Three new species of Hypoxylon and new records of Xylariales from Panama

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Abstract

Three new species of Hypoxylon (Hypoxylaceae, Xylariales) are described based on a polyphasic approach that included morphological examination, molecular phylogeny and chemotaxonomic studies of specimens collected in Panama. Specifically, we compared the sexual morph (stromata, asci, and ascospores) of the specimens collected with known species of Hypoxylon and inferred a phylogeny of this genus based on a Randomized Accelerated Maximum Likelihood (RAxML) analysis of partial β–tubulin (TUB2) DNA sequences and the internal transcribed spacer regions (ITS). Hypoxylon baruense sp. nov. is phylogenetically related to H. subgilvum but differs in the shape of stromata, and by having larger ascospores and a smooth perispore. Hypoxylon bellicolor sp. nov. is phylogenetically well differentiated, featuring effused–pulvinate stromata with orange granules and ostioles lower than the stromatal surface. Hypoxylon sporistriatatunicum sp. nov., is phylogenetically related to H. shearii var. minor but differs in the shape of the stromata, in having ostioles higher than the stromatal surface, and in having larger ascospores. The secondary metabolite profiles of these species were studied by HPLC–DAD–MS and these correspond to the results of the morphological and phylogenetic studies. Additionally, we also report Amphirosettinia evansi, H. howeanum, H. cinnabarinum and Stilbohypoxylon quisquiliarum from Panama for the first time and Citrus sinensis as a new host of H. cinnabarinum. With this work, the number of species of Xylariales and Hypoxylon reported from Panama have increased to 103 and 18, respectively.

Key words – Biodiversity – Fungi – Sordariomycetes – Hypoxylaceae

Introduction

The order Xylariales comprises 26 families that include approx. 2,500 species in 210 genera (Hongsanan et al. 2017). Species in this order are common worldwide, though the highest diversity of Xylariales is found in the tropics (see Dayarathne et al. 2017, Li et al. 2017, Sir et al. 2016b for
recent records of new tropical taxa). Of the 26 families of Xylariales (Helaly et al. 2018), the Xylariaceae and Hypoxylaceae are two of the most diverse and include the specimens studied in this work. The Xylariaceae (Tul. & C. Tul. [as “Xylariet”]) Selects fung Carpol (Paris) 2: 3 (1863) emend M. Stadler & L. Wendt) is second to Amphisphaeriaceae (Xylariales) in terms of species richness, and comprises 823 species in 32 genera (Wendt et al. 2018). Species of Xylariaceae produce a geniculosporium–like asexual state, and in general, their stromata do not contain extractable pigments in 10% KOH (Wendt et al. 2018). Recently, 674 species were segregated from Xylariaceae and distributed into three families (Graphostromataceae, Hypoxylaceae, and Lopadostomataceae) while several more were segregated but are currently considered incertae sedis within Xylariales and Sordariomycetes, due to the lack of sufficient molecular data and information on the types of the asexual morph (Wendt et al. 2018). The Hypoxylaceae contains more than 360 species in 18 genera including recently described new taxa (Wendt et al. 2018, Daranagama et al. 2018, Lambert et al. 2019, De Long et al. 2019, Sir et al. 2019). The recent update of Sordariomycete families (Hyde et al. 2020) even listed 422 species in 19 genera.

The first records of Xylariales from Panama were based on specimens collected in Barro Colorado Island, Panama Canal Area, in the 1920s (Weston 1933, Standley 1933), and included 11 species of Hypoxylon, but only four of them are currently accepted in this genus: *H. haematostroma*, *H. fuscum*, *H. hypomiltum*, and *H. rubiginosum*. These records were followed by the reports of *H. subgilvum* and *H. dieckmani* from the Panama Canal Area by Dennis in 1956, 1970 respectively. More recent collections were recorded for western Panama by Carmona et al. 2009 (*H. anthochroum*, *H. crocopeplum*, *H. investiens*, *H. fendleri*, and *H. lividipigmentum*), Piepenbring et al. 2012 (*H. pelliculosum*), and Kuhnt et al. 2015 (*H. trugodes*). Despite these studies, the reports of Xylariales from Panama are very scarce; only 95 species have been reported in the country for this highly diverse order (Piepenbring 2013). Recent surveys of Sordariomycetes in Panama conducted by our research group suggest that many species of Xylariales remain to be described. Here we present new records of Xylariales from Panama and the description of three new species of *Hypoxylon* based on comparative morphology, molecular phylogeny, and chemotaxonomy.

This study was based on specimens collected at six sites in the Republic of Panama and they are characterized based on a polyphasic approach (morphological, DNA based phylogeny and secondary metabolite profiling).

**Materials & Methods**

**Collection of specimens and preparation of cultures**

Since the scope of this study was to make an inventory of *Hypoxylon*, a genus whose stromata almost exclusively occur on woody, dicotyledonous angiosperms, the collection work focused on the forests that are known for a high diversity of such potential hosts. Two sites in the Panama Canal Area: Soberania National Park (SNP) and Camino de Cruces Park (CCP). Four sites in the western province of Chiriquí: Barú Volcano National Park (BVNP), La Concepción, Sortová, and La Amistad International Park (PILA, Chiriquí side). Four of these sites (SNP, CCP, Sortová and Concepción) are localized in lowlands at <700 meters above sea level (m.a.s.l.) and two at elevations higher than 1500 m.a.s.l. (PILA and BVNP).

Each of the sites were visited at least one time and specimens of fungi with typical morphological characters of Xylariaceae and Hypoxylaceae were collected, placed in paper bags, dried overnight at ambient temperature to remove excess humidity and transported to the laboratory for detailed observation and isolation of pure cultures. In the laboratory, perithecia were removed from the stromata using a sterile scalpel under a dissecting stereomicroscope (Nikon SMZ800, Melville, NY, USA), placed on a microscope slide with 50 µl of sterile water and crushed to release ascospores. Thereafter, 10 µl of the ascospore suspension were transferred to Petri dishes with potato dextrose agar (PDA) supplemented with rifampicin (PDA+r). After 24 hours the media were observed for sporulation and monosporic cultures were generated. In rare cases, cultures were
generated from multiple germinated spores or cultured from a small piece of the stromata. The cultures were preserved in 10% glycerol at –20°C and maintained in corn meal agar (CMA) slants at 8°C. Cultures were grown in: Potato dextrose agar (PDA), 2 % malt extract agar (2%MEA), V8 agar, oatmeal agar (OA), and potato carrot agar (PCA).

Morphological observations

Sexual structures of the collected specimens were extracted from fresh material, immersed in distilled water and 10 % KOH respectively, and size measurements were performed. Melzer’s reagent was used to test the presence of an amyloid reaction of the apical apparatus. The color of the stromata and the extractable pigments were reported following the codes according to Rayner (1970). The stroma and perithecia of each specimen were photographed with a camera (ZEISS Axioacam ICc 5, Jena, Germany) connected to the microscope (ZEISS Axio Scope.A1, Germany). Asci and ascospores were observed, photographed, and measured using an Olympus BX53 microscope equipped with an Olympus DP73 camera and the CellSens Dimensions Software (Olympus, Japan). Specimens were preliminary identified morphologically using the key to species of Hypoxylon by Ju & Rogers (1996), Fournier et al. (2015) and Sir et al. (2016a), and in the case of Stilbohypoxylon by Petrini (2004). Further identification was accomplished using both, morphological and phylogenetic analyses (see below). Dried specimens were deposited in the herbarium of the Autonomous University of Chiriquí, Faculty of Natural and Exact Sciences, Chiriquí, Panama (UCH).

DNA extraction, amplification, and sequencing

DNA was extracted from 5 days old mycelial cultures grown on PDA media. Approximately a square centimeter of mycelium, taken from the growth front of the cultures was scraped off the surface of the medium and transferred to an extraction tube. The DNA was extracted using the Gentra Puregene Tissue kit (QIAGEN, Germany) following the manufacturer’s instructions. The TUB2 gene region was amplified using the primers T1 and T22 (O’Donnell & Cigelnik 1997). Amplifications were performed in 25 µl assays containing: 5–15 ng of genomic DNA, 200 µM of each dNTP, 2.5 units of Taq DNA Polymerase (QIAGEN, Germany), 2 µM of each primer and 10x buffer with 15 mM MgCl2; using the iCycler thermal cycler ABI 2720 (Applied Biosystems, USA) under the following reaction conditions: 5 min at 94°C, followed by 32 cycles of 45 s at 94°C, 45 s at 50°C, and 1.5 min at 72°C, with a final extension period of 10 min at 72°C. The ITS gene region was amplified according to Mejía et al. (2008).

PCR products were purified using ExoSAP–IT (USB, Cleveland, USA) following the manufacturer’s instructions, and the purified DNA was used for further cycle sequencing reactions with the BigDye Terminator v 3.1 kit (Applied Biosystems, Life Technologies Corporation, Carlsbad CA). The cycle sequencing reactions were performed using the same PCR primers and for TUB2 additionally, the internal primers T2 and T12 (O’Donnell & Cigelnik 1997). The reactions samples were purified with the Big Dye Xterminator kit and the PCR products were sequenced with an Applied Biosystems 3500 Genetic Analyzer (Life Technologies, Carlsbad, CA).

Phylogenetic analysis

DNA sequences of the new species were analyzed for quality and edited using the software Sequencher 5.1 (versión 5.1, Gene codes corporations, Ann Arbor, USA). The generated DNA sequences were collated against deposited sequences in the GenBank® database using the Basic Local Alignment Search Tool for Nucleotide sequences (Benson et al. 2013). Authentic ITS and TUB2 sequences of suitable Hypoxylon taxa from published studies were selected for the phylogenetic analyses (Table 1). Furthermore, the type species of prominent Hypoxylon sister genera were also included and Xylaria hypoxylon (Xylariaceae) was the outgroup. MAFFT alignments (G-INS-i, PAM 200/ k=2, GOP = 1.53, OV = 0.123; Katoh & Kuma 2002) of the ITS and TUB2 sequence dataset were calculated respectively, using the MAFFT v7.017 plug-in of Geneious® 7.1.9 (http://www.geneious.com, Kearse et al. 2012).
Table 1 List of strains used in the phylogenetic analyses. GenBank accession numbers for the ITS and TUB2 sequences are given. Strains derived from type specimens are labelled with T (holotype), IT (isotype), ET (epitype). Sequences derived from this study are highlighted in **bold**. Scientific names follow Index Fungorum (http://www.indexfungorum.org/).

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<th>Species name</th>
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<th>Location</th>
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<td>JX183075</td>
<td>JX183072</td>
<td>Martinique</td>
<td>T</td>
<td>Bills et al. (2012)</td>
</tr>
<tr>
<td><em>Hypoxylon rickii</em></td>
<td>MUCL 53309</td>
<td>KC968932</td>
<td>KC977288</td>
<td>Martinique</td>
<td>ET</td>
<td>Kuhnert et al. (2014)</td>
</tr>
<tr>
<td><em>Hypoxylon rubiginosum</em></td>
<td>MUCL 52887</td>
<td>KC477234</td>
<td>KY624311</td>
<td>Germany</td>
<td>ET</td>
<td>Kuhnert et al. (2014)</td>
</tr>
<tr>
<td><em>Hypoxylon samuelsii</em></td>
<td>MUCL 51843</td>
<td>KC968916</td>
<td>KC977286</td>
<td>Guadeloupe</td>
<td>ET</td>
<td>Kuhnert et al. (2014)</td>
</tr>
<tr>
<td><em>Hypoxylon shearii var. minor</em></td>
<td>BCRC 34093</td>
<td>EF026142</td>
<td>AY951753</td>
<td>Mexico</td>
<td>IT</td>
<td>Hsieh et al. (2005)</td>
</tr>
<tr>
<td><em>Hypoxylon specazzianum</em></td>
<td>STMA 14082</td>
<td>KU604573</td>
<td>KU604582</td>
<td>Argentina</td>
<td>T</td>
<td>Sir et al. (2016a)</td>
</tr>
<tr>
<td><strong>Hypoxylon sporistriatatunicum sp. nov.</strong></td>
<td><strong>MC50, ex UCH9542</strong></td>
<td><strong>MN056426</strong></td>
<td><strong>MK908140</strong></td>
<td><strong>Panama</strong></td>
<td></td>
<td><strong>This study</strong></td>
</tr>
<tr>
<td><em>Hypoxylon subgilvum</em></td>
<td>BCRC 34094</td>
<td>JQ009314</td>
<td>AY951754</td>
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<td>Hsieh et al. (2005)</td>
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<td><em>Hypoxylon subrutiloides</em></td>
<td>F 202416</td>
<td>FJ185304</td>
<td>FJ185281</td>
<td>New Zealand</td>
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<td>Platas et al. (2009)</td>
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<td><em>Hypoxylon ticinense</em></td>
<td>BCRC 34097</td>
<td>JQ009317</td>
<td>AY951757</td>
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<td>Hsieh et al. (2005)</td>
</tr>
<tr>
<td><em>Hypoxylon ulmophilum</em></td>
<td>BCRC 34100</td>
<td>JQ009320</td>
<td>AY951760</td>
<td>Primorsky (Russia)</td>
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<td>Hsieh et al. (2005)</td>
</tr>
<tr>
<td><em>Hypoxylon vogesiaciun</em></td>
<td>CBS 115273</td>
<td>KC968920</td>
<td>KX271275</td>
<td>France</td>
<td></td>
<td>Kuhnert et al. (2014; ITS), Kuhnert et al. (2017; TUB2)</td>
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<tr>
<td><em>Jackrogersella multiformis</em></td>
<td>CBS 119016</td>
<td>KC477234</td>
<td>KX271262</td>
<td>Germany</td>
<td>ET</td>
<td>Kuhnert et al. (2014)</td>
</tr>
<tr>
<td><em>Pyrenopolyporus hunteri</em></td>
<td>MUCL 52673</td>
<td>KY610421</td>
<td>KU159530</td>
<td>Ivory Coast</td>
<td>ET</td>
<td>Kuhnert et al. (2017)</td>
</tr>
<tr>
<td><em>Xylaria hypoxylon</em></td>
<td>CBS 122620</td>
<td>KY610407</td>
<td>KX271279</td>
<td>Sweden</td>
<td>ET</td>
<td>Wendt et al. (2018)</td>
</tr>
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</table>

The obtained alignments were cured using the Castresana Lab Gblocks Server v0.91b at low stringency settings (allowance of smaller final blocks & gap positions within the final blocks; [http://molevol.cmima.csic.es/castresana/Gblocks_server.html](http://molevol.cmima.csic.es/castresana/Gblocks_server.html), Talavera & Castresana 2007,
Castresana 2000) and flanking positions with missing sequence data was replenished with “?” . A modeltest (N=88) was performed for both cured alignments respectively, with default settings in jModeltest 2.1.10 v20160303 (Darriba et al. 2012), BIC values were calculated for all tested substitution models and the best substitution model for a combined alignment was chosen. The cured ITS and TUB2 alignment were concatenated, and a maximum likelihood analysis (ML) was performed with RAxML7.2.8 (Stamatakis 2006, 2014, Stamatakis & Alachiotis 2010) starting with a complete random tree, GTR+G+I as substitution model and 1000 bootstrap replicates, carried out in Geneious®. The ML tree was rooted with Xylaria hypoxylon as outgroup, exported as scalable vector graphic (svg) and opened in Inkscape 0.92.3 (© 1989, 1991 Free Software Foundation, Inc., https://www.inkscape.org) for layout implementation (Fig. 1).

HPLC profiling
Stromatal extracts were obtained by removal of small amounts of the stromata tissue, immersion in acetone and extraction in an ultrasonic bath at 40°C for 15 min. The reaction tubes were centrifuged and the supernatant was used for chemical analyses using high performance liquid chromatography coupled with diode array and electrospray mass spectrometric detection (HPLC/DAD–ESIMS) as described in Kuhnert et al. (2017), and the gradient was the same as described by Surup et al. (2018). The mass spectra, UV–visible spectra and retention times were compared with an internal database comprising standards of known compounds from Xylariales to identify correlating peaks. The results are depicted in Fig. 5. Some characteristic metabolites are shown in Fig. 6.

Results
Phylogenetic analyses
For the phylogenetic analysis the ITS and TUB2 sequences of the eight collected Panamanian species were compared with sequences of 58 taxa, including sequences of many type and authentic species of Hypoxylon (Kuhnert et al. 2014, Wendt et al. 2018). Sequences of the type species of sister genera to Hypoxylon, namely Anulohypoxylon truncatum, Daldinia concentrica, Hypomontagnella monticulosas, Jackrogersella multiformis and Pyrenopolyopus huneri were included as well.

The MAFFT alignment of ITS and TUB2 consisted, respectively of 1672 and 2024 characters prior curing and 363 and 1085 after (21% and 53% of the original alignment length). Excluded flanking regions were [54-59], [99-113], [115-119], [125-136], [545-551], [591-603], [606-610], [620-625], [638-647], [651-656], [662-828], [835-848], [850-871], [895-911], [913-945], [962-968], [970-975] and [1007-1018] for the ITS alignment; and [126-133], [197-202], [204-208], [421-431], [439-443], [450-487], [528-539], [548-561], [576-604], [674-721], [760-764], [886-893], [895-955], [1034-1042], [1047-1341], [1343-1479], [1481-1735], [1737-1849], [1898-1905] and [1919-1936] for the TUB2 alignment. The modeltest identified GTR+I+G as sixth and fifth best suited substitution model for the cured ITS (–ln(L) = 5553, K = 140, BIC = 11932) and TUB2 (In(L) = 13461, K = 140, BIC = 27901) alignment, respectively and the best substitution model for the calculation of a ML tree based on the combined alignment of the cured ITS and TUB2 alignments (ITS-TUB2 alignment, length: 1448 characters). The RAxML analysis resulted in the ML tree depicted in Fig. 1 with a –ln(L) value of 19353 and a tree length of 8.2866 (model information: α = 0.947863; inv = 0.547936; substitution rates: A→C = 0.765339, A→G = 3.433984, A→T = 1.232713, C→G = 0.519272, C→T = 5.779039, G→T = 1.000000; base frequencies: fπ(A) = 0.20635, fπ(C) = 0.301368, fπ(G) = 0.243091, fπ(T) = 0.249276).

The calculated ML tree showed strong bootstrap support for most of the terminal clades but lacked general support for the tree backbone. This issue has been observed in previous studies of Xylariales (Hsieh et al. 2005, Kuhnert et al. 2014, Wendt et al. 2018) and could possibly be overcome by including further phylogenetic markers and taxa.
Figure 1 – Phylogenetic tree of Hypoxylon. Maximum Likelihood analysis (RaxML) inferred from a cured & combined MAFFT alignment of ITS and TUB2 DNA sequences. Bootstrap support values from 1000 replicates were indicated at the respective nodes. The tree was rooted with Xylaria hypoxylon as outgroup and taxa derived from type material are indicated with superscripts T for holotype, ET for epitype, IT for isotype. Sequences highlighted in bold were derived from this study.
The postulated new species of Hypoxylon clustered predominantly in fully supported clades. Hypoxylon baruense sp. nov. clustered with Hypoxylon subgilvum (BS 100%) while H. sporistriatatunicum sp. nov. appears closely related to H. shearii var. minor (BS 99%). Hypoxylon bellicolor sp. nov. occurred in a separate clade with only 56% BS support. Hence, it is likely that closer relatives have still not been found as yet and further collections of new Hypoxylon species are needed for a better phylogenetic resolution. However, our DNA based analysis herein support our morphological observations and analysis of the secondary metabolites by HPLC and justify the erection as new species of Hypoxylon. Furthermore, the collected specimen of H. cinnabarimum (MC 97), H. fendleri (MC 25), H. haematostroma (MC 34) and H. howeanum (MC 62 & 65), clustered respectively in fully supported clades with their reference taxon, which confirms their identification.

**Description of new species of Hypoxylon**

**Hypoxylon baruense** M. Cedeño–Sanchez, L. Wendt & L.C. Mejía sp. nov.  
Mycobank number: MB 832717; Facesoffungi number: FoF 07186  
**Etymology** – Named after the Barú Volcano National Park, where the species was collected for the first time.

  **Stromata** – effused–pulvinate, sessile, with inconspicuous perithecial mounds, 0.3 – 1.7 cm long x 0.2 – 1.3 cm broad x 0.2 cm thick (n=1); surface Rust (39), Blood Colour (3); with orange granules beneath the surface and between the perithecia; with KOH–extractable pigments Greenish Yellow (16) or Luteous (12).  
  **Perithecia:** obvoid to tubular, 0.3 mm broad x 0.5 –0.6 mm high (n=6).  
  **Ostioles:** lower than the stromatal surface.  
  **Asci:** 120 – 157 μm x 5 – 7 μm (n=6), with apical apparatus bluing in Melzer’s reagent, 2 – 3.6 μm long x 1–1.4 μm broad (n=5).  
  **Ascospores:** dark brown, unicellular, ellipsoid–inequilaterial, 10–15 x 5–7.6 μm (n=50), with straight conspicuous germ slit less than spore–length; perispore indehiscent in 10% KOH, smooth.

Culture characteristics – Colonies on PDA covering a 60 mm Petri dish in 3 weeks, mycelium white above, reverse dark green, with concentric zones. No asexual morph observed in the culture media used i.e. PDA, 2% MEA, V8 agar, oatmeal agar and potato carrot agar.

Secondary metabolites: Binaphthalene tetrol (BNT) as major component, mitorubrinol acetate as minor component and various unknown lipophilic components.

**Distribution** – Panama  
**Holotype** – Panama, Chiriquí, Barú Volcano National Park, Quetzales trail, latitude 8º50'47.5" longitude 82º31'47.9", on dead trunk, 23 April 2016, M. Cedeño–Sanchez (UCH9545).  
**Ex type**: MC66 deposited at HZI.  
**Notes** – Hypoxylon baruense sp. nov. is closely related to H. subgilvum, but can be differentiated as it has a smooth perispore indehiscent in 10% KOH and larger ascospores. There is only one other species of Hypoxylon with indehiscent perispore reported in Panama, H. cinnabarimum, but H. baruense differs from this species by having rust and blood colored stromata surface and KOH– extractable pigments with greenish yellow or luteous. In addition, H. subgilvum contains mitorubrins as major components but is lacking BNT (Hellwig et al. 2005).

**Hypoxylon bellicolor** M. Cedeño–Sanchez, L. Wendt & L.C. Mejía, sp. nov.  
Mycobank number: MB 832716; Facesoffungi number: FoF 07188  
**Etymology** – Lat. “bellus”: pretty, color (referring to the color of the stromata).  
**Stromata** – effused–pulvinate, sessile, with conspicuous perithecial mounds, 0.4 – 1.4 cm x 0.4 – 0.7 cm (n=4); surface Fulvous (43), Rust (39); with orange granules beneath the surface; with KOH–extractable pigments Sienna (8), Luteous (12).  
**Perithecia:** obvoid, 0.1 – 0.2 mm broad x 0.2 – 0.3 mm high (n=6).  
**Ostioles:** lower than the stromatal surface.  
**Asci:** not seen.  
**Ascospores:** dark brown, unicellular, ellipsoid, 10–12 x 4–6 μm (n=13), with germ slit less than spore–length; perispore dehiscent in 10% KOH, smooth.
Culture characteristics – on PDA covering a 60 mm Petri dish in 4 weeks, mycelium white above, reverse dark brown, with concentric zones. No asexual morph observed in the different culture media used i.e. PDA, 2% MEA, V8 agar, Oatmeal agar and potato carrot agar.

Figure 2 – Hypoxylon baruense sp. nov. (Holotype UCH9545). a Stroma. b Ostioles. c KOH–extractable stromatal pigments. d Perithecia (cross section). e PDA culture. f Amyloid apical apparatus. g Ascospores. h Ascus. Scale bars: d = 0.3 mm, e = 10 μm, g = 10 μm, f = 20 μm.

Secondary metabolites – Stromata contain BNT in small amounts and otherwise yield little pigments.

Distribution – Panama.

Holotype – Panama, Chiriquí, Bugaba, latitude 09°14’59.2” longitude 79°41’32.8”, on dead trunk, 9 February 2016, M. Cedeño (UCH9543). No Ex type culture exists as the culture obtained and used for phylogenetic analyses (MC36) did not survive.

Notes – This species can be distinguished by having the following combination of morphological characters: effused–pulvinate stromata, umbilicate ostioles, and ascospore size 10–12 x 4–6 μm. Hypoxylon bellicolor, H. macrocarpum and H. brevisporum have effused–pulvinate stromata, ostioles lower than the stromatal surface and dehiscent perispore in 10% KOH. However,
H. bellicolor has much larger ascospores (size) than H. brevisporum; and H. bellicolor has fulvous stromata and obovoid perithecia while H. macrocarpum has violet–purple or vinaceous reddish–purple stromata and ovoid larger perithecia.

Figure 3 – Hypoxylon bellicolor sp. nov. (Holotype UCH9543). a Stroma. b Ostioles. c Perithecia (cross section). d PDA culture. e KOH–extractable stromatal pigments. f Ascospores with dehiscent perispore in 10% KOH. Scale bars: a = 5 mm, b = 2 mm, c = 0.5 mm, f = 10 μm.

Hypoxylon sporistriatatunicum M. Cedeño–Sanchez, L. Wendt & L.C. Mejía, sp. nov. Mycobank number: MB 832718; Facesoffungi number: FoF 07187

Etymology: Referring to the striated perispore.

Stromata – glomerate, sessile, with conspicuous perithecial mounds, 0.2 – 0.3 cm long x 0.2 – 0.4 cm broad (n=15); surface Fawn (87); with orange granules beneath the surface; with KOH–extractable pigments Luteous (12), Sienna (8), Greenish Yellow (18). Perithecia: obovoid, 0.3 – 0.4 mm broad x 0.4 – 0.5 mm high (n=8). Ostioles: slightly higher than the stromatal surface. Asci: 92–140 x 7–9 μm (n=18), with apical apparatus bluing in Melzer’s reagent, 2.7–3 μm long x 0.5–1.1 μm broad (n=10). Ascospores: dark brown, unicellular, ellipsoid, with rounded ends, 10.4–13.2 x 5.4–7.3 μm (n=50), with germ slit almost the length of the spore; perispore dehiscent in 10% KOH, with conspicuous coil–like ornamentation.

Culture characteristics: on PDA covering a 60 mm Petri dish in 4 weeks, mycelium white above, reverse dark brown, with concentric zones. No asexual morph observed in the different culture media used i.e. PDA, 2% MEA, V8 agar, Oatmeal agar and Potato carrot agar.

Secondary metabolites – Stromata contain hypomiltin as major component and other azaphilones similar to rubiginosin C as well as BNT as minor components. Macrocarpone A was also detected tentatively.
Distribution – Panama

Holotype – Panama, Chiriquí, International Park La Amistad, latitude 8°53’39.4” longitude 82°36’55”, on dead trunk, 27 March 2016, M. Cedeño (UCH9542). Ex type culture (MC50), deposited at HZI.

Additional specimen examined – Panama, Chiriquí, Barú Volcano National Park Park, Quetzales trail, latitude 8°50’50.3” longitude 82°31’39.6”, on dead trunk, 23 April 2016, M. Cedeño (UCH9551).

Figure 4 – Hypoxylon sporistriatatunicum sp. nov. (Holotype UCH9542). a Stroma. b Ostioles. c Perithecium cross section. d KOH–extractable stromal pigments. e Ascospores with striated perispore. f PDA culture. g Dehiscent perispore in KOH 10%. h Asci. Scale bar: a = 1 cm, b = 1 mm, c = 0.2 mm, e = 10 μm, g = 10 μm, H = 20 μm.
Notes – *Hypoxylon sporistriatatunicum* sp. nov. is closely related to *H. shearii* var. *minor*, but differs from this species by presenting hemispherical to spherical stroma, ostioles higher than the surface, and larger ascospores. Additionally, *H. sporistriatatunicum* has a combination of features that make it different to other species of *Hypoxylon* including glomerate stromata, ostioles slightly higher than the stromatal surface, dehiscent perispore in 10% KOH, and conspicuous coil–like ornamentation of the perispore. From a chemotaxonomic point of view, it is interesting that the prevailing component in the stromatal extract (hypomiltin) is also the main metabolite of *H. perforatum*, which also clusters in the same major subclade. *H. shearii* var. *minor*, the next relative in the phylogenetic tree, was so far not studied by HPLC because the type specimen could not be obtained from the Mexican herbarium (ITCV) on our request and may actually have been lost. However, the typical variety *H. shearii* var. *shearii* was previously shown to contain mitorubrins (Stadler et al. 2008), and the two varieties share orange pigments, hence it is possible that var. *minor* also contains similar stromatal metabolites.

![Figure 5](image_url)

**Figure 5** – Above: Normalized UV–Vis chromatograms of unknown compounds UC1, UC2, UC 3 & 4 from stroma of *Hypoxylon baruense* sp. nov. (Holotype UCH9545 ex-type MC66) and *Hypoxylon bellicolor* sp. nov. (Holotype UCH9543 ex-type MC36). Below: HPLC–UV chromatograms (210nm) of stromatal methanolic extracts of the holotypes of *Hypoxylon baruense* (A), *H. bellicolor* (B) and *H. sporistriatatunicum* (C). Identifiable compounds are BNT (only detectable in traces by HPLC–MS in *H. bellicolor*), mitorubrin (MI) and hypomiltin (HY). Unknown compounds detected are labelled with “UC1–4”.
Figure 6 – Chemical structures of secondary metabolites detected in the new Hypoxylon species from Panama, mentioned in Fig. 5.

New reports of Xylariaceae and Hypoxylaceae from Panama

Amphirostellinia evansii (Læssøe & Spooner) Y.M. Ju, J.D. Rogers & H.M. Hsieh, in Ju, Rogers, Hsieh & Vasilyeva

**Stromata:** hemispherical, sessile, 1–1–3 mm long x 1–1.3 mm broad (n=10); surface brown; the tissue (fungal and host) around the stroma have a stellate pattern. **Perithecia:** round to obovoid, 0.7–0.9 mm broad x 0.7 –0.9 mm high (n=10). **Ostioles:** higher than the stromatal surface. **Asci:** 158 – 247 x 9–10 μm (n=4), with apical apparatus bluing in Melzer’s reagent, 9 – 10 μm high x 6–7 μm broad (n=11). **Ascospores:** dark brown, unicellular, ellipsoid, 20–22 x 8–10 μm (n=14), with spiral germ slit running over the whole spore–length; perispore indehiscent in 10% KOH, smooth.

**Culture characteristics:** no cultures obtained.

**Distribution:** Australia, Great Britain, Panama, USA.

Specimens examined: Panama, Chiriquí, La Amistad International Park, latitude 8º53'46.9" longitude 82º37'1.7", on dead trunk, 27 March 2016, M. Cedeño (UCH9559); latitude 8º53'39.3" longitude 82º36'57.7", on dead trunk, 27 March 2016, Specimen MC54.

Notes: This species is distinguished by having a spiral–shaped germ slit in the ascospores and forming a star–shaped pattern around the stroma, with host tissue and fungus. These characteristics were observed in the identified specimens.

Hypoxylon cinnabarinum (Henn.) Y.M. Ju & J.D. Rogers

**Stromata:** effused–pulvinate, sessile, 1–3 cm long x 0.7–1.8 cm broad (n=3), with conspicuous perithecial mounds; surface Orange (7) on the ostiole side and Saffron (10) in the sterile edges; orange granules beneath the surface and surrounding the perithecia, a line of white granules beneath the perithecia, the tissue below the perithecia black; with KOH–extractable pigments Orange (7). **Perithecia:** obovoid to tubular, 0.3–0.4 mm broad x 0.4 –0.5 mm high (n=8). **Ostioles:** lower than the stromatal surface. **Asci:** 144–160 x 7–10 μm broad (n=6), with apical apparatus bluing in Melzer’s reagent, 1 μm high x 3–4 μm broad (n=7). **Ascospores:** brown to dark brown, unicellular, ellipsoid nearly equilateral, 11–13 x 6–7 μm (n=17), with germ slit of spore–length; perispore indehiscent in 10% KOH, smooth.

**Colonies:** on PDA, white mycelium above, reverse green.

**Distribution:** Brazil, Mexico, New Zealand, Panama, Puerto Rico, Taiwan, Venezuela. Lectotype is from Brazil and was designated by Ju & Rogers (1996). However, the culture used in the phylogenetic studies by Hsieh et al. 2005 and the description of the asexual morph by Ju & Rogers (1996) originated from Mexico. The culture from Mexico was included in the phylogeny presented here and is conspecific with the specimen from Panama (Fig. 1).

Specimens examined: Panama, Chiriquí, Sortová, latitude 08º34'08.9" longitude 82º39'25.9", on dead trunk of Citrus sinensis, 5 August 2016, M. Cedeño (UCH9563, consisting of a dried
specimen); Divalá, on dead branches of a live tree of *Citrus sinensis*, 9 November 2016, M. Cedeño (UCH9546).

Notes: This species has nearly equilateral ascospores with perispore frequently indehiscent in 10% KOH. Based on analyses of morphological characters, Fournier & Lechat (2015) and Fournier et al. (2015) suggested the possibility of two other species of *Hypoxylon* that resemble *H. cinnabarinum* i.e. *H. cf. cinnabarinum* sp. 1 and *H. cf. cinnabarinum* sp. 2. However, they suggested that in the absence of complete cultural, molecular, and chemotaxonomic work for all the specimens that they studied, it was better not to segregate *H. cinnabarinum* into different species (Fournier et al. 2015). The specimens here studied fits the description of *H. cinnabarinum* according to Ju & Rogers (1996) and also the one that Fournier et al. (2015) identified as *H. cf. cinnabarinum* sp. 1, so we decided to keep the specimens collected in Panama as part of this study identified as *H. cinnabarinum* in the broad sense.

**Hypoxylon howeanum** Peck

**Stromata:** hemispherical to spherical, sessile, 5.5 mm long x 4 mm broad x 2.7 mm high (n=6), with inconspicuous perithecial mounds; surface color Fulvous (43), Rust (39), with orange granules beneath the surface; the tissue below the perithecia black, homogeneous; with KOH-extractable pigments Orange (7) or Rust (39). **Perithecia:** obovoid, 0.2–0.3 mm broad x 0.4 mm high (n=10). **Ostioles:** lower than the stromatal surface. **Asci:** 103–150 x 4.5–6 μm (n=5), with apical apparatus bluing in Melzer’s reagent, μm 0.28 – 0.3 high x 1.5 – 1.8 μm broad (n=8). **Ascospores:** brown, unicellular, ellipsoid, with narrowly rounded ends, 8–9 x 4–5 μm (n=17), with germ slit spore–length; perispore dehiscent in 10% KOH, smooth.

Culture characteristics: on PDA, mycelium white above, reverse greenish pigmentation in the center.

Distribution: Australia, Czech Republic, France, Germany, India, Italy, Iran, Japan, Mexico, New Zealand, Norway, Panama, Poland, Spain, South Africa, Turkey, United Kingdom, USA. *Hypoxylon howeanum* occurs on a wide variety of angiosperm hosts in Europe, but almost never on European beech, *Fagus sylvatica*, where the sister species *H. fragiforme* is predominant.

Specimens examined: Panama, Chiriquí, Barú Volcano National Park, Quetzales Trail, latitude 8°50'50.4" longitude 82°31'39.5", on dead branch of *Alnus acuminata*., 23 April 2016, M. Cedeño (UCH9565); latitude 8°50'46.7" longitude 82°31'50.9", on dead branch of *Alnus acuminata*., 23 April 2016, Cedeño MC65.

Notes: This species is characterized by hemispherical to spherical stromata, and ostioles lower than the stromatal surface. *Hypoxylon howeanum* is similar to *H. fragiforme*, the type species of the genus, but differs in having smaller ascospores. In addition, its stromata can colonize a broad variety of hosts (including *Acer* and various species of Salicaceae and Betulaceae), while *H. fragiforme* is mainly restricted to *Fagus* in the temperate Northern hemisphere. The species was found growing on *Alnus acuminata* at 2,500 m.a.s.l. and which is native to Panama.

**Stilbohypoxylon quisquiliarum** (Mont.) J. D. Rogers & Y.–M. Ju

**Stromata:** subglobose to globose, sessile, 0.8 – 1 mm high x 1 – 1.3 mm broad, black surface, with yellow scales (not too much visible). **Ostioles:** higher than the stromatal surface, papillate **Asci:** not found. **Ascospores:** dark brown, unicellular, 26–31 x 12–15 μm (n=8), inequilaterally ellipsoidal, with spiral germ slit running over the whole spore length; perispore indehiscent in 10% KOH, smooth.

Culture characteristics: no culture obtained.

Distribution: Brazil, Costa Rica, Panama, Singapore.

Specimen examined: Panama, Panama, Soberania National Park, pipeline rout trail, on dead trunk, 8 August 2015, M. Cedeño (UCH9547).

Notes: This species is distinguished by the presence of yellow scales in mature stromata, and germinal line of the length of the spore and in spiral (Petrini 2004). The germ slit was clearly
observed in the specimen, but the scales were not clear. It differs from *S. macrosporum* by having smaller ascospores.

**Additional specimens of Hypoxylon collected in this study**

**Hypoxylon fendleri** Berk. ex. Cooke  
*Stromata*: effused–pulvinate, sessile, 3 cm long x 0.7 cm broad (n=1), with inconspicuous perithecial mounds; surface color Fulvous (43), Rust (39), orange granules beneath surface; with KOH–extractable pigments Orange (7) or Rust (39). *Ostioles*: lower than the stromatal surface. *Asci*: with apical apparatus bluing in Melzer’s iodine reagent, 0.6–1 μm high x 1.8–2.2 μm broad (n=9). *Ascospores*: brown, unicellular, ellipsoid, smooth, 8.9–10.2 x 3.9–4.7 μm (n=10), with straight germ slit spore–length; perispore dehiscent in 10% KOH, smooth.

Culture characteristics: on PDA white mycelium, reverse cream color, darkness in the center and light in the edge.  
Distribution: Pantropical.  
Specimen examined: Panama, Chiriquí, Sortová, on dead trunk, 1 January 2016, M. Cedeño (UCH9552).

Notes: This fungus is very common throughout the tropics. In Ju & Rogers (1996) it is mentioned that *Hypoxylon fendleri* differs from *H. trugodes* and *H. crocopeplum* by the color of stromatal pigments extracted with 10% KOH. The specimen treated in this work showed the typical morphological characteristics of *H. fendleri* and this was also supported by the phylogenetic analysis.

**Hypoxylon haematostroma** Mont.  
*Stromata*: plane to effused–pulvinate, sessile, 0.3–1.7 cm long x 0.2–1.3 cm broad x 0.2 cm thick, with inconspicuous perithecial mounds; surface Sienna (8); with KOH–extractable pigments Orange (7), Scarlet (5). *Perithecia*: long tubular, 0.5 mm broad x 2 mm high (n=11). *Ostioles*: lower than the stromatal surface. *Asci*: not found. *Ascospores*: brown, unicellular, ellipsoid, smooth, 15–18 x 6–7 μm (n=11), with straight germ slit spore–length; perispore dehiscent in 10% KOH, smooth.

Culture characteristics: on PDA white mycelium, reverse greenish color, with zones with concentric.  
Distribution: Pantropical  
Specimen examined: Panama, Panama, Soberania National Park, El Charco trail, on dead dicotyledonous trunk, 30 January 2016, M. Cedeño (UCH9555).

Notes: This species is distinctive among species of *Hypoxylon* by having tubular perithecia and red or orange granules below the stromatal surface (Ju & Rogers 1996). Both morphological characteristics were present in the specimen examined. Additionally, the species have brown to dark brown ascospores with a perispore dehiscent in 10% KOH, nevertheless, the size of ascospores is variable according to Fournier et al. (2015) ranging from 12.5 – 18 x 5.9 – 9 μm.

**Key to Hypoxylon species from Panama**

1a. Perispore dehiscent in 10% KOH .................................................................5  
1b. Perispore indehiscent in 10% KOH ..........................................................2  
2a. Ascospores averaging more than 10 μm in length ......................................3  
2b. Ascospores averaging less than 10 μm in length ........................................4  
3a. Ascospores 10–15 x 5–7.6 μm, with KOH–extractable pigments (greenish yellow or luteous) ...............................................................*H. baruens*e  
3b. Ascospores 11–13 x 6–7 μm, with KOH–extractable pigments orange ..........................*H. cinnabarinum*
4a. Perithecia obovoid; KOH–extractable pigments grayish sepia; with faint germ slit .................................................................H. dieckmannii
4b. Perithecia tubular to long tubular; KOH–extractable pigments greenish yellow, dull green or dark green; and straight germ slit ..................................................................................H. investiens
5a. Apical apparatus bluing to lightly bluing in Melzer’s iodine reagent .................................................................6
5b. Apical apparatus not bluing in Melzer’s iodine reagent; ascospores 9–11 x 4.5–5.5 µm with perispore with very conspicuous coil–like ornamentation; perithecia spherical ……H. pelliculosum
6a. KOH–extractable pigments greenish yellow, orange, scarlet, rust, luteous, sienna, bay ………7
6b. KOH–extractable pigments with other than above colors ..........................................................13
7a. Stromata hemispherical to spherical, sometimes effused–pulvinate, KOH–extractable pigments orange, scarlet, rust .........................................................11
7b. Stromata effused–pulvinate or plane with KOH–extractable pigments orange …………………8
8a. Straight to slightly sigmoid germ slit; perithecia spherical, obovoid, ostioles lower than stromatal surface .................................................................H. fendleri
8b. Straight to slightly sigmoid germ slit; perithecia spherical, obovoid, tubular to long tubular …9
9a. Straight germ slit; perithecia spherical to obovoid; stromata effused–pulvinate, pulvinate or even semispherical; ascospores 9–12 x 4–5.5 µm .................................................................H. rubiginosum
9b. Straight to slightly sigmoid germ slit; perithecia obovoid, tubular to long tubular ………..10
10a. Straight to slightly sigmoid germ slit; ascospores 9.5–15 x 4–7 µm; perithecia spherical, obovoid to long tubular, ostioles lower than or same level as the stromatal surface H. crocopeplum
10b. Straight to slightly sigmoid germ slit; ascospores 7–11 x 3.5–5 µm; perithecia obovoid to tubular, ostioles lower than the stromatal surface ..........................................................H. subgilvum
11a. Perithecia long tubular; stromata semispherical to effused–pulvinate, KOH–extractable pigments orange, scarlet; ascospores 13.5–18 x 7–8 µm .................................................................H. haematostroma
11b. Perispora obovoid, stromata semispherical to spherical, ascospores less than 13 µm …………12
12a. Ascospores 8–9 x 4–5 µm, with smooth perispore, apical apparatus bluing in Melzer’s iodine reagent 0.28–0.3x1.5–1.8 µm; KOH–extractable pigments rust, sienna ……………….H. howeanum
12b. Ascospores 11–13 x 6–7 µm, with conspicuous coil–like ornamentation perispore, with apical apparatus bluing in Melzer’s iodine reagent 2.7–3x0.5–1.1 µm; KOH–extractable pigments luteous, sienna, greenish yellow ………….H. sporistriatatunicum
13a. Ascospores light brown to brown, perispore smooth, ascospores 7–9 x 3–4 µm with slightly oblique to sigmoid germ slit .................................................................H. hypomiltum
13b. Ascospores brown to dark brown, perispore smooth or with inconspicuous coil–like ornamentation .................................................................................................14
14a. Straight to slightly sigmoid germ slit, stromata effused–pulvinate ….................15
14b. Sigmoid germ slit, stromata usually hemispherical to pulvinate, sometimes effused–pulvinate, ascospores 8–20 x 4–8 µm .................................................................H. fuscum
15a. Conspicuous perithecial mounds, perithecia obovoid; ascospores 10–12 x 4–6 µm .................................................................H. bellicolor
15b. Inconspicuous perithecial mounds, perithecia obovoid, tubular, long tubular …………16
16a. Ascospores brown, straight to slightly sigmoid germ slit, KOH–extractable pigments dark livid .................................................................................................H. lividipigmentum
16b. Ascospores brown to dark brown, slightly sigmoid germ slit, KOH–extractable pigments of different colors ..................................................................................17
17a. KOH–extractable pigments amber, isabelline, olivaceous, gray alivaceous, greenish olivaceous; ascospores 8.5–13.5 x 4–6 µm .................................................................H. anthochroum
17b. KOH–extractable pigments amber, yellow; ascospores 8–11 x 3.5–4.5 µm …………H. trugodes

Discussion
Morphological observations and analyses of DNA sequence data of Xylariales specimens collected in Panama allowed us to identify three new species of Hypoxylon as well as to document four new records of this genus and three new records of Xylariaceae for the country. The phylogeny
of Hypoxylon obtained in this study based on the concatenated analysis of β–tubulin and ITS loci (Fig. 1) is in general agreement with a recently published phylogeny of Hypoxylon based on multi–locus data (Wendt et al. 2018).

The species treated in this study showed a restricted altitudinal distribution, for example, H. bellicolor sp. nov., H. cinnabarinum and S. quisquiliarum were collected only at lowland (700 m.a.s.l. or lower). In contrast Amphirosellinia evansii, H. sporistriatatunicum sp. nov., H. baruense sp. nov., and H. howeanum were observed in the highlands (1500 m.a.s.l. or higher) of Chiriquí Province. In general, the species observed in this study were found only in one site, except H. sporistriatatunicum sp. nov., which was collected in La Amistad International Park and in the Barú Volcano National Park, both parks located in the province of Chiriquí. Our data suggest that the distribution of Hypoxylon species in Panama is restricted either by locality or elevation, but further studies are necessary to confirm these observations. The distribution of the species could be also related to the type of forest or life zone, for example, La Amistad International Park and the Barú Volcano National Park have six of the twelve life zones of Panama. The Barú Volcano National Park presents two unique life zones in the country: montane very wet forest and low montane wet forest (MiAMBIENTE 2016), unlike Soberania National Park that is predominantly tropical wet forest, and Sortová and Concepción which are premontane very wet forests.

Specimens treated in this study were collected on decomposing dead trunks or dead branches and H. cinnabarinum was collected growing on a dead branch but still attached to a living tree of Citrus sinensis, a new host of this species. This species has been found on the bark of dead branches and trunks of unidentified hosts (Ju & Rogers 1996, Fournier et al. 2015, Fournier & Lechat 2015), as well as on Beilschmiedia tawa and an unidentified Nothofagus species (Ju & Rogers 1996).

This study increased the numbers of known species of Hypoxylaceae of Panama from 30 to 35 and Xylariaceae from 45 to 47. Given the facts that i) several new species were recently reported from this geographic area and ii) many other taxa have been known from the neighbour countries of Panama during the past century, additional studies on the systematics and ecology of these families are called for. Considering the reported biological activities of fungi of the Xylariales (Helaly et al. 2018), including antimicrobials or virulence factors such as the azaphilones and mitorubrinol acetate to be produced by species described here, it is possible that new species from this order might be potential sources of new compounds for biotechnological applications. This information can be of value to promote more studies and in situ conservation efforts of the habitats and diversity of these fungi.

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