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A DESTRUCTIVE DISEASE OF LENTIL: FUSARIUM WILT OF LENTIL

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ABSTRACT

Lentil is a significant dietary source of protein and other essential nutrients in many regions of the world. Among several diseases, Fusarium wilt is the most significant disease. This review covers achievements in the control of Fusarium wilt, the diversity of pathogen and the gap in the control of Fusarium wilt to improve the productivity and production of the crop. Fusarium wilt of lentil caused by the *Fusarium oxysporum* f. sp. *lentis* (*Fol*) is one of the destructive diseases in all lentil growing regions of the world. Under favorable conditions, it caused substantial yield losses on susceptible varieties.The reasons for the low yield of lentils are numerous diseases and pests, poor agricultural practices, lack of good varieties and plant protection technology. The disease develops in patches as common with soil-borne diseases. Symptoms of the disease appeared at both adult and seedling stages in the field. From flowering to the late pod-filling stage, wilt symptoms may be characterized by sudden drooping of the top leaflets. Dark green foliage turns to dull green and then turns yellow, later whole plant or branches appeared wilted. *Fol* frequently isolated from the affected plants. The best way to control the Fusarium wilt of lentil is by growing resistant varieties, chemical control and biological control. In the absence of any control measures, *Fol* is capable of causing a drastic reduction in plant growth and yield parameters. Fusarium wilt of lentil is possessed high destructive potential. Therefore, regular disease monitoring should be carried out, a more comprehensive varietal screening program should be conducted to find out more appropriate resistant sources and in the place of disease hot spots, effective fungicides should be used to minimize the losses caused by Fusarium wilt.

Keywords**:** Disease management, *Fusarium oxysporum*, Fusarium wilt, Lentil, *Lentis*

Introduction

Lentil (*Lens culinaris* Medik) is one of the oldest leguminous pulse crops, which is traced back to 13000 and 7000 years BC in the world and Asia, respectively (Sandhu and Singh, 2007; Zapata *et al.*, 2004). Lentils and chickpeas are the main crops cultivated by human beings 11000 years ago. They were the first moved in modern-agriculture (Zohary and Hopf, 2000). It is also known as "Masoor" in Pakistan. Other names for this crop are Xiǎobiǎndòu (Chinese), Lenteja (Spanish). It is Pakistan's most valuable legume crop.Lentil wilt is the most devastating disease of lentils around the world. In a long-term favorable environment, it can cause up to 100% yield loss (Kumar *et al.*, 2010). Different pathogens, including viruses, be able to infect lentil plants, but fungal pathogens are the most significant. Fungi infect different parts of the plant, resulting in low or unsalable seed production (Taylor *et al.*, 2007). The reduction of lentil yield is caused by biotic and abiotic stress (Erskine, 2009).

Fol is the most critical pathogen of lentil. It is reported that Fusarium wilt occurs in most areas of lentil cultivation. At the seedling stage and later stage of development, plants become infected. In recent years, Fusarium wilt is a high incidence rate of disease. The incidence rate of Fusarium wilt has led to a sharp decline in output, especially in Moghan, Northwest Iran (Mohammadi *et al.*, 2012).

The pathogens such as *Fusarium*, *Pythium*, *Phytophthora*, *Rhizoctonia*, *Sclerotium* and *Verticillium dahlia* are responsible to cause the fungal wilt diseases in crops. The attacked crops showing stunting, wilting, withering, chlorosis, necrosis and defoliation of plant parts which conclusively results in the death of the whole plant. In gardens and fields, the initial symptom of Fusarium wilt is usually the golden yellow of a single leaflet or twig or a slight wilting and drooping of the lower leaves on a single stem (Madhavi *et al.*, 2006).Taylor *et al.* (2007) reported that when sensitive lentil varieties grow in short-season rotation, root diseases are usually the most serious because when environmental conditions are conducive to disease development, pathogen inoculants can rapidly accumulate.

Although it has great potential ecological significance, the present study of *Fusarium oxysporum* excludes the development of literature closely related to control, which is the focal point of this review.

Distribution and Economic Importance of Fusarium wilt

Fusarium disease occurs all over the world. This is persistent in the soil and is also related to seeds (seed dispersal). *Fusarium oxysporum* f.sp. *lentis*(*Fol*) is distributed in numerous countries of Asia, Europe, Africa, and North and South America (Fig. 1).

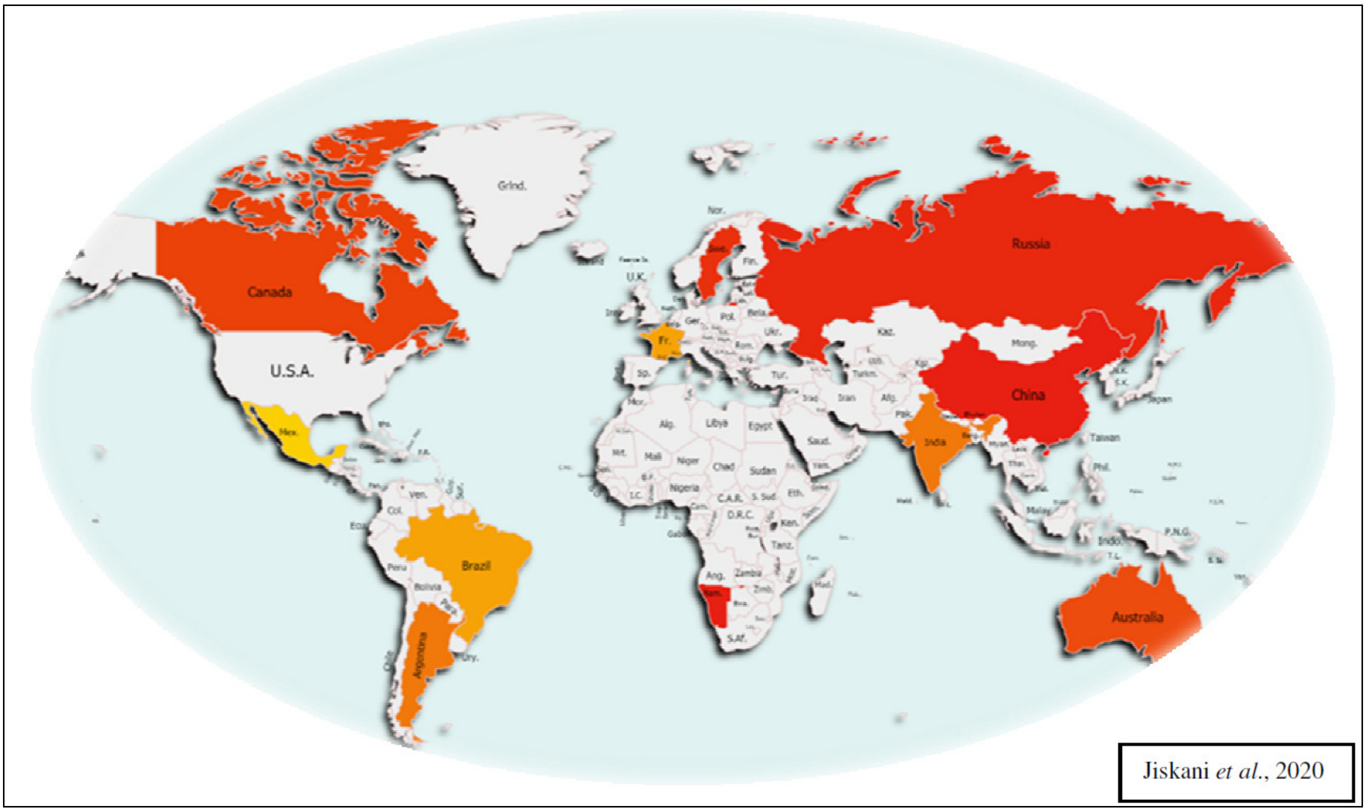

Fig. 1 : Distribution of lentil wilt caused by *Fusarium oxysporum* f.sp. *lentis*

The Fusarium wilt-associated fungus is considered a soil-borne pathogen and can survive for several years in all types of soil in the absence of a host throughout the world. If the soil is already infected with *F. oxysporum* before transplanting the healthy seedling. The infection takes place very quickly in the healthy nursery(Farr *et al.*, 1989).Soil-borne pathogens cause terrible diseases in many crops. They have common characteristics based on their close attachment to the soil, which has a strong impact on their survival and ability to cause disease (Katan, 2017). Fusarium species, together with potato, garlic, and other plants, is one of the common pathogens of Tomato, causing root rot in western Iran (Chehri, 2016).

Fusarium oxysporum species compared with other pathogens, it is almost certain that species cause more economic losses to crops. Although *Fusarium* spp. has a wide range as a complete host, specific strains usually infect only one or more plant species. These specific fungal strains often exhibit high levels of host size, depending on the plant species they can attack and are classified into more than 120 morphological specificities (Armstrong and Armstrong 1981); for instance, *Fusarium oxysporum*. f.sp.*ciceri* causing wilt disease in chickpea host only. Nevertheless, few formaespeciales such as *F. oxysporum* f.sp. *radicis-cucumerinum* and *Fusarium oxysporum* f. sp. *radicis-lycopersici*have wider host ranges, which individually attacking tomato and cucumber plants and having the capability to cause root and stem rot on numerous hosts from distinct plant families(Lievens *et al.*, 2008).

Worldwide reported diseases of lentil, responsible for significant losses to lentil production, are listed in Table 1.

Table 1 : Worldwide reported diseases of Lentil

Disease	Pathogen	References
Alternaria blight	*Alternaria* sp.	(Ostry *et al.*, 2004)
Anthracnose	*Colletotrichum*	(Bhadauria *et al.*, 2015)
Aphanomyces root rot	*Aphanomyces euteiches*	(Vandemark and Porter, 2010)
Ascochyta blight	*Ascochyta lentis*	(Dadu *et al.*, 2019)
Black root rot	*Fusarium solani*	(Ahmed and Shahab, 2018)
Black streak root rot	*Thielaviopsis basicola*	(Musheer *et al.*, 2020)
Botrytis gray mold	*Botrytis cinereal*	(Taheri *et al.*, 2020)
Cercospora leaf spot	*Cercospora cruenta* *Cercospora lentis*	(Iqbal *et al.*, 2019)
Collar rot	*Sclerotium rolfsii*	(Faruk *et al.*, 2020)
Downy mildew	*Peronospora lentis* *Peronospora viciae*	(Sagir *et al.*, 1995)
Dry root rot	*Macrophomina phaseolina*	(Singh and Azam, 2010)

	= *Rhizoctonia bataticola*	(Mitiku, 2017)
Fusarium wilt	*Fusarium oxysporum* f.sp. *lentis*	(Saxena *et al.*, 2019)
Rust	*Uromyces viciae-fabae*	(Arti and Tripathi, 2012)
Sclerotinia stem rot	*Sclerotinia sclerotiorum*	(Akem *et al.*, 2006)
Wet root rot	*Rhizoctonia solani*	(Chang *et al.*, 2008)

Fusarium wilt of lentil has been reported from the lentil-growing areas of the world. While many countries have introduced varieties of lentils resistant to Fusarium wilt/root rot, the losses caused by soil-borne diseases are high where there is a high amount of rainfall.Also, there is a scarcity of information about the management of Fusarium wilt of lentil.

Investigation and collection of lentil seeds and Fusarium wilt samples

Rafique *et al.* (2015) conducted wilt surveys in seven districts. The average incidence rate of disease in Punjab was 100%, with an average incidence of 25.7%, including those of Chakwal, Jhelum, Gujrat, Sialkot, Layyah, Bhakkar, and Khushab.

Altaf *et al.* (2014) conducted survey of 28 locations in 9 regions of Pakistan during the 2012-13 crop season, with a disease prevalence of lentil wilt 100% in the 21 regions.

Singh *et al.* (2010) examined the detection, the site survival rate of Lentil wilt and the highest infection rate was found in Sehore 74-3, with a seed infection rate of 20%.

Chaudhary (2009) investigated the area of the Bundelkhand region of Uttar Pradesh and found that the mortality rate of lentil plants caused by various soil-borne pathogens was in the middle of 19.95-33.30%. The mortality rate in 2006-07 (24.68-33.30%) was higher than that in 2005-2006 (19.95-25.69%). Fusarium wilt of Lentil was most significant and widespread in all examined areas. The proportion of plant death was 49.76-59.17%. The incidence rate was 5-18% in 2005-06 and 7-23% in 2006-07. In 2005-06, the incidence rate of the largest wilt disease in the Mahsi area was 13-18%, and 2006-07 was 9-23% (Srivastava *et al.*, 2008).

Rangaswamy *et al.* (2016) reported that *Fusarium sp.* is one of the most diverse fungi in the world under different soil and climate conditions. Pathogenic variation is a common phenomenon of *Fusarium sp.*

According to (Ravikumar *et al.*, 2007) that the number of plants, the size of seeds and the yield of chickpea crops infected with wilt. Scientists have different opinions on the problem of disease and fungal perpetuation.

Belabid *et al.* (2004) analyzed 32 isolates of *Fusarium oxysporum* from different areas of Northwestern Algeria. All isolates were tested for pathogenicity. The nitrate-free mutant (NIT) was used to test the vegetative compatibility of the isolate. In the same vegetative compatibility group, the isolates were placed to form Heterokaryon. Fol isolates correspond to a single race, but in susceptible lines, their aggression was different.

There is great variability in the classification and description of Fusarium species according to their morphological characteristics. Several DNA based molecular techniques were used to classify the pathogenic population of Fusarium, establish a phylogenetic relationship and genetic variability (Belabid *et al.*, 2004)

Pathogenicity determination:

According to (Rafique *et al.*, 2015) The pathogenic strains identified by identification and morphology showed variability (NARC-08-1 and Masoor -93) lentil genotypes. After inoculation of lentils confirmed the pathogenicity rate of 30 strains (96.77%) of NARC-08-1 were 0 to 100% disease severity index and incidence were 19.33 to 100% respectively. The Masoor-93 strain was 22 (70.97%) pathogenic, the severity index was 0 to 66.66%, the incidence rate was 0 to 100%, and the yield reduction rate was 6.47 to 53.68%. 8 strains (25.81%) were isolated, which caused the highly pathogenic disease response of NARC-08-1 seedlings (average severity index was 94.07%, average incidence rate and yield reduction rate was 100%) and total death of seedlings.

Isolation and pathogenicity of Pathogen

Wash the symptomatic strains thoroughly with tap water, cut the small pieces adjacent to the healthy parts from the infected parts 1-2 mm away from the forward edge of the disease spot, and then cut them with a disinfection blade. These fragments were disinfected with 1% sodium hypochlorite solution for 30 seconds, and in the end, replaced three times disinfect distilled water for removing traces of sodium hypochlorite (Yadav and Yadav, 2019).

100 representative Fol isolates from lentils infected with *Fusarium oxysporum* were collected, these Fol strains were propagated on the medium of cornflour under the condition of glasshouse by CRD. *Fusarium oxysporum* isolates were identified, and the pathogenicity test was carried out on “Vidhokar local” wilt susceptible cultivar under artificial inoculation. Potted lentil plants with sand, maize meal and 10% w/w fungus inoculum. The control plants were grown in a comparable mixture of uninfected sand, sand maize meal media, and autoclaved soil. After emergence, the percentage of wilt disease progress recorded and expressed. The strains with a wilting rate of more than 50% are highly pathogenic, and the strains with a wilting rate of 30-50% are moderately pathogenic (Datta *et al.*, 2011).

Morphological characterization:

Fusarium oxysporum is known as morphologically undifferentiated pathogens. It is pathogenic as well as non-pathogenic and even sometimes it is a very beneficial strain against plant diseases. The number of diseases such as damping-off, root rot, yellows and vascular wilts of very essential economic crops/plants are caused by the pathogenic strains of *Fusarium oxysporum* (Beckman and Roberts, 1995), whereas: the non-pathogenic strains are distinct as the strains for which, yet no host crops have been recognized (Lievens *et al.*, 2008).

Symwptoms and etiology of Lentil Wilt

The disease develops in patches at the adult stage and seedling stage in the field from flowering to late podding stage, the symptoms of wilting occur as top leaflets suddenly droop (Fig. 2). These symptoms can be produced by other infective fungi; therefore, it is not sufficient to confirm the cause of the disease. The signs of symptoms produced by means of Fusarium wilt disease are drooping, yellowing, wilting, and dying of the lower leaves, regularly on one part of the plant. These symptoms may be found sequentially on newer leaves with one or more branches being affected and others remaining healthy. Later a few weeks, browning of the vascular system can be observed by slicing the stem with a knife. This brown discoloration inside the stem can be found from the roots to the top of the plant. Plant growth becomes stunt in warm conditions, the plant may die (Kenneth and Seebold, 2014). Stems and leaves become wilted due to severe infection in roots and vascular vessels which delay water transportation and resulting from the maximum preharvest losses(Sandani and Weerahewa, 2018). Leaves or total branches will flip yellow, then brown and die still connected to the plant described as a yellow-flagging appearance. At an advanced stage, browning of the vascular system can be viewed and pathogen induces severe wilting of plants via blocking off xylem vascular bundles and impeding the movement of water(De Cal *et al.*, 2000). In warm climates, these symptoms seem to occur at some stage in the middle of growth. Previously, in with normal symptoms was leaf chlorosis. The diseased leaves have dried up. In many cases, a part of the plant was first affected. The infection usually occurs in the form of chlorosis, leaf wilting and browning of the vascular system. The cross-section of the stem leads to vascular necrosis (Ignjatov *et al.*, 2012) .

Fig. 2 : Symptoms of *Fusarium oxysporium* f. sp. *lentis*

Symptoms produced by *F. oxysporum* f.sp. *lentis* include stunting, marked reduction of the root system, internal vascular discoloration of the lower stem, and wilting (Tosi and Cappelli, 2001). *Fusarium oxysporum* wilt occurs in the field, which is patchy and occurs in the seedling stage or adult reproductive stage of crops (Stoilova and Chavdarov, 2006). Seedling wilt is characterized by rapid drooping, followed by drying and death of the seedling. Though roots look healthy, proliferation and nodulation are reduced, and usually, the vascular system does not have external discoloration. The adult wilting symptoms appear in the late stage of flowering and pod filling, which shows that the top leaflets of the injured plants droop suddenly, the leaflets close without early shedding, the leaves are dark green, and then the whole plant or individual branches wilt (Mohammadi *et al.*, 2011). The symptoms of wilting in the field include wilting of old leaves, stunting of plant development, and leaf atrophy and curling of the lower part of the plant moving up to the stem of the infected plant. Plants eventually turn yellow and die (Pouralibaba *et al.*, 2017). (Agrios, 2005) pointed out that *Fusarium oxysporum* usually produces wilting, chlorosis, necrosis, vascular system browning, stunting, and shedding. It occurs with other root rot pathogens as a complex, which leads to serious loss of lentil seedlings.

Resistant screening

For screening the resistant germplasm so many different inoculation methods have been described against *Fol* for instance root dip methods (Akaeze *et al.*, 2021), root inoculation methods (Sidharthan *et al.*, 2018) and soil infestation methods (Silva and Bettiol, 2005). The results of pathogenicity depending on the technique used on the host plant with their pathogen population rate and exceptional stage of the disease.

Güney and Güldür (2018) evaluated the consequences of special inoculation strategies against *R. solani, M. phaseolina, F. oxysporum* and *F. solani*. The techniques were used such as root dip with wheat bran and soil infestation with rice grain on the nurseries of pepper. The seedlings of pepper were inoculated with the test pathogens and left for months later transplanting for the growing purpose in aseptic conditions. The pathogenicity test was carried out of all test fungi through the inoculation with the infected rice-grains. The technique root dip inoculation was once tested towards

F. solani and *F. oxysporum* when the soil was once infested with wheat bran approach for *R. solani* and *M. phaseolina* inoculation. The sign of symptoms such as leaf chlorosis, bruising and root rot was appeared by all tested isolates. The soil infestation method with the inoculation of rice grains was noted once the furthermost gorgeous method during the assessment of pathogenicity of fungi. Similar types of foliar symptoms such as root rot severity and decrease in dry weight of roots appeared with the usage of rice grain inoculum with the tested fungi. As with other inoculation methods, all pathogens had the same effect on root rot. However, *Fusarium oxysporum* was the least pathogenic pathogen among the tested fungi that affected the severity of leaf symptoms; for the weight of sparky root and plant, as well as dry root and plant weight, the toxicity of *R. solani*, *M. phaseolina* and *F. solani* was similar when these parameters were used. It provides a valuable suggestion for screening pathogens of pepper seedlings. In the conclusion, it is suggested that the pathogenicity of *F. oxysporum*, *R. solani*, *F. solani* and *M. phaseolina* of pepper were tested by rice-grain inoculation.

Parihar *et al.* (2017) evaluated 20 germplasm, including commercial varieties and advanced lines against Fusarium wilt of lentil at six different places for two consecutive years and found that the genotype and environment highly influenced wilt development. Among 20 cultivars, the least incidence was noted on one advanced line and one commercial variety. To find out resistant germplasm against lentil Fusarium wilt. (Meena *et al.*, 2017) have screened 93 cultivars collected from different sources, including commercial varieties, ICARDA materials, and advanced lines. Out of 93 cultivars, only two were found to be highly resistant to Fusarium wilt.

Pouralibaba *et al.* (2015) screened 196 germplasm of lentil against Fusarium wilt disease in a greenhouse as well as under field conditions. Based on the resulting The Area Under the Disease Progress Curve (AUDPC), 12 entries were pointed out to show a good level of resistance to Fusarium wilt. (Yadav *et al.*, 2017) screened 185 germplasm by sick plot method against Fusarium wilt of lentil under field conditions and found that only 16 appeared resistant, and 23 were moderately resistant.

Chaudhry *et al.* (2008) screened 38 germplasm including indigenous as well as International Center for Agricultural Research in the Dry Areas (ICARDA) materials against Fusarium wilt of lentil by sick plot method under field conditions and found that only one cultivar was highly resistant, seven susceptible, ten moderately resistant and 20 were highly susceptible to Fusarium wilt. (Mohammadi *et al.*, 2012) screened 55 advanced lines under greenhouse conditions (soil was infested before sowing) and field conditions (at disease hot spot) and found that only three lines were resistant to Fusarium wilt both in greenhouse and field conditions.

Management

Uses of different chemicals

Several tactics have been utilized to tackle the disease caused by *Fusarium oxysporum.* Among the chemical methods, the usage of fungicides from the family of benzimidazole*s* andtriazoles are the most important as well as biological methods including the use of microorganisms such as *Pseudomonas, Trichoderma*. For this reason, the continuous study of this fungus is crucial to understand how it can be managed. de la Isla and Macías-Sánchez (2017) studied on three fungicides such as Sulcox, Indofil M-45 and Ridomil MZ-68 against mycelial growth development of *Fol* responsible to cause the Fusarium wilt disease of tomato. The chemical treatment with Sulcox showed the highly efficient(Laila *et al.*, 2018).

Six systemic fungicides, such as Triger 25% EC (Tebuconazole), Difenoconazole, Corel 25% EC (Difenoconazole), Solex (Carbendazim 40% + Triadimefon 10%), Dew (Amistor Top SC (Azoxystrobin + Difenoconazole) and Reflex (Difenoconazole + Propiconazole) were evaluated for 144 and 172 hours at 48, 96 and 15 ppm concentrations against *A. solani*. Corel and Reflex had the best growth inhibition of *A. solani* at all concentrations. All the fungicides had the best inhibition effect at the concentration of 15ppm after 172 hours(Sarfraz *et al.*, 2018). Irum (2007)stated that chemical treatment of Benomyl (50WP) and Carbendazim (50WP) used to be validated to the friendly environment in opposition to *F. oxysporum* f.sp. *ciceri*. The results obtained during the trial that the tested botanical extracts and chemicals had an equivalent capability for the inhibition of pathogen development.

Akhtar *et al.* (2017) evaluated commercially accessible fungicides and bio-fungicides in the laboratory as well as in field conditions against Fusariumwilt pathogen. Initially, 4 distinct fungicides have been assessed under *in-vitro* environments. Three auspicious fungicides, two biopesticides and *Trichoderma harzianum* had been utilized each in the greenhouse and field trials. During lab *(in-vitro)* experiments potato dextrose agar PDA was mixed with fungicides. The treatments @ 1% nearly completely inhibited the growth of *Fol* with varying degrees of achievement whereas Nativo was determined the most wonderful fungicide with a 98% reduction in growth when compared with check. Nativo considerably decreased the disease incidence (32.75 %) by 1%. However, Poly-beta-hydroxyl- butyric-acid efficiently boosted tomato growth. Maximum reduction in disease (30.14 %) was determined by way of Nativo followed by way of Teagro (25.06 %) during the field experiment. Among the test fungicides, Nativo was observed highly efficient for managing *Fol* in the greenhouse as well as in field conditions.

Fareed *et al.* (2015) studied five chemicals to be precise and control in lab conditions in three different concentrations such as 1%, 0.5% and 0.25% against Fusarium wilt disease of cucumber. The highest growth inhibition of fungus mycelia was observed by redomil (1.53cm) followed by a score (1.66cm), copper oxychloride (1.75cm), Cabriotop (1.79cm), and Antracol (1.90cm) as compared to check (3.49cm). Hence Redomil and score were recorded with the highest inhibition % against the test fungus under lab conditions. Redomil was recorded with minimum disease incidence (47.50%) and score (49.72%) as compared to control (55.0%) in the field. Dwivedi *et al.* (1995)verified that the fungicides Thiram and Topsin-M are highly operative at 800 mg/g of soil, decreasing 83.4% populations of *Fol* after 45 days. Amini and Sidovich (2010)assessed six fungicides namely azoxystrobin, bromuconazole, benomyl, carbendazim, fludioxonil, and prochloraz *in-vitro* and *in-vivo* conditions against Fusarium wilt pathogen. The different concentrations such as (0.0001, 0.001, 0.01, 0.1, 1, 10, 100 µg/ml) were made for the evaluation of target pathogen on PDA media. Different concentrations of the above fungicides (0.1,1. 10 and 100 µg/ml) were used to monitor tomato Fusarium wilt. The radial growth of fungi was measured, and the median effective concentration (EC50) value (µg/ml) was calculated. The results showed that all the fungicides tested had unique efficacy in reducing the disease intensity. The pathogens of Prochloraz and bromuconazole were recoded the fantastically wonderful towards the pathogen both *in vitro* and in field condition by benomyl and carbendazim. All the different fungicides tested were found to be less effective. As for the date of use of fungicides, it has been proved that the quality of fungicides applied 7 days after tomato plant infection is poor, which is related to the infection of the previous day. No signs and symptoms of phytotoxicity were found after Prochloraz, Bromuconazole and benomyl, especially in seedlings. However, the fungicides fludioxonil and bromuconazole were phototoxic to tomato seedlings.

Rani *et al.* (2019) observed that seed treatment with carbendazim, chlorpyriphos, copper hydroxide and Hexaconozole significantly reduced the Fusarium wilt incidence and increased the grain yield of treated lentil plants. (De *et al.*, 2001) and (De and Chaudhary, 1999) also found Carbendazim (Bavistin) and carboxin (Vitavax) highly effective against Fusarium wilt of lentil. Both fungicides significantly controlled the Fusarium wilt, thus brought a remarkable increase in yield. In contrast to other researchers, (Ahmed *et al.*, 2002) have concluded that under Northern Syria conditions, fungicides have no significant impact on Fusarium wilt of lentil.

Ankita *et al.* (2013) tested eight fungicides against *Fol* and found that Benlate and Captaf caused significantly maximum inhibition. These two fungicides also performed better under field conditions. They significantly increased the grain yield and 1000 grain weight as well as remarkably reduced the development of Fusarium wilt in lentil plants.

Hoque *et al.* (2014) tested four fungicides, namely Rovral, Secure, Bavistin, and Captan against foot and root rot of lentil caused by *Fusarium oxysporum* and *Sclerotium rolfsii* and observed that all fungicides significantly reduced the diseases and enhanced the lentil yield as compared to the control. However, Secure performed better than other fungicides. (Rafique *et al.*, 2016) reported that out of five fungicides tested against *Fol*, Benomyl, and Thiophanate methyl remarkably checked the in vitro growth of the test pathogen. They also found that seed treatment with these two fungicides significantly suppressed the development of Fusarium wilt, in plants grown in artificially infested potting mix. Benomyl and Thiophanate methyl remarkably enhanced the seed germination and yield, as well as significantly reduced the incidence and severity of Fusarium wilt.

Subedi *et al.* (2017) reported that out of 8 treatments, Vitavax (Carboxin) and Bavistin (Carbendazim appeared highly effective against Fusarium wilt/root rot complex diseases of lentil under field conditions. Both fungicides considerably reduced the disease intensity and remarkably increased the grain yield. (Khalequzzaman *et al.*, 2017) tested seven fungicides against foot and root rot of lentil caused by *Fusarium oxysporum* and *Sclerotium rolfsii* and found Vitavax and Bavistin highly effective. These two fungicides not only effectively controlled the targeted diseases but also enhanced all yield parameters.

Kumari *et al.* (2018) found that lentil seed treatment with Carbendazim + Thiram effectively minimized the development of wilt caused by *Fol* and brought a remarkable increase in plant growth and yield parameters including plant length, plant weight, number of pods, pods weight, and grain weight. (Chandra *et al.*, 2020) found that fungicides combination along with botanicals and antagonistic effectively controlled the Fusarium wilt. The best combination they found was Metalaxyl + Mancozeb + Neem leaf extract + *P. fluorescens* followed by Metalaxyl + Mancozeb + *P. fluorescens*.

As with all soil-borne disorders, for seedling diseases sanitation essential for efficient control. As the number of competitive microorganisms decreases, *F. oxysporum* can rapidly regenerate in fumigated soil (Marois *et al.*, 1983). Hence, it is essential to prevent moving pathogens from infected sites into production areas. Another vector introduced into the inoculum is the seed and can carry the propagules of *F. oxysporum* (Graham and Linderman, 1983; James, 1987).

Uses of plant extracts

The usage of plant extracts against the eradication of pathogens from the host is an auspicious, operative, harmless and eco-friendly approach. Botanical Plant extracts and fungicides have an equivalent capacity for decreasing mycelial growth of Fusarium wilt pathogen in tomato (Laila *et al.*, 2018). The conclusions of his study recommended that the extraordinary price of chemical fungicides and their unsafe effect on human beings and living organisms. The botanical plant and antagonistic bio-agents are the significant basis of compounds that are very useful against some pathogenic fungi and these are the decent substitutes of fungicides. Chand and Singh (2005) defined that the wilt disease incidence in chickpea caused by *Fusarium oxysporum* f. sp. *ciceri* can be reduced with the usage of plant extract.

Laila *et al.* (2018)reviewed the potential of *Moringa oleifera*, *Calotropis procera*, *Wedeliacalend ulacea*, *Nigella sativa*, *Tricosanthes dioica*, *Andrographis paniculata*, *Momordica charantia*, *Curcuma domestica*, and *Trigonellafoenum-graceum* as plant extracts against the Fusarium wilt disease of tomato associated fungus *Fol*. The result showed that approximately all tested plant extracts were successful in decreasing the colony mycelial growth of Fol at 25% concentration. The maximum inhibition (87%) of the test pathogen was recorded when treated with Calotropis *proceraon plant* extract at 25% concentration after 12 DAI. The lowermost inhibition (27%) of the same pathogen was noted when treated with *Momordica charantia* plant extract at 5% concentration after 12 DAI of inoculation.

The efficacy of aqueous extracts of four plant species was studied *in-vitro* conditions. The tested extracts were efficient in decreasing the colony mycelial development of *Fusarium oxysporum* f.sp. *ciceri*. The maximum fungal growth inhibition (80%) was observed in *A. indica* and *D. metel* treated plates even at the lowest 10% concentration. Both plant extracts can inhibit the fungal growth, whereas the extracts of *Ocimum sanctum* were noted as the less effective with the lowest (60%) inhibition as compared with the other tested extracts(Irum, 2007). The methanolic extracts from leaves, bark and fruit of *Eucalyptus citriodora* (Hook.) were prepared and their antifungal activity was tested against *F. oxysporum* at different concentrations (0 to 5%). The extract of leaves was found the best extracts with the highest 98% inhibition in fungal growth whereas; bark and fruit extracts noted as less successful displaying 50–60% inhibition. The results determine that methanolic added extract of *E. citriodora* leaves have capability to inhibit the pathogenic fungus and it also granted around 85% control of disease in chilli plants with considerably high strength of defense associated enzymes(Shafique *et al.*, 2015).

Mostly, all plant extracts showed good bioactivity against *F. oxysporum*. However, the efficacy of plant extracts was largely influenced by the extraction solvent, the concentration of the extract, or both. The low concentration of 12.5% methanol extract from *A. indica* had higher bioactivity against *Fol*, which was a potential fungicide for *Fusarium oxysporum* (Akaeze *et al.*, 2021). Mishra *et al.* (2014) studied 20 different plant extracts for the management of *Fol* through poisoned food technique in the laboratory. The *Ageratum conyzoides* extract showed the highest (95.57%) toxicity to the test pathogen. The results were observed significant among the tested extracts against the test pathogen. Moreover, the highest inhibition % 90.33 was noted by *Ageratum haustonianum* extracts followed by84.97% and 79.19% inhibition by using *Clerodendrum inermae* and *Terminalia bellirica* extracts against the test pathogen.

Chohan *et al.* (2011) assessed few medicinal plant extracts for the controlling of fungal disease caused by *F. oxysporum* f. sp. *gladioli* in the laboratory. The concentrations 2, 4, 6 and 8% were made from selected plants such as *Azadirachta indica, Tagetes erecta, Ocimum basilicum Allium sativum* and *Datura stramonium*. The highest mycelial growth inhibition (83.5) of target pathogen was observed by *A. indica* extract at (8%) concentration and (34.5%) at 2% concentration followed by *T. erecta, A. sativum* and *D. stramonium* that inhibited the mycelial growth at 8% concentration *viz.* 58.5, 35and 28.5% respectively. The lowest mycelial growth inhibition of *F. oxysporum was* recorded by *O. basilicum*. Singha *et al.* (2011)assessed the efficacy of *Piper betle*L. (PbC) crude chloroform extract for managing the tomato Fusarium wilt disease associated with *Fol* pathogen. The results presented that PbC (1%) in the soil is highly effective in decreasing the population of *Fol* pathogen in the soil as compared to carbendazim fungicide.

Uses of biocontrol agents

Vargas-Inciarte *et al.* (2019)tested *T. koningiopsis*, *T. virens*, *T. spirale* and *T. harzianum* against *Fusarium oxysporum* wilt disease. The *T. spirale* was observed highly effective in all experiments. *T. spirale* was capable to reduce 79% growth of Fusarium. The other tested bioagents were also observed highly effective in the laboratory and in filed against *Fusarium* sp. reducing 70% disease incidence. These bioagents resulted in a positive impact on the growth of inoculated plants. During the greenhouse trial, the *T. spirale* treated plants were observed highly effective producing a higher yield and lowest infection % of Fusarium wilt disease. The strain of *T. spirale* tested during the whole research having excellent potential and in the future to become a regular biocontrol agent of Fusarium wilt disease.

Javaid *et al.* (2014) evaluated antagonistic performance of different *Trichoderma* species such as *Trichoderma pseudokoningii, T. reesei, T. harzianum, T. koningii, T. aureoviridi, T. hanatus,* and *T. viridi* against two very much challenging soil-borne plant pathogenic fungi such as *Fol* and *Macrophomina phaseolina*. The tested *Trichoderma* species were found effective against the tested fungi.The dual culture technique was used and resulting in 45–65% inhibition in radial growth of *M. phaseolina* whereas, 59–74% inhibition was noted by *Fol*. *T. harzianum, aureoviridi* and *T. hanatus* were recorded as the highest successful biological control agents against both tested fungi as compare to others.

Sarfraz *et al.* (2018) conducted *in-vitro* trial to find out the capability of *Trichoderma* isolates, selected plant extracts and fungicides versus to *A. solani.* The selected *Trichoderma* species were *T. harzianum, T. viride* and *T. hamatum.* The dual culture technique was used to check their efficacy after 48, 96, 144 and 172 hrs.The maximum percent inhibition of *A. solani* was observed by *T. hamatumin-vitro trial* followed by *T. hazianum* and *T. viride* after 172 hrs. Hussain *et al.* (2016) studied *in-vitro* and in screen house experiments against the Fusarium wilt disease of tomato. The bioagent was selected as *Penicillium* sp. EU0013_90S root colonizing fungus. A dual culture technique was performed to check the inhibitory efficacy of EU0013_90S on separate fungal pathogens particularly tomato Fusarium wilt disease-causing pathogens such as *Fol* race 1 and race 2. The radial colony mycelial growth of the target pathogens was reduced by area of distinct lengths.

Sultana and Ghaffar (2013)tested few bioagents such as *Trichoderma viride, T. harzianum, Bacillus subtilis, Stachybotrysatra* and *Gliocladium virens* for manging *F. oxysporum*in the laboratory and field. The results indicated that all tested bioagents extremely lowered the mortality % as well as root infection % in the seedlings of bottle gourd and cucumber artificially infested with *F. oxysporum*. The *T. harzianum* was found highly efficient in decreasing mortality and root rotting infection % in the cucumber and bottle gourd seedling. Anitha and Rabeeth (2009)studied *Streptomyces griseus* as an antagonistic agent against *Fol* causing tomato Fusarium wilt disease. The formulation of *Streptomyces griseus* based on talcum powder was established, whether single or with or not including chitin and examined under greenhouse conditions. After storage at 30℃ and 4℃, the life span of *S. griseus* with 122 ×10 and 118×10 cfu/g reached equilibrium within 105 days. In greenhouse experiments, a large number of *S. griseus* preparations were used to control the incidence rate of *F. oxysporum*. The treatment methods were seed treatment and seed soaking. The results showed that the minimal disease severity of (SFSg 5) *S. griseus* suspension (root dipping) and chitin modified S. *griseus* (root dipping) was related to chitinase enzyme preparation. In order to effectively control the disease, *S. griseus* was placed in the root system before *Fusarium oxysporum* infestation followed by seed treatment.

Future Directions

Very less research is published against fusarium wilt of lentil, more research is needed to introduce new resistant varieties against Lentil wilt. More long-term disease resistant and high-yield varieties with economic characteristics need to be cultivated.

Conclusions

If the long-term environment is favorable, *Fusarium oxysporum* may cause a 100% yield loss. In the absence of any control measures, *Fol* is capable of causing a drastic reduction in plant growth and yield parameters. Fusarium wilt of lentil is possessed high destructive potential. Therefore, regular disease monitoring should be carried out, more proper sanitation processes comprising, regular cleaning of field equipment and regular removing of diseased plant parts, which can increase the amount of inoculation in the soil. Diseased plants or plant parts should be burned or disposed of to eliminate inoculum or at least to ensure that they do not contaminate the production area. A more comprehensive varietal screening program should be conducted to find out more appropriate resistant sources. In the place of disease hot spots, effective fungicides should be used to minimize the losses caused by Fusarium wilt. Similar symptoms in lentils may be caused by several pathogenic Fusarium species. These characteristics emphasize the importance of ensuring that pathogenic Fusarium species exhibiting similar symptoms in defined geographical areas are precisely identified and differentiated and provide appropriate molecular protocols. This will help to understand the etiology and epidemiology of lentil diseases caused by various species of Fusarium, and to encourage the cultivation of new lentil varieties. In the next few years, a very dynamic process will continue to develop effective molecular markers in plant breeding.

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