Comparative study of the diversity of zoosporic fungi (oomycetes and chytrids) in freshwater bodies in Assiut Governorate, Egypt and Jeddah Governorate, Saudi Arabia

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The diversity, occurrence and regional distribution of heterotrophic straminipiles and true zoosporic fungi (oomycetes and chytrids) recovered from freshwater bodies in two geographically and ecologically distant regions, the governorates of Assiut, Egypt and Jeddah, Saudi Arabia, were extensively investigated and compared in this study. For this purpose, one hundred surface water samples were collected from different localities of freshwater bodies in each governorate during the period from January 2009 to March 2013. In addition, the correlation between physicochemical characteristics (temperature, pH, total soluble salts and organic matter content) of the samples as abiotic factors affecting the diversity and occurrence of zoosporic mycobiota were considered during this research.

The results indicate that Assiut Governorate is richer and more diverse in taxa of zoosporic fungi (22 identified and 3 unidentified species classified into 8 genera) than Jeddah Governorate (9 identified and 2 unidentified species belonging to 4 genera). The most dominant genera recovered from the samples were *Saprolegnia* and *Achlya*, but these genera showed various frequencies of occurrence. Generally, the majority of the prevalent isolated species of zoosporic fungi were different in the two regions, and identical genera and species showed clear differences in terms of occurrence and distribution.

An inverse correlation was revealed between the temperature of the samples and the diversity of isolated zoosporic fungal species. An inconsistent trend was found between the pH of the samples and species diversity: while the correlation was positive in Assiut Governorate, it was negative in Jeddah Governorate. The total soluble salts and organic matter content of the samples in the two governorates correlated positively with the diversity of isolated species.

Key words: occurrence, regional distribution, heterotrophic straminipiles, *Saprolegnia*, *Achlya*, *Allomyces*, water characteristics.

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V rámci této studie byl proveden extenzivní výzkum a srovnání diverzity, výskytu a rozšíření heterotrofních straminipil a pravých zoosporických hub (oomycet a chytridií), odebraných ze sladkých vod ve dvou geograficky i ekologicky vzdálených regionech – guvernorátech Asijút v Egyptě a Džidda v Saúdské Arábii. Za tímto účelem bylo v období od ledna 2009 do března 2013 odebráno v každém guvernorátu sto vzorků povrchových vod z různých lokalit. Mimoto byla v rámci dané studie zkoumána i korelace mezi fyzikálně-chemickými faktory, ovlivňujícími biodiverzitu (teplota, pH, obsah rozpustných solí a organické hmoty), a výskytem zoosporických hub.

Výsledky naznačují, že větší druhová bohatost a diverzita zoosporické mykobioty je v asijútském guvernorátu (22 určených a 3 neurčené druhy, spadající do 8 rodů) než v oblasti kolem Džiddy (9 určených a 2 neurčené druhy ze 4 rodů). Dominantními rody v odebraných vzorcích povrchových vod byly *Saprolegnia* a *Achlya*, nicméně zástupci těchto rodů vykazují značnou variabilitu ve frekvenci jejich výskytu ve vzorcích z uvedených dvou regionů. Obecně lze říci, že převládající druhy zoosporických hub se v daných regionech většinou dosti různí a v případě shodných rodů a druhů lze vidět zřetelné rozdíly v jejich výskytu a rozšíření.

Pokud jde o abiotické faktory, vychází negativní korelace mezi teplotou zkoumaných vzorků vody a diverzitou izolovaných druhů. Nejasný trend se ukazuje ve srovnání hodnot pH vody a druhové diverzity; zatímco v guvernorátu Asijút je korelace pozitivní, v guvernorátu Džidda je negativní. Naproti tomu celkový obsah rozpustných solí a organické hmoty má vždy kladný vliv na diverzitu zjištěných druhů.

INTRODUCTION

Zoosporic fungi are a polyphyletic group including taxa now known to have very diverse phylogenetic histories (Baldauf 2008, Gleason et al. 2017a). Zoosporic fungi are a term for both aquatic fungi and fungus-like organisms with motile spores (Dick 1989, Wong et al. 1998, Shearer et al. 2007). In modern classification, Straminipila, which are frequently found in the *Saprolegniales* and *Peronosporales* orders in the class of *Oomycetes*, are phylogenetically and systematically separated from the kingdom Fungi, whereas *Chytridiomycetes* and *Blastocladiomycetes* (traditionally regarded as chytrids in wide sense, although belonging to separate clades) are united into the kingdom Fungi (James et al. 2006, Thines et Kamoun 2010). Straminipila share many ecological functions and traits such as trophic strategies, morphological and physiological characteristics similar to true fungi (Alexopoulos et al. 1996, Wong et al. 1998, Beakes et al. 2014). In studies dealing with these groups together (oomycetes and chytrids) the common term 'zoosporic fungi' is used to cover both and to simplify the terminology (Czeczuga et Muszyńska 2004).

Zoosporic fungi are universally present in freshwater systems and are of great significance in the structural and functional organisation of these ecosystems. They play significant ecological roles in nutrient cycling and the biological processes in freshwaters such as water self-purification and energy transfer from allochthonous and autochthonous particles to other components of the food chain (Mil'ko 1983, Mil'ko et Zakharova 1984, Dudka et Vasser 1987, Gleason et al. 2017b). Zoosporic fungi are predominantly saprotrophs, but some species possess the ability to cause some economically important plant diseases (Gleason et al. 2017b) and to parasitise some other hydrobionts, causing epiphytoses and mycoses (Sigee 2005).

A recent estimate based on molecular evidence suggests a global fungal diversity of about 1.5 million species (Hawksworth et Lücking 2017). The current knowledge of fungal diversity is rather limited (Tedersoo et al. 2014) particularly in aquatic systems, where the number of described species is low (ca. 3000–4000 species) as compared to terrestrial fungi (Jones et al. 2014). Consequently, the number of newly discovered fungal species in aquatic systems is predicted to increase (Voigt et Kirk 2011). Gessner et Van Ryckegem (2003) suggested that there are ca. 20,000 different species of freshwater fungi, yet only ~5% of them have been described. Jones et al. (2014) reported that zoosporic fungi comprise more than 500 species of chytrids and members of fungus-like organisms. The documented overall species richness of freshwater fungi (<4200 species) suggests that there are still many freshwater habitats and substrates to be surveyed.

Changes in diversity and regional distribution of oomycetes and chytrids in aquatic environments may be affected by fluctuations in the physical and chemical characteristics of the water (Czeczuga et Muszyńska 2004, Pascoal et al. 2005, Paliwal et Sati 2009, Marano et al. 2011). Some authors (Misra 1982, Pires-Zottarelli 1990, Marano et al. 2008, Khallil et al. 2020) found that the highest frequency of zoosporic fungi was recorded at the lowest temperatures. Voronin (2008) points out that temperature is an important factor governing the development and occurrence of zoosporic fungi. With increasing temperature, the amount of dissolved oxygen decreases and consequently, the occurrence of fungi is impacted negatively. Previous studies on the dependence of zoosporic fungi distribution on water hydrogen concentrations have revealed that these organisms may be found in water bodies of variable pH values and that there are groups preferring acidic, neutral-alkaline and alkaline waters, although the species diversity of zoosporic fungi varies in these conditions (Lund 1934, Sparrow 1968, Batko 1975, Okane 1982). Sparrow (1968) and Gleason et al. (2010, 2017b) claimed that several zoosporic fungi withstand an increase or decrease in pH through the formation of resistant structures. An increase in salinity results in growth retardation, a decrease in biomass accumulation, and a disturbance in the reproductive functions. Zoosporic fungi can also tolerate higher salt concentrations at lower temperatures (Harrison et Jones 1971, Padgett et al. 1985). Concerning the influence of dissolved organic matter content (DOM) on the distribution of zoosporic fungi, most results predict that species richness increases with increasing DOM, but only if temperature and salt concentrations are relatively low (Iofina 1987).

Although many geographical regions on the globe have been investigated for the diversity and occurrence of zoosporic fungi in different freshwater habitats (e.g. Sparrow 1960, Karling 1977, Czeczuga et Proba 1987, El-Hissy et Khallil 1989a, Voronin 1989, Khallil 1990, El-Hissy et Oberwinkler 1999, Ali et Nasser 2001, Paul et Steciow 2004, El Androusse et al. 2006, Pandey et Singh 2006, Ali 2007, Marano et al. 2008, Farkha et Abdulrahman 2011, Dubey et al. 2016, Khallil et al. 2020, Masigol et al. 2020, and others), some freshwater resources have not yet been explored for zoosporic fungi. Only a small number of studies on the diversity, occurrence and regional distribution of zoosporic fungi have been conducted in freshwater bodies in Saudi Arabia, but none of them including the Jeddah region. Therefore this region was our choice for studying the diversity of zoosporic fungi also for the following reasons: (i) the ecology of these organisms has not been explored in the region; (ii) the Jeddah region is geographically distant and has habitats differing from the Assiut region, which makes it a suitable candidate to compare the diversity and occurrence of zoosporic fungi; (iii) our laboratories are situated nearby the sampling sites in both regions.

The main objective of the present work was thus to assess the diversity, occurrence and regional distribution of communities of saprotrophic oomycetes and chytrids inhabiting water bodies in two geographically and ecologically distant regions, Assiut Governorate, Egypt and, for the first time, Jeddah Governorate, Saudi Arabia. Another target of the study was to assess the correlation between physicochemical characteristics (temperature, pH, organic matter, and total soluble salts) of water samples as abiotic factors and the diversity and regional distribution of zoosporic fungal species in the two regions.

MATERIAL AND METHODS

Locations of the study, sampling sites.

Water sampling sites in Assiut Governorate, Egypt. Assiut Governorate (approx. 375 km south of Cairo) has an area of 25,926 km^2. It depends on water from the Nile for drinking and irrigation. The climate is arid, i.e. hot and dry in summer with mild winters.

The area was divided into 10 locations for the collection of freshwater samples, as shown in a map (Fig. 1A). They include Dairut, El-Qossiya, Manfalout, Abnub, Alfatth, Abo-Teg, Sahil Saleem, El-Badary, Sedfa and El-Ghanyeem. Small canals fed by the Nile were the source of collected water samples.

Water sampling sites in Jeddah Governorate, Saudi Arabia. Jeddah Governorate is located on the west coast of Saudi Arabia and has an area of approx. 1,765 km^2. It depends on water from the Red Sea for drinking. Jeddah's climate is directly affected by its geographical location where temperature and humidity rise during the summer.

Ten different sites in Jeddah Governorate, as shown in a map (Fig. 1B), were sampled. Seven sites (Wadi Kos, Wadi Merriykh, Al Mattar, Thowal, Industrial City, Asfan and Salman Gulf) were naturally

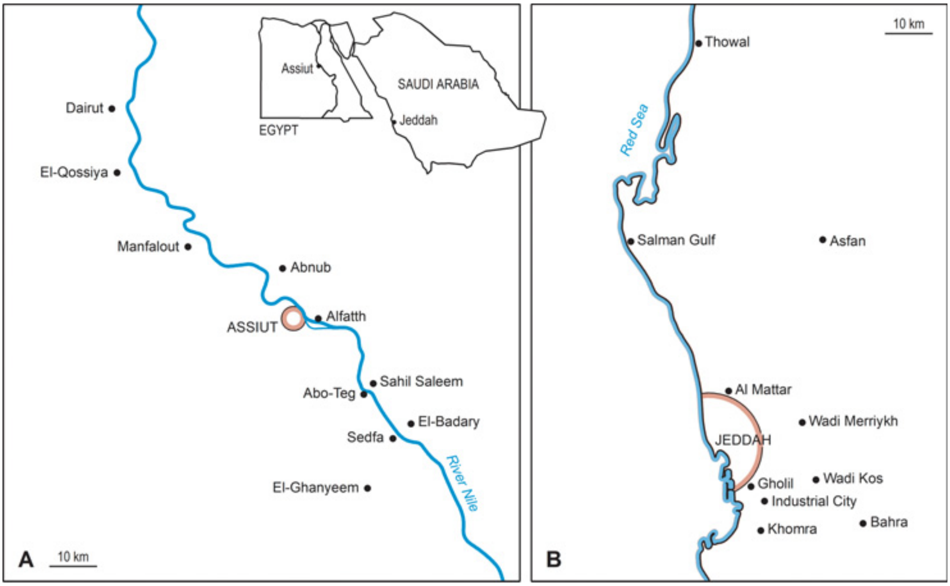

Fig. 1. Map showing the different sampling sites in Assiut (**A**) and Jeddah (**B**) Governorates.

formed ponds filled by rainfall, the other three sites (Khomra, Gholil and Bahra) were 8–10 metre deep water wells.

Surface water sampling. Over a period of more than four years, from January 2009 to March 2013, ten freshwater samples were collected at each of the above mentioned locations, i.e. 100 samples per governorate, 200 samples in total. No flora was observed at the margins of lotic or lentic water bodies or floating on their surface during the sampling throughout the study.

Each sample was collected in six clean, sterile glass bottles (500 ml each). Five of these contained eight sterilised, germinating sesame seeds each as bait material for zoosporic fungi (Khallil 1984). The sixth bottle did not contain sesame seeds and was used to estimate some physicochemical parameters of the samples. The samples were taken directly to the laboratory to investigate zoosporic mycobiota and to determine physicochemical factors.

Physicochemical characteristics of the samples. Water temperature was always measured and recorded at the time of sampling using a mercury thermometer. The pH value of the samples was determined using a pH-meter (model HORIBA B-112; Horiba, Kyoto, Japan) (Jackson 1958). The total soluble salt concentration was measured using a CyberScan CON 20 (Eutech Instruments, Singapore) with the electrodes immersed in the water. The organic matter content was determined following the Walkley and Black method (Jackson 1958). A volume of 50 ml of water was homogenised by chromic acid (for oxidation of organic matter to CO_2) and excess of chromic acid was back-titrated against ferrous sulphate solution using diphenylamine as indicator.

Mycological analysis.

Recovery of zoosporic fungi from the samples. For the recovery of zoosporic fungi including saprotrophic filamentous oomycetes and chytrids from the collected samples, the baiting technique was employed at 20±2 °C. Each sample containing baits of sesame seeds was poured under aseptic conditions into 5 Petri dishes (12 cm diameter), placed into an incubator at 20±2 °C and left overnight (24 hours) for colonisation of the seeds by fungal zoospores (El-Hissy et Khallil 1991). After 24 hours, the colonised seeds were transferred to an equivalent number of Petri dishes (10 cm diameter) containing sterilised distilled water to which crystalline penicillin (2000 μg/l) was added to suppress bacterial contamination (Roberts 1963). These dishes were then incubated again at 20±2 °C for three weeks. The dishes were examined daily for zoosporic taxa of heterotrophic straminipiles and true zoosporic fungi. For further reviving of zoosporic fungi, the colonised sesame seeds were transferred to other Petri dishes containing sterilised distilled water after each microscopical examination.

The numbers of isolation cases and occurrence levels of each recovered taxon of zoosporic fungi (genus or species, listed in Tables 3 and 4) were calculated from the total number (100) of collected samples in either governorate. To obtain total counts, the fungal species appearing on one sesame seed in each Petri dish was counted as one colony.

Purification of recovered species of zoosporic fungi. The isolated species of zoosporic fungi were purified on solid media for preservation in pure cultures and for subsequent use. Most of the *Oomycetes* were purified on glucose-peptone (GP) agar medium (Willoughby et Pickering 1977). However, some species of zoosporic fungi required specific media for their purification, e.g. *Aphanomyces* species, which were purified on glucose yeast extract agar (GYEA) (Hatai et Egusa 1979), whilst *Allomyces* species, belonging to *Blastocladiomycetes*, were purified on yeast-peptone starch medium (YpSs) as mentioned by Emerson (1941). After successive sub-culturing of radiating young hyphae, pure stock cultures were maintained on the above mentioned mediums. The fungal cultures were stored at 8–12 °C in the culture collection of the Laboratory of Aquatic Fungi, Botany and Microbiology Department, Faculty of Science, Assiut University, and sub-cultured every 2–3 months.

Identification of zoosporic fungal genera and species. The following references were used for the identification of the recovered genera and species of zoosporic fungi, mainly based on morphological characteristics, during this study: Coker (1923), Johnson (1956, 1971), Sparrow (1960), Scott (1961), Seymour (1970), Karling (1977) and Rattan et al. (1978).

Although PCR techniques would have been useful for species identification, sequencing of the samples was not performed due to lacking facilities. Therefore, the limits of the traditional approach to identification must be taken into account. The unidentified species failed to produce sexual reproductive organs and were identified to the genus level only.

Statistical analysis. Simple correlation statistical analysis was performed. This analysis was employed to explore the correlation between abiotic factors of water samples, such as temperature, pH value, total soluble salts and organic matter content, and the diversity of the recovered species of zoosporic fungi in these samples in both study regions.

RESULTS

PHYSICOCHEMICAL CHARACTERISTICS OF THE SAMPLES

In the present study, the physicochemical characteristics of 100 surface water samples collected from ten sites in Assiut Governorate as presented in Tab. 1 can be summarised as follows. The water temperature at the time of sampling ranged between 14.5 °C (El-Qossiya and Alfatth) and 28.2 °C (Abo-Teg), pH ranged between 5.8 (Dairut) and 8.7 (El-Badary), total soluble salt concentration varied from 104 mg/l (El-Qossiya) to 403 mg/l (Dairut), and organic matter content fluctuated between 16 mg/l (Dairut) and 424 mg/l (Abnub).

Tab. 1. Minima and maxima of physicochemical characteristics at ten sites in Assiut Governorate, Egypt.

Site	Temperature (°C)		pH		Total soluble salts (mg/l)		Organic matter content (mg/l)	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Dairut	15.0	21.0	5.8	8.3	110	403	16	84
El-Qossiya	14.5	20.0	6.4	8.6	104	323	23	75
Manfalout	18.5	22.0	6.7	8.5	106	278	29	83
Abnub	19.5	27.1	7.0	8.1	121	264	118	424
Alfatth	14.5	20.0	7.5	8.6	114	230	133	395
Abo-Teg	19.5	28.2	7.8	8.5	118	219	32	86
Sahil Saleem	18.5	27.5	7.5	8.3	110	293	44	93
El-Badary	18.5	25.2	7.3	8.7	107	200	35	104
Sedfa	19.1	25.7	7.2	8.5	121	244	46	115
El-Ghanyeem	17.5	25.3	7.5	8.1	111	260	53	122

Tab. 2. Minima and maxima of physicochemical characteristics at ten sites in Jeddah Governorate, Saudi Arabia.

Site	Temperature (°C)		pH		Total soluble salts (mg/l)		Organic matter content (mg/l)	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Wadi Kos	28.5	32.0	6.7	8.9	106	278	27	73
Wadi Merriykh	29.8	33.0	6.6	8.7	110	291	22	67
Al Mattar	29.1	32.5	6.0	9.1	106	278	27	73
Thowal	30.2	32.0	6.7	8.7	114	265	34	76
Khomra	32.5	35.0	6.5	8.9	126	309	57	198
Industrial City	31.9	37.0	6.8	8.4	137	344	65	177
Gholil	30.2	37.3	6.9	8.9	112	357	35	108
Asfan	32.3	37.0	6.6	8.5	125	218	101	186
Salman Gulf	33.1	36.5	6.8	8.7	125	242	67	177
Bahra	29.6	36.2	6.7	8.3	126	233	81	173

Also, some abiotic characteristics of the samples from Jeddah Governorate were determined as displayed in Tab. 2. The water temperature in Jeddah was higher than that recorded in Assiut, ranging between 28.5 °C (Wadi Kos) and 37.3 °C (Gholil), pH ranged between 6.0 (Al Mattar) and 9.1 (also Al Mattar), total soluble salt concentration varied from 106 mg/l (Wadi Kos and Al Mattar) to 357 mg/l (Gholil), and organic matter content fluctuated between 22 mg/l (Wadi Merriykh) and 198 mg/l (Khomra).

ZOOSPORIC FUNGI

Assiut Governorate, Egypt

The results presented in Tab. 3 indicate that 22 identified and 3 unidentified species belonging to 8 genera of zoosporic fungi were recovered. Some specimens were photographed during this research to record their morphological traits, and are displayed in the Electronic supplement. The total diversity was represented by 2,741 isolates of zoosporic fungi.

Saprolegnia was the prevalent genus in the water samples from Assiut Governorate, occurring frequently (72 samples), yielding 694 isolates. It was represented by 7 identified and 1 unidentified species. They included *S. ferax*, occurring in 38 samples producing 291 isolates, *S. parasitica* and *Saprolegnia* sp. occurring in 24 and 17 samples, with 141 and 133 isolates, respectively. *Saprolegnia diclina*, *S. monoica*, *S. hypogyna*, *S. furcata* and *S. eccentrica* had rare occurrences (8, 5, 3, 2 and 2 samples) producing 47, 20, 25, 26 and 11 isolates, respectively. *Saprolegnia* was recovered from all investigated sites in Assiut. *Saprolegnia ferax* was collected from all sites, *S. parasitica* from all sites except Abo-Teg, and *Saprolegnia* sp. from all sites except El-Ghanyeem. *Saprolegnia monoica* was isolated from only one site (Abnub), whereas each of the remaining species was collected from 2 sites: *S. diclina* (El-Qossiya and Alfatth), *S. hypogyna* (El-Badary and El-Ghanyeem), *S. furcata* (Sedfa and El-Ghanyeem) and *S. eccentrica* (Dairut and Alfatth).

Also *Achlya* had a high incidence (67 samples) yielding 1,112 isolates. It was represented by 8 identified and 1 unidentified species (broadest species spectrum in Assiut). They included *A. proliferoides* occurring in 27 samples yielding 468 isolates, *A. dubia* and *Achlya* sp. in 20 and 15 samples producing 256 and 206 isolates, respectively. The other species had low incidences: *A. flagellata*, *A. americana*, *A. prolifera*, *A. hypogyna* were found in 7, 5, 4 and 2 samples yielding 40, 77, 41 and 16 colonies, respectively; *A. conspicua* and *A. caroliniana* were each found in 1 sample producing 5 and 3 colonies, respectively. *Achlya* was recovered from all investigated sites in Assiut Governorate. *Achlya proliferoides* was isolated from 8 sites but lacked at 2 sites (El-Badary and Sedfa), *A. dubia* was recovered from all sites except El-Ghanyeem, *Achlya* sp. was isolated from all sites except Sahil Saleem, *A. americana* appeared at only 2 sites (Dairut and Alfatth), *A. flagellata* was isolated from 3 sites (Abnub, Alfatth and Sedfa), *A. prolifera* emerged from 3 sites (Sahil Saleem, El-Badary and Sedfa), and *A. hypogyna* was collected from only 2 sites (Dairut and Alfatth). Two species of *Achlya* were isolated from only one site in Assiut. These were *A. conspicua* and *A. caroliniana* (both Alfatth).

Dictyuchus (*D. sterilis*) had a moderate occurrence (47 samples) yielding 526 isolates. It was collected from all investigated sites in Assiut.

Tab. 3. Total counts (TC), number of isolation cases (NIC) and occurrence levels (OL) for zoosporic fungal genera and species recovered from 100 surface water samples at ten different sites in Assiut Governorate, Egypt.
The number of isolation cases is the number of sampling sites at which a genus or species was recorded. Counts for genera represent numbers of sites with occurrence of the genus (regardless of the numbers of its species).
Occurrence levels: H = high occurrence, more than 50 samples out of 100 water samples; M = moderate occurrence, 25–50 samples; L = low occurrence, 12–24 samples; R = rare occurrence, fewer than 12 samples.

Genus, species	Dairut		El-Qossiya		Manfalout		Abnub		Alfatth		Abo-Teg		Sahil Saleem		El-Badary		Sedfa		El-Ghanyeem		Total			
	TC	NIC	TC	NIC	TC	NIC	TC	NIC	TC	NIC	TC	NIC	TC	NIC	TC	NIC	TC	NIC	TC	NIC	TC	%TC	NIC	OL
Achlya	127	8	74	5	75	5	189	10	156	10	138	6	76	6	76	4	89	7	112	6	1112	40.57	67	H
A. americana Humphrey	46	2	-	-	-	-	-	-	31	3	-	-	-	-	-	-	-	-	-	-	77	2.81	5	R
A. caroliniana Coker	-	-	-	-	-	-	-	-	3	1	-	-	-	-	-	-	-	-	-	-	3	0.11	1	R
A. conspicua Coker	-	-	-	-		-	-	-	5	1	-	-	-	-	-	-	-	-	-	-	5	0.18	1	R
A. dubia Coker	34	3	21	1	33	3	29	2	15	2	35	1	15	1	27	2	47	5	-	-	256	9.34	20	L
A. flagellata Coker	-	-	-	-	-	-	19	4	6	1	-	-	-	-	-	-	15	2	-	-	40	1.46	7	R
A. hypogyna Coker et Pemberton	12	1	-	-	-	-	-	-	4	1	-	-	-	-	-	-			-	-	16	0.58	2	R
A. prolifera Nees	-	-	-	-	-	-	-	-	-	-	-	-	13	2	26	1	2	1	-	-	41	1.50	4	R
A. proliferoides Coker	20	2	30	1	26	1	139	8	45	3	81	4	48	4	-	-	-	-	79	4	468	17.07	27	M
Achlya sp.	15	1	23	1	16	1	2	1	47	6	22	1	-	-	23	1	25	1	33	2	206	7.52	15	L
Allomyces	24	2	20	4	27	3	12	4	15	4	65	4	67	4	51	6	22	3	-	-	303	11.05	34	M
A. anomalus Emers.	3	1	10	2	17	2	8	2	15	4	65	4	32	2	3	1	8	3	-	-	161	5.87	21	L
A. javanicus Kniep	-	-	10	2	-	-	4	2	-	-	-	-	-	-	-	-	14	1	-	-	28	1.02	5	R
A. macrogynus Emers. et Wilson	21	1	-	-	10	1	-	-	-	-	-	-	35	2	48	6	-	-	-	-	114	4.16	10	R
Aphanomyces	-	-	8	1	8	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16	0.58	2	R
Aphanomyces sp.	-	-	8	1	8	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16	0.58	2	R
Brevilegnia	10	1	-	-	-	-	-	-	3	1	-	-	7	1	-	-	-	-	9	1	29	1.06	4	R
B. unisperma (Coker et Braxton) Coker et Braxton	10	1	-	-	-	-	-	-	3	1	-	-	7	1	-	-	-	-	9	1	29	1.06	4	R

Genus, species	Dairut		El-Qossiya		Manfalout		Abnub		Alfatth		Abo-Teg		Sahil Saleem		El-Badary		Sedfa		El-Ghanyeem		Total			
	TC	**NIC**	**TC**	**NIC**	**TC**	**NIC**	**TC**	**NIC**	**TC**	**NIC**	**TC**	**NIC**	**TC**	**NIC**	**TC**	**NIC**	**TC**	**NIC**	**TC**	**NIC**	**TC**	**%TC**	**NIC**	**OL**
Dictyuchus	54	5	45	5	3	1	54	8	157	9	32	2	43	3	43	4	67	8	28	2	526	19.19	47	M
D. sterilis Coker	54	5	45	5	3	1	54	8	157	9	32	2	43	3	43	4	67	8	28	2	526	19.19	47	M
Leptomitus	-	-	-	-	-	-	-	-	23	3	-	-	-	-	12	2	-	-	9	1	44	1.61	6	R
L. lacteus C. Agardh	-	-	-	-	-	-	-	-	23	3	-	-	-	-	12	2	-	-	9	1	44	1.61	6	R
Pythium	-	-	-	-	-	-	-	-	8	1	-	-	-	-	-	-	9	1	-	-	17	0.62	2	R
P. inflatum V.D. Matthews	-	-	-	-	-	-	-	-	8	1	-	-	-	-	-	-	9	1	-	-	17	0.62	2	R
Saprolegnia	47	4	82	10	73	5	79	8	45	7	25	4	49	6	105	9	112	9	77	10	694	25.32	72	H
S. diclina Humphrey	-	-	34	6	-	-	-	-	13	2	-	-	-	-	-	-	-	-	-	-	47	1.71	8	R
S. eccentrica (Coker) R.L. Seym.	8	1	-	-	-	-	-	-	3	1	-	-	-	-	-	-	-	-	-	-	11	0.40	2	R
S. ferax (Gruith.) Kutz	29	3	16	4	30	3	23	5	23	3	18	4	26	2	44	4	40	5	42	5	291	10.62	38	M
S. furcata Maurizio	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14	1	12	1	26	0.95	2	R
S. hypogyna (Pringsh.) de Bary	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18	2	-	-	7	1	25	0.91	3	R
S. monoica Pringsh.	-	-	-	-	-	-	20	5	-	-	-	-	-	-	-	-	-	-	-	-	20	0.73	5	R
S. parasitica Coker	7	1	17	3	11	2	10	2	3	1	-	-	16	4	25	3	36	4	16	4	141	5.14	24	L
Saprolegnia sp.	3	1	15	1	32	2	26	2	3	3	7	1	7	1	18	3	22	3	-	-	133	4.85	17	L
Total count	**262**	**10**	**229**	**10**	**186**	**10**	**334**	**10**	**407**	**10**	**260**	**10**	**242**	10	**287**	**10**	**299**	**10**	**235**	**10**	**2741**	**100**		
Number of genera	**5**		**5**		**5**		**4**		**7**		**4**		**5**		**5**		**5**		**5**					
Number of identified species	**11**		**8**		**7**		**10**		**16**		**5**		**9**		**9**		**11**		**8**					
Number of unidentified species	**2**		**3**		**3**		**2**		**2**		**2**		**1**		**2**		**2**		**1**					

The chytrid *Allomyces* also had a moderate occurrence (34 samples) yielding 303 isolates and was represented by three species, namely *A. anomalus* with a low occurrence (21 samples) producing 161 isolates, *A. macrogynus* and *A. javanicus* both with a rare occurrence (10 and 5 samples) producing 114 and 28 isolates, respectively. *Allomyces* was collected from all investigated sites except El-Ghanyeem. *Allomyces anomalus* was collected from 9 sites (absent from El-Ghanyeem), *A. macrogynus* from 4 sites (Dairut, Manfalout, Sahil Saleem and El-Badary), and *A. javanicus* from 3 sites (El-Qossiya, Abnub and Sedfa).

Leptomitus lacteus, *Brevilegnia unisperma*, *Pythium inflatum* and *Aphanomyces* sp. occurred rarely (6, 4, 2 and 2 samples) with 44, 29, 17 and 16 isolates, respectively. *Leptomitus lacteus* was collected from 3 sites (Alfatth, El-Ghanyeem and El-Badary), and *Brevilegnia unisperma* from 4 investigated sites in Assiut (Dairut, Alfatth, Sahil Saleem and El-Ghanyeem). *Pythium inflatum* was collected from 2 sites (Alfatth and Sedfa), and *Aphanomyces* sp. also occurred at 2 sites (El-Qossiya and Manfalout).

Jeddah Governorate, Saudi Arabia

The results in Tab. 4 indicate that 9 identified and 2 unidentified species belonging to 4 genera of zoosporic fungi were recovered. The total diversity was represented by 1,221 isolates of zoosporic fungi.

Achlya was the prevalent genus of the recovered zoosporic fungi from the water samples in Jeddah Governorate and had a moderate occurrence (47 samples) yielding 488 isolates. It was represented by 3 identified and 1 unidentified species (broadest species spectrum in Jeddah Governorate), of which *A. dubia* and *Achlya* sp. had a low occurrence: 22 and 19 samples yielding 250 and 179 isolates, respectively. *Achlya prolifera* and *A. proliferoides* had a rare occurrence (7 and 1 samples) producing 53 and 6 isolates, respectively. *Achlya* was recovered from all the investigated sites in Jeddah except for Gholil. *Achlya dubia* occurred at 5 sites (Wadi Kos, Wadi Merriykh, Al-Mattar, Thowal and Industrial City) but was not found at the other five sites, the unidentified *Achlya* sp. appeared at 4 sites (Wadi Kos, Thowal, Salman Gulf and Bahra), *A. prolifera* was isolated from 3 sites (Wadi Merriykh, Khomra and Asfan), and *A. proliferoides* was recovered from only one site, Bahra.

Saprolegnia also had a moderate frequency of occurrence (37 samples) yielding 392 isolates. *Saprolegnia* is similar to the genus *Achlya* and together represented the broadest species spectra in Jeddah. *Saprolegnia* was also represented by 3 identified and 1 unidentified species. They included *S. ferax* and *Saprolegnia* sp. both in low occurrence (19 and 15 samples) producing 205 and 161 isolates, respectively, and *S. monoica* and *S. hypogyna* with a rare occurrence (4 and 2 samples) yielding 18 and 8 isolates, respectively. *Saprolegnia* was found

Tab. 4. Total counts (TC), number of isolation cases (NIC) and occurrence levels (OL) of zoosporic fungal genera and species recovered from 100 surface water samples at ten different sites in Jeddah Governorate, Saudi Arabia.
The number of isolation cases is the number of sampling sites at which a genus or species was recorded. Counts for genera represent numbers of sites with occurrence of the genus (regardless of the numbers of its species).
Occurrence levels: H = high occurrence, more than 50 samples out of 100 water samples; M = moderate occurrence, 25–50 samples; L = low occurrence, 12–24 samples; R = rare occurrence, fewer than 12 samples.

Genus, species	Wadi Kos		Wadi Merriykh		Al-Mattar		Thowal		Khomra		Industrial City		Gholil		Asfan		Salman Gulf		Bahra		Total			
	TC	NIC	TC	NIC	TC	NIC	TC	NIC	TC	NIC	TC	NIC	TC	NIC	TC	NIC	TC	NIC	TC	NIC	TC	%TC	NIC	OL
Achlya	92	9	120	7	68	8	90	7	23	2	33	4	-	-	25	4	18	2	19	4	488	39.97	47	M
A. dubia Coker	6	1	115	7	68	8	28	2	-	-	33	4	-	-	-	-	-	-	-	-	250	20.48	22	L
A. prolifera Nees	-	-	5	1	-	-	-	-	23	2	-	-	-	-	25	4	-	-	-	-	53	4.34	7	R
A. proliferoides Coker	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	1	6	0.49	1	R
Achlya sp.	86	9	-	-	-	-	62	5	-	-	-	-	-	-	-	-	18	2	13	3	179	14.66	19	L
Allomyces	-	-	-	-	51	3	14	2	32	2	19	2	4	1	16	2	-	-	16	2	152	12.45	14	L
A. anomalus Emers.	-	-	-	-	51	3	14	2	-	-	19	2	4	1	16	2	-	-	16	2	120	9.83	12	L
A. macrogynus Emers. et Wilson	-	-	-	-	-	-	-	-	32	2	-	-	-	-	-	-	-	-	-	-	32	2.62	2	R
Dictyuchus	45	3	-	-	-	-	-	-	57	3	22	2	26	2	17	2	12	1	10	1	189	15.48	14	L
D. sterilis Coker	45	3	-	-	-	-	-	-	57	3	22	2	26	2	17	2	12	1	10	1	189	15.48	14	L
Saprolegnia	54	4	-	-	40	3	50	4	103	7	9	2	27	4	35	6	33	3	41	4	392	32.10	37	M
S. ferax (Gruith.) Kutz	15	1	-	-	40	3	50	4	64	5	9	2	27	4	-	-	-	-	-	-	205	16.78	19	L
S. hypogyna (Pringsh.) de Bary	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	2	-	-	-	-	8	0.66	2	R
S. monoica Pringsh.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18	4	18	1.47	4	R
Saprolegnia sp.	39	4	-	-	-	-	-	-	39	2	-	-	-	-	27	4	33	3	23	2	161	13.19	15	L
Total count	**191**	**10**	**120**	**7**	**159**	**10**	**154**	**10**	**215**	**10**	**83**	**10**	**57**	**7**	**93**	**10**	**63**	**6**	**86**	**10**	**1221**	**100**		
Number of genera	**3**		**1**		**3**		**3**		**4**		**4**		**3**		**4**		**3**		**4**					
Number of identified species	**3**		**2**		**3**		**3**		**4**		**4**		**3**		**4**		**1**		**4**					
Number of unidentified species	**2**		**0**		**0**		**1**		**1**		**0**		**0**		**1**		**2**		**2**					

missing from only one site, Wadi Merriykh. *Saprolegnia ferax* was absent from 4 sites and the unidentified *Saprolegnia* sp. from 5 of the 10 investigated sites, whereas *S. hypogyna* and *S. monoica* both appeared at only one site (Asfan and Bahra, respectively).

Dictyuchus sterilis had a low incidence (14 samples) yielding 189 isolates. It was recovered from 7 sites and absent from Wadi Merriykh, Al-Mattar and Thowal.

Also *Allomyces* had a low occurrence (14 samples) yielding 152 isolates and was represented by 2 species, namely *A. anomalus* in 12 samples yielding 120 isolates and *A. macrogynus* in 2 samples producing 32 isolates. *Allomyces* occurred at 7 sites; *A. anomalus* was obtained from 6 sites (Al-Mattar, Thowal, Industrial City, Gholil, Asfan and Bahra), while *A. macrogynus* only appeared at the site of Khomra.

Discussion

Diversity and regional distribution of zoosporic fungi

Limits of species spectrum assessment

Although PCR techniques would have been useful for species identification, sequencing of the samples was not performed due to lacking facilities. Therefore the limits of traditional approach to identification must be taken into account. Lacking PCR technique facilities such as equipment and chemicals as well as their high cost were limitations which forced us to identify the isolated zoosporic fungal species on a morphological basis. In addition, our study was performed in two different laboratories in two countries, both lacking a facility to identify isolated zoosporic fungi based on molecular characters.

In principle, some zoosporic fungal species also need to be identified on a molecular basis, especially in the case of species which show very close similarities in their morphological features making their identification on morphological basis difficult and laborious.

On the other hand, it is important to note that molecular techniques cannot replace or eliminate the use of classical morphological taxonomy tools, but should be used to complement studies to achieve a complete, accurate and sufficiently descriptive identification. Mycologists have traditionally used morphology (phenotypic characters), such as spore-producing structures formed as a result of asexual or sexual reproduction, as a sole means of identifying fungal species (Hyde et al. 2010) and even today it is still employed as a means of species identification in the mycological community. The use of morphology in fungal species identification is very important to understand the evolution of morphological characters.

From our extensive expertise and studies in ecology and taxonomy over a period of approximately forty years we can affirm that the identification of zoosporic fungal species based on morphological characteristics offers several traits through which the researcher can easily observe several phenomena via microscopic examination. These may include the morphogenesis of fungal species represented by hyphal growth, sporangial formation and discharge mechanisms, sexual and asexual reproductive structures, and reproduction and stages of dormant structures, which cannot be achieved with molecular taxonomy. Also, the life cycle of economically important zoopathogenic or phytopathogenic zoosporic fungal species which may be useful for further studies and experiments is easily recognised, determined and explained via microscopic examination. Thus, monitoring of these species in their lethal stages on economically important plants and animals via extensive laboratory experiments may lead to the development of novel methods for their combat and control in field applications.

In this study we used traditional identification of the isolated species of zoosporic fungi to compensate for not using molecular techniques, hoping that these techniques will be applied, besides the traditional technique, in our future studies when circumstances will be more favourable. We keep using all outdated and modern monographs and keys of traditional identification of zoosporic fungi since the initiation of this branch of mycological taxonomy by pioneer mycologist Coker. The handbook by Coker (1923), although outdated, is the best monograph for those who study zoosporic fungi based on morphological features, and we expect that it will remain without competition for many years to come and sacred to all mycologists working on the subject of zoosporic fungi worldwide. This handbook is provided with adequate morphological illustrations and explanations of the included species. Sometimes new species not included in Coker (1923) have been recovered, which then had to be described in papers on these newly recorded species. However, a number of later monographs, handbooks and papers provide the nomenclature and taxonomy of these species on morphological basis and bridge this gap.

Occurrence of zoosporic fungi in different regions

Our results indicate that the most abundant genera of zoosporic fungi recovered from the water samples in Assiut and Jeddah Governorates were *Saprolegnia* and *Achlya*, respectively, contributing to the broadest species spectra in the two regions. The composition of the fungal communities was found to be dominated by species of these genera, just like in various water ecosystems elsewhere, such as Lake Ohrid, on the North Macedonian-Albanian border in southeastern Europe (Čomić et al. 2010), Lake Skadar, on the border of Albania and Montenegro (Ristanovic 1981), Lake Sjenica, in Central Serbia (Ranković 2004), some lakes in Poland (Czeczuga 1991a, 1991b) and Estonia (Voronin 1989), and in the Sivanamman Pond, northern Sri Lanka (Digamadulla et al. 2016).

A similar outcome was achieved by El-Hissy et Khallil (1989a, 1991), El-Hissy et al. (1982, 1992, 1994, 2001) and El-Nagdy (2000) in their studies on the diversity of zoosporic fungi from the River Nile and various water habitats in Egypt. Also, some researches into ponds filled with rainwater and well waters in Saudi Arabia showed similar results to those reported by El-Nagdy et al. (1992), El-Nagdy et Nasser (2000), El-Nagdy et El-Zayat (2001), Ali et Nasser (2001), Nasser (2003) and Gashgari et Al-Hzmi (2006).

Saprolegnia is considered one of the most frequent genera in water habitats on the globe. It was reported to be dominant in water samples collected in the Tübingen District, Germany (El-Hissy 1994) and also in water samples of rivers and ponds in Poland (Czeczuga 1995a, 1995b, 1996a, 1996b, Czeczuga et Mazalska 1996, Kiziewicz 2004, 2005, 2009). *Saprolegnia* species were isolated from waters in different countries such as Japan, the Philippines, Australia and throughout South Asia (Blazer et al. 2002), and also from water samples taken from a river in the Province of Burgundy, France (Paul et Steciow 2004). Furthermore, *Saprolegnia* species predominated in water samples of polluted drainages in the Nile Delta, Lower Egypt (Ali 2007) and were isolated from waters of some Egyptian fish farms and fish hatcheries (Ali 2009) and from diseased fish species (Ali et al. 2011) as well as from a water spring in Iraq (Farkha et Abdulrahman 2011) and freshwater samples from Anzali Lagoon, Iran (Masigol et al. 2020).

Also *Achlya* was found to be a prevalent genus of zoosporic fungi in water systems. It was collected from different water sources in Egypt by many researchers such as El-Hissy et al. (1982, 1992, 2001, 2004) and Khallil et al. (1993). El-Nagdy et al. (1992) reported that *Achly*a was a dominant genus in samples of accumulated rainwater in Saudi Arabia. Frequent occurrence of *Achlya* species was also confirmed in e.g. water reservoirs in Morocco (El Androusse et al. 2006), polluted drainage water samples collected in the Nile Delta in Lower Egypt (Ali 2007), water samples collected from the Kosi River in India (Paliwal et Sati 2009), lakes in the Ełckie District in Poland (Godlewska et al. 2016), and recently from freshwater in Iran (Masigol et al. 2020).

The genera *Dictyuchus* and *Allomyces* have repeatedly been recorded from water systems in Egypt by El-Hissy et al. (1982, 1992, 1994, 2001). Khallil et Abdel-Sater (1992) observed *Allomyces* and *Dictyuchus* species in water samples collected at the Manquabad Superphosphate Factory polluted with industrial effluents in Assiut, at moderate and high incidences, respectively. Elsewhere, *Dictyuchus* was reported to be an abundant genus of zoosporic fungi in three lotic environments of the Río de La Plata system, Argentina (Marano et Steciow 2006), water samples from the Kosi River in India (Paliwal et Sati 2009) and lakes in the Ełckie District, Poland (Godlewska et al. 2016). In India, *Allomyces* was firstly reported from waters in Upper Lake at Bhopal by Pandey et Singh (2006) and was recovered from water samples from the Tunga River by Devi et al. (2009) and Nainital Lake, State of Uttarakhand in each season of the year by Dubey et al. (2016).

Some genera of zoosporic fungi including *Leptomitus* (*L. lacteus*), *Brevilegnia* (*B. unisperma*), *Pythium* (*P. inflatum*) and *Aphanomyces* (*Aphanomyces* sp.) were recovered only from the water samples in Assiut Governorate with rare incidence. Khallil et al. (2020) also obtained *Brevilegnia* as a less frequent genus of zoosporic fungi from the El-Zinnar irrigation canal and the El-Ibrahimia canal, which receive treated sewage water and industrial effluents. However, Marano et Steciow (2006) recovered *Aphanomyces* and *Pythium* at high occurrence in three lotic environments of the Río de La Plata system, Argentina.

Physicochemical characteristics of the samples and their correlation with the diversity of zoosporic fungi

Influence of temperature

The water temperature in Assiut Governorate ranged between 14.5 °C (Alfatth) and 28.2 °C (Abo-Teg). In Jeddah it was higher, ranging between 28.5 °C (Wadi Kos) and 37.3 °C (Gholil).

A simple statistical correlation analysis revealed an inverse correlation between water temperature and number of isolated zoosporic fungal species in both Assiut and Jeddah (Tab. 5), i.e. the water samples richest in zoosporic fungi collected in either Assiut or Jeddah had relatively low or moderate temperatures.

These results show that temperature is an important physicochemical factor affecting the diversity and occurrence of zoosporic fungi. It was found that low temperatures yielded wide spectra of fungal species and vice versa, as also reported by Alabi (1974), Dick (1976), Lund (1978), El-Hissy et Khallil (1989a), El-Nagdy (2000) and El-Nagdy et El-Zayat (2001). Similarly, Rattan et al. (1980) mentioned that temperature is the most important environmental factor affecting the occurrence and periodicity of freshwater fungi. In addition, Smith et al. (1984) reported that temperature has a universal influence controlling the activities and distribution of microorganisms and plays an important role governing the frequency, diversity and seasonal variations of saprolegniaceous fungi. Also Voronin (2008) confirmed that temperature affects reproduction and distribution of aquatic fungi. Most zoosporic fungi are unable to grow and survive in extreme environmental conditions because wall-less zoospores are susceptible to osmotic, mechanical and temperature shocks, and depend on water for dispersal (Gleason et al. 2008). Some other authors (Logvinenko 1981, Meshcheryakova 1981, Smith et Rimmer 1981) reported that the optimum temperature for the development of saprolegniaceous fungi fluctuates within the range of 12 °C to 26 °C.

Furthermore, El-Hissy et Khallil (1989a) mentioned that the seasons richest in zoosporic fungi were those of low or moderate temperature (15–23 °C). Conversely, summer (high temperatures) was the season poorest in zoosporic fungi. Also several other studies showed that water samples characterised by relatively low or moderate temperatures were the richest in zoosporic fungi (Waterhouse 1942, Srivastava 1967, Rooney et McKnight 1972, Ismail et al. 1979, Misra 1982). Farkha et Abdulrahman (2011) isolated 12 species of fungi from 4 stations of the Sarchnar water spring in Iraq. They concluded that water temperature affects the occurrence and distribution of aquatic fungi, the richest number of fungi being recorded at low or moderate water temperatures of 16–21 °C.

On the other hand, some observations provided somewhat inconsistent results. In this regard, some data confirm that some zoosporic fungi may develop at temperatures of 30 °C to 40 °C (Chrowdhry et Aggarwal 1980, Khulbe 1981, Willoughby et Copland 1984).

Influence of pH

The pH of water samples measured in Assiut Governorate ranged between 5.8 (Dairut) and 8.7 (El-Badary), but in Jeddah they ranged between 6.0 and 9.1 (both Al Mattar).

A statistical analysis revealed inconsistent results concerning the relation between the pH of water samples in both governorates and the number of isolated zoosporic fungal species. While the correlation was positive for Assiut, it was negative for Jeddah (Tab. 5).

Suzuki (1960) observed that acidic waters contain fewer water moulds. Shearer et Webster (1985) found that the pH of the River Teign exhibited an impoverished mycobiota upstream (pH 5.4–6.0) compared to the less acidic (pH 7.0–7.2) downstream section. In addition, Khallil et Abdel-Sater (1992) reported that water moulds disappeared completely from a water site exposed directly to industrial effluents with very low pH from Manquabad Superphosphate Factory (Assiut). On the other hand, Khulbe (1980) revealed that the occurrence of zoosporic fungi was correlated to pH and recovered a high diversity of fungal taxa in some lakes of the Nainital District (India) with a pH of 7.3 to 8.8. Similarly, Dubey (1990) found that alkaline waters in Turkey are more favourable for the diversity of zoosporic fungi. Dubey et al. (1994) recovered and identified more taxa of zoosporic fungi from streams with a high pH than from those with a low pH.

Controversy over the preference of zoosporic fungi for acidic or alkaline waters has drawn the attention of interested mycologists trying to find a satisfactory interpretation. In this regard, Sparrow (1968) and Gleason et al. (2010, 2017b) observed that several water moulds withstand an increase or decrease in pH through the formation of resistant structures. In addition, Smith et al. (1984)

stated that pH has a complex impact not only on mycelium growth, reproduction, enzyme activity and zoospore activity, but also affects the availability of essential inorganic nutrients.

However, Ali et Nasser (2001) reported that pH did not affect fungal occurrence and did not reflect any regular pattern in the distribution of zoosporic fungi. Also Ali (2007) found that pH had no influence on the diversity of zoosporic fungi isolated from polluted water of Egyptian drainages. El-Nagdy et al. (1992), El-Nagdy et Nasser (2000) and Nasser (2003) confirmed this conclusion in their studies of the occurrence and distribution of zoosporic fungi in waters at different sites in Saudi Arabia. Similar results, affirming that the pH of water samples does not display any regular pattern in the diversity of zoosporic fungi, were also reported by Al-Saadi et al. (1979), El-Hissy et al. (1982), Carranco et al. (1984), El-Hissy et Khallil (1989a) and El-Hissy et Oberwinkler (1999). Also Gupta et Mehrotra (1989) concluded that pH was an insignificant factor concerning the abundance and occurrence of water moulds. Gleason et al. (2010) reported that zoosporic fungi were recovered frequently growing on different substrates in water habitats of extremely low pH. Recently, Khallil et al. (2020) found that pH did not exhibit any considerable influence on the diversity of straminipiles and true zoosporic fungi recovered from water receiving treated sewage and industrial effluents.

Influence of soluble salts

The concentrations of total soluble salts in water samples from Assiut ranged from 104 mg/l (El-Qossiya) to 403 mg/l (Dairut). In Jeddah it ranged between 106 mg/l (Wadi Kos) and 357 mg/l (Gholil).

The results of simple statistical correlation analysis indicate that total soluble salt concentration has a positive correlation with the number of isolated zoosporic fungal species in both governorates (Tab. 5).

In accordance with our results, El-Hissy et al. (1996) indicated a positive correlation between the concentration of total soluble salts of water samples and the occurrence of zoosporic fungi in Aswan High Dam Lake (Egypt). El-Hissy et Khallil (1989a) reported that saprolegniaceous fungi were recovered from water at sites having a salinity exceeding 1.5%. Also, Gleason et al. (2006) reported that several species of zoosporic fungi could survive various salt contents. Voronin (2008) stated that fungi tolerate relatively high salt concentrations at rather low temperatures.

In contrast, some authors, e.g. Harrison et Jones (1974), found that high salinities limited the occurrence of these fungi. Similar results were obtained by Wagner-Merner (1980), who found that the highest salinity in which water moulds occurred was 0.28%, that the ecological distribution pattern of some *Saprolegniaceae* appeared to be limited by salinity, and that high total soluble salt concentrations affected the occurrence of aquatic fungi negatively. In addition, El-Hissy et Khallil (1989b) revealed that high salinity levels progressively reduced mycelial growth rate, zoospore germination, sexual reproduction and respiration rate of water moulds. Similarly, Ali (2007) concluded an inverse correlation between total soluble salts and the diversity of zoosporic fungi isolated from polluted water drainages across the Nile Delta. In a recent study, Khallil et al. (2020) revealed that the poorest samples of zoosporic fungi collected from aquatic sites were found to have relatively high concentrations of total soluble salts.

Our results are not compatible with El-Hissy et al. (2004), who found that the total soluble salt concentrations of the four major Egyptian lakes had no effect on zoosporic fungal density in any lake. The positive statistical correlation between the total soluble salts contents of water samples and the diversity and regional distribution of the recovered taxa of zoosporic fungi in this study may be understood by the low levels of estimated salinity in the two regions.

Fairly similar results were obtained by El-Hissy et Khallil (1989a), El-Hissy (1994) and Ali et Nasser (2001) in their studies on the occurrence and distribution of zoosporic fungi in various water habitats.

Influence of organic matter content

The organic matter content of water samples in Assiut ranged between 16 mg/l (Dairut) and 424 mg/l (Abnub), while in Jeddah it ranged between 22 mg/l (Wadi Merriykh) and 198 mg/l (Khomra).

The results of statistical analysis showed that the organic matter content in both governorates is positively correlated with the number of isolated zoosporic fungal species (Tab. 5).

Hence, the water samples richest in zoosporic fungi collected from both governorates were characterised by a high content of organic matter. In agreement with our results, Misra (1982) found that ponds with a high organic matter content due to vegetation have a higher frequency and diversity of fungi. In addition, El-Hissy et Khallil (1989a) mentioned that water samples with a high organic matter content were rich in aquatic fungi. Also, Ali et Nasser (2001) concluded that water samples with a relatively high organic matter content collected in Saudi Arabia were the richest in zoosporic fungi. Moreover, a positive correlation between the occurrence of aquatic fungi during the monsoon period and organic matter content of water samples was found by Devi et al. (2009). Furthermore, Iofina (1987) and Voronin (2008) claimed that levels of dissolved organic matter in water bodies positively influence the diversity and occurrence of taxa of zoosporic fungi, but only if salinity and temperature are relatively low.

Converse results were obtained by Paliwal et Sati (2009), who identified the maximum number of isolated zoosporic fungal species in a water area with

Tab. 5. Simple correlation analysis between physicochemical characteristics of the water samples and the number of zoosporic fungal species.
+ positive correlation; – inverse correlation.

Physicochemical characteristics	Correlation with number of zoosporic fungal species	
	Assiut Governorate	Jeddah Governorate
Temperature	–0.600	–0.270
pH	+0.074	–0.420
Total soluble salts	+0.033	+0.320
Organic matter content	+0.588	+0.532

relatively low organic matter content. In a recent study, our results came in contrast to those reported by Khallil et al. (2020), who found that water directly receiving effluents, having the highest levels of organic matter content, was the poorest in zoosporic fungi.

Some other results reflected no relation between the organic matter content of water samples and the occurrence or distribution of zoosporic fungi (El-Hissy et Oberwinkler 1999, Nasser 2003).

CONCLUSIONS

This study confirmed that communities of zoosporic fungi in lotic water bodies in Assiut Governorate, Egypt were richer and more diverse than in lentic water habitats in Jeddah Governorate, Saudi Arabia. The variations in diversity and occurrence of zoosporic fungi in the two governorates may be due to differences in water characteristics as well as ecological and geographical conditions of the two regions. Our study recommends further research efforts necessary to provide a more precise and reliable assessment of the diversity and distribution of zoosporic fungi in Saudi Arabia due to the various water resources and ecological diversity of the extensive geographical area of Saudi Arabia.

Researchers specialised in this field should collect more species of zoosporic fungi from lotic water bodies to study the biological roles of these fungi and their applications in several processes such as organic matter biodegradation, recycling of nutrients in water ecosystems, water purification, degradation and elimination of heavy metals and other pollutants, bioremediation, etc.

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