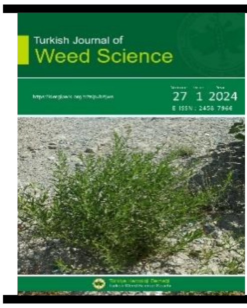

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Derleme Makale / Review Article

Diversity and Geographic Distribution of Fungi on Broomrape Species

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ABSTRACT

Broomrapes (*Orobanche* spp. and *Phelipanche* spp.) are annual root parasitic weeds from the Orobanchaceae family. Broomrape species have a wide host range causing yield losses in crop production. Broomrape control is challenging due to dependency, prolific seed production, long-term seed viability in soil, and unique physiological and biological characteristics. Traditional weed control methods, including mechanical, physical, and chemical, may be limited in their effectiveness in the management of broomrape. In biological control, identification and utilizing soil-borne microorganisms are considered potentially effective. Notably, fungi isolated from various broomrape species and different hosts are extensively documented in the literature. During the 70-year period from 1954 to the present, in the studies conducted in 25 different countries from 4 continents, 104 fungal species belonging to 42 genera have been reported from five main broomrape species. With this review prepared by an extensive literature review, the fungal diversity in broomrape species has been revealed and is intended to be a resource for researchers working on this subject.

Keywords: *Phelipanche* spp., *Orobanche* spp., fungus, *Fusarium*, fungal diversity, broomrape

Canavar Otu Türlerindeki Fungusların Çeşitliliği ve Coğrafik Dağılımları

ÖZET

Canavar otları (*Orobanche* spp. ve *Phelipanche* spp.), Orobanchaceae familyasına bağlı tek yıllık kök paraziti yabancı otlardır. Canavar otu türlerinin konukçu dizisi oldukça geniş olup, tarımsal üretimde verim kayıplarına neden olmaktadırlar. Canavar otları ile mücadele konukçuya bağlı yaşamaları, çok sayıda tohum oluşturmaları ve tohumlarının uzun yıllar toprakta canlı kalabilmeleri ve bu bitkilerin benzersiz fizyolojik ve biyolojik özellikleri nedeniyle zordur. Geleneksel yabancı ot mücadele yöntemlerinden mekanik, fiziksel ve kimyasal mücadele yöntemleri bu yabancı otların mücadelesinde sınırlı kalabilmektedir. Biyolojik mücadelede toprak kökenli mikroorganizmaların tanılanması ve kullanımının etkili olabileceği düşünülmektedir. Farklı canavar otu türlerinden ve farklı konukçulardan izole edilen funguslara literatürde geniş ölçüde yer verilmiştir. 1954 yılından günümüze kadar geçen 70 yıllık süre boyunca, 4 kıtadan 25 farklı ülkede yürütülen çalışmalarda, 5 ana canavar otu türünden 42 cinse ait 104 farklı fungus türü rapor edilmiştir. Geniş bir literatür taraması ile hazırlanan bu derleme ile canavar otu türlerindeki fungal çeşitlilik ortaya konulmuş olup, bu bilgilerin bu konuda çalışan araştırıcılara kaynak oluşturması amaçlanmaktadır.

Anahtar Kelimeler: *Phelipanche* spp., *Orobanche* spp., fungus, *Fusarium*, fungal çeşitlilik, canavar otu

INTRODUCTION

The largest family among parasitic plant families is the Orobanchaceae family, which is represented by 102 genera and over 2100 species (Nickrent, 2020). Among the holoparasitic plants of the Orobanchaceae family, species belonging to the *Orobanche* and *Phelipanche* genera cause significant yield and quality losses in different crops in the Mediterranean region. These two genera include around 200 species and cause notable yield losses in several crop families, including Apiaceae, Asteraceae, Brassicaceae, Cucurbitaceae, Fabaceae, and Solanaceae (Parker & Riches, 1993; Westwood et al., 2012). The holoparasitic species that cause damage to major agricultural crops and are considered primary parasitic weeds worldwide are *Orobanche cernua* Loefl., *Orobanche cumana* Wallr., *Orobanche crenata* Forsk., *Phelipanche aegyptiaca* Pers. (Pomel) (=syn: *O. aegyptiaca*), and *Phelipanche ramosa* L. (=syn: *O. ramosa*).

O. cernua Loefl. causes damage to the Asteraceae (especially sunflower) and Solanaceae family (especially tomato, tobacco, and eggplant) (Parker & Riches, 1993). Its distribution extends particularly to the Middle East, Southern and Eastern Europe, and North Africa, as well as to Asia and Australia. *O. cernua* has been reported in tobacco fields in India (Swarnalatha et al., 2020) and more recently in onion production areas (Akhter et al., 2018), in tomato and tobacco production areas in Iran (Nosratti et al., 2020; Tahmasbali et al., 2021), in tomato and eggplant production areas in Jordan (Abu-Irmaileh, 1991; Qasem, 2009), in sunflower fields in Türkiye (Demirci et al., 2003), and on various hosts in China (Wang et al., 2016). *O. cumana* Wallr. causes damage exclusively to sunflowers within the Asteraceae family (Labrousse et al., 2001). *O. cumana*, which has become the most significant threat to sunflower production worldwide, causes damage particularly in Russia, Ukraine, Moldova, Romania, Türkiye, Bulgaria, Spain, Israel, and Hungary, but also in Syria, Egypt, and the North African coasts (Antonova et al., 2013; Jebri et al., 2017; Kaya, 2014; Molinero-Ruiz et al., 2015). *O. crenata* Forsk. causes damage to various cultivated plants belonging to at least four families. It inflicts damage on crops in the Fabaceae family (especially faba bean) and the Apiaceae family (especially carrot), and to a lesser extent, on crops in the Cucurbitaceae and Asteraceae families (Parker & Riches, 1993). There is no host specificity (Musselman & Parker, 1982). *O. crenata* causes significant economic losses, especially in the cultivation of faba bean (*Vicia faba* L.) (Negewo et al., 2022; Stoddard et al., 2010). However, this species also damages lentil (*Lens culinaris* Medik.) (En-Nahli et al., 2021; Fernández-Aparicio et al., 2008), pea (*Pisum sativum* L.) (Castillejo et al., 2004; Rubiales et al., 2009), chickpea (*Cicer arietinum* L.) (Rubiales et al., 2009; Rubiales et al., 2003), tomato (*Solanum lycopersicum* L.) (Dor et al., 2010), lettuce (*Lactuca sativa* L.) (Landa et al., 2006), carrot (*Daucus carota* subsp. *sativus* (Hoffm.) Schübl. & G.Martens) (Eizenberg et al., 2001). The geographic distribution of *O. crenata* is primarily in the Mediterranean region, including North Africa, and also extends to the Near East and Western Asia (Musselman & Parker, 1982). It has been reported that the majority of red lentil production areas in the Southeastern Anatolia Region of Türkiye are infested with *O. crenata* along with *P. aegyptiaca/P. ramosa* (Aksoy et al., 2016). According to recent reports, in Morocco, root weight, root length, and root diameter in carrots have decreased by 19.98%, 20.04%, and 9.10%, respectively, due to *O. crenata*. Additionally, *O. crenata* has been reported to reduce quality parameters in carrots, with total yield losses ranging from approximately 21 to 27 t/ha (Chedadi et al., 2020). *Phelipanche ramosa* L. is the species with the widest range of hosts compared to other broomrape species. It causes significant yield losses in important crop families such as Asteraceae (sunflower), Brassicaceae (mustard, rape, cabbage), Fabaceae (chickpea, lentil), Solanaceae (tomato, potato, tobacco, eggplant), and Cucurbitaceae (melon, watermelon, cucumber). *Phelipanche aegyptiaca* Pers. (Pomel), similar to *P. ramosa*, also has a broad host range, but it has been reported to cause more damage than *P. ramosa* specifically in cultivated plants belonging to the Cucurbitaceae family (Parker & Riches, 1993).

In areas where broomrape populations are very high, crop yields decline significantly, often leading farmers to abandon production. In recent years, factors such as global warming, unpredictable weather conditions, increased trade, changes in agricultural practices, and globalization have greatly increased the damage to crops and the likelihood of these species spreading to new regions where they have not yet been found. Parasitic plants are distinct from all other weeds because they attach to the host's vascular system through haustoria, establishing a physical and physiological connection throughout their entire parasitic life cycle. This parasitic relationship occurs underground, where the parasitic plant obtains water, minerals, and carbohydrates from its host crop. As a result of successful parasitism, the resources of the host plant are depleted, leading to irreversible qualitative and quantitative reductions in crop yield when shoots emerge to the soil surface (Joel, 2013). The unique life cycle of parasitic plants, their production of thousands of tiny, dust-like seeds, their remarkable reproductive ability, and the vascular tissue connection between host and parasite severely limit the control options for these weed species (Fernández-Aparicio et al., 2016; Shilo et al., 2016). Many studies have been conducted on broomrape management including crop rotation, deep plowing (Shevchenko et al., 2024), trap cropping (Kleifeld et al., 1994), nitrogen fertilization (Ye et al., 2023), development of resistant varieties (Fernández Martínez et al., 2012) and chemical control (Alonso et al., 1998). Studies have also been conducted on the biological control of broomrapes, aiming to inhibit seed germination and control broomrape plants during their initial parasitic stages by isolating and using soil microorganisms such as fungi and bacteria. Various fungal species have been isolated and identified for their potential use in controlling broomrape in different countries and on different hosts worldwide. Various species belonging to the genus *Fusarium* have been isolated from different hosts of *O. cernua* (Aybeke, 2017; Goussous et al., 2009; Hameed et al., 2001; Karam Pur et al., 2004; Taslakh'yan & Grigoryan, 1978; Wang et al., 2016), from *O. cumana* in sunflower (Bedi & Donchev, 1991; Ding, Zhang, et al., 2012; Dor & Hershenhorn, 2009; Taslakh'yan & Grigoryan, 1978; Zhang et al., 2022), from *O. crenata* in faba bean (Abouzeid & El-Tarabily, 2010; Al-Menoufi, 1986; Hameed et al., 2001; K. H. Linke et al., 1992; Nemat Alla et al., 2008; Suh, 2011), and from *P. aegyptiaca* causing damage in various hosts (Başbağcı et al., 2023; Panchenko, 1974; Rostami et al., 2017; Saremi & Okhovvat, 2008; Wang et al., 1985). Additionally, species of the genus *Alternaria* have been isolated (Dor & Hershenhorn, 2009; Hameed et al., 2001; Thomas et al., 1999). Although the majority of hosts affected by *P. ramosa* overlap with *P. aegyptiaca,* surveys conducted especially in tobacco have isolated species of *Rhizoctonia* (Gibot-Leclerc et al., 2022), *Fusarium* (Ampova et al., 1967; Boari & Vurro, 2004; Fischl et al., 2001) and *Alternaria* (Boari & Vurro, 2004; Gibot-Leclerc et al., 2022).

In recent years, numerous studies have been conducted to isolate fungal species from broomrape species in agricultural fields and examine their potential effects. These studies were undertaken to understand the biological activities of fungi on broomrape species and to determine their herbicidal effects. This review article aims to provide a summary of the research conducted to date on fungus species isolated from broomrape species and to serve as a resource for researchers working in this field.

Fungal Species Isolated From Major Broomrape Species Damaging Crops

Many studies are revealing the fungal diversity in broomrape species conducted by researchers in various countries. In the 70-year period from 1954 to 2024, 104 different fungal species belonging to a total of 42 genera have been reported, in association with the five major broomrape species, *Orobanche cernua*, *O. cumana*, *O. crenata*, *Phelipanche aegyptiaca* and *P. ramosa* (Table 1.)

Table 1. Fungal species isolated from main broomrape species

Fungal species	**Broomrape species***				
	Orobanche cernua	*Orobanche cumana*	*Orobanche crenata*	*Phelipanche aegyptiaca*	*Phelipanche ramosa*
Acremonium fusicoides	-	-	-	+	-
Alternaria sp.	-	-	+	-	+
Alternaria alternata	-	-	+	+	+
Alternaria solani	+	-	-	-	-
Alternaria infectoria	-	-	+	-	+
Aspergillus sp.	-	-	-	+	-
Aspergillus alliaceus	+	-	-	-	-
Aspergillus niger	-	-	+	-	-
Aspergillus ochraceus	-	-	-	-	+
Botrytis sp.	-	-	-	-	+
Cephalosporium sp.	+	-	-	-	-
Chaetomium sp.	-	-	+	-	-
Cladosporium sp.	-	-	-	-	+
Cladosporium cladosporioides	-	-	-	+	-
Cladosporium herbarum	+	+	+	-	-
Cochliobolus spicifer	-	-	+	-	-
Colletotrichum lagenarium	-	-	-	+	-
Cylindrocarpon sp.	-	-	+	-	-
Cylindrocladium sp.	+	-	-	-	-
Dendrophoma sp.	+	-	-	+	-
Epicoccum sp.	+	-	-	-	-
Epicoccum nigrum	-	-	-	+	+
Fusarium sp.	+	+	+	+	+
Fusarium acuminatum	-	-	-	+	+

Table 1. Continued

Fusarium andiyazi	-	-	-	+	-
Fusarium artrosporioides	-	-	-	+	-
Fusarium avenaceum	-	-	+	-	+
Fusarium brachygibbosum	-	+	-	-	+
Fusarium camptoceras	-	-	-	-	+
Fusarium cerealis	-	+	-	-	+
Fusarium chlamydosporum	-	-	-	+	+
Fusarium compactum	-	-	+	+	+
Fusarium culmorum	-	-	-	-	+
Fusarium diversisporum	-	-	-	+	-
Fusarium equiseti	-	+	+	+	+
Fusarium fujikuroi	-	-	-	+	+
Fusarium flocciferum	-	-	-	+	-
Fusarium foetens	-	-	-	+	-
Fusarium graminearum	-	-	-	-	+
Fusarium hostae	-	-	-	+	-
Fusarium incarnatum	-	-	-	+	+
Fusarium lacertarum	-	-	-	+	-
Fusarium lateritium	-	-	-	-	+
Fusarium moniliforme	+	-	-	-	-
Fusarium nygamai	-	-	-	-	+
Fusarium orobanches	-	-	-	+	+
Fusarium oxysporum	+	+	+	+	+
Fusarium oxysporum f. sp. *orobanche*	-	-	-	+	+
Fusarium oxysporum f. sp. *orthoceras*	-	+	-	+	+

Table 1. Continued

Fusarium pallindoroseum	-	-	-	+	-
Fusarium proliferatum	-	+	-	+	+
Fusarium redolens	-	-	-	+	+
Fusarium reticulatum	-	-	-	+	-
Fusarium sambucinum	+	+	+	+	+
Fusarium scirpi	-	-	-	+	-
Fusarium semitectum	-	-	-	+	-
Fusarium solani	+	+	+	+	+
Fusarium sporotrichioides	-	-	-	-	+
Fusarium thapsinum	-	-	-	+	-
Fusarium torulosum	-	-	-	+	-
Fusarium tricinctum	-	-	-	+	+
Fusarium venenatum	-	-	-	-	+
Fusarium verticillioides	-	+	-	+	+
Fusarium virguliform	-	-	-	+	-
Gliocladium varians	-	-	-	-	+
Macrophomina phaseolina	+	-	-	+	+
Monilia humicola	+	-	-	-	-
Mortierella alpina	-	-	-	+	-
Mucor odoratus	-	-	+	-	-
Mucor sciurinus	-	+	-	-	-
Myrothecium verrucaria	-	-	-	-	+
Papulaspora sp.	-	-	-	+	-
Penicillium sp.	+	-	+	-	+
Penicillium cyclopodium	-	-	+	-	-
Phoma complanata	-	-	-	+	-
Phoma dennisii	-	-	-	+	-

Table 1. Continued

Phomopsis sp.	-	-	+	-	+
Pithomyces chartarum	-	-	-	-	+
Plectosphaerella sp.	-	-	-	-	+
Plectosphaerella cucumerina	-	+	-	-	-
Plectosphaerella ramiseptata	-	-	-	-	+
Plectosporium tabacinum	-	-	-	-	+
Pleosporineae sp.	-	-	-	-	+
Pullularia sp.	-	-	-	+	-
Pythium sp.	-	+	-	-	+
Rhizoctonia sp.	+	-	+	+	-
Rhizoctonia sp. AG-A	-	-	-	-	+
Rhizoctonia solani	+	-	-	+	+
Rhizopus oryzae	-	-	-	+	-
Sarocladium strictum	-	-	-	-	+
Sclerotinia sp.	-	-	+	-	+
Sclerotinia minor	-	+	-	-	-
Sclerotinia sclerotiorum	+	+	-	-	-
Sclerotium rolfsii	+	-	-	-	+
Sordaria fimicola	-	-	-	+	-
Stemphylium botryosum	-	-	+	-	-
Stereum sp.	-	-	-	-	+
Talaromyces trachyspermus	-	-	-	-	+
Trichoderma koningii	-	-	-	+	-
Trichoderma harzianum	-	-	-	+	-
Trichothecium roseum	-	-	-	+	-
Ulocladium atrum	-	-	+	-	-
Ulocladium botrytis	-	-	+	-	-
Ulocladium consortiale	-	-	+	-	-

*+: isolated, -: non-isolated

Fungal species isolated from nodding broomrape (*Orobanche cernua*)

Studies determining the fungal diversity in nodding broomrape (*Orobanche cernua*) have been particularly focused on the Asian continent. To date, in studies carried out by different researchers in tomato, eggplant, tobacco and sunflower fields, 19 different fungal species have been reported from *O. cernua* plants in India, Iran, Jordan, China, Armenia and Türkiye (Table 2).

Table 2. Fungal species isolated from nodding broomrape (*Orobanche cernua*)

Fungal species	Host of the broomrape	Geographic origin	Reference
Sclerotium rolfsii	Tobacco	India	(Raju et al., 1995)
	Tomato, eggplant	India	(Gupta & Pavgi, 1970)
Fusarium solani	Tomato	Iran	(Karam Pur et al., 2004)
	Eggplant	Jordan	(Goussous et al., 2009)
Fusarium sambucinum	-	Armenia	(Taslakh'yan & Grigoryan, 1978)
Cladosporium herbarum			
Monilia humicola			
Fusarium oxysporum	Tomato	Iran	(Karam Pur et al., 2004)
	Eggplant	Jordan	(Goussous et al., 2009)
	Sunflower	Türkiye	(Aybeke, 2017)
	Tobacco, sunflower	China	(Wang et al., 2016)
Sclerotinia sclerotiorum	-	India	(Narasimhan & Thirumalachar, 1954)
	Tomato	Iran	(Karam Pur et al., 2004)
Fusarium moniliforme	Tomato	Iran	(Karam Pur et al., 2004)
Rhizoctonia solani			
Macrophomina phaseolina			
Alternaria solani			
Fusarium sp.	Tomato	Jordan	(Hameed et al., 2001)
	Eggplant	Jordan	(Goussous et al., 2009)
Dendrophoma sp.	Tomato, eggplant	Jordan	(Hameed et al., 2001)
Rhizoctonia sp.			
Penicillium sp.			
Cephalosporium sp.	Tomato, eggplant	Jordan	(Goussous et al., 2009)
Cylindrocladium sp.			
Epicoccum sp.			
Aspergillus alliaceus	Sunflower	Türkiye	(Aybeke, 2020)

Sclerotium rolfsii was isolated from *O. cernua* plants in tomato and eggplant cultivation areas in India (Gupta & Pavgi, 1970). In another study conducted in India, this fungal species was reported from *O. cernua* in tobacco fields (Raju et al., 1995). Narasimhan & Thirumalachar (1954) also reported *S. sclerotiorum* from this broomrape species in India.

In Iran, *Fusarium solani, F. oxysporum, F. moniliforme, Sclerotinia sclerotiorum, Rhizoctonia solani, Macrophomina phaseolina* and *Alternaria solani* fungal species were isolated from *O. cernua* by Karam Pur et al. (2004) in tomato cultivation areas. *A. solani* and *F. moniliforme* have been reported for the first time in this study for all broomrape species.

In another study conducted by Goussous et al. (2009) in Jordan, *Cephalosporium* sp., *Cylindrocladium* sp., *Epicoccum* sp., *Fusarium* sp., *F. oxysporum* and *F. solani* species were isolated from this broomrape in tomato ve eggplant areas. *Cephalosporium* sp. and *Cylindrocladium* sp. have been reported for the first time in this study for all broomrape species. Hameed et al. (2001) reported that *Fusarium* sp., *Dendrophoma* sp., *Rhizoctonia* sp. and *Penicillium* sp. fungal species were isolated from *O. cernua* in tomato and eggplant cultivation areas.

In another study conducted by Wang et al. (2016) in China, *F. oxysporum* was isolated from symptomatic *O. cernua* plants in tobacco and sunflower cultivation areas.

In the only study in Armenia where fungal diversity was determined in broomrape species, Taslakh'yan & Grigoryan (1978) reported that, *F. sambucinum, Cladosporium herbarum* and *Monilia humicola* fungal species were isolated from *O. cernua* plants. Morever, *M. humicola* was detected only in this study in broomrape species.

In a study conducted in Türkiye, Aybeke (2017) isolated *Fusarium oxysporum* from symptomatic *O. cernua* plants in sunflower cultivation areas in Edirne province. In another study conducted by the same researcher, *Aspergillus alliaceus* was reported on this broomrape species (Aybeke, 2020). This fungal species is the first to be reported in all broomrape species.

Fungal species isolated from sunflower broomrape (*Orobanche cumana*)

When we examine the studies identifying fungal agents in the Orobanche cumana species, it is seen that Asian countries come to the fore (Table 3).

Table 3. Fungal species isolated from sunflower broomrape (*Orobanche cumana*)

Fungal species	Host of the broomrape	Geographic origin	Reference
Fusarium oxysporum f. sp. *orthoceras*	Sunflower	Bulgaria	(Bedi & Donchev, 1991)
Fusarium cerealis	Sunflower	China	(Ding, Zhang, et al., 2012)
Fusarium solani			(Ding, Zhang, et al., 2012; Zhang et al., 2022)
Fusarium oxysporum			(Ding, Zhang, et al., 2012; Zhang et al., 2022)
Pythium spp.			(Ding, Zhang, et al., 2012)
Sclerotinia sclerotiorum			(Ding, Zhao, et al., 2012)
Plectosphaerella cucumerina			(Xu et al., 2016)
Sclerotinia minor			(Zhang et al., 2018)
Fusarium brachygibbosum			(Xia et al., 2018)
Fusarium equiseti			(Zhang et al., 2022)
Fusarium proliferatum			(Zhang et al., 2022)
Fusarium verticillioides	Sunflower	China	(Zhang et al., 2022)
		Israel	(Dor et al., 2009)

Table 3. Continued

Fusarium sp.	Sunflower, tobacco	China	(Kong et al., 2006)
Fusarium sambucinum	-	Armenia	(Taslakh'yan & Grigoryan, 1978)
Mucor sciurinus			
Cladosporium herbarum			

There are many studies conducted by different researchers on this subject, especially in China. Ding, Zhang, et al. (2012) stated that, *F. cerealis*, *F. solani*, *F. oxysporum* and *Pythium* spp. were isolated from *O. cumana* in sunflower cultivation areas. This study is the first report of *F. cerealis* and *Pythium* spp. on sunflower broomrape. In another study conducted in the same year, Ding, Zhao, et al. (2012) isolated *Sclerotinia sclerotiorum* from symptomatic broomrape. This fungal species was reported with only this study on sunflower broomrape. Xu et al. (2016) reported that *Plectosphaerella cucumerina* was isolated from this broomrape in China. This fungal species is the the first to be reported in all broomrape species. *S. minor*, which was also detected only in this broomrape species, was reported by Zhang et al. (2018). In other study conducted in the same year by Xia et al. (2018), *Fusarium brachygibbosum* was isolated from lesioned *O. cumana* plants. In another study where different Fusarium species were identified, Zhang et al. (2022) reported that *F. oxysporum*, *F. solani*, *F. equiseti*, *F. proliferatum* and *F. verticillioides* were isolated from *O. cumana*. *F. equiseti* and *F. proliferatum* were only reported with this study on *O. cumana*. Kong et al. (2006) isolated *Fusarium* sp. from *O. cumana* in sunflower and tobacco cultivation areas.

In studies determining fungal species in sunflower broomrape in the Asian continent, *F. verticillioides* in Israel (Dor et al., 2009), *F. sambucinum*, *Mucor sciurinus* and *Cladosporium herbarum* in Armenia (Taslakh'yan & Grigoryan, 1978) were reported. *M. sciurinus* was reported only in this study for all broomrape species.

In the only study conducted on this subject in the European continent, (Bedi & Donchev, 1991) isolated *Fusarium oxysporum* f. sp. *orthoceras* from *O. cumana* in sunflower cultivation areas.

Fungal species isolated from crenate broomrape (*Orobanche crenata*)

It is noteworthy that the studies in which fungal species were identified from crenate broomrape (*Orobanche crenata*) were generally in faba bean cultivation areas. The studies were not limited to a single continent but were carried out by different researchers in African, Asian and European countries (Table 4).

Table 4. Fungal species isolated from crenate broomrape (*Orobanche crenata*)

Fungal species	Host of the broomrape	Geographic origin	Reference
Fusarium oxysporum	Faba bean	Greece	(Suh, 2011)
		Egypt	(Abouzeid et al., 2005; Abouzeid & El-Tarabily, 2010; Al-Menoufi, 1986; Nemat Alla et al., 2008)
	-	Syria, Morocco, France	(K. H. Linke et al., 1992)
Fusarium solani	Faba bean	Egypt	(Abouzeid et al., 2005; Abouzeid & El-Tarabily, 2010; Al-Menoufi, 1986)
	-	Syria, Morocco, France	(K. H. Linke et al., 1992)

Table 4. Continued

Alternaria sp.	-	Syria, Morocco, France	(K. H. Linke et al., 1992)
	Faba bean	Egypt	(Abouzeid et al., 2005; Al-Menoufi, 1986)
Sclerotinia sp.	Faba bean	Egypt	(Al-Menoufi, 1986)
Fusarium sp.	Faba bean	Egypt	(Abouzeid & El-Tarabily, 2010)
		Jordan	(Hameed et al., 2001)
		Tunisia	(K. H. Linke et al., 1992)
Fusarium compactum	-	Syria, Morocco, France	(K. H. Linke et al., 1992)
	Faba bean	Egypt	(Abouzeid & El-Tarabily, 2010)
Fusarium sambucinum	Faba bean	Egypt	(Abouzeid & El-Tarabily, 2010)
Fusarium avenaceum			
Rhizoctonia sp.	Faba bean	Jordan	(Hameed et al., 2001)
Cheatomium sp.			
Penicillium sp.			
Alternaria alternata	Faba bean	Jordan	(Hameed et al., 2001)
	-	Syria, Morocco, France	(K. H. Linke et al., 1992)
Cladosporium herbarum	-	Armenia	(Taslakh'yan & Grigoryan, 1978)
	-	Syria, Morocco, France	(K. H. Linke et al., 1992)
Alternaria infectoria	-	Syria, Morocco, France	(K. H. Linke et al., 1992)
Aspergillus niger			
Cochliobolus spicifer			
Phomopsis sp.			
Stemphylium botryosum			
Fusarium equiseti			
Ulocladium atrum			
Ulocladium botrytis	Faba bean	Germany	(Müller-Stöver & Kroschel, 2005)
	-	Syria, Morocco, France	(K. H. Linke et al., 1992)
Ulocladium consortiale	-	Syria, Morocco, France	(K. H. Linke et al., 1992)
Cylindrocarpon sp.			

Table 4. Continued

Mucor odoratus	-	Armenia	(Taslakh'yan & Grigoryan, 1978)
Penicillium cyclopodium			

There are many reports in which fungal detection studies have been carried out on *O. crenata* in faba bean cultivation areas in Egypt. Al-Menoufi (1986) isolated *F. oxysporum*, *F. solani*, *Alternaria* sp. and *Sclerotinia* sp. from symptomatic *O. crenata* plants. This study is the first report of *Sclerotinia* sp. on *O. crenata.* Similarly, Abouzeid et al. (2005) isolated *F. oxysporum*, *F. solani* and *Alternaria* sp. on this broomrape species. Another study reporting the *F. oxysporum* on *O. crenata* was also conducted by Nemat Alla et al. (2008). Abouzeid & El-Tarabily (2010) reported *Fusarium* sp., *F. oxysporum*, *F. solani*, *F. compactum*, *F. sambucinum* and *F. avenaceum* on *O. crenata*. In Tunisia, Boutiti et al. (2008) also isolated *Fusarium* sp. from *O. crenata* in faba bean cultivation areas.

In a comprehensive study covering three different continents and conducted by Linke et al. (1992), *F. oxysporum, F. solani, F. compactum, F. equiseti, Alternaria* sp., *A. alternata, A. infectoria, Aspergillus niger, Cladosporium herbarum, Cochliobolus spicifer, Phomopsis* sp., *Stemphylium botryosum*, *Ulocladium atrum, U. botrytis, U. consortiale* and *Cylindrocarpon* sp. fungal species were isolated from *O. crenata* in Syria, Morocco and France. *A. niger*, *C. spicifer*, *S. botryosum*, *U. atrum*, *U. consortiale* and *Cylindrocarpon* sp. species were only reported with this study in broomrape species.

Fungal diversity was also revealed in different regions of *O. crenata* in faba bean cultivation areas. In a study conducted in Armenia, Taslakh'yan & Grigoryan (1978) reported that *Cladosporium herbarum*, *Mucor odoratus* and *Penicillium cyclopodium* fungal species were isolated from *O. crenata*. *M. odoratus* and *P. cyclopodium* were only reported in this study on broomrape species.

Hameed et al. (2001) isolated *Alternaria alternata*, *Fusarium* sp., *Rhizoctonia* sp., *Cheatomium* sp. and *Penicillium* sp. in Jordan. *Cheatomium* sp. was reported only with this study on broomrape species. In Germany, a study in which the fungal species *Ulocladium botrytis* was identified by Müller-Stöver & Kroschel (2005). Suh (2011) determined to presence of *F. oxysporum* on *O. crenata* in Greece. This study is the first report of fungal agents on broomrape species in Greece.

Fungal species isolated from Egyptian broomrape (*Phelipanche aegyptiaca*)

Studies on the determination of fungal diversity in the Egyptian broomrape (*Phelipanche aegyptiaca*), which has a very wide host range, were carried out in the Asian continent. So far, 52 different fungal species from this broomrape species have been reported by many different researchers in Russia, Iran, Türkiye, Uzbekistan, Jordan, Palestine, Nepal, Israel, China and India (Table 5).

Table 5. Fungal species isolated from Egyptian broomrape (*Phelipanche aegyptiaca*)

Fungal species	Host of the broomrape	Geographic origin	Reference
Colletotricum lagenarium	Watermelon	Russia	(Stankevich, 1971)
Fusarium oxysporum f. sp. *orthoceras*	Watermelon	Russia	(Panchenko, 1974)
Fusarium oxysporum f. sp. *orobanche*	-	Iran	(Saremi & Okhovvat, 2008)

Table 5. Continued

Fusarium orobanches	Tobacco	Uzbekistan	(Kabulov & Khalimov, 1974)
	Melon	China	(Wang et al., 1985)
Fusarium sp.	Tomato	Iran	(Rostami et al., 2017)
	Tomato, eggplant	Jordan	(Hameed et al., 2001)
	Tomato	Türkiye	(Başbağcı et al., 2023)
Table 5. Continued			
Fusarium fujikuroi	Tomato	Türkiye	(Cignitas et al., 2024)
Dendrophoma sp.	Tomato, eggplant	Jordan	(Hameed et al., 2001)
Pullularia sp.			
Aspergillus sp.			
Fusarium oxysporum	-	Iran	(Darvishnia et al., 2013)
	Tobacco, mustard	Nepal	(Thomas et al., 1999)
	Tomato	Iran	(Dehaghi et al., 2008; Rostami et al., 2017)
	Melon	Israel	(Amsellem et al., 2001)
	Melon	Israel	(Cohen, 2001)
Fusarium acuminatum	Tomato	China	(Chai et al., 2018)
Fusarium chlamydosporum	-	Iran	(Darvishnia et al., 2013)
Fusarium semitectum			
Fusarium reticulatum			
Fusarium pallindoroseum			
Fusarium diversisporum			
Fusarium virguliform			
Fusarium proliferatum	Tomato	Iran	(Rostami et al., 2017)
Fusarium redolens			
Fusarium equiseti			
Fusarium lacertarum			
Fusarium verticillioides			
Fusarium sambucinum			

Table 5. Continued

Fusarium andiyazi			
Fusarium thapsinum			
Fusarium hostae			
Fusarium torulosum			
Fusarium foetens			
Fusarium flocciferum			
Fusarium arthrosporioides	Melon	Israel	(Amsellem et al., 2001)
	Melon	Israel	(Cohen, 2001)
Alternaria alternata	Tomato, eggplant	Jordan	(Hameed et al., 2001)
	Tomato	Israel	(Dor & Hershenhorn, 2009)
	Tobacco, mustard	Nepal	(Thomas et al., 1999)
Fusarium solani	-	Iran	(Darvishnia et al., 2013)
	Tomato	Iran	(Rostami et al., 2017)
	Tomato	Israel	(Dor & Hershenhorn, 2009)
	Tomato, eggplant, cabbage, cauliflower, sage, sunflower, chickpea	Palestine	(Ghannam et al., 2007)
	Rape, mustard	India	(Sharma et al., 2011)
	Tobacco, mustard	Nepal	(Thomas et al., 1999)
Rhizoctonia sp.	Tomato	Türkiye	(Başbağcı et al., 2023)
	Tobacco, mustard	Nepal	(Thomas et al., 1999)
Rhizopus oryzae	Tomato	China	(Zhang et al., 2013)
Acremonium fusicoides	Tobacco, mustard	Nepal	(Thomas et al., 1999)
Cladosporium cladosporioides			
Epicoccum nigrum			
Fusarium compactum			
Fusarium equiseti			
Fusarium incarnatum			
Fusarium proliferatum			
Fusarium scirpi			

Table 5. Continued

Fusarium tricinctum			
Mortierella alpina			
Papulaspora sp.			
Phoma complanata			
Phoma dennisii			
Sordaria fimicola			
Trichoderma koningii			
Trichoderma harzianum			
Trichothecium roseum			
Macrophomina phaseolina	Tomato	Israel	(Dor & Hershenhorn, 2009)
Rhizoctonia solani			

Amsellem et al. (2001) reported that *F. oxysporum* and *F. arthrosporioides* fungal species were isolated from *P. aegyptiaca* in melon cultivation areas in Israel. Likewise, these two fungal species also isolated by Cohen (2001) in Israel.

In a study conducted in Nepal, Thomas et al. (1999) reported that, 21 fungal species belonging to 12 genera were isolated from *P*. aegyptiaca in tobacco and mustard cultivation areas and that these were *Acremonium fusicoides, Alternaria alternata, Cladosporium cladosporioides, Epicoccum nigrum, Fusarium compactum, F. equiseti, F. incarnatum, F. oxysporum, F. proliferatum, F. scirpi, F. solani, F. tricinctum, Mortierella alpina, Papulaspora* sp., *Phoma complanata, P. dennisii, Sordaria fimicola, Rhizoctonia* sp., *Trichoderma koningii, T. harzianum* and *Trichothecium roseum*. Among these fungal species, *A. fusicoides, C. cladosporioides, F. scirpi, M. alpina, Papulaspora* sp., *P. complanata, P. dennisii, S. fimicola, T. koningii, T. harzianum* and *T. roseum* were reported only in this study on broomrape species.

Hameed et al. (2001) isolated *A. alternata, Fusarium* sp., *Denrophoma* sp., *Pullularia* sp. and *Aspergillus* sp. on *P. aegyptiaca* in tomato and eggplant cultivation areas. *Aspergillus* sp., *Denrophoma* sp. and *Pullularia* sp. fungal species were reported only in this study in broomrape species.

In Russia, the fungal agent *Colletotrichum lagenarium* was detected from *P. aegyptiaca* in watermelon by Stankevich (1971). This fungal species is first reported by this study. In other study conducted in Russia, Panchenko (1974) isolated *F. oxysporum* f. sp. *orthoceras* on *P. aegyptiaca* in watermelon.

F. orobanches was isolated on *P. aegyptiaca* plants in tobacco areas in Uzbekistan (Kabulov & Khalimov, 1974), and in melon areas in China (Wang et al., 1985).

Dor & Hershenhorn (2009) isolated *Macrophomina phaseolina, Alternaria alternata, Rhizoctonia solani* and *F. solani* on *P. aegyptiaca* in tomato cultivation areas in Israel. *M. phaseolina* was reported only in this study on Egyptian broomrape. Ghannam et al. (2007) reported that *F. solani* and *F. oxysporum* were isolated from *P. aegyptiaca* in tomato, eggplant, cabbage, cauliflower, sage, sunflower and chickpea cultivation areas.

There are many studies in Iran in which fungal agents have been detected from *P. aegyptiaca*, and many species, especially those belonging to the Fusarium genus, have been reported. Dehaghi et al. (2008) isolated *F. oxysporum* on *P. aegyptiaca* in tomato. In other study conducted in the same year, Saremi & Okhovvat (2008) isolated *F. oxysporum* f. sp. *orobanche* from lesioned *P. aegyptiaca* plants.

Darvishnia et al. (2013) reported that *F. chlamydosporum, F. solani, F. semitectum, F. oxysporum, F. reticulatum, F. pallindoroseum, F. diversisporum* and *F. virguliform* fungal species were isolated from this broomrape species. Among them, *F. diversisporum, F. pallindoroseum, F. reticulatum, F. semitectum* and *F. virguliform* were reported only in this study on broomrape species. In another study conducted in Iran by Rostami et al. (2017), *Fusarium* sp., *F. flocciferum, F. foetens, F. solani, F. torulosum, F. hostae, F. thapsinum, F. andiyazi, F. sambucinum, F. verticillioides, F. lacertarum, F. equiseti, F. redolens, F. oxysporum* and *F. proliferatum* fungal species were isolated on *P. aegyptiaca* in tomato. This study is the first report of *F. andiyazi, F. flocciferum, F. foetens, F. hostae, F. lacertarum, F. thapsinum* and *F. torulosum* on broomrape species.

In another study conducted in India, Sharma et al. (2011) isolated *F. solani* on *P. aegyptiaca* in rape and mustard cultivation areas. In another study reporting fungal agents belonging to the Fusarium genus, Chai et al. (2018) isolated *F. acuminatum* on *P. aegyptiaca* in tomato fields in China. Zhang et al. (2013) isolated *Rhizopus oryzae* on this broomrape species in tomato areas in China. This fungal species is first reported in this study on broomrape species.

In Türkiye, in a study conducted by Başbağcı et al. (2023), it was reported that, *Fusarium* spp. and *Rhizoctonia* spp. were isolated on lesioned *P. aegyptiaca* plant on tomato cultivation areas in Antalya, Burdur and Isparta provinces. In another study, Cignitas et al. (2024) isolated *F. fujikuroi* from Egyptian broomrape on tomato areas in Türkiye. This study is the first report of this fungal species on *P. aegyptiaca.*

Fungal species isolated from branched broomrape (*Phelipanche ramosa*)

There are many studies in which fungal diversity has been determined on branched broomrape (*Phelipanche ramosa*) in different continents and countries around the world. To date, 49 fungal species have been reported from *P. ramosa* plants in different cultivation areas by many researchers (Table 6).

Table 6. Fungal species isolated from branched broomrape (*Phelipanche ramosa*)

Fungal species	**Host of the broomrape**	**Geographic origin**	**Reference**
Rhizoctonia solani	Tomato	USA	(Duafala et al., 1976)
	Tobacco	France	(Gibot-Leclerc et al., 2022)
Sclerotium rolfsii	Tomato	Chile	(Galdames & Diaz, 2010)
Fusarium solani	Tomato	Hungary	(Hodosy, 1981)
	Tobacco	Hungary	(Fischl et al., 2001)
	Tomato, cauliflower, tobacco	Italy	(Boari & Vurro, 2004)
	Tomato, eggplant, melon, watermelon	Iran	(Mohammadi, 2014)
	Faba bean	Egypt	(Abouzeid & El-Tarabily, 2010)
Fusarium oxysporum	Tomato	Hungary	(Hodosy, 1981)
	Tomato, cauliflower, tobacco	Italy	(Boari & Vurro, 2004)
	Tobacco	Hungary	(Fischl et al., 2001)
	Tobacco	Italy	(Nanni et al., 2005)
	Tobacco	France	(Gibot-Leclerc et al., 2022)
	Tomato	Egypt	(Nemat Alla et al., 2008)
	Faba bean	Egypt	(Abouzeid & El-Tarabily, 2010)

Table 6. Continued

Fusarium orobanches	Tobacco	Bulgaria	(Ampova et al., 1967)
Fusarium oxysporum f. sp. *orobanche*	Tomato, cabbage	Ukraine	(Timchenko & Dovgal', 1972)
Fusarium oxysporum f. sp. *orthoceras*	Tomato, cabbage	Ukraine	(Fomin, 1954)
Fusarium lateritium *Gliocladium varians*	-	Armenia	(Taslakh'yan & Grigoryan, 1978)
Fusarium equiseti	Tomato	Hungary	(Hodosy, 1981)
	Tomato, cauliflower, tobacco	Italy	(Boari & Vurro, 2004)
	Faba bean	Egypt	(Abouzeid & El-Tarabily, 2010)
Alternaria sp.	Tomato, cauliflower, tobacco	Italy	(Boari & Vurro, 2004)
	Tobacco	France	(Gibot-Leclerc et al., 2022)
Fusarium sp.	Tomato, cauliflower, tobacco	Italy	(Boari & Vurro, 2004)
	Tobacco	Macedonia	(Tashkoski, 2013)
	Tomato, eggplant	Jordan	(Hameed et al., 2001)
	Faba bean	Egypt	(Abouzeid & El-Tarabily, 2010)
Fusarium acuminatum	Tomato, cauliflower, tobacco	Italy	(Boari & Vurro, 2004)
	Tomato	Iran	(Gholizadeh & Hemmati, 2019)
	Faba bean	Egypt	(Abouzeid & El-Tarabily, 2010)
Fusarium camptoceras *Fusarium nygamai* *Fusarium sambucinum* *Myrothecium verrucaria* *Plectosporium tabacinum*	Tomato, cauliflower, tobacco	Italy	(Boari & Vurro, 2004)
Fusarium compactum	Tomato, cauliflower, tobacco	Italy	(Boari & Vurro, 2004)
	Faba bean	Egypt	(Abouzeid & El-Tarabily, 2010)
Fusarium proliferatum	Tomato, cauliflower, tobacco	Italy	(Boari & Vurro, 2004)
	Tomato	Iran	(Gholizadeh & Hemmati, 2019)
	Faba bean	Egypt	(Abouzeid & El-Tarabily, 2010)

Table 6. Continued

Fusarium chlamydosporum	Tomato, cauliflower, tobacco	Italy	(Boari & Vurro, 2004)
	Tomato	Iran	(Gholizadeh & Hemmati, 2019)
Fusarium verticillioides	Tomato, cauliflower, tobacco	Italy	(Boari & Vurro, 2004)
	Tobacco	France	(Gibot-Leclerc et al., 2022)
	Faba bean	Egypt	(Abouzeid & El-Tarabily, 2010)
Alternaria infectoria	Tobacco	France	(Gibot-Leclerc et al., 2022)
Botrytis sp.			
Cladosporium sp.			
Epicoccum nigrum			
Fusarium avenaceum			
Fusarium brachygibbosum			
Fusarium cerealis			
Fusarium culmorum			
Fusarium incarnatum			
Fusarium graminearum			
Penicillium sp.			
Phomopsis sp.			
Pithomyces chartarum			
Plectosphaerella ramiseptata			
Plectosphaerella sp.			
Pleosporineae sp.			
Rhizoctonia sp. AG-A			
Sarocladium strictum			
Sclerotinia sp.			
Stereum sp.			
Fusarium equiseti	Tobacco	France	(Gibot-Leclerc et al., 2022)
	Tomato	Iran	(Gholizadeh & Hemmati, 2019)
Alternaria alternata	Tomato, eggplant	Jordan	(Hameed et al., 2001)
	Tomato, eggplant, melon, watermelon	Iran	(Mohammadi, 2014)

Table 6. Continued

Pythium sp.	Tomato, eggplant, melon, watermelon	Iran	(Mohammadi, 2014)
Aspergillus ochraceus	Tomato	Iran	(Gholizadeh & Hemmati, 2019)
Fusarium fujikuroi			
Macrophomina phaseolina			
Talaromyces trachyspermus	Tomato	Iran	(Gholizadeh & Hemmati, 2019)

In a study conducted by Duafala et al. (1976) isolated *Rhizoctonia solani* from *P. ramosa* in tomato areas in USA. In another study conducted in America continent, Galdames & Diaz (2010) isolated *Sclerotium rolfsii* on *P. ramosa* in tomato areas in Chile. This fungal species was reported only by this study on branched broomrape.

On the other hand, in studies conducted in European countries, it is seen that fungal agents related to the Fusarium genus come to the fore. Hodosy (1981) isolated *F. solani*, *F. oxysporum* and *F. equiseti* on *P. ramosa* in tomato areas in Hungary. Similarly, *F. solani* and *F. oxysporum* also isolated in tobacco fields in Hungary by Fischl et al. (2001). In Italy, in a study conducted by Boari & Vurro (2004), *Alternaria* sp., *Fusarium* sp., *F. acuminatum, F. camptoceras, F. chlamydosporum, F. compactum, F. equiseti, F. nygamai, F. oxysporum, F. proliferatum, F. sambucinum, F. solani, F. verticillioides, Myrothecium verrucaria* and *Plectosporium tabacinum* fungal species were isolated from *P. ramosa* in tomato, cauliflower and tobacco cultivation areas. Among these fungal species, *F. camptoceras, F. nygamai, M. verrucaria* and *P. tabacinum* were reported only in this study on broomrape species. In another study conducted by Nanni et al. (2005) in Italy, *F. oxysporum* was isolated from *P. ramosa* in tobacco areas. Gibot-Leclerc et al. (2022) obtained *Alternaria* sp., *A. infectoria, Botrytis* sp., *Cladosporium* sp., *Epicoccum nigrum, F. avenaceum, F. brachygibbosum, F. cerealis, F. culmorum, F. equiseti, F. incarnatum, F. graminearum, F. oxysporum, F. redolens, F. sambucinum, F. solani, F. sporotrichioides, F. tricinctum, F. venenatum, F. verticillioides, Penicillium* sp., *Phomopsis* sp., *Pithomyces chartarum, Plectosphaerella ramiseptata, Pleosporineae* sp., *Rhizoctonia solani, Rhizoctonia* sp. AG-A, *Sarocladium strictum, Sclerotinia* sp. and *Stereum* sp. fungal species from symptomatic *P. ramosa* plants in tobacco areas in France. *Botrytis* sp., *F. culmorum, F. graminearum, F. sporotrichioides, F. venenatum, P. chartarum, P. ramiseptata, Plectosphaerella* sp., *Pleosporineae* sp., *Rhizoctonia* sp. AG-A, *S. strictum* and *Stereum* sp. fungal species were reported only in this study on broomrape species. *Fusarium* sp. was reported by Tashkoski (2013) on *P. ramosa* in tobacco areas in Macedonia. In the only study reporting the *F. oxysporum* f. sp. *orobanche* species in this broomrape species, Timchenko & Dovgal' (1972) isolated the fungus on tomato and cabbage areas in Ukraine. In another study conducted in tomato ve cabbage cultivation areas in Ukraine, Fomin (1954) obtained *F. oxysporum* f. sp. *orthoceras* on *P. ramosa*. Ampova et al. (1967) isolated *F. orobanches* on *P. ramosa* in tobacco areas in Bulgaria.

In Asia, there are studies in Jordan and especially in Iran where symptomatic fungi have been identified on *P. ramosa* plants. Hameed et al. (2001) isolated *Alternaria alternata* and *Fusarium* sp. on *P. ramosa* in tomato and eggplant areas in Jordan. Mohammadi (2014) obtained *F. solani*, *A. alternata* and *Pythium* sp. from lesioned *P. ramosa* plants in tomato, eggplant, melon and watermelon cultivation areas in Iran. Gholizadeh & Hemmati (2019) reported that *Aspergillus ochraceus, F. fujikuroi, F. acuminatum, F. equiseti, F. chlamydosporum, F. proliferatum* and *Macrophomina phaseolina* fungal species were isolated from symptomatic *P. ramosa* plants in tomato areas in Iran. *A. ochraceus* was reported only by this study on all broomrape species. In Iran, Hemmati & Gholizadeh (2019) isolated *Talaromyces trachyspermus* on this broomrape in tomato areas. This fungal species was also reported only in this study in all broomrape species. In Armenia, Taslakh'yan & Grigoryan (1978) reported that *F. lateritium* and *Gliocladium varians* were isolated on *P. ramosa*. *G. varians* was reported only with this study on broomrape species.

It is evident that the studies carried out on this subject in the African continent stand out in Egypt. Nemat Alla et al. (2008) isolated *F. oxysporum* on *P. ramosa* in tomato areas in Egypt. Abouzeid & El-Tarabily (2010) reported that, *Fusarium* sp., *F. oxysporum*, *F. solani*, *F. compactum*, *F. verticillioides*, *F. equiseti*, *F. proliferatum* and *F. acuminatum* were obtained from this broomrape species in faba bean areas in Egypt.

Fungal Species Isolated From Other Broomrape Species

Apart from the 5 main damaging broomrape species mentioned above, there are few studies on fungal diversity in other broomrape species (Table 7).

Table 7. Fungal species isolated from other broomrape species

Broomrape species	Fungal species	Host of broomrape	Geographic origin	Reference
Orobanche spp.	*Fusarim solani*	Tomato	Iran	(Ghasemi et al., 2013)
	Fusarium oxysporum			
Orobanche alba	*Alternaria tenius*	-	Armenia	(Taslakh'yan & Grigoryan, 1978)
	Hyphoderma roseum			
Orobanche reticulata	*Fusarium lateritium*			
	Coniosporium arundinis			
	Fusarium moniliforme			
	Penicillium natatum			
Orobanche mutelii	*Fusarium lateritium*			
	Cladosporium fasciculatum			
	Fusarium gibbosum			
	Verticillium microsporum			
	Rhizopus microsporus			
	Rhizopus nigricans			
Orobanche rosea	*Cladosporium brevi-compactum*			
	Trichoderma glaucum			
Orobanche alsatica	*Fusarium solani*			
	Monilia candida			
	Monosporium sylvaticum			
Orobanche colorata	*Aspergillus glaucus*			
	Mortierella stylospora			
Orobanche orientalis	*Aspergillus versicolor*			
	Rhizopus atrocarpi			

Table 7. Continued

Orobanche lutea	*Stemphylium botryosum*			
Orobanche caesia	*Geotrichum candidum*			
Orobanche nana	*Cladosporium fasciculatum*			
Orobanche foetida	*Fusarium* sp.	Faba bean	Tunisia	(Boutiti et al., 2008)

In Iran, Ghasemi et al. (2013) isolated *F. solani* and *F. oxysporum* on *Orobanche* spp. in tomato areas. In Armenia, Taslakh'yan & Grigoryan (1978) isolated *Alternaria tenius* and *Hyphoderma roseum* on *O. alba; Cladosporium fasciculatum*, *Fusarium gibbosum*, *F. lateritium*, *Verticillium microsporum*, *Rhizopus microsporus* and *R. nigricans* on *O. mutelii*; *Coniosporium arundinis*, *F. lateritium*, *F. moniliforme* and *Penicillium natatum* on *O. reticulata*; *Cladosporium brevi-compactum* and *Trichoderma glaucum* on *O. rosea*; *F. solani*, *Monilia candida* and *Monosporium sylvaticum* on *O. alsatica*; *Aspergillus glaucus* and *Mortierella stylospora* on *O. colorata*; *Aspergillus versicolor* and *Rhizopus atrocarpi* on *O. orientalis*; *Stemphylium botryosum* on *O. lutea*; *Geotrichum candidum* on *O. caesia* and *Cladosporium fasciculatum* on *O. nana*. Among these fungal species, *A. tenius, H. roseum, C. arundinis, P. natatum, C. brevi-compactum, T. glaucum, M. candida, M. sylvaticum, A. glaucus, M. stylospora, A. versicolor, R. atrocarpi*, *G. candidum* and *C. fasciculatum* were reported only with this study on broomrape species. In Tunisia, Boutiti et al. (2008) isolated *Fusarium* sp. on *O. foetida* in faba bean cultivation areas.

Geographic Distributions Of Fungal Species Isolated From Broomrape Species

So far, studies on fungal diversity in the five main damaging broomrape species and other broomrape species have been conducted across four different continents and in 25 countries. Researchers in different parts of the world have carried out studies identifying fungal agents from broomrape species in 12 different countries (Iran, India, Jordan, Türkiye, China, Israel, Russia, Palestine, Nepal, Uzbekistan, Armenia and Syria) from Asia, 8 (Ukraine, Greece, Almanya, France, Hungary, Italy, Bulgaria and Macedonia) from Europe, 3 (Egypt, Tunisia and Morocco) from Africa and 2 (USA and Chile) from America.

As a result of these studies, the highest number of fungal species were reported in France with 36 different species, followed by Iran (33), Armenia (29), Nepal (21), Syria (16) and Morocco (16) in decreasing order. Fungal diversity is also high in China, Italy, Egypt and Jordan. 15 different fungal species have been reported in China and Italy, 13 in Egypt and 12 in Jordan. In countries with fewer reported fungal species, 7 different species have been reported in Israel, 5 in Türkiye, 3 in India and Hungary, and 2 in Russia, Palestine, Ukraine, and Bulgaria. Only 1 fungal species has been reported in Macedonia, Tunisia, Chile, USA, Greece, Germany and Uzbekistan (Figure 1).

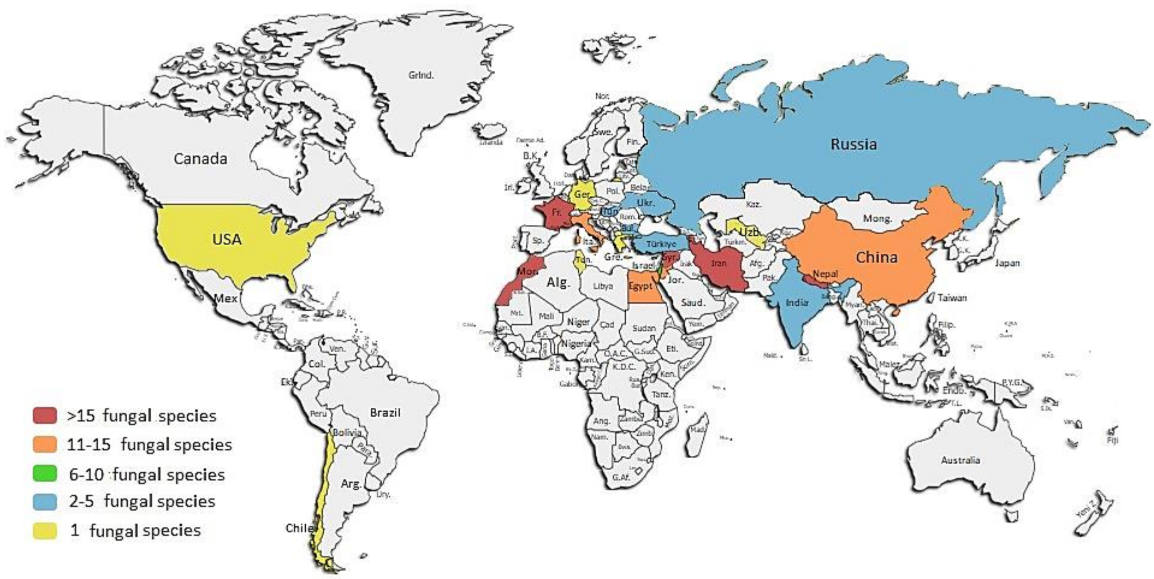

Figure 1. Geographic distributions of fungal species isolated from broomrape species

The Potential and Risk of Fungal Species as Mycoherbicides for Broomrape Management

Fungi-based formulations for weed control are known as mycoherbicides (Bailey, 2014). Furthermore, extracts from plants or microorganisms that exhibit phytotoxic effects, along with purified or semi-purified natural phytotoxins, are termed bioherbicides (Bordin et al., 2018). As described above, various fungal species have been identified on broomrape species in many countries. Several strategies have been explored and tested for the use of these fungal species as a bioherbicide for broomrape management. For example, the use of mixed pathogens has shown moderate to high efficacy in the control of *P. aegyptiaca* and *O. cumana* (Dor, 2003). The combined application of *Fusarium oxysporum* Schlecht. f.sp. orthoceras (Appel & Wollenw.) Bilai with BTH (Benzo (1,2,3) thiadiazole-7-carbotioic acid S-methyl ester) as a resistance induced chemical in sunflower improves the efficacy to control *O. cumana* compared to the use of the fungus alone (Müller-Stöver et al., 2005). It has been suggested that the effectiveness of fungi as biological control agents could be enhanced through fermentation, formulation, and application technologies (Sauerborn et al., 2007), but this approach has generally not been pursued. Studies have been conducted to genetically enhance the virulence of fungal isolates against broomrape. The aim was to increase the virulence of *Fusarium oxysporum* (FOXY) and *F. arthrosporioides* (FARTH) isolates against *O. aegyptiaca* by overexpression of indole-3-acetic acid (IAA) production. The *tryptophan-2-monooxygenase* (*iaaM*) and *indole-3-acetamide hydrolase* (*iaaH*) gene, which are part of the IAA biosynthesis pathway, was transformed into fungal protoplasts, resulting in transgenic FOXY and FARTH isolates that overproduce IAA. These isolates led to a reduction in both the number of broomrape shoots (Cohen et al., 2002). *Nep1* is an extracellular fungal protein that induces necrosis in a variety of dicotyledonous plants, including invasive weed species (Keates et al., 2003). FOXY and FARTH were also cloned into the protoplasts of *Fusarium oxysporum* f. sp. erythroxyli and *Colletotrichum coccodes* (Wallr.) Hughes to enhance their virulence. None of the FOXY *NEP1* mutant fungi exhibited hypervirulence, but the FARTH mutant killed *P. aegyptiaca* faster than the wild type (Meir et al., 2009). Transformed *Fusarium* sp. was not tested in the field due to the refusal of regulatory authorities for permission (Watson, 2013). *Fusarium oxysporum* f. sp. *orthoceras* was successfully developed as a mycoherbicide in the former USSR (K. Linke et al., 1992). This fungus cultivated on sterilized barley seed or on a medium containing corn flour and straw, this preparation also known "Product F" maintaines the fungus for 80 days (Panchenko, 1975). Aside from the historical reference to Product F in Russia, there has been no practical application of fungi for the biocontrol of broomrape to date (Gressel, 2001). Because the fungal species lack adequate virulence for effective application in the field, which implies that virulence may need to be enhanced through transgenic methods or that alternative isolates should be explored (Cohen et al., 2002). The host range of the fungus and the selectivity of its formulations must be validated both theoretically and experimentally. Some mycoherbicides are derived from broad-spectrum pathogens that have been documented on both target weeds and crops. These pathogens can be utilized in specific scenarios when susceptible crops are not part of the crop rotation in the area where weed biocontrol is implemented. However, if the conditions for using mycoherbicides are not adhered to, there is a risk of damage to the crops being protected (Jiang & Wang, 2023). To date, only seven out of the 15 registered mycoherbicides are potentially available, yet none are widely utilized. This is partly due to the fact that most of these products are selective biologicals developed to target specific problematic weed species (Berestetskiy, 2021). Biocontrol agents are generally perceived as environmentally safe. However, factors such as allergenicity and toxicity, their persistence in soil, and their impact on beneficial organisms also need to be assessed. Knowledge about these properties of phytopathogens is limited, with the exception of certain *Alternaria* species and a broad spectrum of *Fusarium* fungi (Chou et al., 2014; Żukiewicz-Sobczak, 2013).

CONCLUSIONS and FUTURE TRENDS

The main agriculturally important broomrape species are *Orobanche cernua* Loefl., *Orobanche cumana* Wallr., *Orobanche crenata* Forsk., *Phelipanche aegyptiaca* Pers. (Pomel) and *Phelipanche ramosa* L. species, especially the fungus species detected on broomrape, 104 different fungal species belonging to 42 genera have been reported since 1954 until today. Research on fungal species isolated from broomrape provides crucial information about their biological activities and potential uses, and these fungi could serve as an important source of bioherbicides. These fungal species have the possibility of synthesizing a wide variety of bioactive substances belonging to all groups of natural compounds that can be used as prototypes of the pesticides. The potential of these fungi as producers of biologically active compounds could be very high. However, it was not a commercial success, and no product reached the market. Although there is no commercial product on the market, the 'bioherbicide' approach may be promising by reconsidering the fungal isolates obtained from previous studies in the light of new scientific and technological advances and testing their effectiveness under field conditions in different hosts.

Declaration of interest statement

The authors declare that they have no conlflict of interest.

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