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A checklist of fungi isolated from honey (2000 – 2022)

Ivo Roxo[1,2*], António Luís Amaral[2,3,4,5], António Portugal[1,6] and João Trovão[1,6]

[1] *FitoLab—Laboratory for Phytopathology, Instituto Pedro Nunes, Rua Pedro Nunes, Quinta da Nora 3030-199, Coimbra, Portugal*
[2] *Polytechnic Institute of Coimbra, Coimbra Institute of Engineering, Rua Pedro Nunes, Quinta da Nora 3030-199, Coimbra, Portugal*
[3] *CEB - Centre of Biological Engineering, Universidade do Minho, Campus de Gualtar 4710-057, Braga, Portugal*
[4] *LABBELS –Associate Laboratory, Centre of Biological Engineering, Universidade do Minho, Campus de Gualtar 4710-057, Braga/Guimarães, Portugal*
[5] *Instituto de Investigação Aplicada, Laboratório SiSus, Rua Pedro Nunes, Quinta da Nora 3030-199, Coimbra, Portugal*
[6] *University of Coimbra, Centre for Functional Ecology - Science for People & the Planet, Associate Laboratory TERRA, Department of Life Sciences, Calçada Martim de Freitas 3000-456, Coimbra, Portugal*

* Corresponding author, E-mail: ivoroxo@sapo.pt

Abstract

Mycological studies focusing on fungal species thriving on honey related products have a series of critical applications ranging from the expansion of basic scientific knowledge, the exploration of their industrial utilization, understanding their contributions to food spoilage and even environmental pathogen monitoring. During the last two decades, several works dealing with the isolation and characterization of fungal species thriving on honey have been published. Nonetheless, a thorough summarization of these results has not yet been compiled. This work analyses and compiles a checklist of fungi isolated and identified/described from honey nectar, honey blossom and honeydew between the years 2000 and 2022. Based on this assessment, we detected that over one hundred and thirty entries have been reported from honey samples worldwide. Consequently, this work provides a checklist of such fungi, that will be of interest to mycologists, microbiologists, food scientists working on the topic, and also beekeepers.

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Introduction

Beekeeping (or apiculture) is a zootechnical activity that aims to sustain and exploit, economically and rationally, the domestic bee *Apis mellifera*, in an effort to obtain their direct products and by-products. Goods such as honey, propolis, pollens, royal jelly, bee bread, waxes and apitoxins (bee venoms) have a wide and diverse range of applications, including in the cosmetic, food, pharmacological and therapeutical industries (Pasupuleti et al. 2017). This is noted, for instance, in the expansion of apitherapy (an alternative therapy that uses products coming directly from honeybees) in Western cultures in the last few years[1]. Moreover, beekeeping is also considered a valuable example of an environmentally sustainable production system, with notorious positive impacts on global biodiversity and agriculture. Overall, this activity is mainly characterized by three advantageous outcomes, namely: (1) a confluence of economic interests (by the production of honey and by-products of the hive, which can provide financial gains), (2) social impact (since it contributes to the fixation of the rural population in territories where other economic activities are hard to be develop or maintain), and (3) a contribution to environmental conservation, sustainability and health (through pollination of cultivated and wild fields)[2].

According to the European Union and Portuguese legislation (Decree-Law 179/2004) and the *Codex Alimentarius* (CODEX STAN 12-1981), honey is a natural sweetener produced by honey bees from: (1) flower nectars (blossom honey or nectar honey), or (2) carbohydrate-rich secretions of plants or even excretions of plant-sucking phytophagous aphids (honeydew), after combination with the animal specific molecules, placement, dehydration, and storage in the honey comb (to ripen and mature)[3–5]. Honey is composed by sugars turned into a super saturated solution containing mainly the monosaccharides (fructose and glucose, in a concentration not lower than 60%) and by a much lesser amount of oligosaccharides, organic acids, enzymes (amylases and α-glucosidase) and colloidal particles[3].

The quality of honey is mainly determined by its sensorial, chemical, physical and microbiological characteristics. From a microbiological perspective, honey can have two sources of contamination by microorganisms: (1) primary sources: including pollen, the digestive tracts of honey bees, dust, air, soil and nectar (more difficult to control), and (2) secondary sources: arising from human honey manipulation, while also including risks related to air quality, food handlers, cross-contamination and the sanitary state of the equipment and buildings used in the process (more easily controlled by good manufacturing practices)[6]. And though the European Commission sets maximum levels of mycotoxins for various types of food products, they are often incomplete when considering bee products[7].

Honey spoilage is not an often-reported phenomenon, mainly due to their associated antimicrobial properties, which result from several different factors. These include contributions from the formation of hydrogen peroxide (H_2O_2), floral source, low pH, low moisture content, low redox potential, low protein content, high osmolarity, high viscosity and limitations to oxygen penetration[8–11]. On the other hand, an important physicochemical property that can affect the development of

class	order	family	genus		Synonym	Studied substrate:
Phylum *Ascomycota* Caval.-Sm.						
Dothideomycetes O.E. Erikss. & Winka	Capnodiales Woron.	Cladosporiaceae Chalm. & R.G. Archibald	Cladosporium Link	Cladosporium cladosporioides (Fresen.) G.A. de Vries.		Nectar Honey; Honeydew[4, 15, 26].
				Cladosporium sp. Link.		Honey Blossom; Honeydew; Nectar Honey[6, 14, 17, 22, 24–25].
	Dothideales Lindau	*Saccotheciaceae* Bonord.	Genus *Aureobasidium* Viala & G. Boyer	*Aureobasidium pullulans* (de Bary & Löwenthal) G. Arnaud.		Nectar Honey; Honeydew[4].
				Aureobasidium sp. Viala & G. Boyer.		Honey Blossom; Honeydew; Nectar Honey[22, 25].
	Incertae sedis	*Seuratiaceae* Vuill. ex M.E. Barr	*Atichia* Flot.	*Atichia* sp. Flot..		Honey Blossom; Honeydew[17].
			Seuratia Pat.	*Seuratia* sp. Pat..		Honey Blossom; Honeydew[17].
	Mytilinidiales E. Boehm, C.L. Schoch & Spatafora	*Mytilinidiaceae* Kirschst.	*Peyronelia* Cif. & Gonz. Frag.	*Peyronelia* sp. Cif. & Gonz. Frag..		Honey Blossom; Honeydew[17].
	leosporales Luttr. ex M.E. Barr	*Pleosporaceae* Nitschke	*Alternaria* Nees	*Alternaria alternata* (Fr.) Keissl..		Nectar Honey; Honeydew[4, 15].
				Alternaria multiformis (E.G. Simmons) Woudenb. & Crous.		Honey Blossom; Honeydew[3].
				Alternaria sp. Nees.		Honey Blossom; Honeydew; Nectar Honey[6, 14, 17, 22, 25].
			Stemphylium Wallr.	*Stemphylium* sp. Wallr..		Honey Blossom[25].
		Didymellaceae Gruyter, Aveskamp & Verkley	*Epicoccum* Link	*Epicoccum* sp. Link.		Honey Blossom; Honeydew[14, 17].
			Phoma Sacc.	*Phoma* sp. Sacc..		Honey Blossom; Honeydew[14, 17].
		Torulaceae Corda	*Torula* Pers.	*Torula mellis* Fabian & Quinet.		Honey Blossom; Honeydew[17].
				Torula sp. Pers..		Honey Blossom; Honeydew[17].
Eurotiomycetes O.E. Erikss. & Winka	*Ascosphaerales* Gäum. ex Benny & Kimbr.	*Ascosphaeraceae* L.S. Olive & Spiltoir	*Ascosphaera* L.S. Olive & Spiltoir	*Ascosphaera atra* Skou & K. Hackett.		Honey Blossom; Honeydew[3].
				Ascosphaera sp. L.S. Olive & Spiltoir.		Honey Blossom; Honeydew[17].
			Bettsia Skou	*Bettsia alvei* (Betts) Skou ex Pitt, Lantz, Pettersson & Leong.		Honey Blossom; Honeydew[3; 17].
	Chaetothyriales M.E. Barr	*Cyphellophoraceae* Réblová & Unter.	*Cyphellophora* G.A. de Vries	*Cyphellophora jingdongensis* H. Yang & K.D. Hyde.		Nectar Honey[23].
	Eurotiales G.W. Martin ex Benny & Kimbr.	*Aspergillaceae* Link	*Aspergillus* P. Micheli ex Haller.	*Aspergillus discophorus* Samson, Zalar & Frisvad.	*Emericella discophora.*	Nectar Honey; Honeydew[4].
				Aspergillus nidulans (Eidam) G. Winter.	*Emericella nidulans.*	Nectar Honey[26].
				Aspergillus qinqixianii Y. Horie, Abliz & R.Y. Li.	*Emericella qinqixianii.*	Nectar Honey; Honeydew[4].
				Aspergillus asperescens Stolk.		Honey Blossom; Honeydew[3].
				Aspergillus candidus Link.		Nectar Honey; Honeydew[12, 15, 26].
				Aspergillus clavatus Desm..		Honey Blossom; Honeydew[14].
				Aspergillus flavus Link.		Honey Blossom; Honeydew; Nectar Honey[12, 14–15, 26].
				Aspergillus fumigatus Fresen..		Honey Blossom; Honeydew; Nectar Honey[6, 12, 14–15, 26].

(to be continued)

Table 1. (continued)

class	order	family	genus		Synonym	Studied substrate:
				Aspergillus montevidensis Talice & J.A. Mackinnon.		Honey Blossom; Honeydew[3].
				Aspergillus niger Tiegh..		Honey Blossom; Honeydew; Nectar Honey[4, 6, 12, 14–15, 26].
				Aspergillus ochraceus G. Wilh..		Honey Blossom; Honeydew; Nectar Honey[14–15].
				Aspergillus proliferans G. Sm..		Nectar Honey; Honeydew[4].
				Aspergillus pseudoglaucus Blochwitz.		Honey Blossom; Honeydew[3].
				Aspergillus sp. P. Micheli ex Haller.	*Emericella* sp. and *Eurotium* sp..	Honey Blossom; Honeydew; Nectar Honey[6, 14, 17, 24–25].
				Aspergillus spelunceus Raper & Fennell.		Nectar Honey; Honeydew[4].
				Aspergillus terreus Thom.		Nectar Honey[15].
				Aspergillus versicolor (Vuill.) Tirab..		Honey Blossom; Honeydew; Nectar Honey[14–15, 26].
			Paecilomyces Bainier	*Paecilomyces* sp. Bainier.		Nectar Honey; Honey Blossom[22].
			Penicillium Link	*Penicillium italicum* Wehmer.		Nectar Honey; Honeydew[4].
				Penicillium solitum Westling.	*Penicillium crustosum*.	Honey Blossom; Honeydew[17].
				Penicillium apimei R.N. Barbosa, Souza-Motta, N.T. Oliveira & Houbraken.		Nectar Honey[20].
				Penicillium aurantiogriseum Dierckx.		Honey Blossom; Honeydew[14].
				Penicillium brevicompactum Dierckx.		Honey Blossom; Honeydew; Nectar Honey[6, 14, 17].
				Penicillium brocae S.W. Peterson, Jeann. Pérez, F.E. Vega & Infante.		Nectar Honey[20].
				Penicillium camemberti Thom.		Honey Blossom; Honeydew[3].
				Penicillium chrysogenum Thom.		Honey Blossom; Honeydew; Nectar Honey[6, 14, 17].
				Penicillium citrinum Thom.		Honey Blossom; Honeydew; Nectar Honey[3, 14, 20].
				Penicillium commune Thom.		Nectar Honey[6].
				Penicillium corylophilum Dierckx.		Honey Blossom; Honeydew; Nectar Honey[3–4, 6, 14, 26].
				Penicillium cravenianum Visagie & K. Jacobs.		Honey Blossom; Honeydew[3].
				Penicillium decumbens Thom.		Nectar Honey; Honeydew[4].
				Penicillium echinulatum Biourge.		Nectar Honey; Honeydew[4].
				Penicillium expansum Link.		Honey Blossom; Honeydew; Nectar Honey[6, 14].
				Penicillium griseofulvum Dierckx.		Honey Blossom; Honeydew; Nectar Honey[6, 14, 17].
				Penicillium sp. Link.		Honey Blossom; Honeydew; Nectar Honey[4, 12, 14–15, 17, 20, 22, 24–25].
				Penicillium meliponae R.N. Barbosa, Souza-Motta, N.T. Oliveira & Houbraken.		Nectar Honey[20].
				Penicillium mellis R.N. Barbosa, Souza-Motta, N.T. Oliveira & Houbraken.		Nectar Honey[20].
				Penicillium polonicum K.W. Zaleski.		Nectar Honey; Honeydew[4, 6].

(to be continued)

Table 1. (continued)

class	order	family	genus		Synonym	Studied substrate:
				Penicillium raistrickii G. Sm..		Honey Blossom; Honeydew[14].
				Penicillium sclerotiorum J.F.H. Beyma.		Nectar Honey[20].
				Penicillium wotroi Houbraken, López-Quint., Frisvad & Samson.		Nectar Honey[20].
			Talaromyces C.R. Benj.	*Talaromyces affinitatimellis* Rodr.-Andr., Stchigel & Cano.		Honey Blossom; Honeydew[3].
				Talaromyces basipetosporus Stchigel, Cano & Rodr.-Andr..		Honey Blossom; Honeydew[3].
				Talaromyces brunneosporus Rodr.-Andr., Cano & Stchigel.		Honey Blossom; Honeydew[3].
				Talaromyces funiculosus (Thom) Samson, N. Yilmaz, Frisvad & Seifert.	*Penicillium funiculosum*.	Nectar Honey[26].
				Talaromyces brasiliensis R.N. Barbosa, Souza-Motta, N.T. Oliveira & Houbraken.		Nectar Honey[20].
				Talaromyces scorteus (Nakaz., Y. Takeda & Suematsu) S.W. Peterson & Jurjević.		Nectar Honey[20].
			Xerochrysium Pitt	*Xerochrysium xerophilum* (Pitt) Pitt.		Honey Blossom; Honeydew[3].
		Monascaceae J. Schröt.	*Monascus* Tiegh.	*Monascus mellicola* R.N. Barbosa, Souza-Motta, N.T. Oliveira & Houbraken.		Nectar Honey[20].
				Monascus pilosus K. Satô ex D. Hawksw. & Pitt.		Honey Blossom; Honeydew[3].
				Monascus purpureus Went.		Honey Blossom; Honeydew[3].
				Monascus ruber Tiegh..		Honey Blossom; Honeydew[3].
	Incertae sedis	*Eremascaceae* Engl. & E. Gilg	*Eremascus* Eidam	*Eremascus albus* Eidam.		Honey Blossom; Honeydew[3].
	Onygenales Cif. ex Benny & Kimbr.	*Helicoarthrosporaceae* Stchigel, Rodr.-Andrade & Cano	*Helicoarthrosporum* Stchigel, Cano & Rodríguez-Andrade	*Helicoarthrosporum mellicola* Stchigel, Cano & Rodríguez-Andrade.		Honey Blossom; Honeydew[3].
		Incertae sedis	*Strongyloarthrosporum* Rodr.-Andr., Cano & Stchigel	*Strongyloarthrosporum catenulatum* Rodr.-Andr., Cano & Stchigel.		Honey Blossom; Honeydew[3].
Leotiomycetes O.E. Erikss. & Winka	*Helotiales* Nannf.	*Incertae sedis*	*Coniothecium* Corda	*Coniothecium* sp. Corda.		Honey Blossom; Honeydew[17].
			Triposporium Corda	*Triposporium* sp. Corda.		Honey Blossom; Honeydew[17].
		Myxotrichaceae Locq. ex Currah	*Oidiodendron* Robak	*Oidiodendron mellicola* Rodr.-Andr., Cano & Stchigel.		Honey Blossom; Honeydew[3].
			Skoua A.A. Wynns	*Skoua asexualis* Rodr.-Andr., Cano & Stchigel.		Honey Blossom; Honeydew[3].
				Skoua fertilis (Stoppel) A.A. Wynns.		Honey Blossom; Honeydew[3].
		Sclerotiniaceae Whetzel	*Botrytis* Micheli ex Pers.	*Botrytis* sp. P. Micheli ex Pers..		Honey Blossom; Honeydew[14, 17].
Saccharomycetes G. Winter	*Incertae sedis*	*Incertae sedis*	*Oosporidium* Stautz	*Oosporidium* sp. Stautz.		Honey Blossom; Honeydew[17].
	Saccharomycetales Luerss.	*Incertae sedis*	*Candida* Berkhout	*Candida* sp. Berkhout.		Honey Blossom; Honeydew[17].
				Candida lundiana Saks., M. Suzuki, Lumyong, Ohkuma & Chantaw.		Nectar Honey[28].

(to be continued)

Table 1. (continued)

class	order	family	genus		Synonym	Studied substrate:
				Candida parapsilosis (Ashford) Langeron & Talice.		Nectar Honey[5].
				Candida suthepensis Saks., M. Suzuki, Lumyong, Ohkuma & Chantaw..		Nectar Honey[28].
			Starmerella C.A. Rosa & Lachance	*Starmerella magnoliae* (Lodder & Kreger-van Rij) C.A. Rosa & Lachance.	*Candida magnoliae*.	Honey Blossom; Honeydew; Nectar Honey[3, 5].
				Starmerella sorbosivorans (S.A. James, C.J. Bond & I.N. Roberts) C.A. Rosa & Lachance.	*Candida sorbosivorans*.	Honey Blossom; Honeydew; Nectar Honey[3, 5].
		Lipomycetaceae E.K. Novák & Zsolt	*Lipomyces* Lodder & Kreger-van Rij	*Lipomyces* sp. Lodder & Kreger-van Rij.		Honey Blossom; Honeydew[17].
		Saccharomycetaceae G.Winter	*Debaryomyces* Klöcker	*Debaryomyces hansenii* (Zopf) Lodder & Kreger-van Rij.		Nectar Honey; Honeydew[4].
			Pichia E.C. Hansen	*Pichia* sp. E.C. Hansen.		Honey Blossom; Honeydew[17].
				Pichia membranifaciens (E.C. Hansen) E.C. Hansen.		Nectar Honey[5].
			Saccharomyces Meyen	*Saccharomyces* sp. Meyen.		Honey Blossom; Honeydew; Nectar Honey[12, 17].
				Saccharomyces cerevisiae (Desm.) Meyen.		Honey Blossom; Honeydew; Nectar Honey[5, 17].
			Schwanniomyces Klöcker	*Schwanniomyces* sp. Klöcker.		Honey Blossom; Honeydew[17].
			Zygosaccharomyces B.T.P. Barker	*Zygosaccharomyces favi* G. Péter, Čadež & Dlauchy.		Nectar Honey[16].
				Zygosaccharomyces gambellarensis Torriani, M. Lorenzini, Salvetti & Felis.		Honey Blossom; Honeydew[3].
				Zygosaccharomyces mellis Fabian & Quinet.		Honey Blossom; Honeydew; Nectar Honey[3–5, 17].
				Zygosaccharomyces priorianus Klöcker.		Honey Blossom; Honeydew[17].
				Zygosaccharomyces rouxii (Boutroux) Yarrow.		Honey Blossom; Honeydew; Nectar Honey[5, 17].
				Zygosaccharomyces siamensis Saks., M. Suzuki, Chantaw., Ohkuma & Lumyong.		Honey Blossom; Honeydew; Nectar Honey[3, 28].
				Zygosaccharomyces sp. B.T.P. Barker.		Honey Blossom; Honeydew[17].
		Trichomonascaceae Kurtzman & Robnett	*Blastobotrys* Klopotek	*Blastobotrys meliponae* R.N. Barbosa, Boekhout, G.A. Silva, Souza-Motta & N. Oliveira.		Nectar Honey; Honeydew[19].
		Wickerhamomycetaceae Kurtzman, Robnett & Bas.-Powers	*Wickerhamomyces* Kurtzman, Robnett & Bas.-Powers	*Wickerhamomyces* sp. Kurtzman, Robnett & Bas.-Powers.	*Hansenula* sp..	Honey Blossom; Honeydew[17].
Schizosaccharomycetes O.E. Erikss. & Winka	*Schizosaccharomycetales* O.E. Erikss.	*Schizosaccharomycetaceae* Beij. ex Klöcker	*Schizosaccharomyces* Lindner	*Schizosaccharomyces* sp. Lindner.		Honey Blossom; Honeydew[17].
				Schizosaccharomyces octosporus Beij.		Honey Blossom; Honeydew[17].
Sordariomycetes O.E. Erikss. & Winka	*Hypocreales* Lindau	*Cordycipitaceae* Kreisel ex G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora	*Engyodontium* de Hoog	*Engyodontium* sp. de Hoog.		Nectar Honey[24].
		Hypocreaceae De Not.	*Trichoderma* Pers.	*Trichoderma hamatum* (Bonord.) Bainier.		Nectar Honey[26].

(to be continued)

Table 1. (continued)

class	order	family	genus		Synonym	Studied substrate:
				Trichoderma sp. Pers..		Honey Blossom; Honeydew[14, 17].
		Incertae sedis	*Acremonium* Link	*Acremonium* sp. Link.		Honey Blossom; Honeydew; Nectar Honey[15, 17].
			Sarocladium W. Gams & D. Hawksw.	*Sarocladium strictum* (W. Gams) Summerb..	*Acremonium strictum*.	Nectar Honey[26].
				Sarocladium sp. W. Gams & D. Hawksw..	*Cephalosporium* sp..	Honey Blossom; Honeydew[17].
		Nectriaceae Tul. & C. Tul.	*Fusarium* Link	*Fusarium* sp. Link.		Honey Blossom; Honeydew; Nectar Honey[6, 14–15, 17].
				Fusarium oxysporum Schltdl.		Nectar Honey[26].
		Stachybotryaceae L. Lombard & Crous	*Stachybotrys* Corda	*Stachybotrys* sp. Corda.		Nectar Honey; Honey Blossom[22].
	Incertae sedis	*Apiosporaceae* K.D. Hyde, J. Fröhl., Joanne E. Taylor & M.E. Barr	*Arthrinium* Kunze	*Arthrinium* sp. Kunze.		Honey Blossom; Honeydew; Nectar Honey[4, 25].
	Sordariales Chadef. ex D. Hawksw. & O.E. Erikss.	*Chaetomiaceae* G. Winter	*Botryotrichum* Sacc. & Marchal	*Botryotrichum atrogriseum* J.F.H. Beyma.		Nectar Honey[26].
			Chaetomium Kunze	*Chaetomium globosum* Kunze.		Nectar Honey; Honeydew[4].
				Chaetomium sp. Kunze.		Honey Blossom; Honeydew[17]
			Trichocladium Harz	*Trichocladium griseum* (Traaen) X. Wei Wang & Houbraken.		
	Xylariales Nannf.	*ypoxylaceae* DC.	*Daldinia* Ces. & De Not.	*Daldinia concentrica* (Bolton) Ces. & De Not..		Nectar Honey; Honeydew[4].
Phylum *Basidiomycota* R.T. Moore						
Microbotryomycetes R. Bauer, Begerow, J.P. Samp., M. Weiss & Oberw.	*Sporidiobolales* Doweld	*Sporidiobolaceae* R.T. Moore	*Rhodotorula* F.C. Harrison	*Rhodotorula* sp. F.C. Harrison.		Honey Blossom; Honeydew[17].
				Rhodotorula mucilaginosa (A. Jörg.) F.C. Harrison		Nectar Honey[5].
Tremellomycetes Doweld	*Filobasidiales* Jülich	*Filobasidiaceae* L.S. Olive	*Naganishia* Goto	*Naganishia uzbekistanensis* (Á. Fonseca, Scorzetti; Fell) Xin Zhan Liu, F.Y. Bai, M. Groenew. & Boekhout.	*Cryptococcus uzbekistanensis*.	Nectar Honey; Honeydew[4].
	Tremellales Fr.	*Cryptococcaceae* Kütz. ex Castell. & Chalm.	*Cryptococcus* Vuill.	*Cryptococcus neoformans* (San Felice) Vuill..	*Cryptococcus neoformans* var. *grubii*.	Honey Blossom; Honeydew[17].
	Trichosporonales Boekhout & Fell	*richosporonaceae* Nann.	*Cutaneotrichosporon* Xin Zhan Liu, F.Y. Bai, M. Groenew. & Boekhout	*Cutaneotrichosporon mucoides* (E. Guého; M.T. Sm.) Xin Zhan Liu, F.Y. Bai, M. Groenew. & Boekhout.		Nectar Honey[5].
			Vanrija R.T. Moore	*Vanrija humicola* (Dasz.) R.T. Moore.		Nectar Honey[5].
Ustilaginomycetes Warm.	*Ustilaginales* Bek.	*Ustilaginaceae* Tul. & C. Tul.	Not determined.	*Ustilaginaceae* sp. Tul. & C. Tul..		Honey Blossom; Honeydew[17]
Wallemiomycetes Zalar, de Hoog & Schroers	*Wallemiales* Zalar, de Hoog & Schroers	*Wallemiaceae* R.T. Moore	*Wallemia* Johan-Olsen	*Wallemia hederae* S. Jančič, Zalar & Gunde Cimerman..		Nectar Honey[18].
				Wallemia mellicola Jancic, Nguyen, Seifert & Gunde-Cimerman..		Nectar Honey[18].

(to be continued)

Table 1. (continued)

class	order	family	genus		Synonym	Studied substrate:
Phylum *Mucoromycota* Doweld						
Mucoromycetes Doweld	*Mucorales* Dumort.	*Cunninghamellaceae* Naumov ex R.K. Benj.	*Cunninghamella* Matr.	*Cunninghamella elegans* Lendn..	*Cunninghamella bertholletiae.*	Honey Blossom; Honeydew[3].
		Mucoraceae Fr.	*Mucor* P. Micheli ex L.	*Mucor hiemalis* Wehmer..		Nectar Honey[15].
				Mucor sp. P. Micheli ex L..		Honey Blossom; Honeydew; Nectar Honey[12, 14, 17, 22, 25].
				Mucor plumbeus Bonord..		Honey Blossom; Honeydew[3].
				Mucor racemosus Bull..		Nectar Honey[15].
			Rhizopus Ehrenb.	*Rhizopus arrhizus* A. Fisch..	*Rhizopus oryzae.*	Honey Blossom; Honeydew[3]
				Rhizopus sp. Ehrenb..		Nectar Honey[6].
				Rhizopus stolonifer (Ehrenb.) Vuill..		Nectar Honey[15].

Note: *Peronosporaceae* sp. de Bary and *Pythium* sp. Pringsh., have also been isolated, identified and noted as fungi, from Honey Blossom and Honeydew samples[17].

microorganisms in honey is the substrate low water activity (a_w), which inhibits the growth of almost all organisms[11]. Nonetheless, if the moisture content is high enough (above 21%), xerotolerant and xerophile microorganisms can develop causing honey fermentation and spoilage[3,11]. The microbes of interest in honey are primarily yeasts, fungi and spore-forming bacteria, since their presence can influence the products stability and sanitary quality. Since bees collect pollens and nectars, yeast and fungi presence in honey is unavoidable[4,6] and examples of filamentous fungi usually found in honey encompass *Aspergillus, Penicillium*, *Mucor* and *Monascus,* along with some osmophile yeasts such as *Saccharomyces*[6,12]. Moreover, additional common fungal contaminants of honey are the obligate xerophiles *Ascosphaera apis* and *Bettsia alvei*, several xerotolerant species[3], various species of plant pathogenic fungi[13], mycotoxin-producing species[14], and fungi commonly found in pollens and the digestive tract of bees[15].

During the last two decades, several studies focusing on the isolation and characterization of fungal species thriving in honey have been published. However, a thorough summary of these results has not been compiled so far. With this in mind, the aim of this work is to elicit a checklist of fungi isolated from honey, honey blossom and honeydew, during the time period of 2000 to 2022. As such, this work provides critical information that can be helpful to mycologists, beekeepers and the industrial sector to improve honey and quality and production levels.

Materials and methods

The present checklist is based on a survey of scientific papers using morphological and/or molecular methods to identify fungal taxa isolated from honey, honey blossom and honeydew, during the time period of 2000 to 2022[3–6,12,14–28]. Moreover, the checklist was annotated to contain currently accepted fungal names according to the Index Fungorum (www.indexfungorum.org) to provide an up-to-date analysis and facilitate future knowledge sharing.

Results

Checklist

Conclusions

So far, more than one hundred and thirty entries have been reported from honey samples worldwide. Overall, the most represented genera are *Penicillium* (23 species), *Aspergillus* (17 species), *Zygosaccharomyces* (7 species) and *Talaromyces* (6 species). Consequently, most representative fungal families isolated from honey are *Aspergillaceae*, *Saccharomycetaceae* and *Trichocomaceae*. *Aspergillus*, *Penicillium* and *Talaromyces* species are considered to hold important industrial and pharmacological applications, but also to be associated with food spoilage, mycotoxins production, and human and plant diseases (e.g., Houbraken et al. 2020). Due to the ability of various of the identified species to produce both mycotoxins and other extracellular enzymes and organic acids, their study is also of significant industrial interest (Silva et al. 2017). Indeed, the industrial applications of *Saccharomycetaceae* and their ability to act as food spoilage yeasts is well known. Moreover, the detection of common bee pathogens (e.g., *Monascus mellicola*) also highlights the importance of such studies to monitor bee pathogens and, consequently, maintain or improve ecosystem balance and biodiversity.

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Conflict of interest

The authors declare that they have no conflict of interest.

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