









# *Mucor minutus* (Baijal & B.S. Mehrotra) Schipper: a rare mucoralean fungi isolated for the first time in northeastern Brazil

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## Abstract

*Mucor minutus* (Baijal & B.S. Mehrotra) Schipper is described for the first time from northeastern Brazil. The specimen was isolated from the soil of Florestas do Jussará, an upland forest fragment in Pernambuco state. In Brazil, *M. minutus* has previously been isolated only from the state of São Paulo from the soil of the Atlantic Forest. The occurrence of *M. minutus* in Florestas do Jussará is presented and discussed, and a detailed description and illustration of the specimen are presented. This article contributes to the knowledge of mucoralean distribution.

## Keywords

Mucoromyceta, Mucoraceae, taxonomy, upland forest

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## Introduction

*Mucor* Fresen. is the most representative genus within the order Mucorales Fr., family Mucoraceae Fr., and phylum Mucoromycota Doweld, with approximately 91 described species (Wijayawardene et al. 2020). Species of this genus are characterized by forming simple or branched sporangiophores arising directly from the substrate which bear globose and/or subglobose, non-apophysate sporangia, and with a few species producing rhizoids (e.g., *M. luteus* Linnem. Ex Wrzosek and

*M. irregularis* Stchigel, Cano, Guarro & E. Álvarez, Benny et al. 2014). Species of this genus are typically saprobes, commonly isolated from the soil, stored grains, and decomposing fruits (Santiago et al. 2013; Lima et al. 2015). However, some taxa are able to cause mucormycosis, as is the case of *M. circinelloides* Tiegh., *M. indicus* Lendn., *M. irregularis*, and *M. lusitanicus* Bruderl. (Hoffmann et al. 2013; Walther et al. 2013; Wagner et al. 2019).

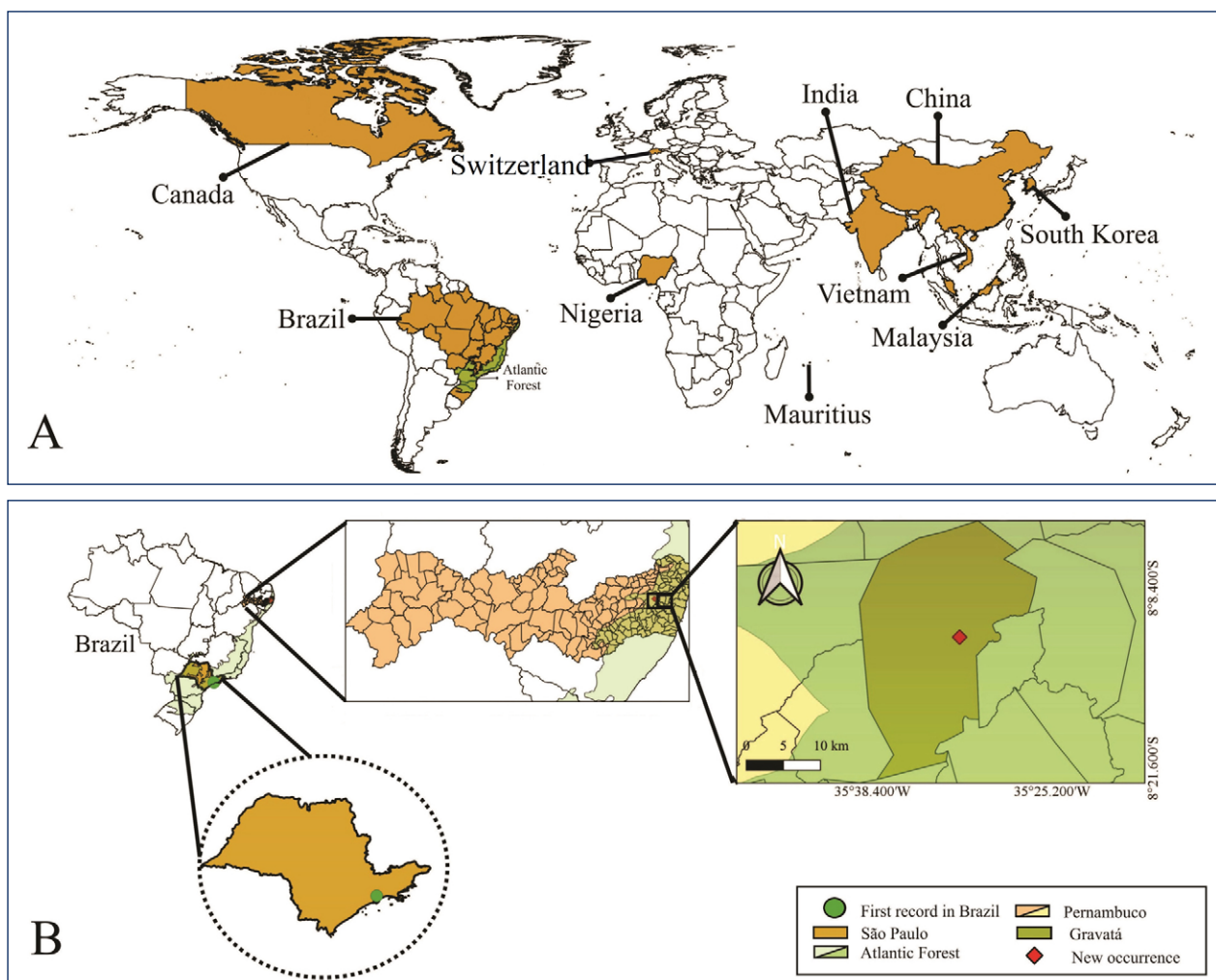
*Mucor minutus* (Baijal & B.S. Mehrotra) Schipper may be morphologically differentiated from other species by concomitantly forming long, sympodially and monopodially branched sporangiophores, in addition to small, repeatedly sympodially branched sporangiophores, obovoid to ellipsoidal or infrequently pyriform columellae, as well as subspherical or slightly ellipsoidal sporangiospores (Schipper 1975). Unfortunately, knowledge of the ecology and distribution of *Mucor minutus* is limited. So far, this species has been reported from Canada (from soil, ITS sequence is available in GenBank: KU556591: unpublished data), Brazil (from soil: Schoenlein-Crusius et al. 2006), China (substrate unspecified, ITS sequence available in GenBank, MT089979: unpublished data), India (holotype, from soil: Baijal and Mehrotra 1966), Malaysia (from soil: Lee et al. 2012), Nigeria (substrate unspecified, ITS sequence available in GenBank, MN606270: unpublished data), Republic of Mauritius (from soil, ITS sequence available in GenBank, MN871809: unpublished data), South Korea (from soil: Nguyen et al. 2017), Switzerland (from soil in cucumber rhizosphere: Girlanda et al. 2001), and Vietnam (from soil, ITS sequence available in GenBank, EU076933: unpublished data) (Fig. 1A). In Brazil, *M. minutus* was

previously isolated from an area of the Atlantic Forest, located in the municipality of Cubatão, state of São Paulo (Schoenlein-Crusius et al. 2006) (Fig. 1B)

During a study on the diversity of Mucorales in an upland forest fragment in Pernambuco, northeastern Brazil, a specimen morphologically similar to *M. minutus* was isolated. The identity of the species was confirmed by sequencing the ITS region of rDNA. Here, we present and discuss the occurrence of *M. minutus*. We also provide the description and illustration this rare species isolated from soil samples in the semiarid region of Brazil.

## Methods

**Soil collection.** Soil samples were collected in January 2018 from Florestas do Jussará, an upland forest area in the semiarid region of Brazil, located in the municipality of Gravatá (08°12'S, 035°32'W), 85.5 km from Recife (Fig. 1B). The climate is tropical with a dry summer, and an average annual temperature of 22 °C. The average annual rainfall is 725 mm, with rains concentrated between March and July (Siqueira-Filho and Machado 2001). Using sterilized spatulas, soil samples up to 5 cm deep were collected from 10 different points, respecting



**Figure 1. A.** Occurrence of *Mucor minutus*. **B.** First occurrence of *M. minutus* (URM 7894) in the semiarid region of Brazil at Reserva Florestas do Jussará, municipality of Gravatá, Pernambuco state.

a minimal distance of 50 m between each on. Samples were placed in clean plastic bags and stored in polystyrene boxes with ice for transport to the laboratory of the Universidade Federal de Pernambuco (UFPE).

**Isolation, purification, and identification.** A 5 mg sample of soil collected at each one of 10 sampling points was added to Petri dishes containing wheat germ agar culture medium (Benny 2008) plus chloramphenicol (NeoFenicol-Neo Química; 100 mg/L), in triplicate. The plates were stored on a laboratory bench at room temperature ( $26 \pm 2$  °C) for 7 days. To purify the specimens, fragments of mycelia were removed from the Petri dishes under a stereomicroscope (Leica EZ4) and transferred to Petri dishes with malt extract agar (MEA) (Benny 2008) plus chloramphenicol (80 mg/L). Fragments of mycelia were transferred to slides with 2% KOH or lactophenol blue and observed using light microscopy (Leica DM500). Each specimen was identified by comparing the macroscopic aspect (colony color and appearance) and microscopic structures (shape and size of the sporangio-phores, columellae, sporangia, and sporangiospores), according to the description of Schipper (1975). Seventy-five measurements were made for each fungal structure from plates incubated at 25 °C for 7 days in the dark on MEA. A living culture (URM 7894) is deposited in the culture collection Micoteca URM of the Universidade Federal de Pernambuco.

**DNA extraction, PCR, sequencing and phylogenetic analysis.** Cultures grown in test tubes containing MEA were incubated at 28 °C for 6 days to obtain fungal biomass. After the material was transferred to 2 mL microtubes with screw caps, 0.5 g of acid-washed glass beads of two different diameters (150–212 µm and 425–600 µm, 1:1; Sigma, USA) were added to each tube. The material was crushed by stirring at high speed in a Fast-Prep homogenizer. Genomic DNA was extracted as described by de Oliveira et al. (2016). The mycelium was washed with chloroform: isoamyl alcohol (24:1) and then homogenized in 2% cetyltrimethylammonium bromide buffer. The DNA was precipitated in isopropanol, washed with 70% ethanol, and resuspended in 50 µL of ultrapure water. To amplify the ITS region both primers ITS1 and ITS4 were used (White et al. 1990). Polymerase chain reactions were performed as described by de Oliveira et al. (2014). The newly obtained sequence was deposited in the GenBank database (MW436702). The fungal sequences were aligned with ClustalX (Larkin et al. 2007) and edited with BioEdit (Hall 1999). Prior to phylogenetic analysis, the optimal nucleotide replacement model was estimated using TOPALi 2.5 (Milne et al. 2004). Phylogenetic analysis based on the ITS region was performed to reconstruct a phylogenetic tree, under a maximum likelihood (with support estimated by a bootstrap analysis with 1000 replicates) and Bayesian inference (two runs over  $2 \times 10^6$  generations with a burn-in of 2500) analyses were performed with PhyML 3.0 (Guindon et al. 2010) and MrBayes 3.2.2 (Ronquist et al.

2012), respectively. The phylogenetic tree was visualized using Treeview (Page 1996) and edited using Inkscape v. 1.1 (<https://inkscape.org/en/>).

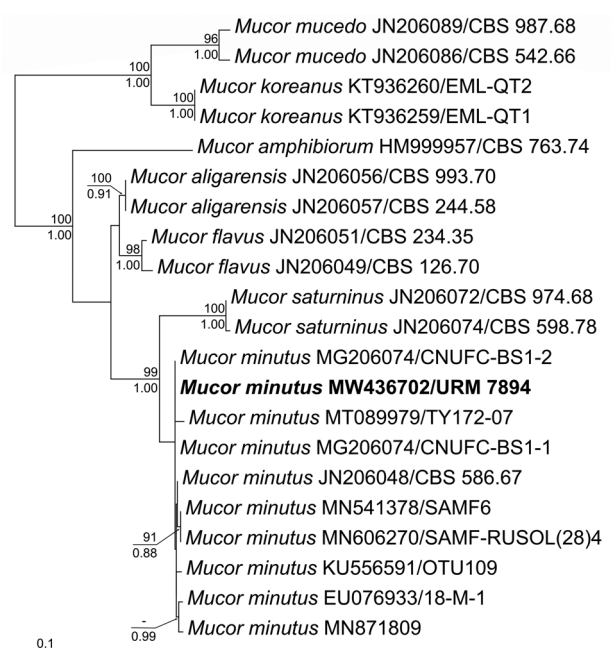
## Results

Altogether, 273 specimens of Mucorales were isolated from the soil samples, among which one (URM 7894) was morphologically identified as *Mucor minutus*. In the BLASTn analysis, the ITS sequence of URM 7894 showed 100% identity with the sequence of *M. minutus* holotype (CBS 586.67, JN206048), which was grouped together in a same clade, and with other sequences of *M. minutus* in the phylogenetic tree (Fig. 2).

### *Mucor minutus* (Baijal & B.S. Mehrotra) Schipper Figure 3

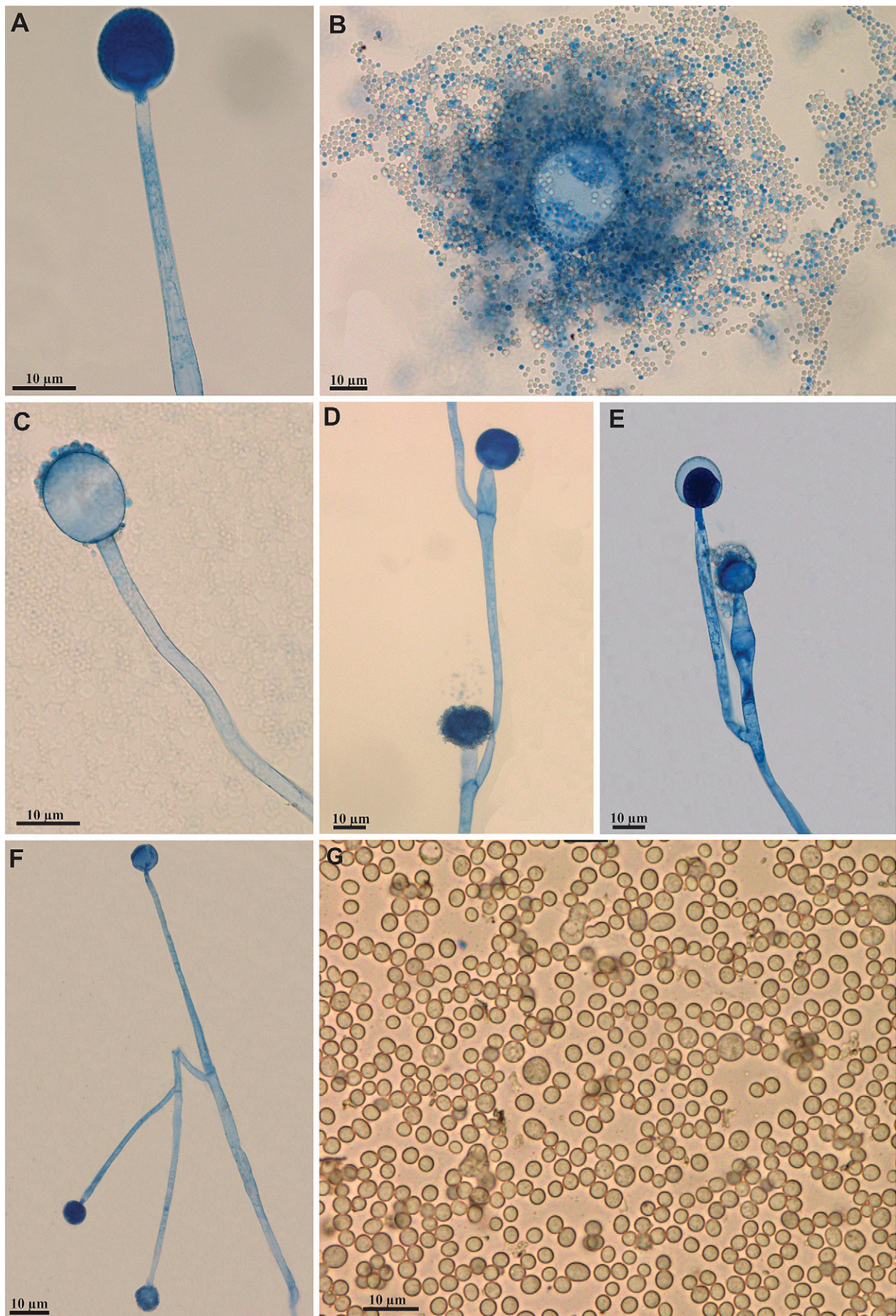
**Material examined.** BRAZIL • Pernambuco, Gravata, Reserve Florestas do Jussará; 08°12'S, 035°32'W; 739 m a.s.l.; January 2018; Ana L.S Melo Alves leg.; in soil; URM 7894, 1 specimen; GenBank accession no. MW436702 (ITS).

**Identification.** Colonies initially white, subsequently turned gray, colonized the entire Petri dish (9 cm in diameter and 1.5 cm in height) in five days on MEA at 25 °C. Long and short sporangiophores common. Long sporangiophores hyaline up to 20 µm in diameter, with monopodial and sympodial branches, smooth-walled. Sporangia of the long sporangiophores brownish, globose, up to 160 µm in diameter, slightly equinulated. Columellae of the long sporangiophores hyaline, obovoid, globose, and infrequently conical and flattened,



**Figure 2.** Phylogenetic tree of *Mucor minutus* and related species constructed using the rDNA (ITS) sequences. *Mucor mucedo* and *Mucor koreanus* were used as an outgroup. Supporting values are for maximum likelihood analysis and Bayesian inference. The sequence obtained in this study is in bold.





**Figure 3.** *Mucor minutus* (URM 7894). **A.** Sporangioophore with sporangium. **B.** Sporangium with columella and esporangiospores. **C.** Sporangioophore with columella. **D–F.** Branched sporangioophore. **G.** Sporangiospores.



25–65 (–85) × 25–80 (–95) µm. Short sporangiophores hyaline, repeatedly sympodially branched, up to 12 µm in diameter, smooth-walled. Sporangia of the short sporangiophores hyaline, up to 120 µm. Columellae of the short sporangiophores conical and subglobose, 9.5–19.5 (–36.5) × 7.0–9.5 (–25.0) µm. Sporangiospores hyaline, subglobose to ellipsoid, 2.5–5.0 (–7.2) × 2.3–3.0 (–4.0) µm. Zygospores not observed.

## Discussion

We report the first occurrence of the rare *Mucor minutus* (URM 7894) in northeastern Brazil, isolated from soil in an upland forest fragment. This species was first described as a variety of *Mucor griseo-ochraceous* Naumov (as *M. griseo-ochraceous* var. *minutus* Bajjal & B.S. Mehrotra) in India (Bajjal & B.S. Mehrotra 1966). Nine years later, Schipper (1975) proposed the new combination *M. minutus* (Bajjal & B.S. Mehrotra) Schipper. As far as we know, this species has only been reported in Brazil, Canada, China, India, Nigeria, Mauritius, South Korea, Switzerland, and Vietnam. Occurrence data from many of these countries is restricted to ITS sequences deposited in GenBank, with no information as to where specimens were collected. Although published manuscripts reported *M. minutus* from soil in Brazil, India, Malaysia, South Korea, and Switzerland, detailed information on collection sites, including soil type, local vegetation, temperature, and precipitation are missing, except for Brazil. Like other specimens of *Mucor*, *M. minutus* is a probably a soil saprobe, as a parasitism interaction has not yet been reported for this species.

Both morphology and phylogeny show that URM 7894 is *M. minutus*, and the morphological characteristics of this specimen are in good agreement with the description by Schipper (1975). However, some morphological differences were observed between URM 7894 and the ex-type. Long sporangiophores up to 20 µm in diameter were observed in our specimen; these are smaller than those described by Schipper (1975), who described the long sporangiophores as up to 30 µm in diameter. The sporangia of the long sporangiophores of URM 7894 were smaller than those described by Schipper (1975), which are up to 175 µm in diameter. Additionally, URM 7894 exhibits columellae of the long sporangiophores that are obovoid, globose, infrequently conical and flattened, and up to 85 × 95 µm, while Schipper (1975) reported columellae of the long sporangiophores as obovoid to ellipsoid, infrequently pyriform, and up to 135 × 97 µm. The columellae of short sporangiophores described here are conical and subglobose, unlike those reported for the ex-type, which are cylindrical to ellipsoid, some conical to flattened. Nguyen et al. (2017) observed the presence of one to three septa below the columellae, unlike our isolate and the ex-type (Schipper 1975), which have no septum below the columellae.

This manuscript contributes to a better understanding of the distribution of *M. minutus*, a rare species

reported from only 10 countries so far. Although most mucoralean species are saprobic and commonly found in soil (Benny et al. 2016), information on the distribution and ecologic niches of these fungi is still scarce (Walther et al. 2019). Unfortunately, there are just a few published manuscripts reporting the occurrence of *M. minutus* (all from soil samples), with little or no information about the biomes where these fungi were found. Thus, new surveys of this species in other substrata, such as dung, decomposing vegetables, and food spoilages in different biomes, may help the understanding on the biology and ecology of this species.

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## Authors' Contributions

LMSG collected the material and formatted the plate; CAFS, TRLC, MOC, and RJVO performed the specified methodology; ALSMA and ALCMAS wrote the text and identified the specimen.

## References

- Bajjal U, Mehrotra BS (1966) Species of *Mucor* from India—II. Sydowia 19: 204–212.
- Benny GL (2008) The methods used by Dr. R.K. Benjamin, and other mycologists to isolate Zygomycetes. Aliso 26: 37–61. <https://doi.org/10.5642/aliso.20082601.08>
- Benny GL, Humber RA, Voigt K (2014) Zygomycetous Fungi: phylum Entomophthoromycota and subphyla Kickxellomycotina, Mortierellomycotina, Mucoromycotina, and Zoopagomycotina. In: McLaughlin D, Spatafora J (Eds.) The Mycota. Systematics and evolution, part A. VII. Second edition. Springer, Berlin, 209–250. [https://doi.org/10.1007/978-3-642-55318-9\\_8](https://doi.org/10.1007/978-3-642-55318-9_8)
- Benny GL, Smith ME, Kirk PM, Tretter ED, White MM (2016) Challenges and future perspectives in the systematics of Kickxellomycotina, Mortierellomycotina, Mucoromycotina, and Zoopagomycotina. In: Li D-W (Ed.) Biology of microfungi, fungal biology. Springer International Publishing, Cham, Switzerland, 65–126.
- de Oliveira RJV, Lima TEF, Cunha IB, Coimbra VRM, da Silva GA, Bezerra JL, Cavalcanti MAQ (2014) *Corniculariella brasiliensis*, a new species of coelomycetes in the rhizosphere of *Caesalpinia echinata* (Fabaceae, Caesalpinioideae). Brazil. Phytotaxa 178 (3): 197–204. <https://doi.org/10.11646/phytotaxa.178.3.5>
- de Oliveira RJV, Bezerra JL, Lima TEF, Silva GA, Cavalcanti MAQ (2016) *Phaeosphaeria nodulispora*, a new endophytic coelomycete isolated from tropical palm (*Cocos nucifera*) in Brazil. Nova Hedwigia 103 (1–2): 185–192. [https://doi.org/10.1127/nova\\_hedwigia/2016/0343](https://doi.org/10.1127/nova_hedwigia/2016/0343)
- Girlanda M, Perotto S, Moenne-Loccoz Y, Bergero R, Lazzari A, Defago G, Bonfante P, Luppi AM (2001) Impact of Biocontrol

- Pseudomonas fluorescens* CHAo and a genetically modified derivative on the diversity of culturable fungi in the cucumber rhizosphere. *Applied and Environmental Microbiology* 67 (4): 1851–1864. <https://doi.org/10.1128/aem.67.4.1851-1864.2001>
- Guindon S, Gascuel O (2003) A simple, fast, and accurate algorithm to estimate large phylogenies by maximum likelihood. *Systematic Biology* 52 (5): 696–704. <https://doi.org/10.1080/10635150390235520>
- Hall TA (1999) BioEdit: a user-friendly biological sequence alignment editor and analysis program for Windows 95/98/NT. *Nucleic Acids Symposium* 41: 95–98. <http://doi.org/10025329089>
- Hoffmann K, Pawłowska J, Walther G, Wrzosek M, de Hoog GS, Benny GL, Kirk PM, Voigt K (2013) The family structure of the Mucorales: a synoptic revision based on comprehensive multigene genealogies. *Persoonia* 30: 57–76. <https://doi.org/10.3767/003158513X66625>
- Larkin MA, Blackshields L, Brown NP, Chenna R, McGettigan PA, McWilliam H, Valentin F, Wallace IM, Wilm UM, Lopez R, Thompson JD, Gibson TJ, Higgins DG (2007) Clustal W and Clustal X version 2.0. *Bioinformatics* 23: 2947–2948. <https://doi.org/10.1093/bioinformatics/btm404>
- Lee SS, Alias SA, Jones EGB, Zainuddin N, Chan HT. 2012. Checklist of fungi of Malaysia. Research pamphlet No 132. Forest Research Institute Malaysia, Kepong, Malaysia, 409 pp.
- Lima DX, Santiago ALCM de A, Souza-Motta CM (2015) Diversity of Mucorales in natural and degraded semi-arid soils. *Brazilian Journal of Botany* 38: 1127–1133. <https://doi.org/10.1007/s40415-015-0156-8>
- Milne L, Wright F, Rowe G, Marshall D, Husmeier D, McGuire G (2004) TOPALi: software for automatic identification of recombinant sequences within DNA multiple Alignments. *Bioinformatics* 20 (11): 1806–1807. <https://doi.org/10.1093/bioinformatics/bth155>
- Nguyen TTT, Jung HY, Lee YS, Voigt K, Lee HB (2017) Phylogenetic status of two undescribed zygomycete species from Korea: *Actinomucor elegans* and *Mucor minutus*. *Mycobiology* 45 (4): 344–352. <https://doi.org/10.5941/myco.2017.45.4.344>
- Page RDM (1996) TreeView: application to display phylogenetic trees on personal computers. *Computer Applications in the Biosciences* 12: 357–358.
- Ronquist F, Huelsenbeck JP (2003) MrBayes 3: Bayesian phylogenetic inference under mixed models. *Bioinformatics* 19 (12): 1572–1574. <https://doi.org/10.1093/bioinformatics/btg180>
- Santiago ALCM de A, Santos PJP, Maia LC (2013) Mucorales from the semiarid of Pernambuco. *Brazilian Journal of Microbiology* 44 (1): 299–305. <https://doi.org/10.1590/S1517-83822013005000027>
- Schipper MAA (1975) *Mucor mucedo*, *Mucor flavus* and related species. *Studies in Mycology* 10: 1–33.
- Schoenlein-Crusius IH, Milanez AI, Trufem SFB, Pires-Zottarelli CLA, Piccolo RAG, Santos ML, Giustra KC (2006) Microscopic fungi in the Atlantic Rainforest in Cubatão, São Paulo, Brazil. *Brazilian Journal of Microbiology* 37 (3): 267–275. <https://doi.org/10.1590/S1517-83822006000300014>
- Siqueira Filho JA, Machado ICS (2001) Reproductive biology of *Canistram aurantiacum* E. Morren (Bromeliaceae) in remnants of the Atlantic Forest, Northeast Brazil. *Acta Botanica Brasilica* 15 (3): 427–443. <https://doi.org/10.1590/S0102-33062001000300011>
- Wagner L, de Hoog GS, Alastruey-Izquierdo A, Voigt K, Kurzai O, Walther G (2019) A revised species concept for opportunistic *Mucor* species reveals species-specific antifungal susceptibility profiles. *Antimicrobial Agents and Chemotherapy* 3: e00653-19. <https://doi.org/10.1128/aac.00653-19>
- Walther G, Pawłowska J, Alastruey-Izquierdo UM, Wrzosek H, Rodríguez-Tudela JU, Dolatabadi S, Chakrabarti UM, de Hoog GS (2013) DNA barcoding in Mucorales: an inventory of biodiversity. *Persoonia* 30: 11–47. <https://doi.org/10.3767/003158513X665070>
- Walther G, Wagner G, Kurzai O (2019) Updates on the taxonomy of Mucorales with an emphasis on clinically important taxa. *Journal of Fungi* 5 (4): 106. <https://doi.org/10.3390/jof5040106>
- White TJ, Bruns T, Lee S, Taylor J (1990) Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics. In: Innis MA, Gelfand DH, Sninsky JJ, White TJ (Eds.) *PCR protocols: a guide to methods and applications*. Academic Press, San Diego, USA, 315–322.
- Wijayawardene NN, Hyde KD, Al-Ani LKT, Tedersoo L, Haelewaerters D, Rajeshkumar KC, Zhao RL, Aptroot A, Leontyev DV, Saxena RK, Tokarev YS, Dai DQ, Letcher PM, Stephenson SL, Ertz D, Lumbsch HT, Kukwa M, Issi IV, Madrid H, Phillips AJL, Selbmann L, Pfliegler WP, Horváth E, Bensch K, Kirk PM, Kolaříková K, Raja HA, Radek R, Papp V, Dima V, Ma J, Malosso E, Takamatsu S, Rambold G, Gannibal PB, Triebel D, Gautam AK, Avasthi S, Suetrong S, Timdal E, Fryar SC, Delgado G, Réblová M, Doilom M, Dolatabadi S, Pawłowska J, Humber RA, Kodsueb R, Sánchez-Castro I, Goto BT, Silva DKA, de Souza FA, Oehl F, da Silva GA, Silva IR, Błaszczowski J, Jobim K, Maia LC, Barbosa FR, Fiuza PO, Divakar PK, Shenoy BD, Castañeda-Ruiz RF, Somrithipol S, Lateef AA, Karunarathna SC, Tibpromma S, Mortimer PE, Wanasinghe DN, Phookamsak R, Xu J, Wang Y, Tian F, Alvarado P, Li DW, Kušan I, Matočec N, Maharachchikumbura SSN, Papizadeh M, Heredia G, Wartchow F, Bakhshi M, Boehm E, Youssef N, Hustad VP, Lawrey JD, Santiago ALCMA, Bezerra JDP, Souza-Motta CM, Firmino AL, Tian Q, Houben J, Hongsan S, Tanaka K, Dissanayake AJ, Monteiro JS, Grossart HP, Suija A, Weerakoon G, Etayo J, Tsurukau A, Vázquez V, Mungai P, Damm U, Li QR, Zhang H, Boonmee S, Lu YZ, Becerra AG, Kendrick B, Brearley FQ, Motiejūnaitė J, Sharma B, Khare R, Gaikwad S, Wijesundara DSA, Tang LZ, He MQ, Flakus A, Rodríguez-Flakus P, Zhurbenko MP, McKenzie EHC, S tadler M, Bhat DJ, Liu JK, Raza M, Jeewon R, Nassonova ES, Prieto M, Jayalal RGU, Erdogdu M, Yurkov A, Schnittler M, Shchepin ON, Novozhilov YK, Silva-Filho AGS, Gentekaki E, Liu P, Cavender JC, Kang Y, Mohammad S, Zhang LF, Xu RF, Li YM, Dayarathne MC, Ekanayaka AH, Wen TC, Deng CY, Pereira OL, Navathe S, Hawksworth DL, Fan XL, Dissanayake LS, Kuhnert E, Grossart HP, Thines M (2020) Outline of fungi and fungus-like taxa. *Mycosphere* 11 (1): 106–1456. <https://doi.org/10.5943/mycosphere/11/1/8>