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Three new records of *Aureoboletus* Pouzar (Boletaceae, Boletales) from Mexico

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Abstract
In this paper, *Aureoboletus auriflammeus* (Berk. & M.A. Curtis) G. Wu & Zhu L. Yang, *A. innixus* (Frost) Halling, A.R. Bessette & Bessette and *A. roxanae* (Frost) Klofac are described as new records from Mexico. These species are distributed in temperate montane cloud forest and mixed forests and may grow associated forming mycorrhizas with *Fagus grandifolia* Ehrh. subsp. *mexicana* (Martínez) E. Murray, *Quercus laurina* Humb et Bonpl., *Q. sartorii* Liebm. and *Q. scytophylla* Liebm. Descriptions, distribution, photographs and a key for the species of *Aureoboletus* from Mexico are presented.

Keywords
Boletes, edible fungi, mixed forest, montane cloud forest, mycorrhizal fungi.

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Introduction

The genus *Aureoboletus* Pouzar was proposed in 1957, the type species being *Aureoboletus gentilis* (Quél.) Pouzar. The species of *Aureoboletus* are recognized by the boletoid basidiomata, the viscid to dry pileus and the golden yellow pores that keep the color despite herborized. Microscopically, they are recognized by the yellowish subfusoid spores, smooth to rarely striated walls and the pileipellis composed by ixotricodermium or trichodermium (Singer 1986, Wang and Yao 2005, Klofac 2010, Halling et al. 2015, Bessette et al. 2017, Wu et al. 2016).

The species of *Aureoboletus* form mycorrhizal associations with many plants, including Fagaceae, Betulaceae and Pinaceae, playing an important role in the translocation of nutrients in the forest (Newman and Reddell 1987, Binder and Hibbett 2006, Tedersoo et al. 2010). Furthermore, some *Aureoboletus* species are edible and, as several mycorrhizal boletes, represent an alternative food resource (Bessette et al. 2017). Currently 35 species are recognized worldwide from America, Asia and Europe (Wang and Yao 2005, Klofac 2010, Shi and Liu 2013, Zhang et al. 2014, 2015a, 2015b, Wu et al. 2016).

In Mexico, 6 species of this genus have been described: *A. auriporus* (Peck) Pouzar (García et al. 1986), *A. flaviporus* (Earle) Klofac, (Ayala 1996), *A. moravicus* (Vaček) Klofac (García-Jiménez et al. 1998), *A.*

projectellus (Murrill) Halling (Singer et al. 1992), *A. russellii* (Frost) G. Wu & Zhu L. Yang (García and Castillo 1981, García-Jiménez et al. 1998, Ayala-Vásquez et al. 2018), and *A. singeri* (Gonz.-Velázq. & R. Valenz.) Har. Takah. & Taneyama (Singer et al. 1992, González-Velázquez and Valenzuela 1995). As a result of mycological explorations carried out in several Mexican states, *A. innixus* (Frost) Halling, A.R. Bessette & Bessette, *A. auriflammeus* (Berk. & M.A. Curtis) G. Wu & Zhu L. Yang, and *A. roxanae* (Frost) Klofac, are recorded for the first time from Mexico.

Methods

Several mycological explorations were conducted in the Mexican states of Hidalgo, Oaxaca, Queretaro and Jalisco from 2003 to 2017 (Fig. 1). The vegetation types in the sampling sites were dominated by montane cloud forest and mixed forests with *Pinus* L. and *Quercus* L. The sampling methods proposed by Lodge et al. (2004) were used. The color was described according to Kornerup and Wanscher (1978). Hand cuts were made using KOH (potassium hydroxide) 5%, NH_4OH (ammonia hydroxide), Meltzer reagent and Congo red for microscopical descriptions (e.g. cellular elements of the pileus, stipe and hymenia). The size of the microcharacters such as basidia, cystidia and basidiospores were determined by measuring at least 20 elements each. The next abbreviations are used: *Q* refers to the length/wide ratio of the basidiospores; *X* refers to mean; *N* refers the total number of spores measured. Studied specimens were deposited at the Mycologial Herbarium José Castillo Tovar (ITCV) in the Instituto Tecnológico de Ciudad Victoria and Universidad de Guadalajara (IBUG). Also, a key for the *Aureoboletus* species occurring in Mexico was made.

Results

Aureoboletus auriflammeus (Berk. & M.A. Curtis) G. Wu & Zhu L. Yang. Figure 2.

New records. Mexico: Hidalgo, Tlanchinol municipality, 20°58′55″N, 98°38′06″W, Jesús García, 12 July 2003, (Garcia-ITCV-14461). Same place, 20°58′59″ N, 098°37′59″ W, Jesús García, 13 July 2003, (Garcia-ITCV-14435). Same place, 20°59′11″ N, 098°37′39″ W, Jesús García, 13 July 2003, (Garcia-ITCV-14451), Same place, 20° 59′11″ N, 098°37′39″ W, Jesús García, 28 July 2014, (Garcia-ITCV-19849).

Identification. Pileus 10–25 mm in diameter, convex to plane-convex, orange (6A8) to brown-orange (6C8), tomentose to pulverulent surface. Hymenophore adhered, pores 0.2–0.3 mm, dark yellow (4A8) to orange (5A7), tubes 2.5–3.5 mm length, concolorous to the pores, never bruising when cut. Context 2–3 mm thick, whitish to pale yellow (4A2), never bruising when cut. Stipe 17–35 × 4–8 mm, whitish to pale yellow (4A3) at the base and apex with fibrillose surface. Odor fungoid. Taste fungoid. Chemical reaction not studied.

Basidiospores 9–10 (13) × 3– 4 (5) µm, (X = 10.3 × 4, Q = 2.5, N=30), ellipsoid to subfusiform, smooth, hyaline to olive green in KOH, some with visible suprahilar depression, thin-walled. Basidia 19–27 × 7–8 µm, clavate, hyaline in KOH, 4-spored, thin-walled. Pleurocystidia 20–68 × 4–13 µm, fusoid, mucronate-rostrate, some clavate, with pigments or hyaline in KOH,

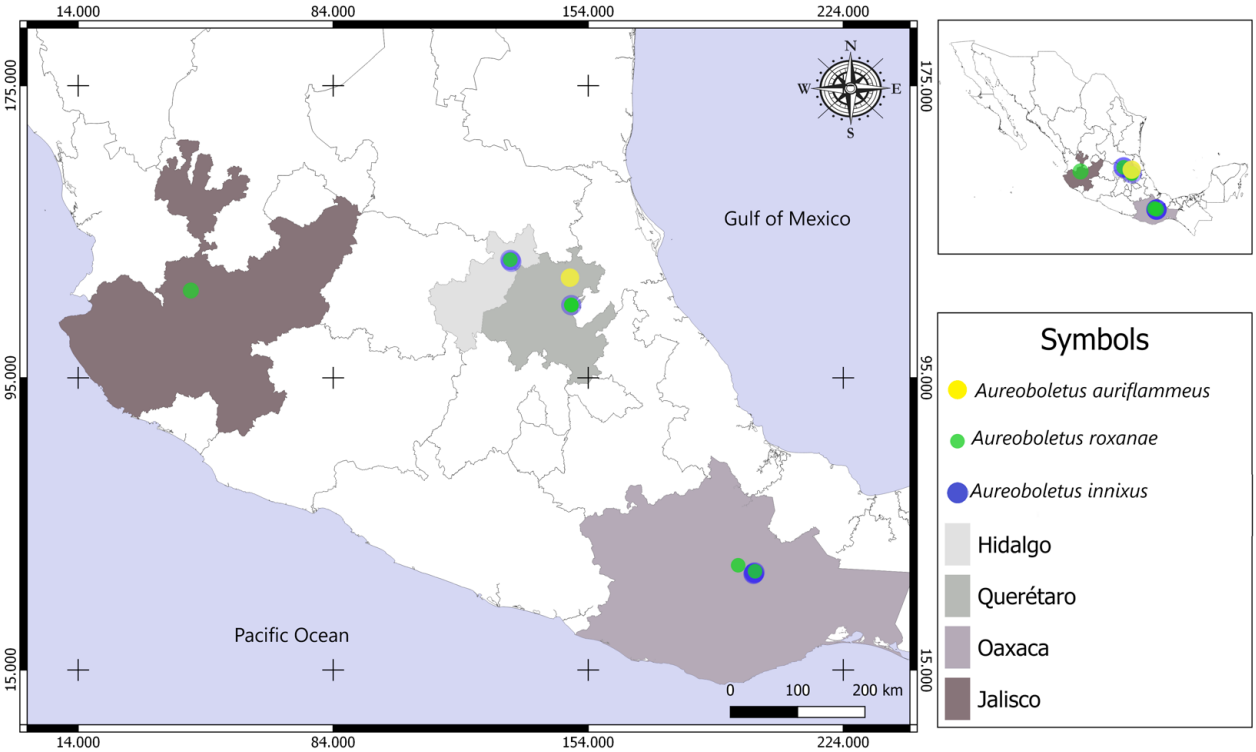

Figure 1. Current distribution of *A. auriflammeus*, *A. innixus* and *A. roxanae* in Mexico.

Figure 2. *Aureoboletus auriflammeus* (Garcia-ITCV-19849). **a–c.** Basidiomata. **d.** basidiospores. **e.** Basidia and pleurocystidia. **f.** Cheilocystidia. **g.** Stipitipellis. **h.** Pileipellis. Scale bars: a = 10 mm; d–h = 10 µm.

thin-walled. Cheilocystidia 40–60 × 9–17 µm, sphaeropedunculate or clavate, some broadly ventricose-rostrate, hyaline to pale yellow to deep golden incrusting pigments in KOH, deep yellow in Melzer, thin-walled. Hymenophoral trama boletoid; hyphae subcylindrical to cylindrical, 3–9 µm wide. Stipitipellis composed by caulocystidia 26–50 × 6–13 µm, mucronate, clavate, hyaline to yellowish in KOH, thin-walled. Pileipellis composed by a trichodermium with terminal cells of 25–70 × 4–11 µm, cylindrical, clavate, to subclavate, yellow in KOH, bright yellow incrusting pigments and crystals.

Habit and habitat. Scattered Under *Quercus germana* Schltdl. & Cham. and *Q. sartorii* Liebm in montane cloud forest.

Distribution. USA, Mexico, and Belize.

Taxonomic remarks. *Aureoboletus auriflammeus* is characterized by the orange to brown-orange basidiomata, the pulverulent pileus surface, the bright yellow incrusting pigments and crystals of the pileipellis with clavate and cylindrical terminal cells. The material agrees with the features quoted by Baroni (1998), Ortíz-Santana et al. (2007) and Bessette et al. (2017) although, the material described from Belize by Ortíz-Santana et al. (2007) has shorter cheilocystidia (20.8–43.2 × 8–14.4 pm) and basidiospores (8.8–10.4 × 4–4.8 µm).

Aureoboletus innixus (Frost) Halling, A.R. Bessette & Bessette. Figure 3.

New records. Mexico, Oaxaca state, Mixistlán de la Reforma municipality, Tsaadenkuubaakm town, 17°08′34″ N, 096°04′49″ W, Olivia Ayala-Vásquez, 30 July 2017, (Ayala-Vásquez-ITCV-932). Santa María Mixistlán town, 17°07′58″ N, 096°05′21″ W, Olivia Ayala-Vásquez, 02 August 2017, (Ayala-Vásquez-ITCV-944), Same place, 17°07′25″ N, 096°05′41″ W, Olivia Ayala-Vásquez, 14 September 2017, (Ayala-Vásquez-ITCV-1041). Hidalgo state, Zacualtipán municipality, 20°37′47″ N, 098°36′48″ W, Jesús García, 27 July 2014, (García-ITCV-19800). Querétaro state, Jalpan municipality, 21°11′24″ N, 099° 26′34″ W, Jesús García, 5 September 1998, (García-ITCV-11060). Jalpan municipality, 21°12′46″ N, 099°27′ 23″ W, Jesús García, 5 September 1998, (García-ITCV-11061).

Identification. Pileus 27–48 mm in diameter, convex to plane-convex, grayish pink (12B6) when young, dark red (12F8) to red-brown (10F7) when mature, decurving when aged, dry surface, sometimes moist in young specimens, areolate when aged. Hymenophore adhered, pores 0.5–2 mm diameter, circular to angular, golden yellow (4A8) to yellow greenish, not bruising. Tubes 2.5–4 mm, concolorous to the pores, not bruising. Context 6–12 mm thick, white to whitish yellow (1A1-1A2), bruising vinaceous violet (3A5), brownish olive (30F8) in the stem. Stipe 60–80 × 7–15 mm, clavate to bulbous, brown to orange-brown (7A6-7A5) in the middle and basal part, yellow at the apex, dry, furfuraceus, longitudinally aligned surface, with yellow mycelium at the base. Odor fungoid. Taste fungoid. Chemical reactions. NH_4OH: pileus and stipe turn reddish-orange, pores turn brown, negative in the context. KOH: pileus turns brown-orange (5C8), pores and context turn brown (5F7), stipe

Figure 3. *Aureoboletus innixus* [García-Jiménez, 19800 (ITCV)]. **a, b.** Basidiomata. **c.** Basidiospores. **d.** Basidia. **e.** Pleurocystidia. **f.** Cheilocystidia. **g.** Stipitipellis. **h.** Pileipellis. Scale bars: a = 10 mm; d–h = 10 µm.

turns dark brown (6F8).

Basidiospores 8–12 × 3–5 µm, (X = 9.6 × 4, Q = 2.4, N = 30), ellipsoid to subfusoid, smooth, pale brown in KOH, brown in Melzer, suprahilar depression visible in some spores, thin-walled. Basidia 32–43 × 9–11 µm, clavate, pale brown in KOH, four-spored, with short sterigmata, thin-walled. Pleurocystidia 35–45 × 8–12 µm, mucronate, ventricose-rostrate, obclavate, hyaline in KOH, pale brown in Melzer, thin-walled. Cheilocystidia 40–52 × 9–10 µm, ventricose, rostrate, hyaline in KOH, brown in Melzer, thin-walled. Hymenophoral trama boletoid; hyphae subcylindrical to cylindrical, 3–10 µm wide. Stipitipellis composed by caulocystidia, 40–60 × 8–20 µm, mammelate, clavate, hyaline to brown in KOH, brown in Melzer, thin-walled. Pileipellis composed by a trichodermus with terminal cells, 25–110 × 8–19 µm, cylindrical, mucronate to clavate, brown-yellowish in KOH, thin-walled.

Habit and habitat. Solitary or scattered under *Quercus scytophylla* Liebm. and *Quercus rugosa* Neé in montane cloud forest and oak forest.

Distribution, Canada, USA, and Mexico.

Taxonomic remarks. *Aureoboletus innixus* is characterized by the red-brown to brown pileus that becomes areolate when mature and the attenuated stipe. This species can be confused with *A. auriporus* by the color and size of the pileus but is distinguished by the viscid pileus and the larger spores (11–16 × 4–6 µm). *Aureoboletus roxanae* has similar spore size; however, that species shows pale yellow hymenophore, immutable context and pale brown pileus. The material agrees with the features quoted by Singer (1986) and Bessette et al. (2017).

Aureoboletus roxanae (Frost) Klofac. Figure 4.

New records. México, Oaxaca state, Mixistlán de la Reforma municipality, Santa Maria Mixistlàn town, 17°09′31″ N, 096°04′27″ W, Olivia Ayala-Vásquez, 24 July 2017, (Ayala-Vásquez-ITCV-898). Santiago Laxopa municipality, 17°14′16″ N, 096°18′25″ W, Jesús García and Olivia Ayala-Vásquez, 01 July 2017, (García and Ayala-Vásquez-ITCV-21478). Hidalgo state, Zacualtipán municipality, La Mojonera, 20°38′01″ N, 098°36′48″ W, Jesús García, 27 July 2009, (García-ITCV-17947). Same place, 20°37′47″ N, 098°36′47″ W, Jesús García, 27 August 2014, (García-ITCV-19805). Jalisco state, Tequila municipality, Volcán de Tequila, 20°48′59″ N, 103°51′78″ W, Ángel Saldivar, 30 September 2017, A. E. Saldivar 260 (IBUG).

Identification. Pileus 40–70 mm in diameter, convex to broadly convex, becoming nearly plane when aged, reddish-brown (8E6-8E8) to pale brown (6D6), surface dry, granular-scaly when young, becoming nearly glabrous, sometimes cracking when mature. Hymenophore adhered, pores 12 mm diameter, angular, whitish when young, pale yellow (1A3) when aged, tubes 5 mm, not bruising blue. Context 9–13 mm thick, whitish to light brown (6F3), not bruising. Stipe 47–70 × 10–13 mm, clavate, brown (6D7-6E7), brownish orange (6C8) surface dry, rivulose to longitudinally striate. Odor fungoid. Taste sweet. Chemical reaction when applying NH_4OH the pileus turns brownish orange (6C8), negative in the hymenophore, context turns brown, stipe turns orange (6A8).

Basidiospores 9–12 × 4–5 µm (X = 10 × 4, Q = 2.5, N = 30) ellipsoid-fusiform, hyaline to greenish in KOH, brown in Melzer, smooth, with suprahilar depression, thin-walled. Basidia 20–31 × 8–11 µm, clavate, four-spored, with granular content, pale brown in KOH, thin-walled. Pleurocystidia 37–60 × 8–11 µm, ventricose-rostrate, hyaline in KOH, yellow in Melzer, thin-walled. Cheilocystidia 55–78 × 10–11 µm, ventricose-rostrate, hyaline to pale brown in KOH, yellow in Melzer, thick-walled. Hymenophoral trama boletoid; hyphae sub cylindrical to cylindrical, 4–12 µm wide. Stipitipellis composed by caulocystidia 35–62 × 9–16 mm, mammillated, mucronate, napiform or clavate, hyaline to pale brown in KOH, yellow in Melzer, thin-walled. Pileipellis composed by a trichodermus with terminal cells 32–82 × 9–14 µm, mucronate-mamillated, obclavate to subclavate, hyaline to pale brown in KOH, yellow in Melzer, with visible granular content, thin-walled, sometimes with gelatinized wall.

Habit and habitat. Solitary under *Q. laurina* and *Fagus grandifolia* Ehrh. subsp. *mexicana* (Martínez) E. Murray in montane cloud forest.

Distribution. Canada, USA, and Mexico.

Taxonomic remarks. *Aureoboletus roxanae* is characterized by the reddish-brown to pale brown pileus, the dry, granular-scaly or glabrous pileus surface and the white to pale yellow pores that do not stain blue. This species has some similar characteristics to those of *A. projectellus* like the basidiomata color, but that species shows long and reticulate stipe and longer spores (18–35 × 7–12 µm). The material agrees with the features quoted by and Coker and Beers (1943) and Bessette et al. (2017).

Key to *Aureoboletus* species occurring in Mexico

1a. Spores with ornamented walls..... 2
1b. Spores smooth..... 3
2a. Stipe reddish, alveolate to reticulate ..... *A. russellii*
2b. Stipe pale brown or pale yellow, smooth .. *A. singeri*
3a. Spores reaching 26 µm long, thick-walled ..... *A. projectellus*
3b. Spores reaching 17 µm, thin-walled..... 4
4a. Pores white to wax yellow 5
4b. Pores golden yellow 6
5a. Stipe base bulbose, pileus orange to brown ..... *A. roxanae*

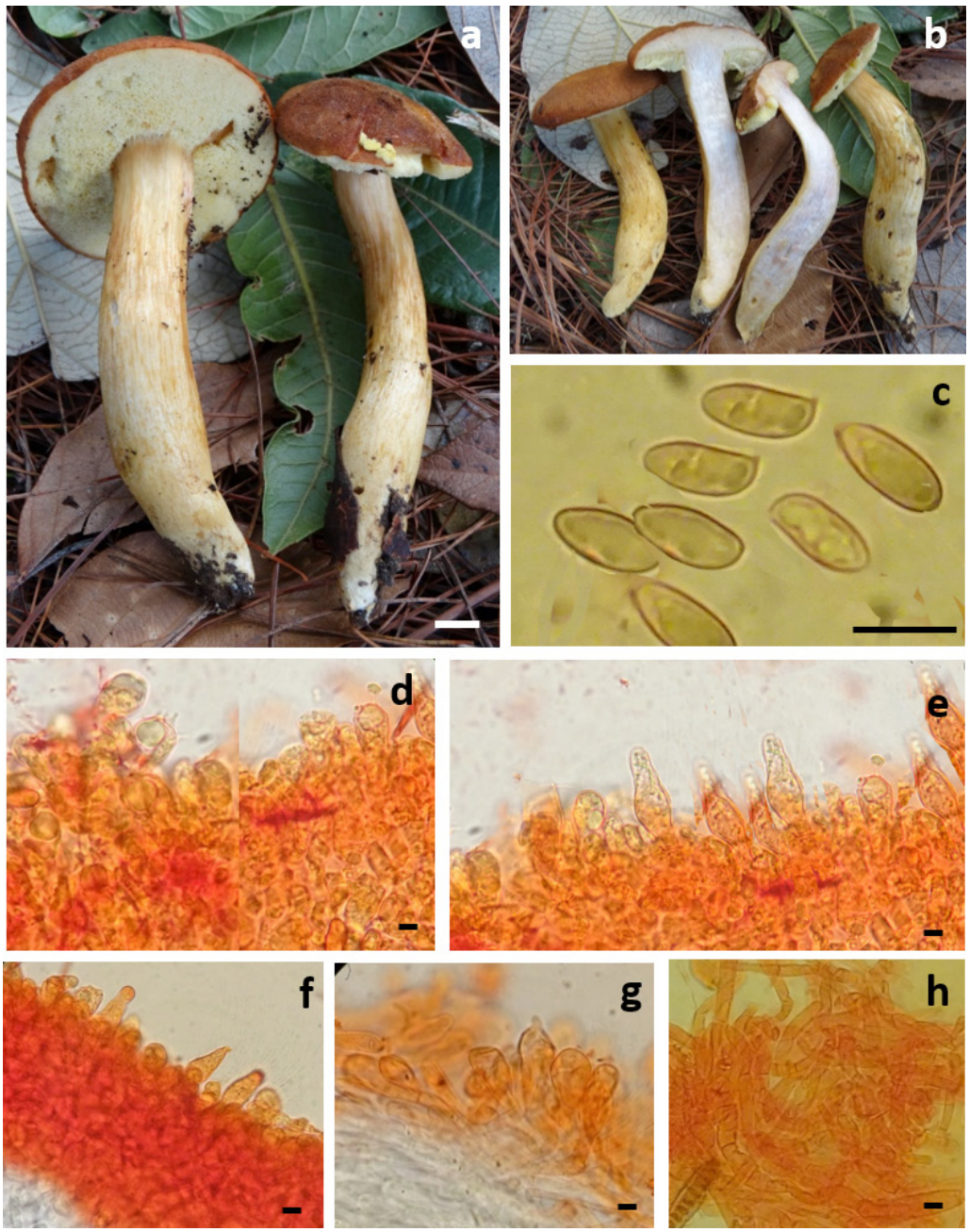

Figure 4. *Aureoboletus roxanae* [García-Jiménez and Ayala-Vásquez 21478 (ITCV)]. **a, b.** Basidiomata. **c.** Basidiospores. **d.** Basidia. **e.** Pleurocystidia. **f.** Cheilocystidia. **g.** Stipitipellis. **h.** Pileipellis. Scale bars: **a** = 10 mm; **d**–**h** = 10 µm.

5b. Stipe base acuminate, pileus purplish to reddish .... *A. moravicus*

6a. Pileus with viscid to subviscid surface 7

6b. Pileus never viscid 8

7a. Stipe reticulate at apex, context bruising orange when cut ..... *A. flaviporus*

7b. Stipe never reticulate, context never bruising when cut ..... *A. auriporus*

8a. Pileus grayish pink, dark red to red-brown .... *A. innixus*

8b. Pileus orange to brown-orange ..... *A. auriflammeus*

Discussion

The 3 species described here are widely distributed in North America, from eastern Canada to Florida and Michigan in the United States, even reaching Belize in Central America (Singer 1947, Snell and Dick 1970, Baroni 1998, Ortiz-Santana et al. 2007, Bessette et al. 2017). The species described are distributed in western and central Mexico, in the states of Jalisco, Oaxaca, Hidalgo and Queretaro, growing in mixed and montane cloud forests. *Aureoboletus auriflammeus* is associated with *Quercus germana* Schltdl. & Cham. and *Q. sartorii* Liebm. in montane cloud forest, *Aureoboletus innixus* is associated with *Fagus grandifolia* subps. *mexicana* in cloud forest, with *Quercus scytophylla* Liebm and *Quercus rugosa* Neé in mixed forest and oak forest and both occur in Eastern Mexico; *Aureoboletus roxanae* is associated with *Quercus laurina* Bonpl. in cloud forests in Eastern and Western Mexico. Interestingly, *A.*

auriflammeus shows a limited distribution. Although the authors have explored oak forests in Mexico, this species has only been found growing under *Quercus* in montane cloud forests of the state of Hidalgo. Bessette et al. (2017) also report this species growing under *Quercus* species. The presence of complicated mountain systems in Mexico contributed to the diversity of *Quercus* and with it the Boletes, mainly the genus *Aureoboletus*.

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Authors' Contributions

OAV and JGJ collected the specimens and identified the collections. AES, OAV and JIF wrote the text and made the illustration, JGJ and FGO revised the manuscript.

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