

Advances in fungi' classifications in 2007-2020

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The classification, taxonomy, and phylogeny of fungi and fungus-like organisms are research areas with rapid and significant progress over the past few decades. Until the 90s of the last century, all fungi and fungus-like organisms belonged to one division (kingdom) *Fungi*, consisting of three classes of lower fungi and three classes of higher fungi. The rapid development of sciences, especially methods and potentialities of molecular biology and biochemistry, led to the cardinal revision of relationships and phylogeny division *Fungi* members. The distribution of *Fungi*'s members in three kingdoms (*Fungi*, *Protozoa*, and *Chromista*) resulted from many studies. The fungi's taxonomy began to be widely used such taxa as subkingdom, phylum, subphylum. Moreover, in 2007 Hibbett et al. (2007) proposed the classification of kingdom *Fungi* which consisted of seven phyla and four subphyla incertae sedis (phylum not assigned). Subsequent studies of scientists from all over the world led to significant enlargement of the proposed classification. Last classifications of kingdom *Fungi* presents high-level systems, consisting of eighteen phyla and seventy six classes by Tedersoo et al. (2018) or nineteen phyla and seventy seven-nine classes by Wijayawardene et al. (2020). In this article, we present an overview of the last existing classifications of kingdom *Fungi*, proposed by Hibbett et al. (2007), by Tedersoo et al. (2018), and by Wijayawardene et al. (2020).

Keywords: fungi, classification, kingdom, subkingdom, phylum, class

Introduction

The living organisms now are distributed on seven kingdoms: *Animalia*, *Archaea*, *Bacteria*, *Chromista*, *Fungi*, *Plantae*, and *Protozoa* (Ruggiero et al., 2015). The viruses which lay on the margin between living and non-living nature are singled out in the eighth kingdom *Viruses* by systematics of <https://www.catalogueoflife.org/>.

Fungi and fungus-like organisms are the largest in number and the most diverse group of causal agents of crops. By the end of the XX century, all of them were part of the kingdom *Fungi*. Particularly in Ukraine, phytopathologists used fungi systematics by Takhtadzian (Takhtadzian, 1991). By this systematics, the kingdom *Fungi* was consisted from two phyla – *Myxomycota* (or slime mold) and *Mycota* (or true fungi). Phylum *Mycota* was divided into three classes of lower fungi (*Chytridiomycetes*, *Oomycetes*, *Zygomycetes*) and three classes of higher fungi (*Ascomycetes*, *Basidiomycetes*, *Deuteromycetes*).

In the last two decades in fungi systematics, many significant changes were carried out. It was caused by molecular biology active progress, which allows detecting relationships among different organisms groups and using electron microscopy and biochemistry (Karatygin, 1999). Thus now there are many new systems of organisms' classifications and in particular, systematics of fungi and fungus-like organisms (Hawksworth et al., 1995; Margulis & Schwartz, 1997; Kusakin & Drozdov, 1994, 1998). As a result, fungi belonging to the one kingdom *Fungi* belonged to the three kingdoms of nature – *Fungi*, *Protozoa*, and *Chromista* (Hawksworth et al., 1995).

Differentiation of fungi species was based on morphology, physiology, trophic specialization, and mating ability. Sequencing of DNA regions and further studying of phylogeny changed the approach to fungi systematics. According to the existing species concept based on the International Commission on the Taxonomy of Fungi, currently fungi species delineate by phenotypic characters, ecological, morphological, and physiological features, molecular markers, and extrolite profiling (for some species) according to existing species concept based on International Commission on the Taxonomy of Fungi and International Code of Botanical Nomenclature (Sharma et al., 2015).

Different scientific names for anamorph and teleomorph stages of pleomorphic fungi have confused their classification and systematics. Double name in fungi systematics ("one fungus – two names") was changed in July 2011 during XVIII International Botanical Congress in Melbourne (Melbourne Code 2011 – "one fungus – one name"). However, when one anamorph may associate with more than one genus of the teleomorph stage, the difficulties still exist (Sharma et al., 2015).

Discussion

During the last fifteen years, the kingdom *Fungi* included from seven phyla (Hibbett et al., 2007) to eighteen phyla (Tedersoo et al., 2018) and even nineteen phyla (Wijayawardene et al., 2020). During this time, many types of research of fungi taxonomy, classification, systematics, and phylogeny was carried out (James et al., 2006; Kirk et al., 2008, 2013; Zhang et al., 2009; Gryganskyi et al., 2012; Wijayawardene et al., 2012, 2017, 2018a, 2018b; Hyde et al., 2013; Phillips et al., 2013; Slippers et al., 2013; Woudenberg et al., 2013; Manamgoda et al., 2014; Phookamsak et al., 2014; Ariyawansa et al., 2015; Jaklitsch et al., 2016; Li et al., 2016; Spatafora et al., 2016; Marin-Felix et al., 2017, 2019; Videira et al., 2017; Valenzuela-Lopez et al., 2018; Voglmayr et al., 2019). This direction of science was and still now an item of different projects for scientists in the world.

Hence by classification of Hibbett et al. (2007) *Fungi* include one subkingdom *Dikaria* and phyla: *Ascomycota*, *Basidiomycota*, *Blastocladiomycota*, *Chytridiomycota*, *Glomeromycota*, *Microsporidia*, *Neocallimastigomycota* that was based on molecular phylogenetic analyses (Table 1). Besides, Hibbett's classification includes four subphyla incertae sedis (phylum not assigned): *Mucoromycotina*, *Entomophthoromycotina*, *Zoopagomycotina*, *Kickxellomycotina*. The total number of classes is thirty-one.

Table 1. The high-level classification of the kingdom *Fungi* (by Hibbett et al., 2007).

Subkingdom	Phylum	Subphylum	Class
	Blastocladiomycota T. Y. James, 2006		Blastocladiomycetes T. Y. James, 2006
	Chytridiomycota M. J. Powell, 2007		Chytridiomycetes Caval.-Sm., 1998 Monoblepharidomycetes J. H. Schaffn., 1909
	Glomeromycota C. Walker & A. Schuessler, in Schubert et al., 2001		Glomeromycetes Caval.-Sm., 1998
	Neocallimastigomycota M. J. Powell, 2007		Neocallimastigomycetes M. J. Powell, 2007
	not assigned	Subphyla incertae sedis Mucoromycotina Benny, 2007	
	not assigned	Entomophthoromycotina Humber, 2007	
	not assigned	Zoopagomycotina Benny, 2007	
	not assigned	Kickxellomycotina Benny, 2007	
Dikarya Hibbett, T. Y. James & Vilgalys, 2007	Ascomycota Caval.-Sm., 1998 (as 'Ascomycota Berk. 1857. stat. nov.')	Pezizomycotina O. E. Erikss. & Winka, 1997	Arthoniomycetes O. E. Erikss. & Winka, 1997 Dothideomycetes O. E. Erikss. & Winka, 1997 Eurotiomycetes O. E. Erikss. & Winka, 1997 Laboulbeniomycetes Engl., 1898 Lecanoromycetes O. E. Erikss. & Winka, 1997 Leotiomycetes O. E. Erikss. & Winka, 1997 Lichinomycetes Reeb, Lutzoni & Cl. Roux., 2004 Orbiliomycetes O. E. Erikss. & Baral, in Eriksson et al., 2003 Pezizomycetes O. E. Erikss. & Winka, 1997 Sordariomycetes O. E. Erikss. & Winka, 1997
		Saccharomycotina O. E. Erikss. & Winka, 1997	Saccharomycetes O. E. Erikss. & Winka, 1997
		Taphrinomycotina O. E. Erikss. & Winka, 1997	Taphrinomycetes O. E. Erikss. & Winka, 1997 Neoelectromycetes O. E. Erikss. & Winka, 1997 Pneumocystidomycetes O. E. Erikss. & Winka, 1997 Schizosaccharomycetes O. E. Erikss. & Winka, 1997
	Basidiomycota R. T. Moore, 1980	Agaricomycotina Dowell, 2001	Agaricomycetes Dowell, 2001 Dacrymycetes Dowell, 2001 Tremellomycetes Dowell, 2001
		Pucciniomycotina R. Bauer, Begerow, J. P. Samp., M. Weiß & Oberw., 2006	Agaricostilbomycetes R. Bauer, Begerow, J. P. Samp., M. Weiß & Oberw., 2006 Cystobasidiomycetes R. Bauer, Begerow, J. P. Samp., M. Weiß & Oberw., 2006 Microbotryomycetes R. Bauer, Begerow, J. P. Samp., M. Weiß & Oberw., 2006 Pucciniomycetes R. Bauer, Begerow, J. P. Samp., M. Weiß & Oberw., 2006
		Ustilaginomycotina R. Bauer, Begerow, J. P. Samp., M. Weiß & Oberw., 2006	Exobasidiomycetes Begerow, Stoll & R. Bauer, 2006 Ustilaginomycetes R. Bauer, Oberw. & Vánky, 1997
		not assigned	Basidiomycota incertae sedis Wallemiomycetes Zalar, de Hoog & Schroers, 2005
		not assigned	Entorrhizomycetes Begerow, Stoll & R. Bauer, 2006

Eleven years later Tedersoo et al. (2018) proposed a classification of the kingdom *Fungi*, consisting of nine subkingdoms, eighteen phyla, and seventy-six classes (Table 2). Five subkingdoms consist of only one phylum: *Aphelidiomycota* – *Aphelidiomycota*, *Blastocladiomycota* – *Blastocladiomycota*, *Basidiobolomycota* – *Basidiobolomycota*, *Olpidiomycota* – *Olpidiomycota*, *Rozellomycota* – *Rozellomycota*, and one subphylum (appropriate name with suffix *-mycotina*). The subkingdom *Chytridiomycota* includes three phyla: *Chytridiomycota* with nine classes, *Monoblepharomycota* with three classes, and *Neocallimastigomycota* with one class. The subkingdom *Zoopagomycota* includes three phyla *Entomophthoromycota* with two classes, *Kickxellomycota* with six classes, and *Zoopagomycota* with one appropriate class. The subkingdom *Mucoromycota* includes four phyla: *Calcarisporiellomycota* with one class, *Glomeromycota* with three classes, *Mortierellomycota* with one class, and *Mucoromycota* with three classes. The subkingdom *Dikarya* except for phyla *Ascomycota* and *Basidiomycota* include the new phylum *Entorrhizomycota*, which proposed Bauer et al. (2015) as the sister group to other *Dikarya*.

In the classification of Tedersoo et al. (2018) every phylum subdivides into one or more subphyla. *Dikarya* phylum *Ascomycota* consists of three subphyla: *Pezizomycotina* with fourteen classes, *Taphrinomycotina* with five classes, and *Saccharomycotina* with one class. Phylum *Basidiomycota* includes four subphyla: *Agaricomycotina* with three classes, *Pucciniomycotina* with ten classes, *Ustilaginomycotina* with four classes, and *Wallemiomycotina* (which in Hibbett et al. classification (2007) was in status *Basidiomycota* incertae sedis class) with two classes.

Table 2. The high-level taxonomy of the kingdom *Fungi* (by Tedersoo et al., 2018).

Subkingdom	Phylum	Subphylum	Class
<i>Rozellomycota</i> Tedersoo et al., 2018	<i>Rozellomycota</i> Doweld, 2013	<i>Rozellomycotina</i> Tedersoo et al., 2018	<i>Microsporidea</i> Corliss & Levine, J. Protozool., 1963
<i>Aphelidiomycota</i> Tedersoo et al., 2018	<i>Aphelidiomycota</i> Tedersoo et al., 2018	<i>Aphelidiomycotina</i> Tedersoo et al., 2018	<i>Aphelidiomycetes</i> Tedersoo et al., 2000
<i>Blastocladiomycota</i> Tedersoo et al., 2018	<i>Blastocladiomycota</i> T. James. 2006	<i>Blastocladiomycotina</i> Tedersoo et al., 2018	<i>Blastocladiomycetes</i> T. James, 2006
<i>Chytridiomycota</i> Tedersoo et al., 2018	<i>Chytridiomycota</i> M. J. Powell, 2007	<i>Chytridiomycotina</i> Tedersoo et al., 2018	<i>Physodermatomycetes</i> Tedersoo et al., 2018
			<i>Chytridiomycetes</i> Caval.-Sm., 1998
			<i>Cladochytriomycetes</i> Tedersoo et al., 2018
			<i>Mesochytriomycetes</i> Tedersoo et al., 2018
			<i>Lobulomycetes</i> Tedersoo et al., 2018
			<i>Polychytriomycetes</i> Tedersoo et al., 2018
			<i>Rhizophlyctidomycetes</i> Tedersoo et al., 2018
			<i>Rhizophyidiomycetes</i> Tedersoo et al., 2018
			<i>Spizellomycetes</i> Tedersoo et al., 2018
			<i>Synchytriomycetes</i> Tedersoo et al., 2018
	<i>Monoblepharomycota</i> Doweld, 2001	<i>Monoblepharomycotina</i> Tedersoo et al., 2018	<i>Monoblepharidomycetes</i> J. H. Schaffn., 1909
			<i>Hyaloraphidiomycetes</i> Doweld, 2001
			<i>Sanchytriomycetes</i> Tedersoo et al., 2018
	<i>Neocallimastigomycota</i> M. J. Powell, 2007	<i>Neocallimastigomycotina</i> Tedersoo et al., 2018	<i>Neocallimastigomycetes</i> M. J. Powell, 2007
<i>Olpidiomycota</i> Tedersoo et al., 2018	<i>Olpidiomycota</i> Doweld, 2013	<i>Olpidiomycotina</i> Doweld, 2013	<i>Olpidiomycetes</i> Doweld, 2013
<i>Basidiobolomycota</i> Tedersoo et al., 2018	<i>Basidiobolomycota</i> Doweld, 2001	<i>Basidiobolomycotina</i> Tedersoo et al., 2018	<i>Basidiobolomycetes</i> Doweld, 2001
<i>Zoopagomycota</i> Tedersoo et al., 2018	<i>Entomophthoromycota</i> Humber, 2012	<i>Entomophthoromycotina</i> Humber, 2007	<i>Entomophthoromycetes</i> Humber, 2012
			<i>Neozygitomycetes</i> Humber, 2012
	<i>Kickxellomycota</i> Tedersoo et al., 2018	<i>Kickxellomycotina</i> Benny, 2007	<i>Kickxellomycetes</i> Tedersoo et al., 2018
			<i>Asellariomycetes</i> Tedersoo et al., 2018
			<i>Barbatosporomycetes</i> Tedersoo et al., 2018
			<i>Dimargaritomycetes</i> Tedersoo et al., 2018
			<i>Harpellomycetes</i> Tedersoo et al., 2018

			Ramicyclidomycetes Tedersoo et al., 2018
	Zoopagomycota M.E. Smith, Spatafora & Stajich, 2016	Zoopagomycotina Benny, 2007	Zoopagomycetes Doweld, 2014
Mucoromyceta Tedersoo et al., 2018	Mucoromycota Doweld, 2001	Mucoromycotina Benny, 2006	Mucoromycetes Doweld, 2001 Endogonomycetes Doweld, 2014
			Umbelopsidomycetes Tedersoo et al., 2018
	Mortierellomycota Tedersoo et al., 2018	Mortierellomycotina Kerst. Hoffm., K. Voigt & P.M. Kirk, 2011	Mortierellomycetes Doweld, 2014
	Calcarisporiellomycota Tedersoo et al., 2018	Calcarisporiellomycotina Tedersoo et al., 2018	Calcarisporiellomycetes Tedersoo et al., 2018
	Glomeromycota C. Walker & A. Schüßler, 2001	Glomeromycotina Spatafora & Stajich, 2016	Glomeromycetes Caval.-Sm., 2011
			Archaeosporomycetes Sieverd., G.A. Silva, B.T. Goto & Oehl, 2011
			Paraglomeromycetes Oehl, G.A. Silva, B.T. Goto & Sieverd., 2011
Dikarya Hibbett, T.Y. James & Vilgalys, 2007	Entorrhizomycota R. Bauer, Garnica, Oberw., K. Riess, M. Weiß & Begerow, 2015	Entorrhizomycotina Tedersoo et al., 2018	Entorrhizomycetes Begerow, Stoll & R. Bauer, 2006
	Basidiomycota R.H. Whittaker ex Moore, 1980	Agaricomycotina Doweld, 2001	Agaricomycetes Doweld, 2001 Dacrymycetes Doweld, 2001 Tremellomycetes Doweld, 2001
		Pucciniomycotina R. Bauer, Begerow, J.P. Samp., M. Weiss & Oberw., 2006	Agaricostilbomycetes R. Bauer, Begerow, J.P. Samp., M. Weiss & Oberw., 2006
			Atractiellomycetes R. Bauer, Begerow, J.P. Samp., M. Weiss & Oberw., 2006
			Classiculomycetes R. Bauer, Begerow, J.P. Samp., M. Weiss & Oberw., 2006
			Cryptomycocolacomycetes R. Bauer, Begerow, J.P. Samp., M. Weiss & Oberw., 2006
			Cystobasidiomycetes R. Bauer, Begerow, J.P. Samp., M. Weiss & Oberw., 2006
			Microbotryomycetes R. Bauer, Begerow, J.P. Samp., M. Weiss & Oberw., 2006
			Mixiomycetes R. Bauer, Begerow, J.P. Samp., M. Weiss & Oberw., 2006
			Pucciniomycetes R. Bauer, Begerow, J.P. Samp., M. Weiss & Oberw., 2006
			Spiculogloeomycetes Q.M. Wang, F.Y. Bai, M. Groenew. & Boekhout, 2015
			Tritirachiomycetes Aime & Schell, 2011
		Ustilaginomycotina R. Bauer, Begerow, J.P. Samp., M. Weiss & Oberw., 2006	Exobasidiomycetes Begerow, M. Stoll, R. Bauer, 2006
			Malasseziomycetes Boekhout, Q.M. Wang & F.Y. Bai, 2014
			Moniliellomycetes Q.M. Wang, F.Y. Bai & Boekhout, 2014
			Ustilaginomycetes R. Bauer, Oberw. & Vánky, 1997
		Wallemiomycotina Doweld, 2014	Geminibasidiomycetes H.D.T. Nguyen & Seifert, 2015 Wallemiomycetes Zalar, de

Ascomycota Whittaker, 1959	R.H.	Pezizomycotina Erikss. & Winka, 1997	O.E.	Hoog & Schroers, 2005 Arthoniomycetes O.E. Erikss. & Winka, 1997 Collemopsidiomycetes Tedersoo et al., 2018 Coniocybomycetes M. Prieto & Wedin, 2013 Dothideomycetes O.E. Erikss. & Winka, 1997 Eurotiomycetes O.E. Erikss. & Winka, 1997 Geoglossomycetes Zheng Wang, C.L. Schoch & Spatafora, 2009 Laboulbeniomycetes Engl., 1897 Lecanoromycetes O.E. Erikss. & Winka, 1997 Leotiomycetes O.E. Erikss. & Winka, 1997 Lichinomycetes Reeb, Lutzoni & Cl. Roux, 2004 Orbiliomycetes O.E. Erikss. & Baral, 2003 Pezizomycetes O.E. Erikss. & Winka, 1997 Sordariomycetes O.E. Erikss. & Winka, 1997 Xylonomycetes R. Gazis & P. Chaverri, 2012
		Taphrinomycotina Erikss. & Winka, 1997	O.E.	Archaeorhizomycetes Rosling & T. James, 2011 Neoelectomycetes O.E. Erikss. & Winka, 1997 Pneumocystidomycetes O.E. Erikss. & Winka, 1997 Schizosaccharomycetes O.E. Erikss. & Winka, 1997 Taphrinomycetes O.E. Erikss. & Winka, 1997
		Saccharomycotina Erikss. & Winka, 1997	O.E.	Saccharomycetes O.E. Erikss. & Winka, 1997

Wijayawardene et al. (2020) proposed *Fungi* classification agreeing with Tedersoo et al. (2018). In this classification, basal clades consist of sixteen phyla, and higher fungi (*Dikarya*) are represented by three phyla (Table 3). The difference between Tedersoo et al. (2018) and Wijayawardene et al. (2020) high-level *Fungi* classification is phylum *Caulochytriomycota* with one class *Caulochytriomycetes* in the last classification. This phylum was introduced by Doweld (2014). Also, Wijayawardene et al. (2018, 2020) did not propose such taxonomy rank as subkingdom, and subphylum was proposed only for phyla *Calcarisporiellomycota*, *Entomophthoromycota*, *Mortierellomycota*, *Mucoromycota* with only one appropriate subphylum (with suffix *-mycotina*) and for phyla *Ascomycota* and *Basidiomycota* (three and four subphyla respectively).

Table 3. The high-level classification of the basal clades and the higher fungi (Wijayawardene et al., 2020).

Phylum	Subphylum	Class
Rozellomycota Doweld		Rudimicrosporea Sprague Microsporidea Corliss & Levine Aphelidiomycetes Tedersoo, Sanchez-Ramirez, Kõljalg, Bahram, M. Döring, Schigel, T.W. May, M. Ryberg & Abarenkov
Aphelidiomycota Tedersoo, Sanchez-Ramirez, Kõljalg, Bahram, M. Döring, Schigel, T.W. May, M. Ryberg & Abarenkov		
Blastocladiomycota T.Y. James		Blastocladiomycetes Doweld Physodermatomycetes Tedersoo, Sanchez-Ramirez, Kõljalg, Bahram, M. Döring, Schigel, T.W. May, M. Ryberg & Abarenkov Neocallimastigomycetes M.J. Powell
Neocallimastigomycota M.J. Powell		
Monoblepharomycota Doweld		Hyaloraphidiomycetes Doweld Monoblepharidomycetes J.H. Schaffn. Sanchytriomycetes Tedersoo, Sanchez-Ramirez, Kõljalg, Bahram, M. Döring, Schigel, T.W. May, M. Ryberg &

Chytridiomycota Doweld

Caulochytridiomycota Doweld

Basidiobolomycota Doweld

Olpidiomycota Doweld

Entomophthoromycota

Humber

Zoopagomycota Gryganskyi,
M.E. Sm., Spatafora & Stajich

Kickxellomycota Tedersoo,
Sanchez-Ramirez,
Bahram, M. Döring, Schigel,
T.W. May, M. Ryberg &
Abarenkov

Glomeromycota C. Walker &
A. Schüssler

Mortierellomycota Tedersoo,
Sanchez-Ramirez,
Bahram, M. Döring, Schigel,
T.W. May, M. Ryberg &
Abarenkov

Calcarisporiellomycota
Tedersoo, Sanchez-Ramirez,
Köljalg, Bahram, M. Döring,
Schigel, T.W. May, M. Ryberg &
Abarenkov

Mucoromycota Doweld

Entomophthoromycotina

Humber

Mortierellomycotina Kerst.
Hoffm., K. Voigt & P.M. Kirk

Calcarisporiellomycotina
Tedersoo, Sanchez-Ramirez,
Köljalg, Bahram, M. Döring,
Schigel, T.W. May, M. Ryberg &
Abarenkov

Mucoromycotina Benny

Abarenkov

Chytridiomycetes Caval.-Sm.

Cladochytriomycetes Tedersoo, Sanchez-Ramirez,
Köljalg, Bahram, M. Döring, Schigel, T.W. May, M. Ryberg
& Abarenkov

Lobulomycetes Tedersoo, Sanchez-Ramirez, Köljalg,
Bahram, M. Döring, Schigel, T.W. May, M. Ryberg &
Abarenkov

Mesochytriomycetes Tedersoo, Sanchez-Ramirez,
Köljalg, Bahram, M. Döring, Schigel, T.W. May, M. Ryberg
& Abarenkov

Polychytriomycetes Tedersoo, Sanchez-Ramirez, Köljalg,
Bahram, M. Döring, Schigel, T.W. May, M. Ryberg &
Abarenkov

Rhizophydiomycetes Tedersoo, Sanchez-Ramirez,
Köljalg, Bahram, M. Döring, Schigel, T.W. May, M. Ryberg
& Abarenkov

Rhizophlyctidomycetes Tedersoo, Sanchez-Ramirez,
Köljalg, Bahram, M. Döring, Schigel, T.W. May, M. Ryberg
& Abarenkov

Spizellomycetes Tedersoo, Sanchez-Ramirez, Köljalg,
Bahram, M. Döring, Schigel, T.W. May, M. Ryberg &
Abarenkov

Synchytriomycetes Tedersoo, Sanchez-Ramirez, Köljalg,
Bahram, M. Döring, Schigel, T.W. May, M. Ryberg &
Abarenkov

Caulochytriomycetes Doweld

Basidiobolomycetes Doweld

Olpidiomycetes Doweld

Entomophthoromycetes Humber

Neozygitomycetes Humber

Zoopagomycetes Doweld

Asellariomycetes Tedersoo, Sanchez-Ramirez, Köljalg,
Bahram, M. Döring, Schigel, T.W. May, M. Ryberg &
Abarenkov

Barbatosporomycetes Tedersoo, Sanchez-Ramirez,
Köljalg, Bahram, M. Döring, Schigel, T.W. May, M. Ryberg
& Abarenkov

Dimargaritomycetes Tedersoo, Sanchez-Ramirez,
Köljalg, Bahram, M. Döring, Schigel, T.W. May, M. Ryberg
& Abarenkov

Harpellomycetes Tedersoo, Sanchez-Ramirez, Köljalg,
Bahram, M. Döring, Schigel, T.W. May, M. Ryberg &
Abarenkov

Kickxellomycetes Tedersoo, Sanchez-Ramirez, Köljalg,
Bahram, M. Döring, Schigel, T.W. May, M. Ryberg &
Abarenkov

Ramicandelaberomycetes Tedersoo, Sanchez-Ramirez,
Köljalg, Bahram, M. Döring, Schigel, T.W. May, M. Ryberg
& Abarenkov

Archaeosporomycetes Sieverd., G.A. Silva, B.T. Goto &
Oehl

Glomeromycetes Caval.-Sm. emend. Oehl, G.A. Silva,
B.T. Goto & Sieverd.

Paraglomeromycetes Oehl, G.A. Silva, B.T. Goto &
Sieverd.

Mortierellomycetes Doweld

Calcarisporiellomycetes Tedersoo, Sanchez-Ramirez,
Köljalg, Bahram, M. Döring, Schigel, T.W. May, M. Ryberg
& Abarenkov

Endogonomycetes Doweld

Mucoromycetes Doweld

Umbelopsidomycetes Tedersoo, Sanchez-Ramirez,
Köljalg, Bahram, M. Döring, Schigel, T.W. May, M. Ryberg

Entorrhizomycota R. Bauer,
Garnica, Oberw., Riess, Weiß &
Begerow

Basidiomycota R.T. Moore

Agaricomycotina Doweld

Pucciniomycotina R. Bauer,
Begerow, J.P. Samp., M. Weiss &
Oberw.

Ustilaginomycotina Doweld

Wallemiomycotina Doweld

Pezizomycotina O.E. Erikss. &
Winka

Ascomycota Caval.-Sm.

Saccharomycotina O.E. Erikss.
& Winka

Taphrinomycotina O.E. Erikss.
& Winka

& Abarenkov

Entorrhizomycetes Begerow, M. Stoll & R. Bauer

Agaricomycetes Doweld

Bartheletiomycetes Thines

Dacrymycetes Doweld

Tremellomycetes Doweld

Agaricostilbomycetes R. Bauer, Begerow, J.P. Samp., M.
Weiss & Oberw.

Atractiellomycetes R. Bauer, Begerow, J. P. Samp., M.
Weiss & Oberw.

Classiculomycetes R. Bauer, Begerow, J. P. Samp., M.
Weiss & Oberw.

Cryptomycocolacomycetes R. Bauer, Begerow, J.P.
Samp., M. Weiss & Oberw.

Cystobasidiomycetes R. Bauer, Begerow, J. P. Samp.,
M. Weiss & Oberw.

Microbotryomycetes R. Bauer, Begerow, J.P. Samp., M.
Weiss & Oberw.

Mixiomycetes R. Bauer, Begerow, J.P. Samp., M. Weiss &
Oberw.

Pucciniomycetes R. Bauer, Begerow, J.P. Samp., M.
Weiss & Oberw.

Spiculogloeomycetes Q.M. Wang, F.Y. Bai, M. Groenew.
& Boekhout

Tritirachiomycetes Aime & Schell

Exobasidiomycetes Begerow, M. Stoll & R. Bauer

Malasseziomycetes Q.M. Wang & F.Y. Bai

Moniliellomycetes Q.M. Wang, F.Y. Bai & Boekhout

Ustilaginomycetes R. Bauer, Oberw. & Vánky

Wallemiomycetes Zalar, de Hoog & Schroers

Arthoniomycetes O.E. Erikss. & Winka

Candelariomycetes Voglmayr & Jaklitsch

Coniocybomycetes M. Prieto & Wedin

Dothideomycetes sensu O.E. Erikss & Winka

Eurotiomycetes Tehler ex O.E. Eriksson & K. Winka

Geoglossomycetes Zheng Wang, C.L. Schoch &
Spatafora

Laboulbeniomycetes Engler

Lecanoromycetes O.E. Erikss. & Winka

Leotiomycetes O.E. Erikss. & Winka

Lichinomycetes V. Reeb, Lutzoni & Cl. Roux

Orbiliomycetes O.E. Erikss. & Baral

Pezizomycetes O.E. Erikss. & Winka

Sordariomycetes O.E. Erikss. & Winka

Xylobotryomycetes Voglmayr & Jaklitsch

Xylonomycetes Gazis & P. Chaverri

Saccharomycetes O.E. Erikss. & Winka

Archaeorhizomycetes Rosling & T.Y. James

Neoelectomycetes O.E. Erikss. & Winka

Pneumocystomycetes O.E. Erikss. & Winka

Schizosaccharomycetes O.E. Erikss. & Winka

Taphrinomycetes O.E. Erikss. & Winka

On the class-level of Wijayawardene et al. (2020) classification, changes were provided in phylum *Rozellomycota*. To this phylum was included the class *Rudimicrosporea* in addition to the class *Microsporidea*. Order *Metchnikovellida* was placed in the class *Rudimicrosporea*.

The changes were provided in phyla *Basidiomycota* and *Ascomycota*. In the phylum *Basidiomycota* class *Bartheletiomycetes* was added to subphylum *Agaricomycotina*. This class was proposed by research results of Mishra et al. (2018) in Research News (2018) for a single species *Bartheletia paradoxa* which is associated with *Ginkgo biloba* as a "living fossil". Moreover, now subphylum *Agaricomycotina* consists of four classes (*Agaricomycetes*, *Bartheletiomycetes*, *Dacrymycetes*, *Tremellomycetes*).

The class *Collemopsidiomycetes* proposed in the subphylum *Pezizomycotina* (phylum *Ascomycota*) by Tedersoo et al. (2018) was excluded. The single order *Collemopsidiales* was placed in the class *Dothideomycetes*. Two new classes of phylum *Ascomycota* (*Candelariomycetes* and *Xylobotryomycetes*), which was proposed by Voglmayr et al. (2019) in the last classification (Wijayawardene et al., 2020) were included in the subphylum *Pezizomycotina*.

One more change in the high-level classification of *Fungi* (Wijayawardene et al., 2020) was in excluding class *Geminibasidiomycetes* with one order *Geminibasidiales* from subphylum *Wallemiomycotina*. This class was proposed by Nguyen et al. (2015) for order *Geminibasidiales* and was including in classification by Tedersoo et al. (2018). In the last classification (Wijayawardene et al., 2020), *Geminibasidiales* is placed in the single subphylum *Wallemiomycotina* class *Wallemiomycetes*.

Despite rapidity and the enormous amount of research in fungi classification and phylogeny significant amount of genera, families, and orders remain in status "incertae sedis" in Wijayawardene et al. (2020). In particular, in the phylum *Ascomycota* remain not assigned family for 534 genera; not assigned order for 449 genera and 82 families; not assigned class for 1485 genera, for 8 families and 2 orders. In the phylum *Basidiomycota* remain not assigned family for 342 genera; not assigned order for 61 genera and 4 families and not assigned class for 11 genera. In the phylum *Blastocladiomycota* remains not assigned family for 1 genus and not assigned order for 1 genus. In the phylum *Chytridiomycota* remain unassigned family for 7 genera; not assigned order for 39 genera and 5 families; not assigned class for 3 genera. In the phylum *Kickxellomycota* remain not assigned family for 3 genera. In the phylum *Mucoromycota* remains not assigned class for 1 genus. In the phylum *Rozellomycota* remain not assigned family for 24 genera; not assigned class and order for 3 families and not assigned class for 5 genera. In the phylum *Zoopagomycota* remains not assigned family for 1 genus.

Conclusion

Researches in fungi classification and phylogeny are an amount and significant for understanding relationships between species. In recent decades we have many changes in the systematics and classification of microorganisms. Despite the progress in fungi classification last several decades, many unclarified positions in systematic are remaining. Rapid progress in scientific development allows supposing revisions and improvements of fungi's classification in a short time.

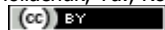
References

- Ariyawansa, H. A., Hyde, K. D., Jayasiri, S. C. et al. (2015). Fungal diversity notes 111-252 – taxonomic and phylogenetic contributions to fungal taxa. *Fungal Diversity*, 75, 27-274. <https://doi.org/10.1007/s13225-015-0346-5>
- Bauer, R., Garnica, S., Oberwinkler, F., Riess, K., Weiß, M., & Begerow, D. (2015). Entorrhizomycota: A New Fungal Phylum Reveals New Perspectives on the Evolution of Fungi. *PLoS ONE*, 10 (7): e0128183.
- Cavalier-Smith, T. (2007). A revised six-kingdom system of life. *Biological Reviews*, 73 (3), 203–66.
- Cavalier-Smith, T. (2018a). Kingdom Chromista and its eight phyla: a new synthesis emphasising periplastid protein targeting, cytoskeletal and periplastid evolution, and ancient divergences. *Protoplasma*, 255, 297–357.
- Cavalier-Smith, T., Chao, E.E. & Lewis, R. (2018b). Multigene phylogeny and cell evolution of chromist infrakingdom Rhizaria: contrasting cell organization of sister phyla Cercozoa and Retaria. *Protoplasma*, 255, 1517–1574.
- Doweld, A. B. (2014). Retrieved from <http://www.indexfungorum.org/Publications/Index%20Fungorum%20no.49.pdf>
- Gryganskyi, A. P., Humber, R. A., Smith M. E. et al. (2012). Molecular phylogeny of the Entomophthoromycota. *Molecular Phylogenetics and Evolution*, 65 (2), 682-694.
- Hawksworth, D. L.; Kirk, P. M.; Sutton, B. C. & Pegler, D. N. (1995). *Ainsworth & Bisby's dictionary of the fungi*. 8.ed. Oxon, UK, CAB International, 650 p.
- Hibbett, D. S., Binder, M., Bischoff, J. F., et al. (2007). A higher-level phylogenetic classification of the Fungi. *Mycological research*, 111, 509-547.
- Hyde, K. D., Jones, E. B. G., Liu, J. K. et al. (2013). Families of Dothideomycetes. *Fungal Diversity*, 63, 1-313.
- Jaklitsch, W. M., Checa, J., Blanco, M. N. et al. (2018). A preliminary account of the Cucurbitariaceae. *Studies in Mycology*, 90, 71–118.
- James, T. Y., Letcher, P. M., Longcore, J. E., Mozley-Standridge, S. E. et al. (2006). A molecular phylogeny of the flagellated fungi (Chytridiomycota) and description of a new phylum (Blastocladiomycota). *Mycologia*, 98 (6), 860-871.
- Karatygin, I. V. (1999). Problems in the macrosystematics of fungi. *Mycology and Phytopathology*, 33 (3), 150-165 (in Russian).
- Kirk, P. M., Cannon, P. F., Minter, D. W., & Stalpers, J. A. (2008). *Ainsworth & Bisby's Dictionary of the Fungi*. 10th Edition. CABI Europe – UK, 771 p.
- Kirk, P. M., Stalpers, J. A., Braun, U., Crous, P. W. et al. (2013). A withoutprejudice list of generic names of fungi for protection under the international code of nomenclature for algae, fungi, and plants. *IMA Fungus*, 4, 381-443. Kusakin, O. G., & Drozdov A. L. (1994). Phylema of the living beings. Part 1. St. Petersburg, 272 p. (in Russian).
- Kusakin, O. G., & Drozdov A. L. (1998). Phylema of the living beings. Part 2. St. Petersburg, 357 p. (in Russian).
- Li, G. J., Hyde, K. D., Zhao, R. L. et al. (2016). Fungal diversity notes 253-366: taxonomic and phylogenetic contributions to fungal taxa. *Fungal Diversity*, 78, 1-237.
- Manamgoda, D. S., Rossman, A. Y., Castlebury, L. A. et al. (2014). The genus *Bipolaris*. *Studies in Mycology*, 79, 221-288. Margulis, L., & Schwartz, K. V. (1997). *Five Kingdoms: An Illustrated Guide to the Phyla of Life on Earth*. New York, 544 p.
- Marin-Felix, Y., Groenewald, J. Z., Cai, L. et al. (2017). Genera of phytopathogenic fungi: GOPHY 1. *Studies in Mycology*, 86, 99-216.
- Marin-Felix, Y., Hernandez-Restrepo, M., Wingfield, M. J. et al. (2019). Genera of phytopathogenic fungi: GOPHY 2. *Studies in Mycology*, 92, 47-133.
- Mishra, B., Choi, Y. J. & Thines, M. (2018). Phylogenomics of *Bartheletia paradoxa* reveals its basal position in Agaricomycotina and that the early evolutionary history of basidiomycetes was rapid and probably not strictly bifurcating. *Mycological Progress*, 17, 333–341.
- Nguyen, H. D. T., Chabot D., Hirooka, Y., Roberson, R. W. & Seifert, K. A. (2015). *Basidioascus undulatus*: genome, origins, and sexuality. *IMA Fungus*, 6 (1), 215–231.
- Outline of Fungi: <https://www.outlineoffungi.org/>
- Phillips, A. J. L., Alves, A., Abdollahzadeh, J. et al. (2013). The Botryosphaeriaceae: genera and species known from culture. *Studies in Mycology*, 76 (1), 51-167.
- Phookamsak, R., Liu, J.-K., McKenzie E. H. C. et al. (2014). Revision of Phaeosphaeriaceae. *Fungal Diversity*, 68 (1), 159-238.
- Research News. (2018). *IMA Fungus*, 9, A68–A70. <https://doi.org/10.1007/BF03449440>
- Ruggiero, M. A., Gordon, D. P., Orrell, T. M., Bailly, N., Bourgoin, T., Brusca, R. C., et al. (2015). A Higher Level Classification of All Living Organisms. *PLoS ONE* 10(4): e0119248.
- Sharma, R., Polkade, A. V., & Shouche, Y. S. (2015). 'Species concept' in microbial taxonomy and systematics. *Current science*, 108 (10), 1804-1814, from
- Slippers, B., Boissin, E., Phillips, A. J. L. et al. (2013). Phylogenetic lineages in the Botryosphaeriales: a systematic and evolutionary framework. *Studies in Mycology*, 76 (1), 31-49.

- Spatafora, J. W., Chang, Y., Benny, G. L. et al. (2016). A phylum-level phylogenetic classification of zygomycete fungi based on genome-scale data. *Mycologia*, 108 (5), 1028-1046.
- Takhtadzian A. L. (Editor-in-chief) (1991). The world of plant. T. 2. Fungi. Moscow, 475 p. (in Russian).
- Tedersoo, L., Sánchez-Ramírez, S., Kõljalg, U. et al. (2018). High-level classification of the Fungi and a tool for evolutionary ecological analyses. *Fungal Diversity*, 90, 135–159. The Catalogue of Life: <https://www.catalogueoflife.org/>
- Valenzuela-Lopez, N., Cano-Lira, J. F., Guarro, J. et al. (2018). Coelomycetous Dothideomycetes with emphasis on the families Cucurbitariaceae and Didymellaceae. *Studies in Mycology*, 90, 1-69.
- Videira, S. I. R., Groenewald, J. Z., Nakashima, C., Braun, U., Barreto, R. W., de Wit, P. J. G. M., & Crous, P. W. (2017). Mycosphaerellaceae – Chaos or clarity? *Studies in Mycology*, 87, 257-421.
- Voglmayr, H., Fournier, J., & Jaklitsch W. M. (2019). Two new classes of Ascomycota: Xylobotryomycetes and Candelariomycetes. *Persoonia*, 42 (1), 36-49.
- Wijayawardene, D. N. N., McKenzie, E. H. C., & Hyde, K. D. (2012). Towards incorporating anamorphic fungi in a natural classification – checklist and notes for 2011. *Mycosphere*, 3 (2), 157-228.
- Wijayawardene, N. N., Hyde, K. D., Al-Ani, L. K. T., et al. (2020). Outline of Fungi and fungus-like taxa. *Mycosphere* 11(1), 1060–1456.
- Wijayawardene, N. N., Hyde, K. D., Lumbsch, H. T., Liu, J. K. et al. (2018a). Outline of Ascomycota: 2017. *Fungal Diversity*, 88, 167–263.
- Wijayawardene, N. N., Hyde, K. D., Rajeshkumar K. C. et al. (2017). Notes for genera: Ascomycota. *Fungal Diversity*, 86 (1), 1-594.
- Wijayawardene, N. N., Pawłowska, J., Letcher, P. M., Kirk, P. M. et al. (2018b). Notes for genera: basal clades of Fungi (including Aphelidiomycota, Basidiobolomycota, Blastocladiomycota, Calcarisporiellomycota, Caulochytriomycota, Chytridiomycota, Entomophthoromycota, Glomeromycota, Kickxellomycota, Monoblepharomycota, Mortierellomycota, Mucoromycota, Neocallimastigomycota, Olpidiomycota, Rozellomycota and Zoopagomycota). *Fungal Diversity*, 92, 43–129.
- Woudenberg, J. H. C., Groenewald, J. Z., Binder, M., & Crous P. W. (2013). *Alternaria* redefined. *Studies in Mycology*, 75, 171-212.
- Zhang, Y., Schoch, C. L., Fournier, J. et al. (2009). Multi-locus phylogeny of Pleosporales: a taxonomic, ecological and evolutionary re-evaluation. *Studies in Mycology*, 64, 85-102.

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