Mycologia Iranica 11(1): 1–17, 2024 Review Article DOI: 10.22043/MI.2024.364726.1273

A review of *Fusarium redolens* Wollenw. as an emerging plant pathogen in Iran

S. Jamali

Department of Plant Protection, College of Agriculture, Razi University, Kermanshah, Iran

Abstract: This study presents scientific research on *Fusarium redolens* Wollenw. A systematic search of the Scopus database from 1956 to 2023 yielded 201 indexed documents. *F. redolens* is an emerging pathogen with a significant impact on pulse crops. Population growth, especially in developing countries, creates a primary problem: food availability, especially protein sources. Chickpeas are an important crop in western Iran, especially in Kermanshah province. Until 2019, most studies attributed chickpea yellowing and root rot to *Fusarium oxysporum* and *Fusarium solani*, respectively. To manage this crop, previous recommendations included planting cereals such as barley and wheat due to the presence of *F. oxysporum* formae speciales in the soil. However, *F. redolens* has now been identified as the major cause of chickpea yellowing and root rot, especially in the western provinces. This Fusarium species have been isolated from 54 species of 50 genera and 29 plant families, with the highest frequency observed in Fabaceae, Poaceae and Asteraceae hosts. Given its pathogenicity to wheat and barley and the unknown presence of formae speciales, rotation with these cereals is no longer considered an appropriate management solution. Further research is needed to develop effective management strategies for the future.

Keywords: Forma specialis, Pathogenicity, Species-specific primer, VOSviewer, Wheat

INTRODUCTION

As a common pathogen, saprobe, and endophyte, Fusarium is one of the most ecologically important genera of soil-dwelling fungi (Summerell et al. 2011). The fungus has been isolated from a wide range of soil types throughout the world. This genus is a member of the class Sordariomycetes, order Hypocreales, division Ascomycota, subdivision Pezizomycotina, and family Nectriaceae (Kirk et al. 2008). Fusarium species exhibit niche differentiation within the complex microbial tapestry of the soil environment. In particular, some species are very efficient at breaking down organic matter in the soil. This decomposition process, known as mineralization, releases essential nutrients for plants and other soil organisms. This contributes significantly to the vital nutrient cycle within the soil ecosystem (Stoner 1981, Paul & Clark 1989, Ruiter et al. 1994). This is due to their capacity for saprobic digestion. Many Fusarium species are important plant pathogens that can cause a range of plant diseases, including foliar diseases, dieback, canker, vascular wilt, seed and fruit decay, onion rot, stem rot, and root rot (Dean et al. 2012, Chehri et al. 2017, Trabelsi et al. 2017, Sharma & Marques 2018). Several studies have demonstrated the endophytic colonization of the root cortex (endorhiza) by non-pathogenic species within the Fusarium genus (Dababat & Sikora 2007). The management of soil-borne plant diseases has proven to be a useful application of these non-pathogenic *Fusarium* (Steinberg et al. 2007, Zhang et al. 2015, Šišić et al. 2017, Shadmani et al. 2018).

Fusarium redolens Wollenw. has recently been reported as an emerging pathogen threatening chickpea production in Iran. Due to the economic importance of chickpea and its vast area of cultivation in Iran, especially in the western provinces, this crop has become the major host for *F. redolens* in the country. This fungus causes significant quantitative economic losses to chickpea production. The area under chickpea cultivation in Iran is about 439,872 hectares, 95% of which is rain-fed. Iran is the ninth largest producer of chickpeas in the world after India, Australia, Ethiopia, Turkey, Myanmar, the Russian Federation, Pakistan, and Mexico (FAOSTAT 2021). Iran produces about 168,000 tons of chickpeas per year, accounting for 2% of global production. More than 80% of chickpea production in Iran comes from the provinces of Kermanshah, Lorestan, Kurdistan, East Azerbaijan, and West Azerbaijan (Western Provinces). Worldwide, the average grain yield of chickpeas is 850 kg·ha^{-1}, and in Asia, it is 919.7

Submitted 16 Jan 2024, accepted for publication 7 June 2024
✉ Corresponding Author: E-mail: jamali454@yahoo.com

http://mij.areeo.ac.ir

kg·ha^{-1} (FAOSTAT 2021). Chickpea yield in Iran is much lower than the world average. The world average yield of chickpea is about 1800 kg·ha^{-1}. In Iran, however, the average yield is only 400 kg·ha^{-1}. Kermanshah province is the leading chickpea producer in Iran, accounting for nearly 28% of the total area (141,520 ha). The Bivanij cultivar dominates the region (except in cold and high-altitude areas) due to its faster maturity, higher biomass, and grain yield compared to other cultivars (Azad, Hashem, ILC482). However, pathogens and poor management practices significantly affect production. Studies show that *F. oxysporum* and related fungi (FOSC) are a major threat in western Iran, where rainfall exceeds 400 mm (Younesi et al., 2020). Therefore, accurate identification of Fusarium species is essential for the development of effective control measures.

Chickpea Fusarium disease history: World

Fusarium species are among the most devastating pathogens of chickpeas globally. The first documented instance of chickpea wilt occurred in India, reported by Butler in 1918. The disease was also reported in Myanmar in 1923, but the exact cause of the disease was unknown until Padwick's successful identification of the causative agent in 1940 (Erwin 1958). In a study conducted by Prasad and Padwick in 1939, a total of 300 Fusarium isolates were collected from chickpeas. These isolates were divided into three different groups. The first group included non-pathogenic isolates, while the second group was found to be responsible for wilt disease. The third group was found to cause seed rot. The Fusarium isolates in the second group were named *F. orthoceras* var. *ciceri*. Erwin isolated some strains of Fusarium from wilted chickpeas in California and named them *F. lateritium* (Erwin 1958). He divided them into two groups: *F. lateritium* f. sp. *crotalariae* (syn: *F. udum* var. *crotalariae*), which causes wilt of sunn hemp (*Crotalaria juncea*), and *F. lateritium* f. sp. *cajani* (syn: *F. udum* var. *cajani*), which causes wilt of lentil (*Cajanus cajan*).

In an experiment, Fusarium strains isolated from chickpea in India were compared to those isolated from chickpea in California (Erwin 1958). Both strains were morphologically and pathogenically similar and were therefore introduced under the name *F. lateritium* f. sp. *ciceri*. Echandi (1970) separated Fusarium isolates from chickpea in Peru and reported them as *F. oxysporum*. It was shown that the isolated Fusarium strains causing wilt symptoms in chickpeas were all *F. oxysporum* and *F. lateritium* was not isolated (Echandi 1970). *F. oxysporum* f. sp. *ciceris* (Padwick) Matuo (Foc) and K. Sato, exhibits two main pathotypes: a yellowing type causing progressive leaf yellowing and vascular discoloration, and a wilting type inducing severe chlorosis, wilting, and vascular discoloration (Trapero-Casas & Jiménez-Díaz 1985). Additionally, eight pathogenic races (0, 1A, 1B/C, 2, 3, 4, 5, and 6) have been identified within this forma specialis (Haware & Nene 1982, del Mar Jiménez-Gasco et al. 2001). Within *F. oxysporum* f. sp. *ciceris*, races 0 and 1B/C are associated with a yellowing symptom, and the remaining races are associated with a wilting symptom (del Mar Jiménez-Gasco et al. 2001, 2003). Yield losses in chickpea due to the presence of this pathogen have been reported to be up to 15% and in some cases up to 70% (Halila & Strange 1996, Honnareddy & Dubey 2006).

At present, based on morphological characteristics, *F. oxysporum* f. sp. *ciceri* has been reported as the major causal agent of chickpea diseases in many parts of the world, including Australia, Canada, Egypt, Ethiopia, India, Pakistan, Peru, Turkey, Spain, Syria, Tunisia, the United States and other countries (Chattopadhyay & Sen Gupta 1967, Echandi 1970, Westerlund et al. 1974, Trapero-Casas & Jimnez-Diaz 1985, Bhatti & Kraft 1992, Haware et al. 1996, Nene et al. 1996, Demirei et al. 1998, Esmaeili Taheri et al. 2011). The morphological similarity between *Fusarium* spp., particularly *F. oxysporum* and *F. redolens*, can lead to misidentification based solely on these characteristics. This overlap raises the possibility that previous identifications of *F. oxysporum* may have included *F. redolens* (Jiménez-Fernández et al. 2011, Saeedi & Jamali 2021). An isolate of *F. redolens* previously thought to be *F. oxysporum* f. sp. *asparagi* was now shown to be *F. redolens* (Blok & Bollen 1997). Molecular techniques have revealed *F. redolens* as the causative agent of chickpea root rot in several countries, including Canada, Lebanon, Morocco, Pakistan, Spain, the Netherlands, and Tunisia (Baayen et al. 2000, Esmaeili Taheri et al. 2011, Leisso et al. 2011, Bouhadida et al. 2017, Rafique et al. 2020). A study by Jiménez-Fernández et al. (2011) showed that infection of chickpea with *F. redolens* induced a disease syndrome similar to that caused by the yellowing pathotype of *F. oxysporum* f. sp. *ciceris*. To date, at least nine Fusarium species have been reported to infect chickpeas around the world. These include *F. culmorum*, *F. equiseti*, *F. graminearum*, *F. hostae*, *F. oxysporum* f. sp. *ciceris*, *F. proliferatum*, *F. redolens*, *F. sporotrichioides* and *F. verticillioides* (Esmaeili Taheri et al. 2011, Jendoubi et al. 2017, Saeedi & Jamali 2021, Younesi et al. 2021, Geraminasab et al. 2023).

Chickpea Fusarium disease history: Iran

Fusarium wilt reduces both seed yield and seed weight in chickpea production in Iran. Chickpea yield losses of up to 15% annually and up to 70% in severe outbreak years have been reported. Chickpea wilting and yellowing diseases were first reported in Iran by Manuchehri and Mesri from Khoy, Shapur, Ahar, Miandoab, Karaj, Gonbad, Shiraz, Isfahan, and Kashan (Manuchehri & Mesri 1966). At that time, the pathogen *F. lateritium* f. sp. *ciceris* was diagnosed by

sending samples of the fungus isolated from infected chickpeas to California. *F. oxysporum* f. sp. *ciceri* was introduced by Banihashemi (1986) as the causal agent of chickpea wilt in Shiraz. In 1993, isolates obtained from the root and crown of wilted chickpea plants in rainfed fields in Lorestan province were identified as *F. oxysporum* (Nazari & Ershad 1993). In Fars province, the causal agent of chickpea root rot, *F. solani* f. sp. *pisi*, and the causal agent of chickpea yellowing and wilting, *F. oxysporum* f. sp. *ciceri*, were identified (Mohammadi & Banihashemi 2005). Graminasab et al. (2014) identified four species, including *F. oxysporum*, *F. solani* (Mart) sacc, *F. proliferatum* (Matsus) Nirenberg, and *F. equiseti* (corda) sacc, as the major causes of wilting and yellowing in chickpea. Since then, several reports have been published on the genetic variability of the pathogen. In Kermanshah province, Nourollahi et al. (2017) found nine fingerprint groups among 45 *F. oxysporum* f. sp. *ciceris* isolates from commercial chickpea fields using five microsatellite primers. Azimi et al. (2017) employed 12 inter simple sequence repeat (ISSR) primers to analyze the genetic diversity of *F. oxysporum* f. sp. *ciceris* isolates from chickpea in Ilam province, Iran. Their study identified 24 distinct fingerprint groups among 47 isolates. This contrasts with previous research in western Iran, which suggested only five pathogenic groups were present (Younessi 2004). Races 1, 2, and 4 were identified based on disease symptoms in chickpeas, as documented by Haware and Nene (1982). Earlier identifications relied primarily on morphological features of the pathogen. *Fusarium oxysporum* f. sp. *ciceris* is widely accepted as the main cause of Fusarium wilt in chickpeas. Until 2009, there were no reports on the pathogenicity of *F. redolens* on crops in Iran. Based on morphological and species-specific primers, Ghanbarzadeh et al. (2014) identified *F. redolens* as a pathogen of red onion, causing basal and bulb rot. Chehri (2016) showed that *F. redolens* is associated with tomatoes in Iran based on morphological and molecular phylogenetic analyses, and his research confirmed the prevalence of *F. redolens* in Iran. Chehri (2018) also showed that *F. redolens* is one of the most common fungi isolated from agricultural soils in Kermanshah province, Iran.

Fusarium redolens has been reported as pathogenic on a wide range of hosts in Iran, including *Cicer arietinum*, *Malus domestica*, *Mentha piperita, Salsola incanescens*, *Triticum aestivum* and *Zea mays* as pathogenic (Habibi et al. 2018, Jahedi et al. 2019, Fallahi et al. 2019, Razghandi et al. 2020, Younesi et al. 2021, Esmaili & Sharifnabi 2023). Interestingly, it has also been found as an endophyte in *Achillea millefolium*, *A. filipendulina* and *Hordeum vulgare* (Shadmani et al. 2021, Hatamzadeh et al. 2023). Studies suggest *F. redolens* may significantly contribute to chickpea black root rot in Iran. Younessi et al. (2021) found it caused high disease rates in certain chickpea varieties. Additionally, Saeedi and Jamali (2021) reported its frequent presence in uncultivated soil and its identification from symptomatic chickpea roots. Their findings warrant further investigation into F. redolens' role and biology in Iran's chickpea crops.

Fusarium redolens

History of research on *Fusarium redolens* between 1956 and 2024

In the period from 1956 to 2024, 201 and 99 published documents were identified fulfilling the search criteria in Scopus and Web of Science, respectively. Figure 1 shows the evolution of the number of publications per year. Between 1956 and 2010 (54 years), 65 documents were published and the number of publications per year was less than five. Most of these articles have been concerned with isolation and pathogenicity *F. redolens* on plants such as carnation (Gerlach & Pag 1961, Baayen et al. 1997), peas and beans (Hepple 1960, Clarkson 1978), asparagus (Gordon-Lennox & Gindrat 1987), oil palm (Ho et al. 1985), maize (O'Donnell *et al*. 1999), rose (Ypema *et al*. 1987) and white pine (Ocamb & Juzwik 1995). An increase in the number of publications was observed from 2010 onward (Figure 1), and a sharp rise in indexed documents was observed in 2021 (n=22). Fifty-six percent of the articles were published between 2016 and 2024. The first article titled "Pathogenicity of the fungus *Fusarium redolens* Wr.; clinico-experimental research" (Kozin 1956) was published in Vestnik venerologii i dermatologii Journal (30:28-31). The paper is written in Russian and focuses on the pathogenicity of the fungus *Fusarium redolens* Wr., through clinico-experimental research.

Figure 2 shows the areas of knowledge related to the studies of *F. redolens* published between 1956 and 2023. In this regard, (i) Agriculture and Biological Sciences (146 documents), (ii) Biochemistry, Genetics, and Molecular Biology (47 documents), and (iii) Immunology and Microbiology (29 documents), contributed with 47.7%, 15.5%, and 9.5% of the indexed documents, respectively. Agriculture and Biological Sciences was ranked first on this list because most of the publications consisted of the isolation, identification, and characterization of *F. redolens* populations associated with different plant species in various countries. The largest number of articles was published in Plant Disease (n=22), followed by Journal of Phytopathology (n=9). The leading countries in studies related to *F. redolens* were China, the United States, the Netherlands, and Iran, which contributed 34, 25, 18, and 15 documents, respectively (Fig. 3).

Figures 4 and 5 show the research-topic map of *F. redolens* studies between 1956 and 2024. The network visualization contains 95 items grouped in four clusters (Fig. 4). In this regard, the biggest node, which corresponds to the keyword with the highest occurrences, was *F. redolens* (Fig. 4). Many isolates of this fungus from plants were initially misidentified

as *F. oxysporum*. Both are within the same cluster (the red one) (Saeedi and Jamali 2021). Here, it is clear the special interest in the pathogenicity of *F. redolens* in plants. This species has been reported as a pathogenic agent in more than 50 host plants.

Figure 5 shows how the research topics moved from species specificity/asparagus/asparagus officinalis/biosynthesis/metabolism/beauvericin/*F. oxysporum* (2010 to 2012), passing by classification/biodiversity/microbiology/*F. edolens*/*F. hostae* (beginning of 2012), molecular analysis/ rDNA/ fungal DNA/ morphology/ phylogenetics /internal transcribed spacer/ morphology (beginning of 2012) to wheat/ controlled study/ root rot/pathogenicity/wilt/symptom/endophytes (end of 2018). Further studies should be focused on the effect of environmental parameters on the severity of *F. redolens* disease and control measures for future outbreaks of *F. redolens* (Saeedi and Jamali 2021).

Taxonomy of *Fusarium redolens*

The exact taxonomic placement of *F. redolens* is a subject of ongoing debate. Wollenweber (1913) first described *F. redolens* and maintained this nomenclature in subsequent publications (Wollenweber 1916-1935, 1931, Wollenweber & Reinking 1935). Traditionally, size differences in macroconidia were the primary way to distinguish *F. oxysporum* from *F. redolens* (Gordon, 1952). However, their similar morphology led to earlier classifications grouping them as the same species (Snyder & Hansen, 1940; Nelson et al., 1983), a variety of *F. oxysporum* (Gordon, 1952; Booth, 1975), or even *F. solani* (Bilaĭ, 1955). The use of molecular methods is necessary to correctly identify and separate *Fusarium* species. Almost all molecular studies for *Fusarium* identification have been based on comparison of rDNA internal transcribed spacers. Previous studies have shown that sequence data from the ITS rDNA region is not sufficient to distinguish the Fusarium taxa studied (Zhao et al. 2011, Raja et al. 2011, Šišić et al. 2018, Alhawatema et al. 2019). Baayen et al. (2000) have successfully used restriction fragment length polymorphism (RFLP) patterns of rRNA internal transcribed spacer (ITS) regions to diagnose *F. oxysporum* and *F. redolens*. *Fusarium oxysporum* is polymorphic for AluI and HinfI and has produced three RFLP fragments. *Fusarium redolens* cannot be distinguished from its close relative *F. hostae* by this technique (Baayen et al. 2001). Many researchers have reported that the *tef1-α* gene has a higher resolution than ITS and can provide a sufficient phylogenetic signal to distinguish between different Fusarium species. The transfer elongation factor gene contains both conserved and variable regions that allow inter- and intraspecific comparisons and is reliable for studying the phylogenetic relationships of *Fusarium* spp. (Kristensen et al. 2005). Modern DNA analysis reveals *F. redolens* as a separate species from *F. oxysporum* (O'Donnell et al., 1998; Baayen et al., 2000, 2001; Bogale et al., 2007). These studies even suggest they aren't closely related. Notably, Baayen et al. (2001) found the *F. nisikadoi-F. miscanthi* group to be closer to *F. oxysporum* than *F. redolens* and its relatives. Other research suggests *F. hostae* is closely related to *F. redolens*, with strong statistical support (Saeedi & Jamali 2021). Bogale et al. (2007) designed a specific primer set (Redolens-F: 5-ATC GAT TTTCCC TTC GAC TC-3; Redolens-R: 5-CAA TGA TGA TTGTGA TGA GAC-3) to identify *F. redolens* isolates. This method effectively differentiates *F. redolens* from other Fusarium species, enabling rapid and straightforward diagnosis. Compared to previous methods involving restriction fragment length polymorphism (RFLP) analysis, these primers allow a simpler distinction between *F. redolens* and *F. oxysporum*.

Inaccurate identification of Fusarium species has the potential to cause significant issues, including inappropriate management practices and the implementation of ineffective control strategies. Currently, the most reliable method for Fusarium identification is DNA sequencing. The gold standard for this involves targeting the translation elongation factor 1-alpha (TEF1) gene region. A publicly available database called FUSARIUM-ID exists for comparing TEF1 sequences against known Fusarium species (Geiser et al. 2004). In some cases, TEF1 alone might not be sufficient for differentiating closely related species. Multi-locus sequence typing (MLST) involves sequencing multiple gene regions, such as TEF1 and RNA polymerase II second largest subunit (rpb2) for a more robust identification.

Pathogenic *Fusarium redolens* isolates

Fusarium redolens has been reported as a pathogenic agent in more than 50 host plants including; soybean (*Glycine max*), Chinese skullcap (*Scutellaria baicalensis*), Tobacco (*Nicotiana tabacum*), alfalfa (*Medicago sativa*), asparagus (*Asparagus officinalis*), Rye (*Secale cereale*), wheat (*Triticum aestivum*), potato (*Solanum tuberosum*), faba bean (*Vicia faba*), parsley (*Petroselinum crispum*), gastrodia (*Gastrodia elata*), lentil (*Lens culinaris*), American Ginseng (*Panax quinquefolius*), Duohua huangjing (*Polygonatum cyrtonema*), black cumin (*Nigella sativa*), Carnation (*Dianthus caryophyllus*), jojoba (*Simmondsia chinensis*), Barley (*Hordeum vulgare*), red clover (*Trifolium pratense*), cotton (*Gossypium hirsutum*), *Lilium candidum*, flax (*Linum usitatissimum*), lanzhou lily (*Lilium davidii* var. *unicolor*), Salsola (*Salsola* sp.), rice (*Oryza sativa*), spinach (*Spinacia oleracea*), onion (*Allium cepa*), rocket (*Diplotaxis tenuifolia*), maize (*Zea mays*), sugar beet (*Beta vulgaris*), white lupin (*Lupinus albus*), tomato (*Solanum lycopersicum*), sunflower (*Helianthus annuus*), roses (*Rosa* spp.), ragwort (*Jacobaea vulgaris*), pea (*Pisum sativum*), oat (*Avena sativa*), *Atractylodes chinensis* and date

palm (*Phoenix dactylifera*) (Larsson & Olofsson 1994, Baayen et al. 2000, Riccioni et al. 2008, Jiménez-Fernández et al. 2011, Esmaeili Taheri et al. 2011, Al-Sadi et al. 2012, Shikur Gebremariam et al. 2015, Jing et al. 2016, Pearson et al. 2016, Bouhadida et al. 2017, Esmaeili Taheri et al. 2017, Chehri 2018, Taylor et al. 2019, Fallahi et al. 2019, Rafique et al. 2020, Le et al. 2020, Maymon et al. 2021, Qostal et al. 2021, Šišić et al. 2022, Abi Saad et al. 2022, Gibert et al. 2022, Li et al. 2022, Litovka et al. 2023, Olszak-Przybyś et al. 2023, Jiang et al. 2023, Armstrong-Cho et al. 2023, Gai et al. 2023, Wang et al. 2023, Jia et al. 2023, Xie et al. 2023). Several types of forest plants that have reportedly been attacked by *F. redolens* are Aleppo pine (*Pinus halepensis*), conifers (*Pinus*, *Cupressus*, *Picea*), and koa (*Acacia koa*) (Lazreg et al. 2014, Dobbs et al. 2023). Disease symptoms caused by *F. redolens* include root rot (Olszak-Przybyś et al. 2023, Armstrong-Cho et al. 2023), root and crown rot (Baayen et al. 2000), crown rot (Shikur Gebremariam et al. 2015), wilt (Jia et al. 2023), vascular wilt (Rafique et al. 2020), collar rot (Le et al. 2020), bulb rot (Cao et al. 2020), seedling blight (Wang et al. 2019), basal rot (Haapalainen et al. 2016), wilting and yellowing (Taylor et al. 2019), ear rot and kernel contamination (Fallahi et al. 2019), damping off (Lazreg et al. 2014), root, crown, and foot rot (Esmaeili Taheri et al. 2017), spear rot (Baayen et al. 2000), and black rot (Ypema et al. 1987).

Non-pathogenic *Fusarium redolens* isolates

Non-pathogenic *F. redolens* isolates have been shown to grow endophytically in the endorhiza of many plants including; rice (*Oryza sativa*), olive (*Olea europaea*), Russian wormwood (*Artemisia Sacrorum*), Salsola (*Salsola* sp.), maigoya (*Coleus forskohlii*), barley (*Hordeum vulgare* L.), oriental paperbush (*Edgeworthia chrysantha*), lemon bergamot (*Monarda citriodora*), Himalayan yew (*Taxus wallichiana*), esparto or needle grass (*Macrochloa tenacissima*), cocoa (*Theobroma cacao*), Chinese foxglove (*Rehmannia glutinosa*), *Stipa grandis*, *Fritillaria unibracteata* var. *wabuensis*, and *Dioscorea zingiberensis* (Su et al. 2010, Xu et al. 2010, Garyali et al. 2013, Pan et al. 2015, Katoch & Pull 2017, Shadmani et al. 2018, Mastan et al. 2019, Razghandi et al. 2020, Gargouri et al. 2020, Ambele et al. 2020, Hong-juan et al. 2021, Nazir et al. 2022, Roy et al. 2023).

Extracted beauvericin from non-pathogenic *F. redolens* isolates of *Dioscorea zingiberensis* has been used effectively as an antibacterial against several bacteria. These include *Agrobacterium tumefaciens*, *Bacillus subtilis*, *Escherichia coli*, *Pseudomonas lachrymans*, *Staphylococcus haemolyticus* and *Xanthomonas vesicatoria* (Xu et al. 2010). Recently, ethyl acetate was isolated from *F. redolens*, increasing the interest in strains of this species, since ethyl acetate showed significant cytotoxic potential against HepG2 cells (Nazir et al. 2022). Metabolites such as 3,4-dihydrocoumarin, 5'-deoxyribonucleoside, harmala alkaloid, benzofuran, and benzothiazole have also been obtained from *F. redolens*, which have inhibitory effects on wheat scab (*Fusarium graminearum*) (Hong-Juan et al. 2021). Mastan et al. (2021) used a consortium of *Trichoderma viride* and *F. redolens* and observed significant enhancement in plant growth, root biomass, and forskolin content of the medicinal plant *Coleus forskohlii*. The peimisine produced by *F. redolens* relieves sputum and cough, has anti-tumour activity and is a potent inhibitor of the angiotensin-converting enzyme (Feng et al. 2015). Taxol is a diterpenoid derived from *F. redolens* with an anti-tumor activity that inhibits microtubulin depolymerization, thereby affecting spindle formation and preventing the mitosis of tumor cells (Garyali et al. 2014). In the study by Roy et al. (2023), the antagonistic activity of *F. redolens* against the rice pathogen *Magnaporthe grisea* was observed. Inoculation of rice plants with *F. redolens* also increased the production of enzymes such as peroxidase, polyphenol oxidase, chitinase, and superoxide dismutase. Katoch and Pull (2017) have shown the antagonistic activity of *F. redolens* against *Sclerotinia* sp. and *Colletotrichum capsici*. They mentioned that the endophyte *F. redolens* could be used effectively to control a wide range of phytopathogens.

Management and formae speciales

To control this disease, various crop management techniques have been suggested, such as crop rotation, sanitation, the use of bacterial or fungal antagonists, and the use of resistant chickpea cultivars. One of the primary methods used in Iran to control *Fusarium* in chickpeas is the rotational planting of wheat and barley. To reduce the Fusarium inoculum in the soil, this is advised. The majority of research in Iran is based on morphological characteristics, and in the majority of the country, *F. oxysporum* has been identified as the most pathogenic agent of chickpeas, causing yellowing and black root rot symptoms (Afshari-Azad 1998, Mohammadi & Banihashemi 2005, 2006, Zamani et al. 2001, 2004, Hasanzade et al. 2008, Haji-Allahverdipoor et al. 2011, Zokaee et al. 2012, Nourollahi et al. 2017). This could be the reason this species hasn't been identified as one of the fungi associated with root disease in Iranian cereal and chickpeas crops in the past. The increase in chickpea cultivation within wheat rotations might be linked to a higher prevalence of *F. redolens* in these fields. Notably, three formae speciales of *F. redolens* have been formally described: *F. redolens* Wollenw. f. sp. *asparagi* Baayen, *F. redolens* f. sp. *spinaciae* (Sherb.) Subramanian, and *F. redolens* f. sp. *dianthi* (Gerlach & Pag 1961, Baayen et al. 1997, 1999).

The concept of forma specialis may limit our understanding of *F. redolens* isolates. Researchers need to consider both aggressiveness and host range variation among individual isolates. A study by Esmaeili Taheri et al. (2011) found *F. redolens* strains isolated from durum wheat caused severe disease in peas, indicating a broader host range for this fungus. Chittem et al. (2015) showed that cereal Fusarium pathogens, including *F. culmorum*, *F. graminearum*, and *F. avenaceum*, are capable of causing disease on pulse crops and dry peas. Moparthi et al. (2021) showed that *F. redolens* from dry pea, chickpea, and pea seeds were aggressive on pulses, wheat, and barley. Kraft and Pfleger (2001) identified F. solani f. sp. pisi as the main cause of pea root rot in Washington fields. This fungus exhibits a broad host range, infecting not only chickpeas but also other non-legumes such as ginseng and mulberry. One isolate of *F. redolens*, previously believed to be part of *F. oxysporum* f. sp. *asparagi*, has been reclassified as *F. redolens* (Blok & Bollen 1997). This isolate was found to be pathogenic on pea and lupin, indicating that it is not host-specific. Borrell et al. (2016) showed that *F. redolens* poses a risk to wheat production, which is greater when rotated with pulse crops. In Iran, particularly in the western provinces, millions of hectares of rain-fed chickpeas are grown each year in rotation with rain-fed wheat. The emergence of *F. redolens* as a pathogen on Iranian crops highlights the need for a deeper understanding of its biology and ecological role. This knowledge is crucial to assess its economic impact and develop effective control strategies, particularly if resistant cultivars prove to be the most viable option. Building on the points above and considering the evidence of cross-pathogenicity, the current forma specialis definition may need revision.

Fusarium redolens: Ecology and Environment

The composition of soil fungal communities, including Fusarium species, is shaped by climate. Different Fusarium species adapt to specific climatic and environmental conditions, leading to variations in their distribution across regions (Saremi & Burgess 2000). Despite existing knowledge on the impact of environmental factors on Fusarium distribution, the specific factors influencing the distribution of *F. redolens* in both agricultural and natural soils remain poorly understood. Elucidating the environmental and climatic determinants of Fusarium distribution would enable predictive modeling of species presence across diverse locations. While prior research has established strong correlations between Fusarium distribution and climatic factors, the broader field of modeling Fusarium species distribution using advanced software tools remains understudied, despite its potential utility. Studies have consistently shown that climatic factors play a significant role in shaping the distribution patterns of Fusarium species (Burgess et al. 1993, Saremi et al. 1997).

Several Fusarium species exhibit distinct geographic distributions. Non-pathogenic species like *F. oxysporum*, *F. solani*, and *F. equiseti* appear widespread (cosmopolitan), while *F. acuminatum* and *F. sambucinum* seem restricted to cooler temperate regions (Abbas et al. 1987, Backhous & Burgess 1995, Burgess et al. 1988, Backhous et al. 2001). This variation likely reflects the influence of environmental factors like temperature, soil properties (texture and organic matter), rainfall patterns, and local vegetation, as previously documented (Summerell et al. 2010).

Saeedi and Jamali (2021) demonstrated a highly significant correlation between species and environmental parameters. In their study, all sampled soils were predominantly alkaline, with pH levels ranging from 7.2 to 9. Jones and Woltz (1981) found that soils with a pH value greater than 7 were the most suppressive for Fusarium wilt (*F. oxysporum*). Several studies have shown that soil pH can influence Fusarium species and disease development. Alkaline soils (higher pH) tend to suppress *F. oxysporum*, a fungal pathogen causing wilt (Borrero et al., 2004; Fang et al., 2012; Deltour et al., 2017). In contrast, *F. redolens* appears to thrive in soils with neutral to slightly alkaline pH, while *F. oxysporum* and *F. solani* prefer more acidic environments. Saeedi and Jamali (2021) demonstrated that *F. redolens* thrives in alkaline conditions. Mycelial growth was highest at a pH of 9.72, while significantly lower at pH 5.8. This aligns with the naturally alkaline soil found in most parts of Iran, including Kermanshah province, where soil pH typically ranges from 7.4 to 8.2 (Qadir et al., 2008; Heidari et al., 2008). These findings suggest that F. redolens may be a significant contributor to chickpea root rot in this region. It's important to note that soil pH also impacts the availability of various nutrients crucial for plant health, including copper, iron, manganese and zinc (Collins & Buol, 1970). Micronutrient acquisition by many organisms relies on siderophores, but their effectiveness is heavily influenced by environmental pH. This is because pH affects both the solubility of metals and the stability of the metal-siderophore complexes (chelation). Consequently, different species have varying abilities to compete for these essential micronutrients depending on the surrounding pH (Boukhalfa & Crumbliss, 2002; Dhungana & Crumbliss, 2005).

A recent study identified several key environmental factors influencing the distribution of Fusarium species in soil (Saeedi and Jamali, 2021). These factors, listed in order of decreasing importance, included soil texture (specifically the ratio of sand, silt, and clay), altitude, calcium carbonate content ($CaCO_3$), electrical conductivity (EC), organic matter content, and lastly, soil pH. Interestingly, the study found that *F. redolens* thrived in soils with a higher clay content compared to *F. oxysporum* and *F. solani*, which preferred soils with very low clay content. Studies have shown that higher clay content in soil can be associated with a decrease

in Fusarium wilt severity (Deltour et al., 2017). Clay can affect pH buffering, nutrient availability, and oxygen diffusion, which may contribute to suppression (Lavie & Stotzky 1986, Dominguez et al. 2001). Saeedi and Jamali (2021) revealed that *F. redolens* was most abundant in soils with low levels of carbon and organic matter. This aligns with observations that loam and sandy loam soils, which typically have low clay content, also tend to have lower organic matter content (Vujanovic et al., 2006). Previous studies have shown a positive link between organic matter content in soil and reduced Fusarium disease in chrysanthemum, flax, and melon (van Rijn et al. 2007, Saadi et al. 2010).

Soil organic matter plays a crucial role in soil health, impacting not only its structure but also factors like pH, buffering capacity, and nutrient availability (Brady & Weil, 2000; Baum et al., 2015). However, the influence of organic matter on Fusarium disease can be complex. While Gehlker and Scholl (1974) found low pH, high organic matter, and clay content to favor the disease in asparagus, Saeedi and Jamali (2021) observed the highest abundance of Fusarium redolens in uncultivated soils with specific electrical conductivity (EC) and calcium carbonate (CaCO3) levels. Interestingly, Nam et al. (2018) reported no significant effect of increasing EC in hydroponic nutrient solutions on lettuce Fusarium wilt. Research on the impact of CaCO3 on Fusarium survival remains limited. Although CaCO3 is used to adjust soil pH and increase calcium (Ca2+) content (He et al., 2014), Benson et al. (2009) suggest Ca2+ might influence various soil-borne diseases, warranting further exploration in the context of Fusarium.

Summary and prospects

While the recent identification of *Fusarium redolens* as a chickpea pathogen in Iran represents a significant advancement, substantial knowledge gaps remain regarding its impact and management. Current research highlights its presence; however, a more comprehensive understanding of *F. redolens* and its interaction with environmental factors is critical for developing effective control strategies.

In-depth investigations are needed to determine how soil properties (texture, pH, electrical conductivity (EC), calcium carbonate (CaCO3) content), temperature, nutrient availability, and organic matter levels influence *F. redolens* disease severity. This knowledge will enable the development of region-specific management practices that consider prevailing soil conditions.

Phylogenetic studies suggest *F. redolens* might be responsible for chickpea black root rot in other Iranian regions. Further research is necessary to confirm this hypothesis. Comparative pathogenicity studies with *F. oxysporum* isolates previously identified from these regions should be conducted. Additionally, morphological identification methods should be complemented with molecular techniques for more precise diagnosis.

A nationwide survey is crucial to map the geographical distribution and prevalence of *F. redolens* affecting chickpeas. Furthermore, the characterization of *F. redolens* isolates from different regions will provide insights into potential strain diversity and virulence variations. This information is essential for developing broadly effective management strategies.

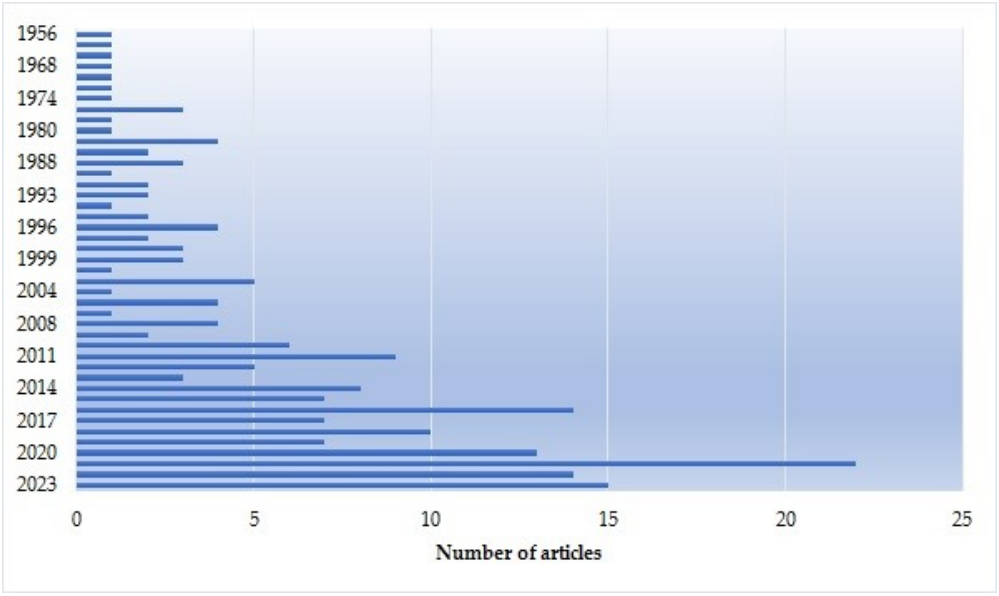

Fig. 1. Annual growth of publications in focus area of *Fusarium redolens* (1956-2023).

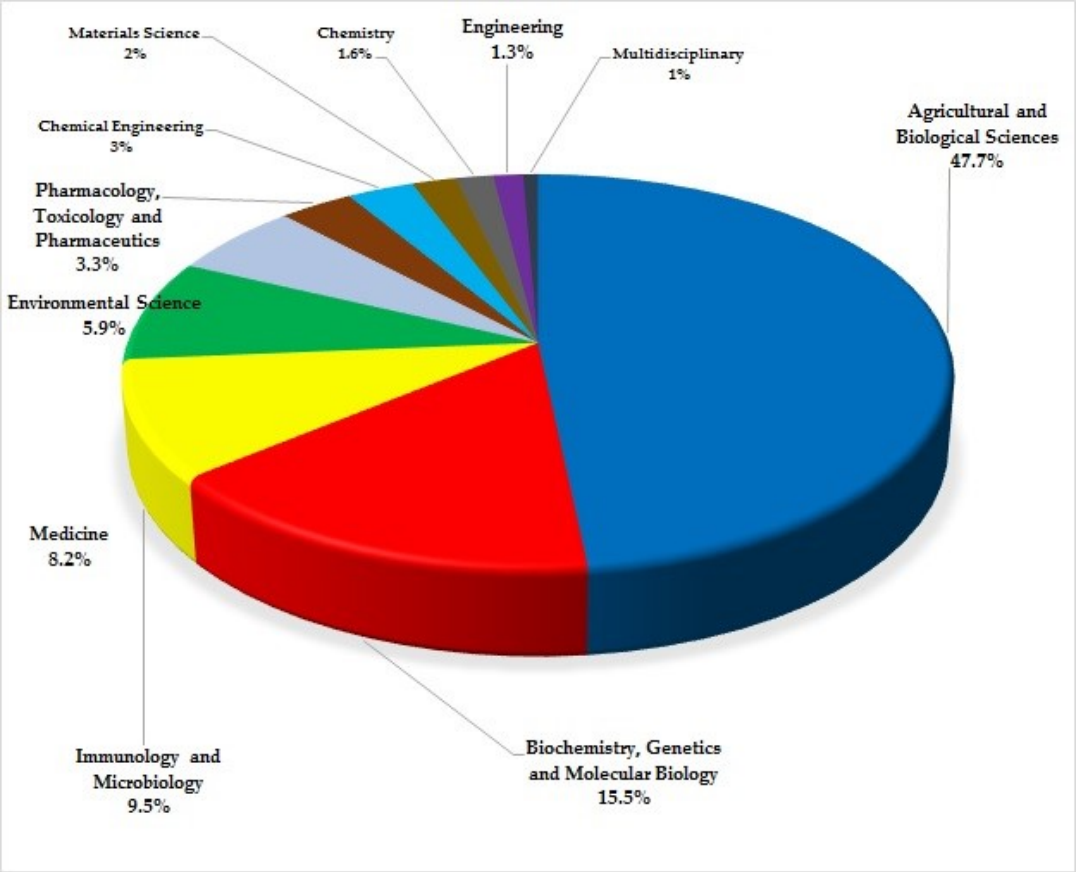

Fig. 2. Evolution of the number of publications related to *Fusarium redolens* between 1956 and 2023.

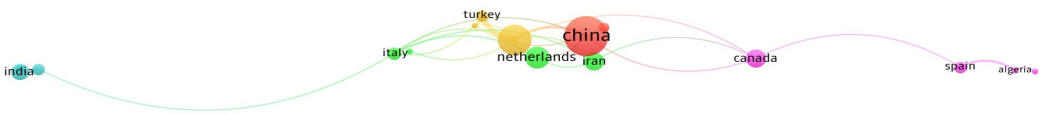

Fig. 3: The network map of co-authorship based on affiliation of authors belonging to different countries.

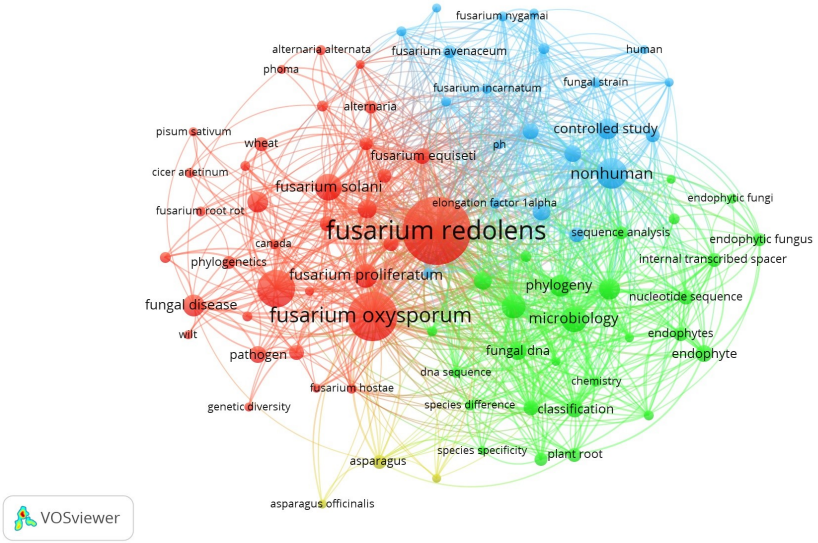

Fig. 4. Network visualization of the research-topic map of studies related to *Fusarium redolens* between 1956 and 2023. The minimum number of occurrences of a keyword is 5.

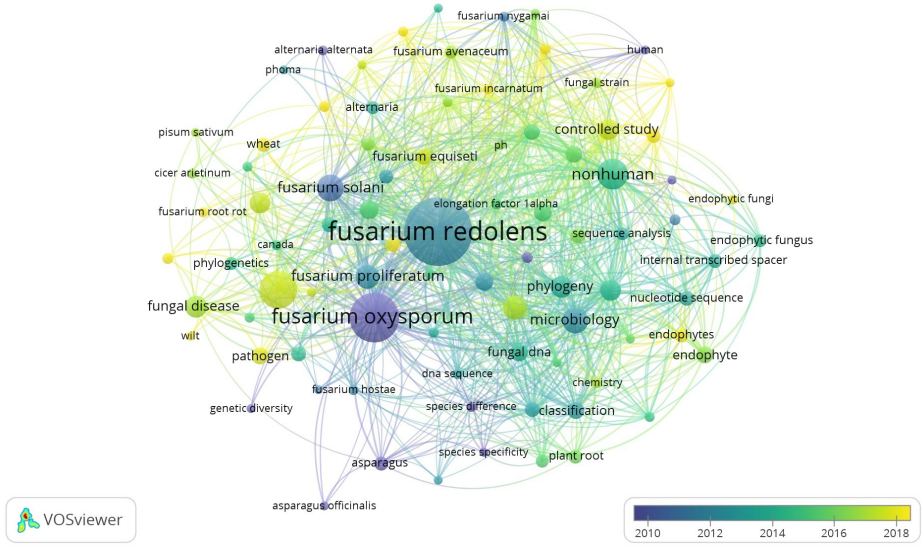

Fig. 5. Overlay visualization of the research-topic map of studies related to *Fusarium redolens* between 1956 and 2023. The minimum number of occurrences of a keyword is 5.

ACKNOWLEDGMENTS

This research was funded by Razi University.

REFERENCES

Abbas, H.K., Mirocha, C.J., Berdal, B.P., Sundheim, L., Gunther, R. and Johnsen, B. 1987. Isolation and toxicity of *Fusarium* species from various areas of Norway. Acta Agriculturae Scandinavica 37(4): 427-435.

Abi Saad, C., Masiello, M., Habib, W., Gerges, E., Sanzani, S.M., Logrieco, A.F., Moretti, A. and Somma, S. 2022. Diversity of *Fusarium* species isolated from symptomatic plants belonging to a wide range of agri-food and ornamental crops in Lebanon. Journal of Fungi 8(9): 897.

Alhawatema, M., Ali Alqudah, A. and Al Tawaha, A.R. 2019. Separation of different *Trichoderma* species based on partial TEF-1α and RPB2 protein coding genes sequences against ITS regions. Bioscience Research 16(1):161-170.

Afshari-Azad, H. 1998. Identification of Iranian fungal isolates causing yellow disease in ckickpea. 13th Iranian Plant Protection Congress, Karaj, 22–26 August.

Al-Sadi, A.M., Al-Jabri, A.H., Al-Mazroui, S.S. and Al-Mahmooli, I.H. 2012. Characterization and pathogenicity of fungi and oomycetes associated with root diseases of date palms in Oman. Crop Protection 37: 1-6.

Ambele, C.F., Ekesi, S., Bisseleua, H.D., Babalola, O.O., Khamis, F.M., Djuideu, C.T. and Akutse, K.S. 2020. Entomopathogenic fungi as endophytes for biological control of subterranean termite pests attacking cocoa seedlings. Journal of Fungi 6(3):126.

Armstrong-Cho, C., Sivachandra Kumar, N.T., Kaur, R. and Banniza, S. 2023. The chickpea root rot complex in Saskatchewan, Canada-detection of emerging pathogens and their relative pathogenicity. Frontiers in Plant Science 14:1117788.

Azimi, M., Rezaee, S. and Baigi, S. 2017. Genetic diversity of *Fusarium oxysporum* f. sp. *ciceri*, the causal agent of Iranian chickpea vascular wilt in ILAM Province using ISSR markers. Research in Plant Pathology 5(2): 39-54.

Baayen, R.P., Van Dreven, F., Krijger, M.C. and Waalwijk, C. 1997. Genetic diversity in *Fusarium oxysporum* f. sp. *dianthi* and *Fusarium redolens* f. sp. *dianthi*. Eropean Journal of Plant Pathology 103: 395–408.

Baayen, R.P., O'Donnell, K., Bonants, P.J., Cigelnik, E., Kroon, L.P., Roebroeck, E.J. and Waalwijk, C. 2000. Gene genealogies and AFLP analyses in the *Fusarium oxysporum* complex identify monophyletic and nonmonophyletic formae speciales causing wilt and rot disease. Phytopathology 90: 891–900.

Baayen, R.P., O'Donnell, K., Breeuwsma, S., Geiser, D.M. and Waalwijk, C. 2001. Molecular relationships of fungi within the *Fusarium redolens-F. hostae* clade. Phytopathology 91(11):1037-44.

Backhouse, D. and Burgess, L.W. 1995. Mycogeography of *Fusarium*: climatic analysis of the distribution within Australia of *Fusarium* species in section *Gibbosum*. Mycological Research 99: 1218–1224.

Backhouse, D., Abubakar, A.A., Backhouse, D., Burgess, L.W. and Summerell, B.A. 2001. Chapter 9-Biogeography of *Fusarium*. In: *Fusarium* Paul E. Nelson Memorial Symposium. (B.E. Summerell, J.F. Leslie, D. Backhouse, W.L. Bryden, & L.W. Burgess eds): 122-137. APS Press, US.

Baum, C., Eichler-Löbermann, B. and Hrynkiewicz, K. 2015. Impact of organic amendments on the suppression of *Fusarium* wilt. In: Organic amendments and soil suppressive in Plant Disease management. (M.K. Meghvansi and A. Varma, eds): 353–362. Springer, UK.

Benson, J.H., Geary, B., Miller, J.S., Jolley, V.D., Hopkins, B.G. and Stevens, M.R. 2009. *Phytophthora erythroseptica* (pink rot) development in Russet Norkotah potato grown in buffered hydroponic solutions I. Calcium nutrition effects. American journal of potato research 86(6): 466–471.

Bhatti, M. A. and Kraft, J. M. 1992. Effects of inoculum density and temperature on root rot and wilt of chickpea. Plant Disease 76: 50-54

Bilai, V.I. 1955. Symbiotrophic properties of *Fusarium* species and other soil fungi. Mycotrophy in plants 1967: 129-141.

Bogale, M., Wingfield, B.D., Wingfield, M.J. and Steenkamp, E.T. 2007. Species-specific primers for *Fusarium redolens* and a PCR-RFLP technique to distinguish among three clades of *Fusarium oxysporum*. FEMS Microbiology Letters 271(1): 27-32.

Blok, W.J. and Bollen, G.J. 1997. Host specificity and vegetative compatibility of Dutch isolates of *Fusarium oxysporum* f.sp. *asparagi*. Canadian Journal of Botany 75: 383-393.

Booth, C. 1975. The present status of *Fusarium* taxonomy. Annual Review of Phytopathology 13(1): 83-93.

Borrell, A.N., Shi, Y., Gan, Y., Bainard, L.D., Germida, J.J. and Hamel, C. 2017. Fungal diversity associated with pulses and its influence on the subsequent wheat crop in the Canadian prairies. Plant and Soil 414: 13-31.

Borrero, C., Trillas, M.I., Ordovás, J., Tello, J.C. and Avilés, M. 2004. Predictive factors for the suppression of *Fusarium* wilt of tomato in plant growth media. Phytopathology 94(10):1094-1101.

Bouhadida, M., Jendoubi, W., Gargouri, S., Beji, M., Kharrat, M. and Chen, W. 2017. First report of

Fusarium redolens causing Fusarium yellowing and wilt of chickpea in Tunisia. Plant Disease 101 (6): 1038.

Boukhalfa, H. and Crumbliss, A.L. 2002. Chemical aspects of siderophore mediated iron transport. Biometals 15: 325–339.

Brady, N.C. and Weil, R.R. 2000. Elements of the nature and properties of soils. Prentice Hall Upper Saddle River, NJ, USA.

Burgess, L.W., Liddell, C.M. and Summerell, B.A. 1988. Laboratory Manual for Fusarium Research. 2nd Ed. The University of Sydney, Sydney Aust.

Burgess, L.W., Forbes, C., Nelson, P.E., Marasas, W.F.O. and Gott, K.P. 1993. Characterization and Distribution of *Fusarium acuminatum* Subsp. *Armeniacum* Subsp. NOv. Mycologia 85: 119-124.

Cao, X., Zhang, M.S., Zhang, X.S., Yu, S.C., Zhao:B., Hou, D., Zhou, Y.R., Li, J., Song, X.Y. and Zhang, Y.Z. 2020. First report of Fusarium redolens causing root and bulb rot disease on lanzhou lily (*Lilium davidii* var. *unicolor*) in China. Plant Disease 104(2):583.

Chattopadhyay, S.B. and Sen Gupta, P.K. 1967. Studies on wilt diseases of pulses. I. Variation and taxonomy of *Fusarium* species associated with wilt disease of pulses. Indian Journal of Mycological Research 5: 45-53.

Chehri, K. 2016. Molecular identification of pathogenic *Fusarium* species, the causal agents of tomato wilt in western Iran. Journal of Plant Protection Research 56(2): 143-148.

Chehri, Kh., Hajeb, S. and Maassoumi, S.M. 2017. Morphological and molecular identification and PCR amplification to determine the toxigenic potential of *Fusarium graminearum* species complex (FGSC) isolated from wild grasses in Iran. Journal of Agricultural Science and Technology 19: 1617-1629.

Chehri, K. 2018. Molecular phylogeny of Fusarium oxysporum species complex isolated from agricultural soils in Iran. Archives of Phytopathology and Plant Protection 51(7-8): 359-372.

Chittem, K., Mathew, F.M., Gregoire, M., Lamppa, R.S., Chang, Y.W., Markell, S.G., Bradley, C.A., Barasubiye, T. and Goswami, R.S. 2015. Identification and characterization of *Fusarium* spp. associated with root rots of field pea in North Dakota. European Journal of Plant Pathology 143:641-649.

Clarkson, J.D.S. 1978. Pathogenicity of *Fusarium* spp. associated with foot-rots of peas and beans. Plant Pathology 27(3): 110-117.

Collins, J.F. and Buol, S.W. 1970. Effects of fluctuations in the Eh-pH environment on iron and/or manganese equilibria. Soil Science 110: 111–118.

Dababat, A.A. and Sikora, R.A. 2007. Importance of application time and inoculum density of *Fusarium oxysporum* 162 for biological control of *Meloidogyne incognita* on tomato. Nematropica 37: 267-275.

Dean, R., Van Kan J.A.L., Pretorius, Z.A., Hammond-Kosack, K.E., Di Pietro, A., Spanu, P.D., Rudd, J.J., Dickman, M., Kahmann, R., Ellis, J. and Foster, G.D. 2012. The Top 10 fungal pathogens in molecular plant pathology. Molecular plant pathology13: 414–430.

del Mar Jiménez-Gasco, M., Pérez-Artés, E. and Jiménez-Diaz, R.M. 2001. Identification of pathogenic races 0, 1B/C, 5, and 6 of *Fusarium oxysporum* f. sp. *ciceris* with random amplified polymorphic DNA (RAPD). European Journal of Plant Pathology 107:237-248.

del Mar Jiménez-Gasco, M. and Jiménez-Díaz, R.M. 2003. Development of a specific polymerase chain reaction-based assay for the identification of *Fusarium oxysporum* f. sp. *ciceris* and its pathogenic races 0, 1A, 5, and 6. Phytopathology 93(2):200-209.

Deltour, P., França, S.C., Liparini Pereira, O., Cardoso, I., De Neve, S., Debode, J. and Höfte, M. 2017. Disease suppressiveness to *Fusarium* wilt of banana in an agroforestry system: influence of soil characteristics and plant community. Agriculture, ecosystems and environment 239: 173–181.

Demirei, E., Eken, C. and Kantar, F. 1998. Wilt and root rot pathogens of chickpea cv. Aziziye-94. Journal of Plant Pathology 80: 175.

Dhungana, S. and Crumbliss, A.L. 2005. Coordination chemistry and redox processes in siderophore-mediated iron transport. Geomicrobiol Journal 22: 87–98.

Dobbs, J.T., Kim, M.S., Reynolds, G.J., Wilhelmi, N., Dumroese, R.K., Klopfenstein, N.B., Fraedrich, S.W., Cram, M.M., Bronson, J. and Stewart, J.E. 2023. Fusarioid community diversity associated with conifer seedlings in forest nurseries across the contiguous USA. Frontiers in Plant Science 14:1104675.

Dominguez, J., Negrin, M.A. and Rodriguez, C.M. 2001. Aggregate water-stability, particle size and soil solution properties in conducive and suppressive soils to *Fusarium* wilt of banana from Canary Islands (Spain). Soil Biology and Biochemistry 33: 449–455.

Echandi, E. 1970. Wilt of chickpeas or garbanzo beans (*Cicer arietinum*) incited by *Fusarium oxysporum*. Phytopathology 60: 1539.

El-Adawy, T.A. 2002. Nutritional composition and antinutritional factors of chickpeas (*Cicer arietinum* L.) undergoing different cooking methods and germination. Plant foods for human nutrition 57:83-97.

Erwin, D. C. 1958. *Fusarium lateritium* f. sp. *ciceri*, incitant of *Fusarium* wilt of *Cicer arietinum*. Phytopathology 48: 498-501.

Esmaeili Taheri, A., Hamel, C., Gan, Y. and Vujanovic, V. 2011. First report of *Fusarium redolens* from Saskatchewan and its comparative

pathogenicity. Canadian Journal of plant pathology 33(4): 559-64.

Esmaeili Taheri, A., Chatterton, S., Foroud, N.A., Gossen, B.D. and McLaren, D.L. 2017. Identification and community dynamics of fungi associated with root, crown, and foot rot of field pea in western Canada. European Journal of Plant Pathology 147:489-500.

Esmaili, Z. and Sharifnabi, B. 2023. *Fusarium* species associated with apple trees decline in Isfahan, Iran. Mycologia Iranica 10(1): 23-34.

Fallahi, M., Saremi, H., Javan-Nikkhah, M., Somma, S., Haidukowski, M., Logrieco, A.F. and Moretti, A. 2019. Isolation, molecular identification and mycotoxin profile of Fusarium species isolated from maize kernels in Iran. Toxins 11(5):297.

Fang, X., You, M.P. and Barbetti, M.J. 2012. Reduced severity and impact of Fusarium wilt on strawberry by manipulation of soil pH, soil organic amendments and crop rotation. Eropean Journal of Plant Pathology 134(3):619-29.

FAOStat 2021. FAOStat, FAO. http://www.fao.org/faostat.

Gai, X.T., Hu, Y.X., Dai, K., Wang, J.M., Jiang, N., Lu, C.H. and Xia, Z.Y. 2023. First Report of Tobacco Fusarium Root Rot Caused by *Fusarium redolens* in China. Plant Disease 107(2):556.

Garyali, S., Kumar, A. and Reddy, M.S. 2013. Taxol production by an endophytic fungus, *Fusarium redolens*, isolated from Himalayan yew. Journal of Microbiology and Biotechnology 23(10):1372-1380.

Geiser, D.M., del Mar Jiménez-Gasco, M., Kang, S., Makalowska, I., Veeraraghavan, N., Ward, T.J., Zhang, N., Kuldau, G.A. and O'donnell, K. 2004. FUSARIUM-ID v. 1.0: A DNA sequence database for identifying Fusarium. European journal of plant pathology 110: 473-479.

Ghanbarzadeh, B., Mohammadi Goltapeh, E. and Safaie, N. 2014. Identification of Fusarium species causing basal rot of onion in East Azarbaijan province, Iran and evaluation of their virulence on onion bulbs and seedlings. Archives of Phytopathology and Plant Protection 47(9):1050-1062.

Gargouri, S., Balmas, V., Burgess, L., Paulitz, T., Laraba, I., Kim, H.S., Proctor, R.H., Busman, M., Felker, F.C., Murray, T. and O'Donnell, K. 2020. An endophyte of *Macrochloa tenacissima* (esparto or needle grass) from Tunisia is a novel species in the *Fusarium redolens* species complex. Mycologia 112(4):792-807.

Gehlker, H. and Scholl, W. 1974. Ecological factors and cultivation problems in connection with parasitic root rot of asparagus. Z Pflanzenk Pflanzen 81:394-406.

Geraminasab, B., Abbasi, S., Jamali, S., Chehri, K. and Younesi, H. 2023. Etiology of root rot, yellows and wilt diseases of chickpea in Kermanshah province. Iranian Journal of Pulses Research 14(1): 63-74.

Gerlach, W. and Pag, H. 1961. *Fusarium redolens* Wr., seine phytopathologische Bedeutung und eine an Dianthus-Arten gefäßparasitäre Form (*F. redolens* Wr. f. *dianthi* Gerlach). Journal of Phytopathology 42(4):349-361.

Gibert, S., Edel-Hermann, V., Gautheron, E., Gautheron, N., Sol, J.M., Capelle, G., Galland, R., Bardon-Debats, A., Lambert, C. and Steinberg, C. 2022. First report of *Fusarium avenaceum*, *Fusarium oxysporum*, *Fusarium redolens*, and *Fusarium solani* causing root rot in pea in France. Plant Disease 106(4):1297.

Gordon, W.L. 1952. The occurrence of *Fusarium* species in Canada: II. Prevalence and taxonomy of *Fusarium* species in cereal seed. Canadian Journal of Botany 30(2):209-251.

Gordon-Lennox, G. and Gindrat, D. 1987. Relationship of root necrosis potential of soil to asparagus (*Asparagus officinalis*) decline in Switzerland. Biology and Fertility of Soils 3: 195-198.

Haapalainen, M., Latvalab, S., Kuivainena, E., Qiua, Y., Segerstedtb, M. and Hannukkalaa, A.O. 2016. *Fusarium oxysporum*, *F. proliferatum* and *F. redolens* associated with basal rot of onion in Finland. Plant Pathology 65: 1310–1320.

Habibi, A., Mansouri, S.M. and Sadeghi, B. 2018. *Fusarium* species associated with medicinal plants of *Lamiaceae* and *Asteraceae*. Mycologia Iranica 5(2): 91-101.

Haji-Allahverdipoor, K., Bahramnejad, B. and Amini, J. 2011. Selection of molecular markers associated with resistance to Fusarium wilt disease in chickpea (*Cicer arietinum* L.) using multivariate statistical techniques. Australian Journal of crop science 5(13): 1801-1809.

Halila, M.H. and Strange, R.N. 1996. Identification of the causal agent of wilt of chickpea in Tunisia as *Fusarium oxysporum* f. sp. *ciceri* race 0. Phytopathologia Mediterranea 67-74.

Hasanzade, F., Falahati Rastegar, M., Jafarpour, B. and Kermani, M. 2008. Identification of *Fusarium solani* f.sp. *pisi* the cause of root rot in chickpea and assessment its genetic diversity using AFLP in Northeast Iran. Research Journal of Biological Sciences 3(7): 737-741.

Hatamzadeh, S., Rahnama, K., White, J.F., Oghaz, N.A., Nasrollahnejad, S. and Hemmati, K. 2023. Investigation of some endophytic fungi from five medicinal plants with growth promoting ability on maize (*Zea mays* L.). Journal of Applied Microbiology 134(1): lxac015.

Haware, M.P. and Nene, Y.L. 1982. Races of *Fusarium oxysporum* f. sp. *ciceri*. Plant Disease 66(9):809-810.

Haware, M. P., Nene, Y. L. and Natarajan, M. 1996. The survival of *Fusarium oxysporum* f. sp. *ciceri* in the absence of chickpea. Phytopathologia Mediterranea 35: 9-12.

He, L., He, B. and Zhao, L. 2014. Effect of particle size distribution of lime sludge on the

hydrophobicity of paper. BioResources 9(1): 1361-1372.

Heidari, A., Mahmoodi, S., Roozitalab, M.H. and Mermut, A.R. 2008. Diversity of clay minerals in the vertisols of three different climatic regions in Western Iran. Journal of Agricultural Science and Technology10: 269-284.

Hepple, S. 1960. Infection of peas by wilt disease fungi. Nature 185(4709): 333-334.

Ho, Y.W., Varghese, G. and Taylor, G.S. 1985. Histopathology of oil palm seedlings infected by, pathogenic *Fusarium oxysporum* isolates from Africa. Journal of Phytopathology 114(4): 312-324.

Hong-juan, C.H.E.N., Xu-hui, Z.H.U.A.N.G., Hai-jie, Z.O.U., Guang-tao, L.I., Wei, H.A.N., Hai-jiang, M.I.A.O., Chuan-lin, D.U. and Xiao-hong, L.U.O. 2021. Analysis on the screening of an endophytic fungi from *Artemisia sacrorum* Ledeb against wheat scab and mass spectrographic Analysis. Science and Technology of Cereals, Oils and Foods 29(6).

Honnareddy, N. and Dubey, S.C. 2006. Pathogenic and molecular characterization of Indian isolates of *Fusarium oxysporum* f. sp. *ciceris* causing chickpea wilt. Current science 661-666.

Jahedi, A., Safaie, N. and Goltapeh, E.M. 2019. *Fusarium avenaceum* and *Fusarium crookwellens* cause onion basal rot in Iran. Archives of Phytopathology and Plant Protection 52(9-10):953-968.

Jendoubi, W., Bouhadida, M., Boukteb, A., Béji, M. and Kharrat, M. 2017. Fusarium wilt affecting chickpea crop. Agriculture 7: 1-16.

Jia, R., Kang, L., Addrah, M.E., Zhang, J., Xu, L., Zhang, Z., Chen, W., Liu, J. and Zhao, J. 2023. Potato wilt caused by co-infection of *Fusarium* spp. and *Verticillium dahliae* in potato plants. European Journal of Plant Pathology 165(2):305-315.

Jimenez-Fernández, D., Navas-Cortés, J.A., Montes-Borrego, M., Jiménez-Díaz, R.M. and Landa, B.B. 2011. Molecular and pathogenic characterization of *Fusarium redolens*, a new causal agent of *Fusarium* yellows in chickpea. Plant Disease 95: 860-870.

Jiménez-Díaz, R.M., Castillo, del Mar Jiménez-Gasco, M., Landa, B.B. and Navas-Cortés, J.A. 2015. Fusarium wilt of chickpeas: Biology, ecology and management. Crop Protection 73:16-27.

Jing, G.A.O., Yuan-yuan, Z.H.A.N.G., Kai, W.A.N.G., Jian, Z.H.A.N.G. and Gui, Z.H.A.N.G. 2016. Identification of sunflower wilt pathogen and its biological characteristics. Chinese Journal of Oil Crop Sciences 38(2):214.

Jones, J.P. and Woltz, S.S. 1981. Fusarium-incited diseases of tomato and potato and their control. In: Fusarium: Diseases, Biology and Taxonomy (E. Nelson, T.A. Toussoun & R.J. Cook, eds): 157-168. Penn State Univ Press, USA.

Jukanti, A.K., Gaur, P.M., Gowda, C.L.L. and Chibbar, R.N. 2012. Nutritional quality and health benefits of chickpea (*Cicer arietinum* L.): a review. British Journal of Nutrition 108(S1): S11-S26.

Katoch, M. and Pull, S. 2017. Endophytic fungi associated with Monarda citriodora, an aromatic and medicinal plant and their biocontrol potential. Pharmaceutical biology 55(1):1528-1535.

Kirk, P., Cannon, P., Minter, D. and Stalpers, J. 2008. Dictionary of the Fungi. Wallingford, UK.

Koul, B., Sharma, K., Sehgal, V., Yadav, D., Mishra, M. and Bharadwaj, C. 2022. Chickpea (*Cicer arietinum* L.) biology and biotechnology: from domestication to biofortification and biopharming. Plants 11(21): 2926.

Kraft, J. M. and Pfleger, F. L. 2001. Compendium of Pea Diseases and Pests. 2nd edn. APS Press, USA.

Kristensen, R., Mona, T.O.R.P., Kosiak, B. and Holst-Jensen, A. 2005. Phylogeny and toxigenic potential is correlated in *Fusarium* species as revealed by partial translation elongation factor 1 alpha gene sequences. Mycological research109(2):173-186.

Larsson, M. and Olofsson, J. 1994. Prevalence and pathogenicity of spinach root pathogens of the genera *Aphanomyces*, *Phytophthora*, *Fusarium*, *Cylindrocarpon*, and *Rhizoctonia* in Sweden. Plant Pathology 43(2):251-260.

Lavie, S. and Stotzky, G. 1986. Interactions between clay minerals and siderophores affect the respiration of *Histoplasma capsulatum*. Applied and Environmental Microbiology 51: 74–79.

Lazreg, F., Belabid, L., Sanchez, J., Gallego, E. and Bayaa, B. 2014. Pathogenicity of *Fusarium* spp. associated with diseases of Aleppo-pine seedlings in Algerian forest nurseries. Journal of Forest Science 60(3): 115-120.

Le, D., Ameye, M., De Boevre, M., De Saeger, S., Audenaert, K. and Haesaert, G. 2021. Population, virulence, and mycotoxin profile of *Fusarium* spp. associated with basal rot of *Allium* spp. in Vietnam. Plant Disease 105(7):1942-1950.

Leisso, R., Miller, Z., Jacobsen, B. and Burrows, M. 2011. Pathogenicity of *Fusarium* spp. to chickpea seed and seedlings (*Cicer arietinum* L.). Canadian Journal of Plant Pathology 33(3): 400–409.

Leslie, J.F. and Summerell, B.A. 2006. The Fusarium laboratory manual. Blackwell, USA.

Li, C., Zhang, M., Li, J., Huang, M., Shao, X. and Yang, Z. 2022. *Fusarium redolens* causes black rot disease in *Gastrodia elata* grown in China. Crop Protection 155:105933.

Litovka, Y.A., Chen, H., Li, W. and Pavlov, I.N. 2023. Fusarioid Fungi Associated with Woody Plants in Russia. Contemporary Problems of Ecology16(4):528-540.

Manuchehri, A. and Mesri, A. 1966. *Fusarium* wilt of chickpea. Iranian Journal of Plant Pathology 3:1-11.

Mastan, A., Bharadwaj, R.K.B., Kushwaha, R.K. and Vivek Babu, C.S. 2019. Functional fungal endophytes in *Coleus forskohlii* regulate labdane diterpene biosynthesis for elevated forskolin accumulation in roots. Microbial ecology 78(4):914-926.

Mastan, A., Rane, D., Dastager, S.G. and Babu, C.V. 2021. Molecular insights of fungal endophyte co-inoculation with *Trichoderma viride* for the augmentation of forskolin biosynthesis in *Coleus forskohlii*. Phytochemistry 184:112654.

Maymon, M., Sharma, G., Hazanovsky, M., Erlich, O., Pessach, S., Freeman, S. and Tsror, L. 2021. Characterization of *Fusarium* population associated with wilt of jojoba in Israel. Plant Pathology 70(4):793-803.

Mohammadi, H. and Banihashemi, Z. 2005. Distribution, pathogenicity and survival of *Fusarium solani*: the causal agents of chickpea wilt and root rot in the Fars province of Iran. Iranian Journal of Plant Pathology 41(4): 687-708.

Mohammadi, H. and Banihashemi, Z. 2006. Vegetative compatibility groups of *Fusarium solani* f. sp. *pisi*, the causal agent of chickpea black root rot in Fars Province of Iran. Iranian Journal of Plant Pathology 42(1): 179-194.

Moparthi, S., Burrows, M., Mgbechi-Ezeri, J. and Agindotan, B. 2021. *Fusarium* spp. associated with root rot of pulse crops and their cross-pathogenicity to cereal crops in Montana. Plant Disease 105(3):548-557.

Nam, M.H., Lee, H.C., Kim, T.I., Lee, E.M. and Yoon, H.S. 2018. Effect of nutrition solution pH and electrical conductivity on *Fusarium* wilt on strawberry plants in hydroponic culture. Research in Plant Disease 24(1): 26-32.

Nazari, K. and Ershad, J. 1993. Etiology of yellowing disease of chickpea in rainfed condition in Lorestan province. Proc. 11th Iran. Plant Protection Congress Rasht 141.

Nazir, A., Hafeez, S. and Habeeb, A.R. 2022. Bioactive potentials of endophyte (*Fusarium redolens*) isolated from *Olea europaea*. Archives of Microbiology 204(4):219.

Nelson, P.E., Toussoun, T.A. and Marasas, W.F.O. 1983. *Fusarium* species: an illustrated manual for identification. Pennsylvania State University Press, USA.

Nene, Y.L., Sheila, V.K. and Sharma, S.B. 1996. A world list of chickpea and pigeonpea pathogens. ICRISAT, Hyderabad, India.

Nourollahi, K.H., Aliaran, A. and Yonessi, H. 2017. Genetic diversity of *F. oxysporum* f. sp. *ciceri* isolates causal agent of wilt chickpea in Kermanshah province using microsatellite markers. Modern Genetic Journal 11(4): 605-615.

Ocamb, C.M. and Juzwik, J. 1995. *Fusarium* species associated with rhizosphere soil and diseased roots of eastern white pine seedlings and associated nursery soil. Canadian Journal of Plant Pathology 17(4): 325-330.

O'Donnell, K., Cigelnik, E. and Nirenberg, H.I. 1998. Molecular systematics and phylogeography of the *Gibberella fujikuroi* species complex. Mycologia 90: 465–493.

O'Donnell, K., Gherbawy, Y., Schweigkofler, W., Adler, A. and Prillinger, H. 1999. Phylogenetic analyses of DNA sequence and RAPD data compared in *Fusarium oxysporum* and related species from maize. Journal of Phytopathology 147(7-8): 445-452.

Olszak-Przybyś, H., Korbecka-Glinka, G. and Patkowska, E. 2023. Identification and pathogenicity of *Fusarium* isolated from soybean in Poland. Pathogens 12(9):1162.

Pan, F., Su, X., Hu, B., Yang, N., Chen, Q. and Wu, W. 2015. *Fusarium redolens* 6WBY3, an endophytic fungus isolated from *Fritillaria unibracteata* var. *wabuensis*, produces peimisine and imperialine-3β-d-glucoside. Fitoterapia 103: 213-221.

Paul, E.A. and Clark, F.E. 1989. Soil microbiology and biochemistry. Academic Press, USA.

Pearson, K.A., Taylor, A.F.S., Fuchs, R.M.E. and Woodward, S. 2016. Characterisation and pathogenicity of *Fusarium* taxa isolated from ragwort (*Jacobaea vulgaris*) roots. Fungal ecology 20:186-192.

Prasad, N. and Padwick, G. W. 1939. The Genus *Fusarium*. II. A species of *Fusarium* as a cause of wilt of gram (*Cicer arietinum* L.). Indian Journal of Agricultural Science 9: 371-380.

Qadir, M., Qureshi, A.S. and Cheraghi, S.A.M. 2008. Extent and characterisation of salt-affected soils in Iran and strategies for their amelioration and management. Land Degradation and Development 19(2): 214-227.

Qostal, S., Kribel, S., Chliyeh, M., Mouden, N., El Alaoui, M.A., Serghat, S. and Ouazzani Touhami, A. 2021. First report of *Fusarium redolens* causing root rot disease of wheat and barley in Morocco. Current Research in Environmental and Applied Mycology (Journal of Fungal Biology) 11(1):263-273.

Rafique, K., Kang, S., Mahmood, T., Ullah, I. and Mahmood, H. 2020. First report of vascular wilt on lentil (*Lens culinaris* Medikus) caused by *Fusarium redolens* in Pakistan. Plant Disease 104(9):2524-2524.

Raja, H.A., Schoch, C.L., Hustad, V.P., Shearer, C.A. and Miller, A.N. 2011. Testing the phylogenetic utility of MCM7 in the Ascomycota. MycoKeys 1: 63–94.

Razghandi, M., Mohammadi, A., Ghorbani, M. and Mirzaee, M.R. 2020. New fungal pathogens and endophytes associated with *Salsola*. Journal of Plant Protection Research 60(4):362-368.

Riccioni, L., Haegi, L. and Valvassori, M. 2008. First Report of Vascular Wilt Caused by *Fusarium redolens* on Lentil in Italy. Plant Disease 92(7): 10.

Roy, S., Sarma, A., Paul, S., Jha, D.K. and Tayung, K. 2023. Plant growth-promoting traits and activation of defense enzymes in traditional rice variety by fungal endophytes isolated from seeds of indigenous rice cultivars of Northeast India. South African Journal of Botany 160:483-492.

Ruiter, P.C., de Bloem, J., Bouwman, L.A., Didden, W.A.M., Hoenderboom, G.H.J., Lebbink, G., Marinissen, J.C.Y., Vos, J.A., Vreeken-Buijs, M.J., Zwart, K.B. and Brussard, L. 1994. Simulation of dynamics in nitrogen mineralisation in the belowground food webs of two arable farming systems. Agriculture, Ecosystems and Environment 51: 199–208.

Saadi, I., Laor, Y., Medina, S., Krassnovsky, A. and Raviv, M. 2010. Compost suppressiveness against *Fusarium oxysporum* was not reduced after one-year storage under various moisture and temperature conditions. Soil Biology and Biochemistry 42: 626–634.

Saeedi, S. and Jamali, S. 2021. Molecular characterization and distribution of *Fusarium* isolates from uncultivated soils and chickpea plants in Iran with special reference to *Fusarium redolens*. Journal of Plant Pathology 103:167-183.

Saremi, H., Backhouse, D. and Burgess, L.W. 1997. Mycogeographic survey of *Fusarium* species in Southeastern new South Wales, Australia. Cereal Research Communications 25(3):611-2.

Saremi, H. and Burgess, L.W. 2000. Effect of soil temperature on distribution and population dynamics of *Fusarium* species. Journal of Agriculture Science and Technology 2: 119-125.

Shadmani, L., Jamali, S. and Fatemi, A. 2018. Effect of barley endophytic fungi against of two pathogenic fungi, *Gaeumannomyces graminis* and *Pythium aphanidermatum*. Biological Control of Pests and Plant Diseases 7(2): 153-158.

Shadmani, L., Jamali, S. and Fatemi, A. 2021. Isolation, identification, and characterization of cadmium-tolerant endophytic fungi isolated from barley (*Hordeum vulgare* L.) roots and their role in enhancing phytoremediation. Brazilian Journal of Microbiology 52: 1097-1106.

Sharma, L. and Marques, G. 2018. *Fusarium*, an entomopathogen-A myth or reality? Pathogens 7(4):2-15.

Shikur Gebremariam, E., Sharma-Poudyal, D., Paulitz, T.C., Erginbas-Orakci, G., Karakaya, A. and Dababat, A.A. 2018. Identity and pathogenicity of *Fusarium* species associated with crown rot on wheat (*Triticum* spp.) in Turkey. European journal of plant pathology 150:387-399.

Siddique, K.H. and Krishnamurthy, L. 2014. Chickpea production technology. Legume Perspectives (3): 29-32.

Šišić, A., Baćanović, J. and Finckh, M.R. 2017. Endophytic *Fusarium equiseti* stimulates plant growth and reduces root rot disease of pea (*Pisum sativum* L.) caused by *Fusarium avenaceum* and *Peyronellaea pinodella*. Eropean Journal of Plant Pathology 148:271–282.

Šišić, A., Baćanović-Šišić, J., Al-Hatmi, A.M.S., Karlovsky, P., Ahmed, S.A., Maier, W., de Hoog, G.S. and Finckh, M. 2018. The 'forma specialis' issue in *Fusarium*: A case study in *Fusarium solani* f. sp. *pisi*. Scientific Reports 8:1252-1269.

Šišić, A., Baćanović-Šišić, J., Schmidt, H. and Finckh, M.R. 2022. Farming system effects on root rot pathogen complex and yield of faba bean (*Vicia faba*) in Germany. Frontiers in Plant Science 13: 1009906.

Snyder, W.C. and Hansen, H.N. 1940. The species concept in *Fusarium*. American Journal of Botany: 64-67.

Steinberg, C., Edel-Hermann, V., Alabouvette, C. and Lemanceau, P. 2007. Soil suppressiveness to Plant Disease. In: Modern Soil Microbiology (J.D. van Elsas, J.K. Jansson, J.T. Trevors eds): 455-477. 2nd edn. CRC Press, USA.

Stoner, M.F. 1981. Ecology of *Fusarium* in non-cultivated soil. In: *Fusarium: Diseases, Biology, and Taxonomy* (E. Nelson, T.A. Toussoun & Cook, R.J., eds): 276–286. Pennsylvania State University Press, USA.

Su, Y.Y., Guo, L.D. and Hyde, K.D. 2010. Response of endophytic fungi of *Stipa grandis* to experimental plant function group removal in Inner Mongolia steppe, China. Fungal Diversity 43:93-101.

Summerell, B.A., Laurence, M.H., Liew, E.C. and Leslie, J.F. 2010. Biogeography and phylogeography of *Fusarium*: a review. Fungal Diversity 44(1):3-13.

Summerell, B.A., Leslie, J.F., Liew, E.C., Laurence, M.H., Bullock, S., Petrovic, T., Bentley, A.R., Howard, C.G., Peterson, S.A., Walsh, J.L. and Burgess, L.W. 2011. *Fusarium* species associated with plants in Australia. Fungal Diversity 46(1):1-27.

Taylor, A., Barnes, A., Jackson, A.C. and Clarkson, J.P. 2019. First report of *Fusarium oxysporum* and *Fusarium redolens* causing wilting and yellowing of wild rocket (*Diplotaxis tenuifolia*) in the United Kingdom. Plant Disease 103(6):1428-1428.

Trabelsi, R., Sellami, H., Gharbi, Y., Krid, S., Cheffi, M., Kammoun, S., Dammak, M., Mseddi, A., Gdoura, R. and Triki, M.A. 2017. Morphological and molecular characterization of *Fusarium* spp. associated with olive tree dieback in Tunisia. 3 Biotech 7: 1-9.

Trapero-Casas, A. and Jimnez-Diaz, R.M. 1985. Fungal wilt and root rot diseases of chickpea in southern Spain. Phytopathology 75: 1146-1151.

Van Rijn, E., Termorshuizen, A.J. and van Bruggen, A.H.C. 2007. Storage method affects disease suppression of flax wilt induced by composts. Soil Biology and Biochemistry 39: 2743–2749.

Vujanovic, V., Hamel, C., Yergeau, E. and St-Arnaud, M. 2006. Biodiversity and biogeography of *Fusarium* Species from Northeastern North

American asparagus fields based on microbiological and molecular approaches. Microbial Ecology 51: 242–255.

Wang, L., Wang, N., Yu, J., Wu, J., Liu, H., Lin, K. and Zhang, Y. 2023. Identification of pathogens causing alfalfa Fusarium root rot in Inner Mongolia, China. Agronomy 13(2):456.

Wang, A., Haapalainen, M., Latvala, S., Edelenbos, M. and Johansen, A. 2019. Discriminant analysis of volatile organic compounds of *Fusarium oxysporum* f. sp. *cepae* and *Fusarium proliferatum* isolates from onions as indicators of fungal growth. Fungal biology 122(10):1013-22.

Westerlund, F.V., Jr Campbell, R.N. and Kimble, K.A. 1974. Fungal root rots and wilt of chickpea in California. Phytopathology 64:432-436.

Wollenweber, H.W. 1913. Studies on the *Fusarium* problem. Phytopathology 3: 24-50.

Wollenweber, H.W. and Reinking, O. A. 1935. Die Fusarien, ihre Beschreibuug, Schadwirkung und Bekiimpfung. Paul Parey, Germany.

Xie, S., Si, H., Zhang, S., Zhou, R., Xue, Y., Wang, S., Wang, S., Duan, Y., Niu, J. and Wang, Z. 2023. Efficacy and potential mechanism of essential oils of three labiatae plants against the pathogenic fungi of root rot disease in *Atractylodes chinensis*. Horticulturae 9(10):1136.

Ypema, H.L., Van De Pol, A. and Bollen, G.J. 1987. Black rot of stentlings of roses: a disease caused by various soil fungi. Scientia horticulturae 33(3-4) :269-280.

Younessi, H. 2004. Identification of the pathogenic races *Fusarium oxysporum* f. sp. *ciceri* in some west provinces of Iran. *In Proceedings of the 16th Iranian Plant Protection Congress, Tehran, Iran.*

Younesi, H., Chehri, K., Sheikholeslami, M., Safaee, D. and Naseri, B., 2020. Effects of sowing date and depth on Fusarium wilt development in chick pea cultivars. Journal of Plant Pathology 102(2):343-350.

Younesi, H., Darvishnia, M., Bazgir, E. and Chehri, K. 2021. Morphological, molecular and pathogenic characterization of Fusarium spp. associated with chickpea wilt in western Iran. Journal of Plant Protection Research 61(4): 402-413.

Zamani, M.R., Motallebi, M. and Harigh, M.J. 2001. Pectic enzyme patterns of *Fusarium oxysporum* virulent isolates from chickpea in Iran. Journal of Science 12(1): 17-21.

Zamani, M.R., Motallebi, M. and Rostamian, A. 2004. Characterization of Iranian isolates of *Fusarium oxysporum* on the basis of RAPD analysis, virulence and vegetative compatibility. Journal of Phytopathology 152: 449–453.

Zhang, Q., Yang, L., Zhang, J., Wu, M., Chen, W., Jiang, D. and Li, G. 2015. Production of anti-fungal volatiles by non-pathogenic *Fusarium oxysporum* and its efficacy in suppression of verticillium wilt of cotton Plant and Soil 392: 101–114.

Zhao, P., Luo, J. and Zhuang, W.Y. 2011. Practice towards DNA barcoding of the nectriaceous fungi. Fungal Diversity 46:183−191.

Xu, L.J., Liu, Y.S., Zhou, L.G. and Wu, J.Y. 2010. Optimization of a liquid medium for beauvericin production in *Fusarium redolens* Dzf2 mycelial culture. Biotechnology and Bioprocess Engineering 15:460-466.

Zokaee, S., Falahati Rastegar, M., Jafar Poor, B., Bagheri, A. and Jahanbakhsh Mashhadi, V. 2012. Genetic diversity determination of *Fusarium oxysporum* f. sp. *ciceri* the causal agent of wilting and chlorosis in chickpea by using RAPD and PCR-RFLP techniques in Razavi and Northern Khorasan Provinces. Iran Journal of Pulses Research 2: 7-16.

مروری بر قارچ *Fusarium redolens* Wollenw. به عنوان یک عامل بیماری‌زای گیاهی نوظهور در ایران

صمد جمالی

گروه گیاهپزشکی، دانشکده کشاورزی، پردیس کشاورزی و منابع طبیعی، دانشگاه رازی، کرمانشاه، ایران

چکیده: مطالعه حاضر مروری بر تحقیقات انجام شده در مورد قارچ *Fusarium redolens* ارائه می‌دهد. جستجوی سیستماتیک در پایگاه داده اسکوپوس از سال ۱۹۵۶ تا ۲۰۲۳، ۲۰۱ سند مرتبط با این قارچ را شناسایی کرد. این قارچ به عنوان یک عامل بیماری‌زای نوظهور، تأثیر قابل توجهی بر حبوبات به ویژه نخود دارد. رشد جمعیت، به ویژه در کشورهای در حال توسعه، یک مشکل اصلی ایجاد می کند که آن دسترسی به غذا، به ویژه منابع پروتئین میباشد. نخود یکی از محصولات مهم کشاورزی در غرب ایران محسوب می‌شود و تا پیش از سال ۲۰۱۹، زرد شدن و پوسیدگی ریشه آن عمدتاً به گونه‌های *F. oxysporum* و *F. solani* نسبت داده می‌شد. توصیه های قبلی برای مدیریت این محصول، کشت غلات مانند جو و گندم به دلیل وجود فرم های ویژه *F. oxysporum* در خاک بود. با این حال، مطالعات اخیر نشان می‌دهند که *F. redolens* عامل اصلی این بیماری، به ویژه در استان‌های غربی کشور است. این گونه از طیف وسیعی از گیاهان شامل ۵۴ گونه متعلق به ۵۰ جنس و ۲۹ خانواده گیاهی جداسازی و گزارش شده است که بیشترین فراوانی آن در خانواده‌های نخود، گندمیان و آفتابگردان مشاهده شده است. با توجه به بیماری‌زایی این قارچ برای گندم و جو، تناوب کشت با این غلات دیگر به عنوان یک راهکار مناسب برای مدیریت بیماری در نظر گرفته نمی‌شود و تحقیقات بیشتری برای توسعه استراتژی‌های موثر مدیریت مورد نیاز است.

کلمات کلیدی: فرمهای تخصصی، بیماریزایی، آغازگرهای اختصاصی گونه، نرمافزار VOSviewer، گندم

مکاتبه کننده: صمد جمالی Email: jamali454@yahoo.com

تاریخ دریافت: ۲۶/۱۰/۱۴۰۲ تاریخ پذیرش: ۱۸/۰۳/۱۴۰۳