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The current status of *Saprolegniales* in Iran: calling mycologists for better taxonomic and ecological resolutions

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Abstract: *Saprolegniales* have been studying for nearly 150 years and have been recognized mainly as freshwater animal pathogens. Similar to the global trend, studies on *Saprolegniales* in Iran have mainly focused on their pathological aspects. Therefore, this review discusses the state of the art of *Saprolegniales* studies in Iran and pinpoints present deficiencies. More than 80% of Iranian studies have examined the impact of various plant extracts and other plant compounds on *Saprolegnia parasitica,* responsible for causing deadly diseases on fish species. On the other hand, recent taxonomic and ecological reports on *Saprolegniales* have addressed this topic in a more abstract manner. Finally, we give recommendations to how to more systematically study *Saprolegniales* in Iran. This review calls mycologists in Iran and elsewhere to study *Saprolegniales* more seriously and in a more coordinated manner.

Key words: Disease management, Diversity, Ecology, *Oomycota*, Systematics, Pathology

INTRODUCTION

The order *Saprolegniales* is one of the major lineages of oomycetes. Although members of *Saprolegniales* have been traditionally known as water molds, they adopt various lifestyles in both aquatic and terrestrial environments. From at least 13 established genera divided into three families, most are freshwater saprophytes frequently found in various freshwater ecosystems populating organic matter, mainly in the littoral zone. Among all freshwater taxa, the order also holds some of the most notorious aquatic animal pathogens, such as *Saprolegnia parasitica* Coker and *Aphanomyces astaci* Schikora which threaten the stability of freshwater ecosystems by causing highly destructive diseases (Hussein et al. 2013, Van Den Berg 2013, Svoboda et al. 2017). The fact that genera of *Saprolegniales* are rarely found in the terrestrial environment does not necessarily mean that non-aquatic members are unimportant. *Aphanomyces euteiches* Drechsler, for example, is one of the significant threats to a variety of legumes (Levenfors et al. 2003, Gaulin et al. 2007). More recently, the contribution of *Saprolegniales* in freshwater food webs has also attracted attention. It has been shown that *Saprolegniales* interact with different trophic levels of food webs through parasitic and/or saprophytic lifestyles, thus, probably altering its energy flow.

Although *Saprolegniales*, as stated above, constitute an oomycetes order of high commercial and ecological relevance, its diversity, pathogenicity, and ecological involvements are still unknown in many regions of the world. Therefore, in this study, we aim to evaluate the current status of *Saprolegniales* in Iran as one of the least studied countries in the world. Research areas which are most in the focus in Iran will be discussed and the latest discoveries will be reviewed accordingly. Then, we will touch upon some of the most enduring challenges faced by scholars who study *Saprolegniales*. Finally, some recommendations for future investigations will be presented. This review is important for Iranian mycologists as it aims to stimulate more systematic and ecologically-driven lines of research for *Saprolegniales* in Iran.

Saprolegniales are successful Saprophytes

Although *Saprolegniales* are mainly considered as “bad microorganisms” inducing various endemic diseases in aquatic animals (discussed in the following sections), most members impact their interconnected habitats positively. Freshwater ecosystems receive a large quantity of organic matter, mainly originating from the terrestrial environment. For example, a constant wave of plant and animal debris is being discharged into the freshwater environment, which peaks during autumn. Immediately, plant debris is being attacked mainly by freshwater fungi and oomycetes, with *Saprolegniales* in a leading rule. Recently, a few studies have shown that *Saprolegniales* colonize and then get engaged in the process of transformation and degradation of plant and animal debris deposited on the sediment surface of the

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littoral zone. Although studies suggest that *Saprolegniales* and fungi both engage in the degradation of cellulose-, hemicellulose-, and chitin-based compounds, interestingly, they behave differently toward lignin- and lignin-like molecules. *Saprolegniales* lack the ligninolytic capability, which points to an ecological partitioning between them and true fungi, as robust lignin degraders (Sigoillot et al. 2012, Armand et al. 2020) (Fig. 1).

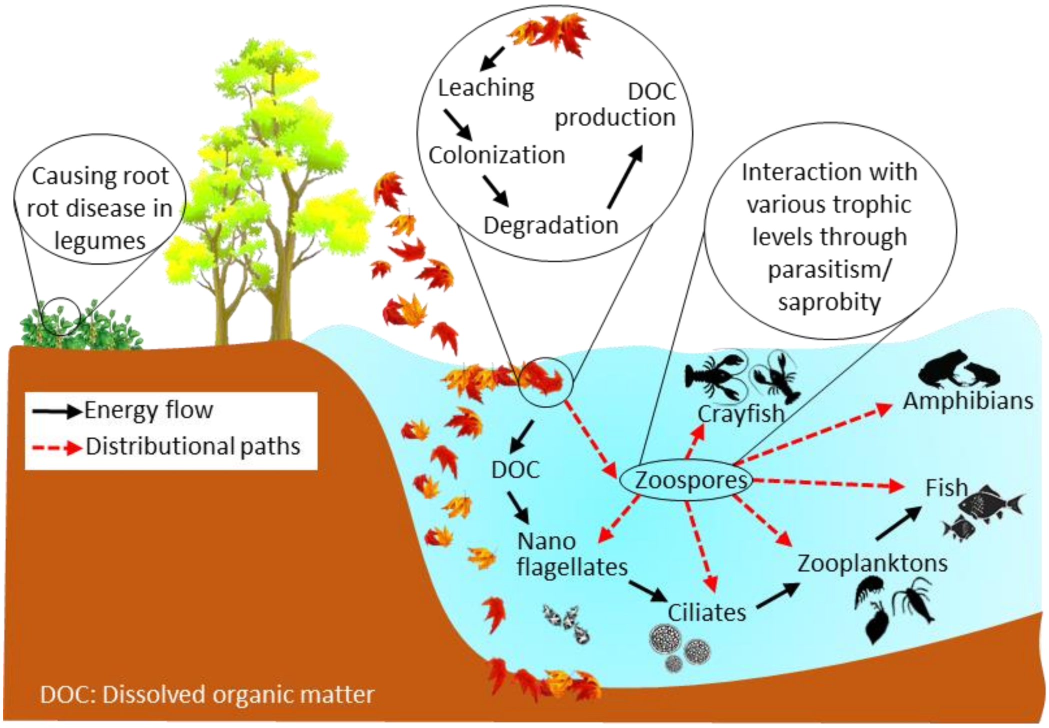

Fig. 1. Depicting contributions of *Saprolegniales* in both aquatic and terrestrial environments.

Pathogenicity of *Saprolegniales*

The order *Saprolegniales* is an exceptional lineage among other oomycete lineages and other eukaryotic life forms as it encompasses both plant and animal obligate parasites. Such a feature naturally implies a very complicated evolutionary history of the *Saprolegniales*, resulting in the acquisition of two completely contrasting lifestyles, *i.e.*, plant and animal parasitism, among taxa (Jiang et al. 2013). Crayfish plague, caused by *A. astaci*, is a severe disease widely distributed across European countries (Holdich et al. 2003). In fact, *A. astaci* is suggested as the most dangerous threat to local European crayfish communities. Another syndrome caused by the *Aphanomyces* species complex is called epizootic granulomatous aphanomycosis (EGA; previously known as aphnomycosis) causes life-threatening lesions in many fish species (Kamilya et al. 2014). The next is *Saprolegnia parasitica* which is probably a poster child for *Saprolegniales*. It causes saprolegniosis against many fish and amphibian species. The symptom of saprolegniosis includes cotton-like growths on the skin and gills, depigmented skin, and sunken eyes. However, as stated above, *Saprolegniales*, or the genus *Aphanomyces* to be more specific, contains a severe plant pathogen too. *Aphanomyces euteiches* causes aphanomyces root rot or common root rot of legumes such as pea (*Pisum sativum* L.) and alfalfa (*Medicago sativa* L.), as two of the main commercial crops mainly in North America, China, India, Australia, and some European countries (Wu et al. 2018).

The symptoms include chlorosis of leaflets in infected seedlings, gray and water-soaked roots and stems which turn light to dark brown, and stunted seedlings (Fig. 2). *Saprolegniales* are also thought to be potential parasites of protists such as cilliatesin freshwater ecosystems. In a few isolated cases, *Aphanomyces* spp. also cause substantial selective pressures in natural *Daphnia* spp. populations (Wolinska et al. 2008). Such a parasitic interaction is important because Daphnia is a keystone species in the freshwater microbial loop that plays an essential role in the energy flow being circulated among prokaryotic and eukaryotic communities (Cuenca et al. 2018) (Fig. 1).

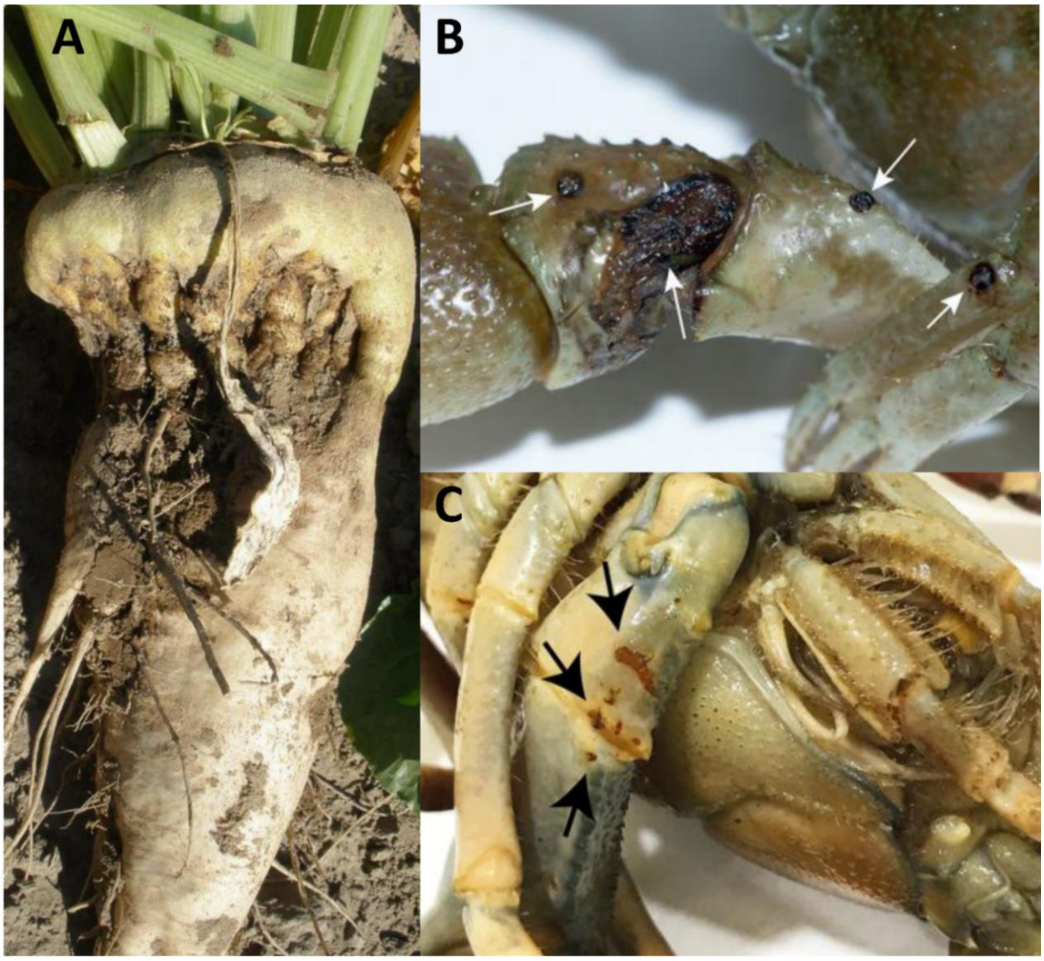

Fig. 2. Symptoms caused by pathogenic *Saprolegniales*. (A) Aphanomyces root rot (*Aphanomyces cochlioides*) external symptoms on mature beet (Photograph by Oliver T. Neher, The Amalgamated Sugar Company, Bugwood.org), (B) and (C) Strong immune reaction, i.e., melanin formation, against infection by *Aphanomyces astaci* visualized as large melanized patches (arrows) on the joint of a chela, and also on a walking leg of *Austropotamobius pallipes* and *Pacifastacus leniusculus* (from Martin-Torrijo et al. 2017; 2018, with permission).

The current status of *Saprolegniales* in Iran

Saprolegniales are infrequently studied in Iran concerning their taxonomy and ecology, similar to other countries worldwide. We found nearly 60 scientific publications published in local and international peer-reviewed journals which dealt with a few aspects of *Saprolegniales*' biology. Most papers have studied the effects of plant extracts on *Saprolegnia parasitica*. Also, the identification and taxonomic position of isolated strains have been studied in some regions. Although ecological contributions of *Saprolegniales* in freshwater ecosystems have been recently received more attention, it is far from being satisfactory. The most important results from these studies will be highlighted in the following paragraphs.

Taxonomy of *Saprolegniales* in Iran

In general, providing a clear taxonomic description of *Saprolegniales* has rarely been conducted in Iran. Nearly all strains have been isolated from fish species (Table 1). Mousavi et al. (2007; 2009) reported *S. parasitica*, *S. mixta* de Bary, *S. monilifera* de Bary, *Achlya oblongata* de Bary, and *Brevilegnia* sp. from affected eggs of the rainbow trout (*Oncorhynchus mykiss*) in Mazandaran Province. *Saprolegnia parasitica*, *S. lapponica* Gäum., *S. ferax* (Gruith.) Kütz., *S. hypogyna* (Pringsh.) Pringsh. and *S. diclina* Humphrey were also isolated as contaminants in rainbow trout eggs in Kermanshah Province (Shahbazian et al. 2010). In two other studies, *Saprolegnia* strains were isolated from rainbow trout eggs and broodstocks in three hatcheries in western Iran (Fadaeifard et al. 2011). Chiasi et al. (2012) and Azizi et al. (2014) also isolated *Saprolegnia* sp. from Caspian kutum (*Rutilus frisii kutum*) eggs and Caspian trout (*Salmo trutta caspius*) skinin Mazandaran Province, respectively. Based on physiological and molecular data, Ghiasi et al. (2013; 2014) also characterized *Saprolegnia* sp. isolates from Persian sturgeon (*Acipenser persicus*), Caspian trout (*Salmo trutta caspius*), and rainbow trout (*O. mykiss*) and showed that some features such as repeated zoospore emergence in *Saprolegnia* could be correlated to the pathogenicity of strains. Additionally, *Saprolegnia* sp. strains were reported from Minnows and Carps in Golestan province (Sharifpour et al. 2014). Nekuie Fard et al. (2011), Khodadadi et al. (2014), and Ghorbani & Azadikhah 2019 considered *Saprolegnia* sp. and *Achlya* sp. strains as one of the reasons responsible for a massive decline in the population of the Danube crayfish (*Astacus leptodactylus*) as well as larval and adult Rainbow trout (*O. mykiss*) in West Azerbaijan Province. Oscar fish (*Astronotus ocellatus*) is another host with typical symptoms of saprolegniosis caused by *Achlya* sp. strains in Khuzestan Province (Peyghan et al. 2019).

Table 1. List of *Saprolegniales* reported from Iran provinces.

Taxon	Substrates*	Location	Reference
Achlya americana Humphrey			
	Decayed twigs, leaves, woods and infected spawns	Fars and Kermanshah	Bolboli & Mostowfizadeh-Ghalamfarsa 2019
A. bisexualis Coker and Couch			
	Typha spp.	Gilan (Anzali lagoon)	Masigol et al. 2020
Achlya oblongata de Bary			
	Rainbow trout eggs	Mazandaran	Mousavi et al. 2007, 2009
***Achlya* sp.**			
	Galician crayfish	West Azerbaijan	Ghorbani & Azadikhah 2019
	Oscar fish	Khuzestan	Peyghan et al. 2019
	Rainbow trout eggs	Mazandaran	Mousavi et al. 2007, 2009
	Typha spp.	Gilan (Anzali lagoon)	Masigol et al. 2020
***Brevilegnia* sp.**			
	Rainbow trout eggs	Mazandaran	Mousavi et al. 2007, 2009
***Dictyuchus* sp.**			
	Typha spp.	Gilan (Anzali lagoon)	Masigol et al. 2018
Saprolegnia* aff. *australis R.F. Elliott			
	Decayed twigs, leaves, woods and infected spawns	Fars and Kermanshah	Bolboli & Mostowfizadeh-Ghalamfarsa 2019
S. anisospore de Bary			
	Typha spp.	Gilan (Anzali lagoon)	Masigol et al. 2020
S. anomala Gandhe & Kurne			
	Decayed twigs, leaves, woods and infected spawns	Fars and Kermanshah	Bolboli & Mostowfizadeh-Ghalamfarsa 2019
S. diclina Humphrey			
	Rainbow trout eggs	Kermanshah	Shahbazian et al. 2010
	Typha spp.	Gilan (Anzali lagoon)	Masigol et al. 2020
S. ferax (Gruith.) Kütz.			
	Decayed twigs, leaves, woods and infected spawns	Fars and Kermanshah	Bolboli & Mostowfizadeh-Ghalamfarsa 2019
	Rainbow trout eggs	Kermanshah	Shahbazian et al. 2010
	Typha spp.	Gilan (Anzali logoon)	Masigol et al. 2020
S. hypogyna (Pringsh.) Pringsh			
	Rainbow trout eggs	Kermanshah	Shahbazian et al. 2010
S. lapponica Gäum			
	Rainbow trout eggs	Kermanshah	Shahbazian et al. 2010

Table 1. Continued.

Taxon	Substrates*	Location	Reference
S. mixta de Bary			
	Decayed twigs, leaves, woods and infected spawns	Fars and Kermanshah	Bolboli & Mostowfizadeh-Ghalamfarsa 2019
	Rainbow trout eggs	Mazandaran Province	Mousavi et al. 2007, 2009
S. monilifera de Bary			
	Rainbow trout eggs	Mazandaran Province	Mousavi et al. 2007, 2009
S. parasitica Coker			
	Rainbow trout eggs	Kermanshah	Shahbazian et al. 2010
	Typha spp.	Gilan (Anzali lagoon)	Masigol et al. 2020
***Saprolegnia* sp.**			
	Bighead carp	Golestan	Sharifpour et al. 2014
	Caspian kutum eggs	Mazandaran	Chiasi et al. 2012
	Caspian trout	Mazandaran	Chiasi et al. 2013, 2014
	Caspian trout skin	Mazandaran	Azizi et al. 2014
	Danube crayfish	West Azerbaijan	Nekuie Fard et al. 2014
	Eurasian carp	Golestan	Sharifpour et al. 2014
	Galician crayfish	West Azerbaijan	Ghorbani & Azadikhah 2019
	Grass carp	Golestan	Sharifpour et al. 2014
	Persian sturgeon	Mazandaran	Chiasi et al. 2013, 2014
	Rainbow trout brood stock and eggs	Farms in western Iran	Fadaeifard et al. 2011
	Rainbow trout eggs	Mazandaran	Mousavi et al. 2007, 2009; Chiasi et al. 2013, 2014
	Rainbow trout	West Azerbaijan (Hasalno dam)	Khodadadi et al. (2014)
	Silver carp	Golestan	Sharifpour et al. 2014

*Bighead carp (*H. nobilis*); Caspian kutum (*Rutilus frisii kutum*); Caspian trout (*Salmo trutta caspius*); Danube crayfish (*Astacus leptodactylus*); Eurasian carp (*Cyprinus carpio*); Galician crayfish (*Astacus leptodactylus*); Grass carp (*Ctenopharyngodon idella*); Oscar fish (*Astronotus ocellatus*); Persian sturgeon (*Acipencer persicus*); Rainbow trout (*Oncorhynchus mykiss*); Silver carp (*Hypophthalmichthys molitrix*)

As the studies mentioned above mainly focused on the pathogenic features of *Saprolegniales*, they rarely gave detailed morphological descriptions to identify strains in the species level accurately. Also, phylogenetic studies, i.e., using sequences to determine the relationship between strains, were almost lacking in all cases (Jeronimo et al. 2015). However, in three cases, a fair improvement has been obtained by giving precise morphometric features and running phylogenetic analysis using ITS and *cox1* sequences. Several *Dictyuchus*, *Saprolegnia*, and *Achlya* spp. strains were isolated from decaying leaves of the dominant local vegetation (*Typha* spp.) collected from the Anzali lagoon in Northern Iran and then morphologically and phylogenetically characterized. Although *Dictyuchus* sp. strains were believed to be a new combination, it remained unclear due to the unavailability of suited reference sequences (Masigol et al. 2018; 2020). In another similar study, Bolboli and Mostowfizadeh-Ghalamfarsa (2019) isolated, described and identified *Saprolegniales* strains from brown decayed twigs, leaves, woods and infected spawns in Fars and Kermanshah Provinces (Southern and Western Iran). In addition to morphologically and phylogenetically identification of six *Saprolegnia* and one *Achlya* species, several strains were not related to any of the previously reported taxa, promising two new *Saprolegnia* species. In their study *S. anomala* Gandhe & Kurne, *S. mixta*, and *A. americana* Humphrey were found new to Iran's mycobiota.

The effect of plant extracts on *Saprolegnia* spp.

In parallel with getting more awareness toward diseases caused by *Saprolegnia* species, controlling strategies were studied to minimize damages to fishes and other aquatic animals. Previously, Malachite green was one of the most common chemicals for controlling saprolegniosis caused by *Saprolegnia* species. However, the application of Malachite green is currently prohibited in many countries due to its carcinogenic nature (Culp et al. 2006). Therefore, scientists have been searching for less dangerous chemicals to control saprolegniosis. Examining safer chemicals, natural compounds such as plant extracts, and biological agents to control the disease have so far been the main research topics in Iran.

Most studies regarding disease management of *S. parasitica* started after Jalilpoor et al. (2006), who reported 7% to 22% mortality of *Acipenser persicus* (Persian sturgeon) eggs during mass incubation at a hatchery in Iran. Regarding plant extracts, several candidates have already been introduced. Mousavi et al. (2006) tested the inhibitory effect of *Eucaliptus camaldolensis* extract on *S. parasitica* leading to better protection of trout's (*O. mykiss*) eggs. In another study, *S. parasitica* showed a high sensitivity to methanolic extracts from the plant *Citrullus colocynthis* (Azizi 2012). Also, Sharifi et al. (2012) reported that a hydroalcoholic extract of the oak placenta could help to prevent Saprolegnia's growth compared to Malachite green. *Zataria multiflora* and *E. camaldolensis* essential oils effectively treated *S. parasitica*-infected rainbow trout (*O. mykiss*) eggs in the aquaculture environment (Khosravi et al. 2012). Multiple other extracts have been proposed as inhibitors of *S. parasitica*: feverfew (*Tanacetum parthenium* (L.) Sch. Bip.) and horse mint (*Mentha longifolia* (L.) Huds.) (Ghasemi Pirbalouti et al. 2009), cashew (*Anacardium occidentale* L.) (Akhlaghi and Bahaedini 2012), common rue (*Ruta graveolens* L.) (Hashemi Karouei et al. 2012), *Artemisia* sp. (Firouzbakhsh et al. 2014), common nettle (*Urtica dioica* L.) (Firouzbakhsh et al. 2015, Alishah et al. 2019, Mehrabi et al. 2020), myrtle (*Myrtus communis* L.) (Salimian et al. 2015), peppermint (*Mentha balsamea* L.) (Hooshangi et al. 2016, Adel et al. 2017), cumin (*Cuminum cyminum* L.), watling street thistle (*Eryngium campestre* L.) (Adel et al. 2020), garden thyme (*Thymus vulgaris*), oregano (*Origanum vulgare* L.) (Golchin et al. 2017, Pazira 2017, Shahrani et al. 2018), aloe vera (*Aloe vera* (L.) Burm f.) (Mehrabi et al. 2017, Mehrabi et al. 2019), clove (*Syzygium aromaticum* (L.) Merr. & L.M.Perry), lavender (*Lavandula spica* L.) (Jookar et al. 2019), chamomile (*Matricaria chamomilla* L.) (Amiri and Meshkini 2019), ajwain (*Trachyspermum ammi* (L.) Sprague ex Turrill) (SavadKouhi et al. 2021), and lemon balm (*Melissa officinalis* L.) (Ggonani and Taghavizad 2021).

To a lesser extent, the application of other chemicals and biological agents such as bacteria have also been studied in several cases. For example, Abtahi et al. (2006) suggested that potassium permanganate is safer than Malachite green and formalin at a given relative concentration to control saprolegniosis in *Acipenser persicus* egg incubation. Other chemicals such as sodium chloride (Khodabandeh and Abtahi 2006), powdered silver zeolite (Johari et al. 2014), fructooligosaccharide (Firouzbakhsh et al. 2014a), colloidal silver nanoparticles (AgNPs) (Johari et al. 2015, Shokouh Saljoghi et al. 2018), zinc oxide nanoparticles (Sedighi et al. 2015), copper nanoparticles (Kalatehjari et al. 2015), and stabilized hydrogen peroxide (Salah et al. 2021) have shown to be effective as well. Additionally, biological agents such as *Pseudomonas huorescence* (Akhlaghi and Bahaedini 2012) and *Pseudomonas aeruginosa* (Moghaddam et al. 2012) have an inhibitory effect against *S. parasitica*. Nevertheless, we need to address the question of the practicality of the abovementioned compounds because studies conducted in Iran have not yet entered the application phase, making the large-scale implementation of these compounds impossible. In contrast, supported by a better understanding of molecular mechanisms, other studies have successfully proven the industrial applicability owing to their immunostimulatory and anti-*Saprolegnia* activities (Caruana et al. 2012, Mostafa et al. 2020, Tandel et al. 2021).

Ecology of *Saprolegniales* in Iran

Ecology of *Saprolegniales* is the least studied aspect of this order in Iran and other countries. There is a long history of isolating *Saprolegniales* taxa from plant and animal debris, mainly from freshwater ecosystems across the world (Grossart et al. 2020). However, very little effort has been made to understand how *Saprolegniales* taxa interact with organic matter. Masigol et al. (2019) postulated that both fungi and *Saprolegniales* are involved in the degradation and transformation of organic matter as they both occupy organic matter populated habitats and share similar physiological features. They isolated *Saprolegniales* from Anazali lagoon and applied plate assay methods and liquid chromatography-organic carbon-organic nitrogen detection (LC-OCD-OND) experiments to determine whether/how/to what extent *Saprolegniales* are involved in carbon cycling in freshwater ecosystems. The authors conclude that *Saprolegniales* functions differently than true fungi due to their different enzymatic capabilities. However, the studies were limited to *Dictyuchus* and *Achlya* species only and hence this topic awaits further exploration. Also, the study revealed that *Saprolegniales* and fungi utilize low molecular weight compounds at different rates pointing to different ecological niches.

Challenges and recommendations for future investigations

As discussed in this review, the studies of *Saprolegniales* suffers from several shortcomings which can be also observed in studies of other oomycetes and fungi. Therefore, we recommended the following lines of research to compensate for such deficiencies and highlight the contribution of *Saprolegniales* to the diversity and functionality of various ecosystems (Fig. 3).

Taxonomic research

Firstly, extensive classic and modern taxonomic studies require a tremendous amount of work as identifying newly reported strains is largely hampered by: I) biased sampling mainly from animals such as fish, crayfish, and amphibian species in Europe and North America, II) lack of precise morphometric features, III) too much emphasis on ITS (internal transcribed spacers of rDNA) sequences, IV) many non-studied regions, V) presence of too many miss-assigned taxa, and VI) handling *Saprolegniales* strains mainly by non-mycologists. Therefore, we recommend intensifying sampling frequency from unexplored regions in the first step. Iran, for example, will be a promising sampling region due to a large variety of internationally and ecologically important freshwater ecosystems such as Anzali lagoon, Urmia lake, Gavkhuni Wetland, Karun River, and other numerous freshwater-related sites. It is expected to find many more previously unknown strains and explore the diversity of *Saprolegniales* (see Rezakhani et al. 2019 for fungal diversity). It will be vital to provide in-depth morphological descriptions and analyses to render them comparable to other studies and delineate taxa boundaries more accurately. Also, multigene phylogenetic studies should be given priority as the sole application of ITS sequences has not been as effective as expected to separate *Saprolegniales* taxa. Other regions such as *cox*1, *cox*2, and LSU have been promising a better resolution to phylogenetic relationships among *Saprolegniales* (Rocha et al. 2016; 2018). By following the above-mentioned activities, not only will currently unknown taxa be revised/removed, but a new combination will appear, leading to a better appreciation of *Saprolegniales* diversity in various Iranian habitats. We are confident of such an improvement in *Saprolegniales* taxonomy as adopting in-depth morphological and multigene phylogenetic studies in its sister orders, *Peronosporales* and *Pythiales*, has completely changed our understanding of their hidden diversity (Kageyama et al. 2014, Scanu et al. 2021).

Diversity research

Studies on *Saprolegniales* have always been limited to culture-dependent methods, making large-scale diversity-based studies very hard to accomplish. Regardless of tremendous efforts to compensate culture-dependent methods' constraints in oomycetes (including *Saprolegniales*) and fungi (Põlme et al. 2020), high throughput sequencing (HTS) techniques can more efficiently and systematically determine the diversity of *Saprolegniales* in any given environment based upon millions of sequences. Unfortunately, not even one single study has ever studied the diversity of freshwater *Saprolegniales* using HTS, metagenomics, and long read sequencing techniques. That is how other important questions can be addressed (Singer et al. 2016). For instance, it will be much more feasible to check whether *Saprolegniales* communities start to shift as biotic and abiotic parameters of the environment are changed. In other words, finding any correlation between *Saprolegniales* communities and various ecosystem features will be possible. However, high-throughput sequencing techniques are expensive, time-consuming, and mostly unavailable in Iran. Indeed, more international collaborations make large-scale comparative studies of various Iranian freshwater ecosystems possible.

Disease management research

Although it has been shown that most plant extracts examined in Iranian studies are effective against *Saprolegnia parasitica*, no studies have gone tested the practicality of using such extracts in an industrial scale to control saprolegniasis. Therefore, the application of these active compounds against saprolegniasis must be given priority to avoid economic damages of *S. parasitica* in natural and farmed populations. Additionally, other diseases caused by *Saprolegniales* should be studied as well. For instance, we have an absolute lack of knowledge concerning the distribution and pathogenicity of *A. astaci* strains in Iran. This should be determined promptly, as endemic Iranian crayfish populations are distributed across the country and they are likely to get infected by virulent strains of *A. astaci*, with severe consequences for interconnected ecosystems. The same is valid with epizootic granulomatous aphanomycosis (EGA) in which the *Aphanomyces* species complex could attach fish species and eradicate local populations.

Ecological research

It has already been established that eukaryotes (fungi in particular) and their interaction with other life forms significantly contribute to global carbon cycling in both terrestrial and aquatic environments. It is predicted that *Saprolegniales* contributions are mainly facilitated through two separate paths. Some taxa have the potential to alter the energy flow at different trophic levels of food webs (De Souza et al. 2014). In addition to their impact on fish, crayfish, and amphibian populations, *Saprolegniales* are believed to interact with keystone planktonic organisms, resulting in altering the established equilibrium between keystone species in food webs (Buaya et al. 2019). Therefore, it is suggested to conduct pathosystem-based studies to determine how significantly *Saprolegniales* alter the genetic composition of different planktonic populations. Meanwhile, new species and genera of *Saprolegniales* will likely to be explored as they are rarely isolated from planktons.

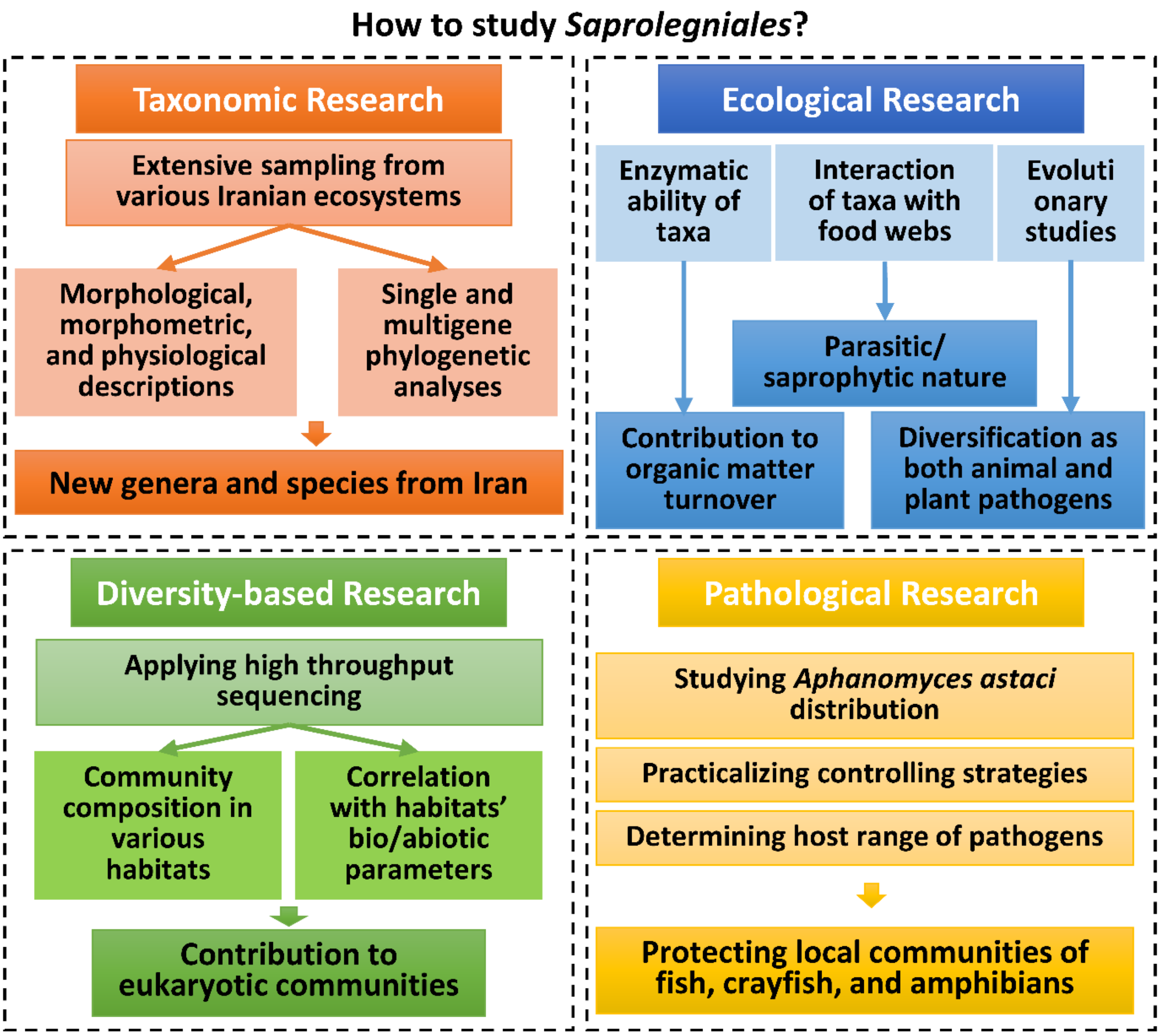

Fig. 3. Proposed avenues of *Saprolegniales* research in Iran.

An outlook

In this article, the current status of *Saprolegniales* in Iran was reviewed. Firstly, we showed that although taxonomical studies have reported several *Saprolegniales* taxa mainly from freshwater ecosystems, many Iranian water-dependent ecosystems have remained unexplored in terms of the diversity of *Saprolegniales*. Additionally, it was revealed that studying saprolegniosis management using plant extracts and other compounds has been the most focused research area in Iran for the last two decades with not much effort to make them practical for large-scale use in the fisheries industry. Finally, understanding the ecological contributions of *Saprolegniales* was spotted as the least studied research area, in spite of a few recent discoveries. Accordingly, we suggested five *Saprolegniales*-oriented research lines that Iranian mycologists are called to focus on, including I) highlighting practical disease management strategies (for both saprolegniosis and crayfish plague) with respect to ecological features of *Saprolegniales* pathogens, II) conducting extensive sampling from unexplored sites, III) providing in-depth morphological and phylogenetic characterization, and IV) evaluating the impact of *Saprolegniales* on the degradation of organic matter and its interactions with different trophic levels of any given food web, especially in freshwater ecosystems.

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وضعیت کنونی راسته ساپرولگنیالز در ایران: فراخوان قارچ‌شناسان برای دست‌یابی به وضوح بیشتر در آرایه‌بندی و بوم‌شناسی

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چکیده : قدمت مطالعه راسته ساپرولگنیالز به ۱۵۰ سال می‌رسد. طی این دوران، اعضای این راسته غالباً به عنوان عوامل بیماری‌زای موجود در آب شیرین شناخته شده‌اند. در ایران نیز جنبه‌های بیماری‌شناختی اعضای این راسته، هم‌سو با مطالعات جهانی، محور اصلی بیشتر پژوهش‌ها بوده است. از این رو، نقد حاضر تازه‌ترین پژوهش‌های صورت گرفته در ایران را بررسی کرده، به نارسایی‌های موجود می‌پردازد. ارزیابی ما نشان داد که تمرکز بیش از ۸۰ درصد از مقاله‌های منتشر شده در ایران روی اثر عصاره‌های گیاهی مختلف و دیگر ترکیبات گیاهی روی گونه‌ی *Saprolegnia parasitica* بیمارگر مهلک ماهیان، بوده است. از سوی دیگر، مشخص شد که پژوهش‌های ایرانی مربوط به آرایه‌بندی و بوم‌شناسی اعضای راسته ساپرولگنیالز به شکلی محدود انجام گرفته است. این نوشتار در نهایت برای مطالعه سازمان‌یافته این راسته در ایران پیشنهادهایی مطرح کرده است. در این مقاله از تمامی قارچ‌شناسان، به ویژه جامعه علمی قارچ‌شناسی ایران، دعوت شده است تا مطالعه راسته ساپرولگنیالز را جدی‌تر و با برنامه‌ریزی منسجم‌تر در دستور کار قرار دهند.

کلمات کلیدی: اُامیکوتا، بوم‌شناسی، بیماری‌شناسی، تنوع، سیستماتیک، مدیریت بیماری

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