were also explored as an alternative to mustard oil cake. Combining sub- lethal heating, residues of mustard (2.5 t ha^{-1}) and an obnoxious weed *Verbisina encelioides* (0.5 t ha^{-1}) and summer irrigation resulted in almost equal control that was achieved when mustard residues were combined with its oil cake (Israel *et al*. 2011).

Use of *Brassica* amendments for *Foc* control requires irrigation in arid soils. In many regions cumin is cultivated with saline irrigation water. Therefore, influence of saline irrigation water on survival of *Foc* was investigated in mustard residue amended soil. In the soil samples analyzed after 120 days, 83% propagules of *Foc* were eradicated in amended compared to a reduction of 55% in non-amended control (Mawar & Lodha 2004). The reduction was greater at 6.60 dSm^{-1} to the extent that almost 91% of viable *Foc* propagules were eliminated in the final soil sample. On the contrary, population of *Fusarium* propagules fluctuated at 10.6 dSm^{-1}. Thus, at this EC level, population of *Fusarium* in the final soil samples was significantly higher than lower EC levels and amended control.

This suggested that saline irrigation water up to 6.6 dSm^{-1} EC did not alter the potential of mustard residues in reducing the soil population densities of *Foc*. Increased EC in amended soil could be a result of release of SO_4^{-} ions during decomposition of mustard residues at low temperatures, which are converted into bio-toxic volatiles at high temperatures. Better survival of fungal propagules at 10.6 dSm^{-1} explains in part why wilt of cumin is more severe in the fields with high saline water irrigation as the host is experiencing two concurrent stresses.

Chemical method

Incidence of wilt was 24.5% with 30 kg N ha^{-1}, followed by 26.8% with 30:10:10 NPK kg ha^{-1}

(Champawat & Pathak 1988a). Increased application of K^+ decreased wilt incidence. Application of carbofuran 3 G @ 66 kg ha^{-1} before sowing was most effective in reducing wilt incidence followed by phorate 10 G @ 20 kg ha^{-1} and aldicarb 10 G @ 20 kg ha^{-1} (Champawat & Pathak 1988b). A combination of seed treatment with carbendazim @ 3g kg^{-1} seed and one spray of carbendazim (0.1%) or benomyl (0.05%) were effective in reducing wilt incidence (Champawat & Pathak 1991a). Soil application of SMDC (Vapam) was effective in checking wilt and increasing plant vigor. Application of carbendazim granules one month after cumin sowing was also effective (Jadeja *et al*. 2002). Seed dressing and soil drenching with methyl thiophanate and carbendazim decreased wilt incidence and increased seed yield. It was found that the herbicide inhibited the mycelial growth of *Foc* (Patel & Patel 1993). Aghnoom *et al*. (1999) studied the effect of fungicides and found that benomyl, iprodione + carbendazim, carboxim + thiram and captan reduced mycelial growth of *Foc.*

Reduction in *Fusarium* infection and increased seed yield $plant^{-1}$ compared to control was recorded as a result of pre- sowing treatments. Combining two day water priming and *T. harzianum* appeared to be the best treatment in reducing fungal infection (Tawfic & Allam 2004a). The increased seed yield was associated with decreased percentage of *Fusarium* infection in landraces 'Quina' and 'Assiut'. Among these, 'Quina' showed less *Foc* infection and higher seed yield than 'Assiut'.

Resistant cultivars

In the absence of an effective way to manage wilt, major research efforts were diverted to identify resistant sources and then to use them in resistance breeding programme. Though a few high yielding strains of cumin, *viz.*, S 404, MC 43, GC 1, GC 3 and RZ 19 have been released in the recent past, so far wilt resistant strains are not available because of limited variability in germplasm (Mathur & Mathur 1966; Champawat & Singh 2008). Negative correlation was observed between volatile oil content and resistance to wilt in cumin genotypes (Agarwal 1996). Soaking cumin seeds in ethephon (800 ppm) increased plant resistance to wilt in Egypt (Omer *et al*. 1997). In Egypt, *in vitro* methods as a pre- requisite for creating new genetic variability or developing genetically modified resistant cultivars with gene introgression from other species have been manipulated (Tawfic & Noga 2001; 2002). Existence of differential susceptibility within cumin varieties in Indian germplasm has been indicated (Malhotra 2007). Some lines have been identified as being tolerant to the *Foc* infection. Analysis of root, stem and leaf tissues of tolerant varieties suggested that tolerance can be attributed to high levels of phenolic compounds such as hydroquinone and umbelliferone (Mandavia *et al*. 2000). Since genetic resources are narrow in cumin, recently the interest in the conservation of this crop in a national germplasm and gene bank has dramatically increased (Tawfic & Mohamed 2006). In cumin growing countries like Egypt, Iran, Pakistan, Turkey and India, farmers mainly produce their own seed (Ebrahimie *et al*. 2006; 2007). Thus, cumin can be considered as a different landrace developed by natural selection under different conditions in various regions and areas of production (Chang 1985). The different landraces may be useful to improve the production of this spice by germplasm introduction.

Biological control

In managing wilt, bioagents have shown potentials in different studies to the extent that many growers have begun their use as a regular practice. Seed dressing with *Trichoderma harzianum* T_2 isolate, lowered disease incidence by 65.4% and was found to be more effective than seed treatment with fungicides (Aghnoom *et al.* 1999). Inoculation of cumin plants with *Glomus fasciculatum, G. mosseae* and *Acaulospora laevis* was found to reduce wilt incidence (Champawat & Pathak 1991b). Similarly, bio-control agents like *T. harzianum, Aspergillus flavus* and *A. niger* inhibited the growth of *Foc* in laboratory (Patel & Patel 1998a). Vyas & Mathur (2002) demonstrated that *Trichoderma* spp. effectively inhibited the growth and/or sporulation of *Foc in vitro* through production of volatile and non-volatile antibiotics. They also reported that *T. aureoviride* and *T. harzianum* as seed plus soil application resulted in significantly higher germination and lower disease. Combination of both the BCA_S was more effective than the individual for wilt suppression. In Egypt, Tawfic & Allam (2004b) isolated three fungal and one bacterial isolates from different locations of Assiut Governorate. These isolates were screened along with a commercial formulation (biocide 'Plant Gourd') against *Foc*. Antagonists *T. harzianum*, *T. viride* and *Bacillus subtilis* and the biocide had a significantly lower percentage of infection compared to control. Least infection was found in pre-sowing treatment with *T. harzianum* (Tawfic & Allam 2004b). In a sample survey of 15 conventional fields, wilt was severe (20%-35%) in five, moderate (< 15%) in six and absent in four fields (Vyas & Mathur 2002). Population of *Trichoderma* spp. was high in field where wilt was low or absent, with low *Foc* population. Combination of *T. aureoviride* and *T. harzianum* was more effective than the individual application for wilt suppression. Among bacterial antagonists, *Lactobacilli* and *Bifidobacterium adolesentis* inhibited *Foc* growth in dual culture tests (Patel & Patel 1998b). Sharma & Bohra (2003) found that leaf extract of *Boerhavia diffusa* was effective in inhibiting the growth of *Foc* and also reduced cumin wilt. Similarly, fresh leaf extracts of *Datura stramonium* and *Calotropis procera* showed maximum antifungal activity against *Foc* (Sharma & Trivedi 2002).

Tea waste was found to be the best for mass multiplication of *T. harzianum* isolate antagonistic to *Foc* (Sharma & Trivedi 2005). Three bacterial antagonistic strains *viz*., *Bacillus subtilis*, *Pseudomonas fluorescens* and *Rhizobium* spp. were multiplied on Nutrient broth, King's broth and Yeast extract manitol broth, respectively. Using easily decomposable organic matter for multiplication of bio agents serves dual functions, firstly as a nutrient base for fungal growth and secondly as soil amendment. Effectiveness of peanut haulms compost as a carrier of species of *Trichoderma* (*T. harzianum*, *T. hamatum* and *T. koningii*) in controlling wilt was studied at Egypt (Haggag & Abo-Sedera 2005). The peanut haulms carrier was able to increase the population of bio control agents, viability, survival, microbial biomass and activity during 12 months period while population of *Trichoderma* species decreased when peat and vermiculite were used as carriers. Detecting *Trichoderma* biochemical activity in compost by HPLC analyses revealed that production of antibiotics such as Gliotoxin, Trichodermin and Gliovirin as well as total phenols increased. Specrophotometric determination of the enzymatic hydrolysates revealed that chitinase, protease, cellulose, β glactosidase and β 1,3- glucanase were also increased. In infested and natural soil with *Fusarium*, amendment with peanut haulms compost inoculated with *Trichoderma* spp. were found to be effective in reducing wilt incidence and pathogen population. Plant growth, yield, nitrogen content and seed oil content were improved. The compost not only provided an environment favorable for plant development but also offered suitable conditions for plant protection and simulation of bio control agent activity.

Aspergillus versicolor isolated from the cruciferous residue amended soil was found to parasitize *Foc* in hot arid climate of India. In *Foc* and *A. versicolor* infested soil, population of *Foc* drastically declined after 15 days causing 93.3% reduction, while with *T. harzianum* infested soil 73.8% reduction in *Foc* was estimated (Israel & Lodha, 2005). This indicated that hyperparasitism of *A. versicolor* over *Foc* was comparable with that of *T. harzianum.* Maximum survival and multiplication of *A. versicolor* was estimated at 50% moisture holding capacity. This biocontrol agent was able to survive and multiply even at 65°C. Better survival and multiplication of *A. versicolor* at low soil moisture content and at high soil temperature are supportive evidence for its adaptation in dry sandy soils, where temperature often reaches 50-60°C during hot summer months.

The demand for cumin is steady but wilt is a continuous threat for the profitable cultivation. The main constraint in managing wilt is lack of resistance in existing germplasm throughout the world. The large scale screening of the germplasm resulted in identification of a few field tolerant varieties, but still there is a need to intensify research efforts to induce resistance either through incorporating resistant genes by using biotechnological tools or by mutations. Because of small flowers, improvements of Apiaceae plant following the classical breeding procedure is generally slow, laborious and time consuming (Hunault *et al*. 1989). Developing sound crop rotations is the most practical way in restricting increase of inoculum density in fields. While exploring other crops for fitting in rotation, care should be taken to ensure that they are of economic value and adaptable to the local environment with less water requirement. Another way is selection of those crops in rotations, which can enhance population of antagonists against *Foc*. Use of organic amendments is a practical and effective management strategy for soil borne plant pathogens. There exists ample scope of using *Brassica* amendments for control of *Foc* wherever *Brassicas* are also cultivated besides cumin. These amendments not only reduce *Foc* population but also enhance population of antagonists in soil. There is also a need to explore other plant residues that may reduce *Foc* population when incorporated into the soil as observed with *Verbisina* residues. Use of efficient native strains of biocontrol agents is another easy and practical approach to induce suppressiveness in cumin growing fields. Concurrently, research efforts should be intensified to explore potentials of fungi, bacteria and actinomycetes antagonistic to *Foc* in order to use a consortium of such bio agents having different mechanism of action against *Foc* rather than relying on one biocontrol agent. Soil solarization is very effective technique to eliminate *Foc* propagules from heavily infested fields but has not been adopted by resource deficient cumin growers in many countries due to high cost of the polythene film. Also, it may be of limited application for large scale production system in open field. However, this strategy can be used to bring down inoculum density to below ETL where more than 50% losses due to wilt has forced growers to abandon cumin cultivation. Thereafter, use of effective crop rotation, tolerant varieties, organic amendments and biocontrol agents in an integrated manner can make cumin cultivation profitable on a sustainable basis.

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