Table 2 List of deadly and potentially deadly macrofungi. Species are grouped according to toxin type and are arranged alphabetically within each group.

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How to be a 'fungi' and not a dead guy: a catalogue of 71 of the world's deadliest macrofungi

Samantha C. Karunarathna[1,2], Peter E. Mortimer[1], Jian-Chu Xu[1,2]

[1]Kunming Institute of Botany, Chinese Academy of Sciences, Kunming 650201, P.R. China; [2]CIFOR-ICRAF China Program, World Agroforestry (ICRAF), Kunming 650201, P.R. China.

Abstract

Of more than 14,000 known species of macrofungi, only a small percentage is deadly or potentially deadly to humans. Despite this low number of deadly species, every year hundreds of people die around the world because of macrofungi poisoning. Insufficient knowledge, unclear taxonomy, a rise in the consumption of fungi, and misleading folklore are all contributing factors to these deaths. The aim of our study is to list and describe 71 of the world's deadliest macrofungi, to raise awareness and knowledge levels for the general public and scientific community. We reviewed 71 species of macrofungi reported to have either killed a human or that are known to produce toxins which could kill a human. This work presents the taxonomy, ecology, phylogeny, and biomedical properties of 71 poisonous mushroom species and can be used as a roadmap by policymakers, researchers, and other stakeholders. Our work sheds light on specific areas in need of further work, such as taxonomic and biomedical research, and suggests ways to better equip the public to avoid future poisoning cases. The goal is to reverse the trend of rising incidents of mushroom poisonings and deaths and ensure the safe consumption of mushrooms in the future.

Introduction

Among the known macrofungal species, 1,069 are considered edible (Boa 2004), and based on our current research, 71 can be considered deadly, or at least potentially deadly. Although this figure represents only a minute fraction of all described macrofungal species (approx. 0.4%), insufficient knowledge, doubtful taxonomies, increased consumption, and misleading folklore have contributed to rising incidents of mushroom poisonings and deaths.

Global statistics indicate approximately 200 to 250 individuals are killed by mushrooms annually (Govorushko et al. 2019, De Olano et al. 2020). In China alone, from 2000 to 2014, there were 1,954 poisoning cases and 409 deaths (an average of about 30 deaths annually), resulting in an approximately 21% fatality rate resulting from mushroom poisonings (Chen et al. 2014). Many mushrooms involved in these cases contain powerful toxins, leading to fatalities within several days of consumption. These toxins are unique and not found in any other living organisms other than fungi (McPartland et al. 1997; Barceloux 2008). For many species outside Europe and North America (Sitta et al. 2020), data on toxins and poisonings are lacking, and up-to-date databases with relevant information on poisonings would be valuable tools for monitoring the occurrence of deadly mushrooms and associated toxins.

For patients suffering from mushroom poisoning (known as mycetism), effective treatment within the first 24 hours after consumption is crucial. Early identification of the mushroom responsible for the poisoning is critical to administrating proper treatment and determining the ultimate outcome of the patient. Although there are standard PCR-based protocols using genetic markers (ITS barcodes) for identifying species of mushrooms, information related to mushroom deadliness, and the corresponding genetic markers, is incomplete and in urgent need of clarification. In most cases of mushroom poisoning, mushroom identification is not recorded or recorded incorrectly, leading to delays in the patient receiving effective treatment. Records show that hospitalized patients who undergo aggressive treatment procedures immediately after the ingestion of amatoxin-containing mushrooms have a mortality rate of only 10%, whereas those admitted 60 or more hours after ingestion have a mortality rate between 50–90% (Buck 1961; McPartland et al. 1997; Degnan 2008). There is no standard treatment regimen for victims of mushroom poisoning, although common treatments include stomach pumping to remove toxic contents (Groves 1979), activated charcoal (Locatelli et al. 2010), penicillin, aggressive hydration, silymarin, N-acetylcysteine, α-lipoic acid (Poucheret et al. 2010; Erden et al. 2013; Yıldırım et al. 2016; Trakulsrichai et al. 2017; Govorushko et al. 2019) as well as liver and renal transplants in severe cases (Piqueras 1989; Enjalbert et al. 2002; Barceloux 2008; Allen et al. 2012; Ward et al. 2013; Garcia et al. 2015). Silymarin, a standardized extract of the milk thistle seeds (*Silybum marianum*), contains a mixture of flavonolignans consisting of silibinin (the major active constituent), isosilibinin, silicristin, silidianin, and others. Silibinin is a mixture of two diastereomers, silybin A and silybin B, found in an approximately equimolar ratio. There have been promising signs regarding silibinin administration for amatoxin treatment (Mengs et al. 2012; Yildirim et al. 2016; Trakulsrichai et al. 2017), but further study is necessary before this can be considered a suitable treatment.

Policy changes based on scientific advances can effectively reduce mushroom poisonings by creating programs that promote public awareness and provide effective training to health practitioners in affected areas (World Health Organization 2004). To that end, we present the taxonomy, ecology, phylogeny, and biomedical properties of 71 species of mushrooms (Table) known to contain deadly toxins for use as a roadmap by policymakers, researchers, and other stakeholders. Our paper sheds light on specific areas in need of further work, such as taxonomic and biomedical research, and suggests ways to better equip the public to avoid future poisoning cases. The ultimate goal is to reverse the trend of rising incidents of mushroom poisonings and deaths and ensure the safe consumption of mushrooms in the future.

Taxon name	Toxins present
Amanita albolimbata	Amatoxins (α-amanitin, β-amanitin); Phallotoxins (phallacidin)
A. amerivirosa	Amatoxins
A. arocheae	Amatoxins
A. bisporigera	Amatoxins (α-amanitin); Phallotoxins (phalloidin, phallacidin)
A. decipiens	Amatoxins
A. dunensis	Amatoxins (a-amanitin, β-amanitin, γ- amanitin)
A. exitialis	Amatoxins (α-amanitin, β-amanitin); Phallotoxins (phallacidin, phallisin, phalloin)
A. fuliginea	Amatoxins (α-amanitin, β-amanitin); Phallotoxins
A. hygroscopica	Amatoxins
A. magnivelaris	Amatoxins
A. marmorata	Amatoxins (α-amanitin, β-amanitin) – only from South African collections; Phallotoxins (phallacidin, phalloidin)
A. ocreata	Amatoxins (α-amanitin, β-amanitin); Phallotoxins (phalloidin, phalloin, prophalloin, phallacidin, phallisin, phallisacin, phallin B)
A. pallidorosea	Amatoxins (α-amanitin, β-amanitin); Phallotoxins (phalloidin)
A. phalloides	Amatoxins (α-amanitin, β-amanitin, g-amanitin; amaninamide, amanulin, proamanulin, amanin, ϵ-amanitin, amanullinic acid); Phallotoxins (phallacidin, phalloidin, phallisacin)
A.porrinensis	Phallotoxins (phalloidin)
A. sturgeonii	Amatoxins
A.suballiacea	Amatoxins
A.subjunquillea	Amatoxins; Phallotoxins
A. subpallidorosea	Amatoxins (α-amanitin, β-amanitin, γ-amanitin, amaninamide, amanullin); Phallotoxins (phalloidin, phallacidin, phallisacin, phallisin); Virotoxins (viroisin, viroidin, alaviroidin)
A. verna	Amatoxins; Phallotoxins
A. virosa	Amatoxins; Phallotoxins; Virotoxins (viroidin, viroisin, deoxoviroisin, ala-viroidin, ala-desoxoviroidin, deoxoviroidin)
A. virosiformis	Amatoxins
Galerina autumnalis	Amatoxins
G. badipes	Amatoxins
G. beinrothii	Amatoxins
G. fasciculata	Amatoxins
G. helvoliceps	Amatoxins
G. marginata	Amatoxins (α-amanitin, β-amanitin, γ-amanitin)
G. sulciceps	Amatoxins
G. unicolor	Amatoxins
G.venenata	Amatoxins
Lepiota boudieri	Amatoxins
L. brunneoincarnata	Amatoxins
L. brunneolilacea	Amatoxins (α-amanitin)
L.a castanea	Amatoxins
L. clypeolarioides	Amatoxins
L. elaiophylla	Amatoxins
L. fuscovinacea	Amatoxins
L. helveola	Amatoxins
L. langei	Amatoxins
L. ochraceofulva	Amatoxins
L. pseudolilacea	Amatoxins
L. spiculata	Amatoxins
L. subincarnata	Amatoxins
L. subvenenata	Amatoxins
L. venenata	Amatoxins
Pholiotina filaris	Amatoxin (α-amanitin)
Cortinarius brunneofulvus	Orellanine
C. eartoxicus	Orellanine
C. orellanus	Orellanine
C. rubellus	Orellanine
C. gentilis	Cortinarins A, B, C
Gyromitra esculenta	Gyromitrin
G. gigas	Gyromitrin
G. infula	Gyromitrin
Inosperma erubescens	Muscarine
Amanita proxima	Toxin substances remain unidentified
A. rhopalopus	Allenic norleucine
A. smithiana	Allenic norleucine
Cortinarius rufulus	Unknown
Cudonia circinans	Monomethylhydrazi-ne
Entoloma sinuatum	Unknown
Ophiocordyceps heteropoda	Ibotenic acid
Paxillus involutus	"X" antigen
Pleurocybella porrigens	Cyanide salts
Russula subnigricans	(2S,3R)-(–)-3-hydroxybaikiain, russuphelins A, russuphelins B-F, russuphelol, cycloprop-2-ene carboxylic acid
Trichoderma cornu-damae	Macrocyclic trichothecenes including roridin E; satratoxin H; satratoxin H 12', 13'-diacetate; satratoxin H 12'-acetate, satratoxin H 13' acetate
Tricholoma equestre	Toxic substances remain unexplained
T. pardinum	Pardinol B, pardinols E-H
T. terreum	Terreumols A-D, terreolides A-F, saponaceolides H-P, saponaceolides Q-S
Trogia venenata	2R-amino-4S-hydroxy-5-hexynoic acid, 2R-amino-5-hexynoic acid, g-guanidinobutyric acid

Table. List of deadly and potentially deadly macrofungi. Species are grouped according to toxin type and are arranged alphabetically within each group.

Image. Fruiting bodies of six of the 71 deadly poisonous mushrooms A. *Amanita phalloides*, B. *Gyromitra esculenta*, C. *Lepiota brunneoincarnata*, D. *AmanitCortinarius orellanusa verna*, E., F. *Inocybe erubescens*

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Materials and methods

In our study we have only included macrofungi, specifically the fruitbodies of macrofungi. All species presented herein are Basidiomycetes, except for four species of Ascomycetes. Taxonomic descriptions in the manuscript were obtained from published papers and adapted for our study; references to these papers have been included in our descriptions. The names and synonyms of the macrofungi were checked against original publications and Index Fungorum (2021), Species Fungorum (2021) and Mycobank (https://www.mycobank.org).

Selection of deadly species

The list of deadly macrofungi presented in this research was prepared based on the following criteria: Available and reliable published reports directly indicating deaths resulting from the consumption of a mushroom (Ammirati et al. 1977; Yamaura et al. 1985; Boiffard 1987; Prast et al. 1988; Benjamin 1995; Volk 1997; Rho et al. 2000; Koichi et al. 2003; Hallen et al. 2007; Ben Khelil et al. 2010; Zhou et al. 2012; Chen et al. 2014; Tulloss and Yang 2020). Mushrooms in this group are listed as:

Category 1: Deadly – known to have resulted in the death of at least one person, irrespective of the age or health of the individual.

Available and reliable reports indicating organ failure or a similar life-threatening condition resulting from mushroom consumption, that, if left untreated could have resulted in death. Mushrooms in this group are listed as:

Category 2: Potentially deadly – resulted in organ failure or a life-threatening condition that would most likely have led to the death of the patient if medical treatment had not been administered.

Mushrooms reported to contain toxins in sufficient concentrations that are deadly to humans (a healthy adult) (Vesconi et al. 1985; Jo et al. 2014). Although no reported deaths have occurred, we emphasize that species within this category still have the potential to kill a human. Mushrooms in this group are listed as:

Category 3: Potentially deadly – although no deaths have been reported, these macrofungi contain toxins in sufficient concentrations to kill a human.

Conclusion

This is the first known attempt to summarize and present a comprehensive body of information on deadly macrofungi. It offers a preliminary roadmap for both policymakers and researchers interested in learning about and reducing the number of mushroom poisonings and fatalities. However, this list is far from complete and will continue to evolve as new species are discovered and unclear taxonomies clarified.

Future awareness campaigns can help reduce deaths. Targeted biogeographical studies can equip policymakers around the globe with the tools necessary for conducting location-specific education campaigns, ensuring vital information reaches those most susceptible to inaccurate data and/or mushroom poisoning.

Future research should use an interdisciplinary approach, involving biologists partnering with social scientists to create a knowledge framework that incorporates local beliefs, local knowledge, and biophysical data. New strategies will be necessary to disrupt the transmission of inaccurate folklore on poisonous mushroom identification, highlight the dangers of such beliefs and raise community awareness regarding the obstacles in safely identifying edible species of mushrooms. Finally, there are still many cases of mushroom-related deaths that lack species attribution, signaling the urgent need for more taxonomical and biochemical research.

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