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CHECKLIST OF FUNGAL SPECIES ASSOCIATED WITH SAFFRON PLANTS (*CROCUS SATIVUS* L.)

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Abstract

Over the past years, a wealth of studies has shown that saffron plants (*Iridaceae*) are subjected to intense fungal colonisation. Saffron (*Crocus sativus*) are perennial, monocotyledonous plants mainly restricted to the temperate areas and represents an economically important crop producing the world's costliest spice. The inventory of fungi associated with saffron is an essential step to explore the fungal diversity and fill the gaps in knowledge of diverse and understudied assemblage related to saffron. In this regard, the data collected from the literature for the diversity of saffron fungi have been revisited and updated here to realize a first inventory list on fungal organisms globally reported. It includes 137 species belonging to four phylums Ascomycota, Basidiomycota, Mucoromycota and Oomycota. Fusarium is the most common genus, with 26 species, followed by Aspergillus and Penicillium, with 15 and 17 species, respectively. The bulk of mycobiome often found in the cormosphere, roots, and rhizosphee suggest they might be involved in corms diseases development, however certains are known to be opportunists and others have a key role in corm protection. In conclusion, throughout this bibliographic inventory, we can point out a great diversity of fungi distinguishing the mycoflora of saffron that grow under appropriate environmental conditions and alerts us to the presence of several sources of infection in saffron fields for this perennial plant.

Keywords: Inventory, Endophytes, Fungi, Saffron, Morocco.

INTRODUCTION

Saffron is a species of crocus mainly growing in temperate and dry climatic conditions. However, its vegetative growth coincides with cold weather. We find it at altitudes varying by 50 m above sea level and more than 2000 m for the case of Morocco (Askaoune) Lage and Cantrell, 2009). A worldwide total yield of about 336 tons was produced on 105.269 hectares (Shokrpour, 2019**)**. In 2019, Iran and Spain were the leading exporters of saffron (Fujii et al., 2022) and contributing about 88% of world's saffron, India (5.80%) followed by Greece, Afghanistan, Morocco, Italy, Spain, China and Azerbaijan. The biological and agronomical features of saffron make it an alternative plant for low-input agriculture, offering good production in sustainable agricultural systems and a source for earning in rural cummunities involved in its cultivation notably for marginal lands, especially where water scarcity severely limits the cultivation of many (Gresta et al., 2008).

Saffron is one of the most precious spices, derived from the dried stigmas of *Crocus sativus* flowers. The saffron plant belonging to the Iridaceae family, is a triploid geophyte species which is propagated only vegetatively by means of corms (Gresta

et al., 2008), the underground stems acting as storage and reproduction structures. Due to its numerous medicinal qualities and pharmacological applications, its demand and consumptions has risen over a period of time. Hence, new technologies will be required to improve and sustain its production. Efforts made to enhance the productivity in the traditional areas and promote the cultivation of saffron in the newer areas will be of great relevance towards achieving this goal if the knowledge on saffron ecosystems, including the potential biotique components as fungi is considered. In Morocco, as in other countries, serious interest in the study of endophytic, pathogenic and saprophytic fungal organisms on saffron crop has recently developed. Research on fungal communities gathered in saffron fields, soil, saffron plants and conducted in different saffron agroecosystems has resulted in the description of taxa that proved to be in some instances new, common on *Crocus sativus* or with restrict occurrence. The majority of studies emphasize on the fungal species affecting corms, being destructive in saffron and having caused severe yield losses in saffron producer's countries (Saeedizadeh, 2014; Palmero et al., 2014; Gupta et al., 2021; Vafaei and Darvishian, 2022; Ren et al., 2023; Caligiore-Gei et al., 2023; Khaledi et al., 2024). Numerous publications have recorded the mycobiota associated with saffron which includes endophytes, pathogenes and saprobes (Raj et al., 2013; Vardasbi et al., 2020; Belfiori et al., 2021). Advent in the methodology for the classification of fungi enables researchers to have more informations about fungi inhabiting living material and soil. High-throughput DNA sequencing techniques have greatly expanded the capability to characterize soil microbiome of saffron soil (Victorino et al., 2021).

Instead, in Morocco, the literature on saffron mycoflora is scarcer and there are four publications which have documented the fungal community of saffron plants and soils (Chamkhi et al., 2018; Bentata et al., 2017; El Aymani et al., 2019, Ourras et al., 2023).

El Aymani et al., (2019) compiled a list of 10 fungal species which were isolated from soil and infected plants. Bentata et al., (2017) have found 2 fungal species which were responsible for root rot disease or death. Recently, Ourras surveyed fungi from healthy or diseased corms and roots and isolated 18 fungal species accompagnied with indetermined fungal fraction. To complete the information, relevant literature was extensively reviewed for scattered records into a unified database. Thus, the present survey aims to collate fungi being reported to date on saffron (*Crocus sativus* L.) in Morocco and elsewhere.

MATERIALS AND METHODS

Bibliographic Datasets

Data considered for the checklist of fungi of fungi recovered from saffron was based on primary literature (scientific publications in international journals with peer review process, books with ISBN number) and secondary literature (review papers, lists). These publications were found by searches, including Google Scholar, Google Connect, Lens.org. An update in taxonomy and systematics of recorded microfungi with their currently accepted name, author names of fungal genus and the corresponding family were achieved by using indexfungorum.org. The publications on reported microfungi across whorlwide were surveyed, with a focus on the terms such as ' corm rot', 'fungi', 'on', and 'saffron', 'Crocus sativus'. The pathogenic nature and other life modes of individual fungal entities were then corroborated based on available literature. The search yielded various results: some articles had all the thematic

keywords and some were specific to fungal communities in association with saffron plants. Genera and species are listed alphabetically with extensive information and references.

Once species were checked for taxonomy in Index fungorum (https://www.indexfungorum.org/names/Names.asp, accessed on 05 June 2024).

Isolation and distribution of each species aspects were assessed by reviewing databases on fungal diversity and pathological studies on saffron plants.

RESULTS

The current list of saffron-fungi includes 137 fungal species referenced by 141 research works published since 1800 to 2024. The inventoried fungal species gathers fungal organisms isolated from healthy and infected saffron corms, organs of *Crocus sativus* in the most producing saffron countries reported by different paper researchs.

Phylum (Phylla) Ascomycota

Cl/Leotiomycetes

O/Helotiales

F/ Sclerotiniaceae

- *Botrytis* sp.

Isolation: corms

Location: Morocco, Netherlands

References: Ourras et al., 2023; Boerema and Hamers, 1989

- *Botrytis cinerea*

Isolation*:* leaves

Location : Italy

References : Belfiori et al., 2021

- *Botrytis fabiopsis*

Isolation: corms

Location: India

References: Wani et al., 2016, 2017

Sclerotinia

Sclerotinia gladioli

Isolation: saffron corm rot

Location: Japon

References: Abe, 1933; Yamamoto et al., 1954; Mizusawa, 1923);

Sclerotinia bulborum

Isolation: undeterminate

Location: Spain

References: Alarcon and Sanchez, 1968

Stromatinia gladioli

Isolation: infected leaf sheath, symptomatic corms

Location: Netherlands, Italy, Spain

References: Schenck 1970. Fiori et *al*., 2007; Muñoz et al., 2020

F/Ploettnerulaceae

Cadophora

Isolation: soil

Location: China

Reference: Lin et al., 2019

- *Cadophora luteo-olivacea*

Isolation: Corm

Location: Italy

References: Wani et al., 2016 ; Belfiori et al., 2023

- *Cadophora malorum*

Isolation: Roots, leaves, corms; corms

Location: India, Iran, Italy

References: Wani et al., 2016;Taheri et al., 2020; Belfiori et al., 2021

F/Myxotrichaceae

Oidiodendron

Isolation: rotting corms

Location: China

References: Ren et al., 2023

Cl/ Dothideomycetes

Pleosporales

F/Pleosporaceae

Alternaria

- *Alternaria* sp.

Isolation: Stems

Location: India

References: Raj, 2013

- ***Alternaria alternata***

Isolation: leaves, corms, infected corms, stems, tepals and stigmas; Corms with some spots,

Location: Iran; Italy; Morocco, India

References: Hossainnia and Mohammadi, 2018; Vafaei and Darvishian, 2022; Belfiori et al., 2021; Ourras et al., 2023; Wani et al., 2016, 2017.

- ***Alternaria chlamydosporigena***

Isolation: Roots

Location: Iran

References: Taheri et al. (2020)

- ***Alternaria infectoria***

Isolation: tepals

Location: Italy

References: Belfiori et al. (2021).

Bipolaris

- *Bipolaris spicifera*

Isolation: corms

Location: Spain

References: Ahrazem et al., (2010); Rubio-Moraga et al., (2013)

- *Cochliobolus* sp.

Isolation: corms

Location : Spain

References : Ahrazem et al., (2010)

Pyrenophora

- *Pyrenophora tritici-repentis*

Isolation: tepals

Location: Italy

References: Belfiori et al., 2021);

Stemphylium

- *Stemphylium vesicarium*

Isolation: leaves

Location: Italy

References: Belfiori et al., (2021)

- *Stagonosporopsis cucurbitacearum*

Isolation : tepals

Location : Italy

References : Belfiori et al., (2021)

Ulocladium

- *Ulocladium* sp.,

Isolation: healthy corms

Location: Morocco

References: Ourras et al. (2023)

F/ Didymellaceae

G/Ascochyta

- Ascochyta rabiei

Isolation: leaves, corms and roots

Location: Iran

References: Taheri et al., (2020)

Epicoccum

- ***Epicoccum* spp.**

Isolation: rotten leaves of saffron plants

Location: Italy

References : Belfiori et al., (2021)

- ***Epicoccum nigrum***

Isolation: rotten stem, saffron bulb

Location: Italy, India

References: Belfiori et al., 2021, Wani et al., 2016 ; Wani et al., 2017

G/Phoma

- *Phoma* spp.

Isolation: corms of saffron

Location: Netherlands; Spain, India, France, Italy, Romania,

References: Boerema, 1976; Pérez-Bueno, 1995; Lopez and Gomez-Gomez, 2009; Thakur et al., 1992; Hassan and Devi, 2003; Madan et al., 1967; Carta et al., 1982; Ionita et al., 1995.

- Phoma crocophi

Isolation: corm

Location: France, Italy, India, Romania

References: Madan et al., (1967); Nannizzi, 1941; Carta et al., 1982; Hassan and Devi, 2003; Ionita et al., 1995).

F/Didymosphaeriaceae

G/Paraphaeosphaeria

Isolation: Healthy and rotted corms

Location: China

References: Ren et al. (2023)

Cladosporiales

F/Cladosporiaceae

- ***Cladosporium* sp.**

Isolation: corms

Location: Spain

References: Ahrazem et al. (2010)

- ***Cladosporium cladosporioides***

Isolation: leaves

Location: Italy

References: Belfiori et al., (2021)

Botryosphaeriales

F/Botryosphaeriaceae

Macrophomina

- *Macrophomina* sp.

Isolation: corms

Location: Italy, India, Iran, Romania

References: Razdan et al., (2018); Kumar (2018)

- *Macrophomina phaseolina*

Isolation: rotten corms

Location: Italy, India, Iran, Romania

References: Carta et al., 1982; Shah and Srivastava (1984); Sud et al., (1999); Gupta et al., (2011); Ionita et al., 1995 ; Gadiri et al., 2019.

Cl/Eurotiomycetes

O/Eurotiales

F/Trichocomaceae

Talaromyces

- ***Talaromyces* sp.**

Isolation: Corm

location: China

References: Du et al., (2023)

- *Talaromyces assiutensis*

Isolation: corms and leaves

Location: Italy

References: Belfiori *et al*. (2021)

- *T. aurantiacus*

Isolation : leaves, corms

location: Iran

References: Vardasbi et al., (2020)

- *Talaromyces cecidicola*

Isolation: corms and stems

Location: Italy

References: Belfiori *et al*. (2021)

- ***Talaromyces cellulolyticus***

Isolation: corms

Location: India

References : Wani et al., (2016, 2017)

- *T. funiculosus*

Isolation: leaves, corms

Location: Iran

References: Vardasbi et al., (2020)

- *Talaromyces pinophilus*

Isolation: corms, leaves

Location: India, Italy, Iran

References: Wani et al., (2016, 2017); Belfiori et al., 2021 ; Vardasbi et al., (2020) **34**

- *T. purpureogenus*

Isolation: Corms, leaves

Location: India, Iran

References : Wani et al., (2016); Vardasbi et al., (2020)

- *Talaromyces verruculosus*

Isolation : Corms

Location: India

References: Wani et al., (2016, 2017)

- *Talaromyces versatilis*

Isolation: Corms, leaves

Location: Iran

References: Vardasbi et al., (2020) [105]

F/Aspergillaceae

G/Aspergillus

***Aspergillus* sp.**

Isolation: roots; rotted corm

Location: Iran, China, India

References: Taheri et al., 2021; Xu and Ge, 1990; Gupta and Vakhlu, 2015; Kumar, 2018.

- ***Aspergillus europaeus***

Isolation: stem of saffron

Location: Iran, Italy

References: Taheri et al., 2020 ; Belfiori et al., 2021

- ***Aspergillus flavipes***

Isolation: infected saffron bulb

Location: Iran

References: (Najari et al., 2018, Saeedizadeh, 2014, Najjar et al., 2017)

- ***Aspergillus flavus***

Isalation: diseased bulb

Location: Iran, India, Egypt

References: diseased bulbs in Iran (Najari et al., 2018, Saeedizadeh, 2014, Najjar et al., 2017), in India (Mansotra et al., 2023); Aziz et al., (1998);

- ***Aspergillus fumigatiaffinis***

Isolation: roots isolated from roots of saffron in

Location: Morocco

Reference : Chamkhi et *al.* (2018)

- ***Aspergillus fumugatis***

Isolation: saffron corms, roots and soil

Location: Morocco

References: El Aymani *et al.* (2019)

- ***Aspergillus Niger***

Isolation: Dry styles**,** infected stem, corms, soil, asymptomatic corm and roots

Location: Egypt, Morocco, China, Spain, Iran

References: Aziz et al., (1998)**;** Lahmess et al., (2021) ; El Aymani et al., 2019; Ourras et al., (2023), Ahrazam et al., (2010), Rubio-moraga et al., (2013); Xu and Ge (1990); Jiening et al., (2022); Najari et al., (2018); Saeedizadeh, (2014, 2016); Najjar et al., (2017); Taheri et al., (2020);

- ***Aspergillus nomius***

Isolation: corms

Location: Morocco

References : Ourras *et al.,* (2023)

- ***Aspergillus ochraceus***

Isolation: Corms

Location: Morocco

References (Ourras et *al*., 2023)

- Aspergillus oryzae

Isolation: dry parts of stylles and stigma

Location: Egypt

References: Aziz et *al*., (1998)

- ***Aspergillus parasiticus***

Isolation: Dry parts of stylles and stigma

Location: Egypt

References: Aziz et *al*., (1998)

- Aspergillus pseudodeflectus

Isolation: rotten corms

Location: India

References: Wani et al., (2016, 2017)

- Aspergillus terreus

Isolation: diseased corms, root

Location: Iran, Egypt, Morocco

References: Saeedizadeh, (2014), Aziz et al., (1998), El Aymani et al., (2019)

- Aspergillus tamarii

Isolation: dry parts of stylles and stigma

Location: Egypt

References: Aziz et *al*., (1998)

- Aspergillus versicolor

Isolation : Corms

Location : Morocco

References: Ourras et al., (2023)

G/Paecilomyces

- ***Paecilomyces marquandii***

Isolation: rotten bulbs

Location: India

References: Wani et al., (2016, 2017)

G/Penicillium

- ***Penicillium* sp.**

Isolation: diseased bulbs, stems, roots, soil,

Location: Italy; France; India, Spain, Morocco, China

References: Saaltink, 1971; Carta et al., 1982; Madan et al., 1967; Kumar, 2018; Gupta and Vakhlu; Raj, 2013; Thakur et al., 1992; Hassan and Devi, 2003; Hassan *et al.,* 2003; Wani, 2004; Ahmed and Sagar, 2006; Husaini *et al.,* 2010; Shah et al., 2018; Razdan *et al*., 2018; Ahrazem et al., 2010; El Aymani *et al*., 2019; Ourras *et al*., 2023; Xu and Ge, 1990; Du et al., 2023.

- ***Penicillium canescens***

Isolation: leaves, corms, roots

Location: Iran, India

References: Taheri et al., (2020), Wani et al., (2016, 2017)

- ***Penicillium chrysogenum***

Isolation: soil

Location: China

References: Shuwen et al., (2019)

- ***P. citreosulfuratum***

Isolation: rotted bulbs

Location: China

References: Tian et al., 2022; Hu et al., 2022

- ***Penicillium citrinum***

Isolation: rotten bulbs, stems

Location: China, Italy

References: Tian et al., 2022; Belfiori et al., 2021

- ***Penicillium corymbiferum***

Isolation: rotten corm

Location: Scotland, Italy, China, Japan, India

References: Sutton and Wale (1985); Capelli et al. (1991); Cappelli and Di Minco (1999); Saaltink (1971); Gu and Zhi (1997); Gupta et *al*. (2011).

- ***Penicillium crocicola***

Isolation: undetermined

Llocation: Japan

References: Yamamoto et *al*. (1956);

- ***Penicillium cyclopium***

Isolation: symptomatic corm

Location: Italy, China

References: Francesconi (1973); Picci (1986); Cappelli et al. (1991); Gu and Zhi (1997); Gu and Zhi (1997); Fiori (2002); Cappelli and Di Minco (1999).

- ***Penicillium digitatum***

Isolation: infected corms

Location: Italy, Iran

References: Carta et al. (1982); Saeedizadeh (2014, 2016); Najjar et al. (2017).

- ***Penicillium griseofulvum***

Isolation: corms

Location: India

References: Wani et *al*. (2016)

- ***Penicillium pinophilum***

Isolation: undeterminate

Location: India

References : Wani et *al*. (2016, 2017)

- ***Penicillium raistriicki***

Isolation : infected saffron corm

Location : Morocco, Spain

References : Lamhass et *al*. (2021); Ahrazem et *al*. (2010); Rubio-Moraga et *al*. (2013).

- ***Penicillium solitum***

Isolation: diseased corm

Location: China

References: Zhang *et al.* (2020)

- ***Penicillium vinaceum***

Isolation: corm of saffron

Location: China

References: Zheng et *al.*(2012)

O/Onygenales

F/ Onygenaceae

- ***Malbranchea circinate***

Isolation :

Location : Italy

References: Belfiori et al., (2021)

O/Chaetothyriales

F/Herpotrichiellaceae

Phialophora

Isolation: Soil and bulb of saffron

Location: China

Reference: Lin et *al*. (2019)

Phialophora mustea

Isolation: Corm

Location: India

References: Raj (2013); Wani et al. (2016)

Cl/Sordariomycetes

Glomerellales

F/ Glomerellaceae

- ***Colletotrichum* sp.**

Isolation : soil

Location : India

References : Mansotra et *al*. (2023)

F/Plectosphaerellaceae

G/*Acrostalagmus*

- *Acrostalagmus luteoalbus*

Isolation: soil

Location: Iran

References: Mohammadi and Amini (2015).

Incertae sedis

F/ Apiosporaceae

- ***Spegazzinia* sp.**

Isolation: stigmas

Location: Italy

Reference: Belfiori et *al*. (2021)

Hypocreales

F/Nectriaceae

G/Fusarium

- *Fusarium* sp.

Isolation: Stem, Soils, corms and roots of saffron plants

Location: China, India, Italy, China, Morocco

References: Xu and Ge (1990); Raj (2013); Hassan and Devi (2003); Hassan *et al*. (2003); Hussaini *et al.,* (2010); Farda et *al*. (2022); Mansotra et *al*. (2023); El Aymani et *al*. (2019).

- *Fusarium acuminatum*

Isolation: infected corms

Location: Iran

References: Vafaei and Darvishian (2022).

- *Fusarium avenaceum*

Isolation: symptomatic corms

Location: Morocco

References: Ourras et *al*. (2023).

- ***Fusarium bulbigenum*** Cke. And Mass var. *blasticola* (Rostr.)

Isolation: undetermined

Location: Japan

References: Yamamoto et *al*. (1954); Mizusawa (1923)

- *Fusarium culmorum*

Isolation: soil, corm, roots, rotted corm

Location: Morocco, China, Iran

References: El Aymani *et al.,* (2019); Xu and Ge (1990); Khaledi et al. (2020)

- *Fusarium fujikuroi*

Isolation: soil

Location: India

References: Mansotra et al. (2023)

- ***Fusarium moniliforme***

Isolation: undeterminate

Location: Spain, India, China

References: Ahrazem et *al*. (2010); Wani (2004); Mansotra et *al*. (2023)

- ***Fusarium moniliforme* var. *intermedium***

Isolation: rotten corm

Location: India

References: Dhar (1992); Sameer et *al*. (2018);

- ***Fusarium neocosmosporiellum***

Isolation: soil

Location: India

References: Mansotra et al., (2023)

- *Fusarium oxysporum*

Isolation: diseased and rotten corms, roots, soil

Locations: India, Italy, Morocco, Spain, Iran, Argentina, China

References: Wani (2004); Kumar (2018); Gupta and Vakhlu (2015); Shah and Srivastava (1984); Kalha et *al*. (2007); Gupta et *al*. (2011); Sud et *al*. (1999); wani et al. (2016, 2017); Shah et *al*. (2018); Hassan Mir et *al*. (2011); Gupta et *al*. (2020); Gupta et *al*. (2021); Najari et *al*. (2018); Saeedizadeh (2014); Najjar et *al*. (2017); Vafaei and Darvishian (2022); Bhagat et *al*. (2022); Khaledi et *al*. (2020); Khaledi et *al*. (2024); Cappelli (1994); Palmero *et al.* (2014); Belfiori et *al*. (2021); Bentata et *al*. (2017); El Aymani et *al*. (2019); Lahmass et *al*. (2021); Ourras et *al*. (2023) ; Lopez and Gomez-Gomez (2009); Rubio-Moraga *et al*. (2013); Galvarez et *al*., (2014); Federico et *al.* (1997); Caligiore-Gei et *al*. (2023) ; Wei et *al*. (2021); Mirghasempour et *al*., (2022b);Tian et *al*. (2022); Ren et *al*. (2023); Luo et *al*. (2023)

- ***Fusarium oxysporum* f. sp. *saffrani***

Isolation: saffron bulbs

Location: Italy

References: Palmero *et al.* (2014);

- ***Fusarium oxysporum* f.sp croci**

Isolation: undetermined

Location: Netherlands

References: Boerema and Hamers (1988, 1989)

- ***Fusarium oxysporum* f.sp tuberosi**

Isolation: infected corms.

Location: Spain

References: Castillo and Gómez-Gómez (2009);

- ***Fusarium oxysporum* f. sp. *glaïeuls***

Isolation: soil and roots, infected corms

Location: Italy; India, China

References: Di Primo et *al*. (2002); Shah and Srivastava (1984), Kalha et *al*. (2007), Gupta et *al*. (2011) ; Sud et *al*. (1999); Kumar (2018); Gupta and Vakhlu (2015); Xu and Ge (1990).

- *Fusarium oxysporum* f.sp gladioli

Isolation: on soil and roots.

Location: Netherlands, Japan, Germany, Italy; India

References: McClelland (1945);Yamamoto et *al*. (1954); Mes et *al*. (1994); Cappelli (1994); Capelli and Di Minco (1998); Di Primo and Cappelli (2000); Primo et *al*. (2002); Hassan Mir et *al*. (2011); Di Primo et *al*. (2002); Gupta et *al*. (2011);

- *F. oxysporum* f. sp. *lycopersici*

Isolation : soil

Location : India

References : Mansotra et *al*. (2023)

- ***F. equiseti***

Isolation: rotten corms

Location: India, China

References: Shah et *al*. (2018); Wani (2004); Ahmed and Sagar (2006); Wei et *al*. (2021)

- *F. pallidoroseum*

Isolation: rotten corms

Location: India

References: Wani (2004); Ahmed and Sagar (2006); Shah et *al*. (2018).

- *Fusarium solani*

Isolation: infected corms, soil, corms, roots

Location: India, China, French; Italy; Spain;

References: Kumar (2018); Gupta and Vakhlu (2015); Gupta et *al*. (2011); Sud et *al*. (1999) ; Shah and Srivastava (1984); Hassan and Devi (2003); Kalha et al. (2007); Razdan et al. (2018); Ahmed and Sagar (2006); Wani (2004); Shah et *al*. (2018); Vafaei and Darvishian (2022); Hassan Mir et *al*. (2011); Mansotra et *al*. (2023);Tian et *al*. (2022); Madan et *al*. (1967); Rubio-Moraga et *al*. (2013).

- ***Fusarium roseum***

Isolation: isolated from rotten bulb; roots, soil

Location: China, Morocco

References: Xu and Ge (1990); El Aymani et *al.* (2019)

- ***Fusarium proliferatum***

Isolation : corm, root

Location : Iran

References : Khaledi et *al*. (2020)

- ***Fusarium culmorum***

Isolation: corm, root

Location: Iran

References: Khaledi et *al*. (2020);

- *F. graminearum*

Isolation: corm, root

Location: Iran

References: Khaledi et *al*. (2020);

- ***Fusarium acuminatum***

Isolation: infected corms

Location: Iran

References: Vafaei and Darvishian (2022)

- ***Fusarium nirenbergiae***

Isolation: symptomatic corms tissues, rotted area on the corm

Location: China

References: Mirghasempour et *al*. (2022a);

- ***F. commune***

Isolation: root, rotten area of saffron corm

Location: China

References : Mirghasempour et *al*. (2022a,b)

- ***F. annulatum***

Isolation: root, symptomatic corms of *Crocus sativus*

Location: China

References: Mirghasempour et *al*. (2022a,b)

- ***Gibberella moniliformis***

Isolation: Soil

Location: India

Reference: Mansotra et *al*. (2023)

- ***Ilyonectria* sp.**

Isolation: Corm

Location : Italy

Reference : Belfiori et *al*. (2021)

- ***Ilyonectria macrodidyma***

Isolation: soil

Location : China

References : Shuwen et *al*. (2019)

- ***Fusicolla***

Isolation: rotting corms

Location: China

References: Ren et *al*. (2023)

Cl/Mortierellomycetes

O/Mortierellales

F/Mortierellaceae

Mortierella

- *Mortierella alpina*

Isolation: soil

Location : India

References : Wani et al., 2016 ; 2017

- ***Mortierella humilis***

Isolation: soil

Location: China

References: Shuwen et al. (2019)

F/Hypocreaceae

G/Trichoderma

- *Trichoderma* sp.

Isolation: corms, roots, soil, stem leaves

Location: China, Morocco, India, Italy

References: El Aymani et al. (2019); Ourras et al. (2023); Raj (2013) ; Belfiori et *al*. (2021).

- *Trichoderma asperellum*

Isolation: saffron fields

Location: India

References: Gupta et *al*. (2020)

- *Trichoderma harzianum*

Isolation : soil

Location : China

References : Mansotra et *al*. (2023)

F/Cordycipitaceae

Beauveria

- ***Beauveria* sp.**

Isolation: Healthy corm, infected corms

Location: Spain, Morocco

References: Ahrazem et *al*. (2010); Ourras et *al*. (2023); Lo´pez and Go´mez-Go´mez (2009)

Parengyodontium

- *Parengyodontium album*

Isolation: corm

Location: Italy

References: Belfiori et *al*. (2021)

Acremonium

- *Acremonium* sp.

Isolation: Healthy corms

Location: Morocco

Reference: Ourras et *al*. (2023)

- *Acremonium alternatum*

Isolation: Infected corms

Location: India

References: Wani et al. (2016; 2017).

O/Microascales

F/Microascaceae

Graphium

Isolation: Healthy and rotted corms

Location: China

References: Ren et *al*. (2023)

O/Sordariales

F/Chaetomiaceae

Ovatospora

- *Ovatospora brasiliensis*

Isolation: stigmas

Location: Italy

Reference: Belfiori et al. (2021)

- *Humicola*

Isolation: Rotted corm

Location: China

Reference : Ren et *al*. (2023)

Cl/ Saccharomycetes

O/Saccharomycetales

F/Dipodascaceae

Geotrichum

- Geotrichum candidum

Isolation: soil

Location: India

References: Mansotra et *al*. (2023)

F/ Debaryomycetaceae,

- ***Meyerozyma caribbica***

Isolation: Corm, stem

Location: Italy

References: Belfiori et *al*. (2021)

Phylum: MUCOROMYCOTA

Cl/Mucoromycetes

O/Mucorales

F/Mucoraceae

Mucor

- ***Mucor* sp.**

Isolation: corm

Location: India

References: Shah *et al*. (2018); Wani (2004); Ahmed and Sagar (2006)

- ***Mucor fragilis***

Isolation : tepals, stigmas

Location : Italy

References*:* Belfiori et *al*. (2021)

- ***Mucor circinelloides***

Isolation: corms, soil

Location: Italy, India

References: Belfiori et *al*. (2021); Mansotra et *al*. (2023).

F/ Rhizopodaceae

Rhizopus

- Rhizopus nigricans

Isolation: infectd corm

Location: Spain, Morocco

References: Ahrazem et *al*. (2010); Rubio-Moraga et *al*. (2013); Lamhass et *al*. (2021).

- ***Rhizopus oryzae***

Isolation: rotted saffron bulb, soil, corms and roots; stem and leaves.

Location: China, Morocco; Italy

References: Xu and Ge (1990); El Aymani et *al*. (2019); Chamkhi et *al*. (2018); Ourras et *al*. (2023), Belfiori et *al*. (2021);

- ***Rhizopus stolonifer***

Isolation: Infected saffron

Location: Iran

References:Najari al. (2018); Saeedizadeh (2014, 2016)

Cl/Mortierellomycetes

O/Mortierellales

F/Mortierellaceae

Mortierella

- *Mortierella alpina*

Isolation: soil

Location : India

References : Wani et *al*. (2016, 2017)

- ***Mortierella humilis***

Isolation: soil

Location : China

References : Shuwen et *al*. (2019)

Cl/ Orbiliomycetes

O/ Orbiliales

F/ Orbiliaceae

- ***Monacrosporium* sp.**

Isolation: on soil and roots.

Location: Morocco

References: Bentata et al. (2017)

Phylum Basidiomycota

Cl/Agaricomycetes

O/Agaricales

F/ Typhulaceae

Sclerotium

- *Sclerotium crocophilum*

Isolation: indeterminate

Location: France

Reference: Bastiou (1872)

- *Sclerotium rolfsii*

Isolation: rotten corm

Location: India

References: Kalha *et al.* (2007); Shah et *al*. (1984); Gupta et *al*. (2011); Sud et al. (1999); Razdan et *al*. (2018)

O/ Cantharellales

F/ Strophariaceae

Rhizoctonia

- ***Rhizoctonia* sp.**

Isolation: stem, corm, diseased saffron bulb

Location: India, France; Italy; Romania

References : Razdan et al. (2018); Wani et al. (2016); Kumar (2018); Gupta and Vakhlu (2015), Raj (2013); Thakur et al. (1992); Hassan and Devi (2003); Shah et al. (1984); Madan et al. (1967); Carta et al. (1982); Ionita et al. (1995).

- ***Rhizoctonia solani***

Isolation: undetermined

Location: southern France, India

References: Duhamel (1728), Hassam Mir et *al*. (2011);

- *Rhizoctonia crocorum*

Isolation: roots, corm

Location: France, Italy, Spain, Romania, India, Greece

References: Alarcon and Sanchez (1968); Bastiou (1972); Madan et *al*. (1967); Carta et *al*. (1982); Ionita et *al*. (1995); Thakur et al. (1992); Hassan and Devi (2003).

- ***Rhizoctonia violacea***

Isolation: soil, corms

Location: France, Italy, Spain, Morocco

References: Bastiou (1872); Voglino (1905); Nannizzi (1941); Pérez-Bueno (1995); De Andrés (1998); Bentata et al. (2017).

- ***Rhizoctonia violacea* var. *crocorum***

Isolation: undetermined

Location: Italy

References: Nannizzi (1941)

Phylum : **Oomycota**

Cl /Peronosporea

O/Peronosporales

F/Pythiaceae

Pythium

- *Pythium* spp.

Isolation: rotten saffron bulbs

Location: Netherlands, France, Italy, India, Romania

References: Schenk (1969); Madan et *al*. (1967); Carta et *al*. (1982); Thakur et *al*. (1992); Hassan and Devi (2003); Ionita et al. (1995).

- *Phytium irregular*

Isolation: root

Location: Netherlands

Reference: Van Os et al. (998)

F/Peronosporaceae

- *Phytophthora* sp.

Isolation: saffron stems and corm

Location: India

References: Raj (2013); Hassan Mir et al. (2011)

DISCUSSION

The check-list includes the names, isolation source, location and references of about 130 microfungi that are assigned to 18 ordre within 11 Classes (Eurotiomycetes, Leotiomycetes, Dothideomycetes, Mucoromycetes, Mortierellomycetes, Agaricomycetes, Saccharomycetes,Tremellomycetes, Orbiliomycetes, and Peronosporea) and 4 phylums Ascomycota, Mucoromycota**,** Basidiomycota, and Oomycota.

The Ascomycota is represented by 72 species divided into 34 genera and 21 families. Within the Ascomycota, at the order level, Eurotiales had the greatest number of species (42 species) followed by Hypocreales (39 species) and the most dominant genera were Fusarium, Penicillium (16 species) and Aspergillus (15 species). Based on the number of species, Fusarium genus should rank first, it displays a great richness with 30 species.

Through concerted endeavors of mycologists and plant pathologists, past surveys on phytopathogenic fungal identification and diagnosis of saffron disease have served as the basis of reviews considered as a mini and specified list of saffron-colonizing fungal organisms (Gupta et al., 2011; 2021) listing more than 23 species associated with diseased saffron plants. Within the category of plant pathogenic fungi, the fusarioid species like *F. nirenbergiae, F. annulatum,* and *F. commune* (Mirghasempour et al., 2022a) as well as *F. avenaceum* (Ourras et al., 2023) were newly introduced in existing databases as for *P. solitum*, encountered in China and recognized as new pathogens on saffron plants (Zhang et al., 2020).

New taxa from Iran were also inventoried among the saffron-cormosphere mycobiota such as *Talaromyces versatilis*, *T. aurantiacus* (Vardasbi et al., 2020) and

Talaromyces cecidicola in Italy by Belfiori et al., (2021). Mycological contributions of Taheri et al., (2020) conducted on saffron in Hamadan province have characterized 7 endophytic species belonged to the Ascomycota group among them Aspergillus europaeus which was retrieved for the first time from this host in Iran and in the world. Opposing the fact that *A. europaeus* is commonly known as soil inhabiting fungi, the research work of Belfiori et al., 2021 approved the findings of Taheri related to A. europaeus. The Aspergillus genus's noteworthy representation on saffron corm, rhizospheric soil was assigned by 15 species following Penicillium genus with 14 species

Moreover, it is worthy the biodiversity of soil mycobiota in saffron grown fields given the limited number of taxa listed. In Morocco, members of 5 genera including Fusarium, Penicillium, Trichoderma, Rhizopus and Aspergillus were isolated (El Aymani et al., 2019). Along this checklist, a few species are the outcome of studies conducted by Mansotra et al. (2023) who report 12 species among them four fusarioid species (*F. oxysporum*, *F. solani*, *F. fujikuroi*, *F. neocosmosporiellum* and *Fusarium* sp.), *Trichoderma* sp., *T. harzianum* and Colletotrichum, *Aspergillus flavus*, *Geotrichum candidum*, *Mucor circinelloides*, *Gibberella moniliformis*, and *Fusarium* sp., This indicates that there are numerous gaps in describing fungal diversity in soil saffron fields. In comparison, we can talk about compositional differences of soil mycobiota endorsed by Victorino et al., (2021) who have used metagenomic analysis to explore the soil fungal communities associated with alpine field-grown Saffron (*Crocus sativus* L.). These authors determined other taxa at the level genus Fusicolla, Blumeria, Colletotrichum, Curvularia, Gibberella, Leptosphaeria, Plectosphaerella, Ramularia, Stigmina.

CONCLUSION

This document constitue the first inventory of fungal species inhabiting saffron rhizosphere, soil and plant parts of Crocus sativus on which some cause plant diseases. The current checklist can be used as a reference by mycologists to retrieve fungal species from existing culture banks in Morocco and aboard mentioned on the website. The study highlighted Aspergillus, Penicillium and Fusarium spp as major candidates for infesting corms and vegetatif parts of saffron. These species are considered to be the most prolific mycotoxigenic species (Bennett and Klich, 2003). This data provided in the Checklist will be useful in the compilation of fungal biodiversity on saffron agrosystem. But, the checklist will, not by any means, be a conclusive list and new records will continue to be added regularly in the future.

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Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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