

Notes on the identity of *Hygrophoropsis rufa* (Basidiomycota, Boletales)

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The rare fungus *Hygrophoropsis rufa* is documented from the Czech Republic for the first time. Both classical and DNA study results have proved that *H. rufa* is a good species, clearly separated from *H. aurantiaca*. Macroscopically, it differs by an orange-brown to dark brown pileus surface. The stability of the observed differences in spores, being slightly smaller and thick-walled in *H. rufa*, has to be confirmed using a larger set of collections. A brief comparison with dark-coloured taxa of the group of *H. aurantiaca* is added. *Hygrophoropsis aurantiaca* var. *atrotomentosa* most probably represents a synonym, but its nomenclatural status has to be clarified.

Key words: *Hygrophoropsidaceae*, taxonomy, phylogeny, variability, Europe.

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Vzácný druh *Hygrophoropsis rufa* je poprvé dobře dokumentován z České republiky. Tradiční i molekulární metody potvrdily, že se jedná o samostatný druh, jasně vymezený vůči druhu *H. aurantiaca*. Makroskopicky se liší oranžovohnědým až tmavohnědým povrchem klobouku. Byly pozorovány i rozdíly ve znacích výtrusů, které jsou u našeho sběru *H. rufa* poněkud menší a mají tlustší stěnu; tyto rozdíly však bude nutno potvrdit studiem většího počtu sběrů. Krátce jsou diskutovány i další tmavě zbarvené taxony z okruhu *H. aurantiaca*. *Hygrophoropsis aurantiaca* var. *atrotomentosa* s největší pravděpodobností představuje synonymum, ale nomenklatorické postavení tohoto jména ještě bude třeba vyjasnit.

INTRODUCTION

During a mycological study of sandstone gorges in the České Švýcarsko (Bohemian Switzerland) National Park, Czech Republic (Holec & Wild 2011), a dark-coloured *Hygrophoropsis* was found and identified as *Hygrophoropsis rufa* (D.A. Reid) Knudsen. The fungus was described (Reid 1972) as *H. aurantiaca* var. *rufa* D.A. Reid and transferred to the rank of species by Knudsen (in Knudsen & Vesterholt 2008). *Hygrophoropsis rufa* is not documented in Czech scientific literature (there are some reports and photographs on the Internet, however lacking

important data) and seems to be rare in Europe (Ludwig 2001, Knudsen & Taylor 2012). In GenBank, there are no sequences of it. Consequently, the Czech collection is described and discussed using both classical and molecular methods. A brief comparison with dark-coloured taxa of the group of *Hygrophoropsis aurantiaca* (Wulfen: Fr.) Maire is added.

MATERIAL AND METHODS

Macrocharacters of fresh fruitbodies were noted directly after the field excursion. Voucher specimens are kept in the PRM herbarium (National Museum, Mycological Department, Prague, Czech Republic). For herbarium acronyms, see Thiers (2013). Microscopic mounts were made in a 5% KOH solution and studied under an Olympus BH-2 light microscope. Melzer's reagent was also used to study spores, hymenium and lamellar trama. Spore sizes of 20 spores measured are presented in the form of the main data range (10–90 percentile values), complemented with extreme values in parentheses.

DNA from dried specimens was isolated according to Holec & Kolařík (2012). The ITS rDNA region and D1/D2 domain of the LSU rDNA gene was amplified using primers ITS1F and NL4, and the same primers, together with primer ITS4, were used for sequencing (see Holec & Kolařík 2012 for details). Sequences were combined with published *Hygrophoropsis* ITS-LSU rDNA sequences (Tab. 1) and aligned in MAFFT v6.861b (Katoh & Toh 2008). *Leucogyrophana mollusca*, a sister taxon to *Hygrophoropsis* (Binder & Hibbett 2006) was chosen for the outgroup. There were a total of 11 sequences (three obtained in this study) and 1369 positions in the final dataset, 217 of which were variable and 33 parsimony informative. Maximum likelihood (ML) searches were conducted in PhyML 3.0 (Guindon et al. 2010), via the Montpellier online server (<http://www.atgc-montpellier.fr/phyml/>) with 1000 bootstrap replicates. The best substitution model (K2-G) was selected in MEGA 5.0 (Tamura et al. 2011).

Abbreviations. alt. – altitude, leg. – collected by, JH: Jan Holec, Q – quotient of length and width of the spores, Qav – mean value of Q of the 20 spores studied.

Material studied

***H. rufa*.** Czech Republic. České Švýcarsko (Bohemian Switzerland) National Park, ca. 4 km N of the village of Jetřichovice, 0.8 km E – 0.5 km NE of the top of Vosí vrch hill, Prýskyřičný důl: central part (50°53.563' N, 14°24.402' E – 50°53.284' N, 14°24.756' E), narrow wet sandstone gorge, covered by *Picea abies* bog forest, rarely with *Fagus* on slopes, with mosses and *Sphagnum* stands at the bottom, alt. 320 m, under *Picea abies*, 16 Aug. 2011, leg. J. Holec, JH 51/2011 (PRM 899303).

***H. aurantiaca*.** Czech Republic. Čáslav, Třemošnice, valley of Doubrava river, *Picea* forest, 26 Oct. 2008, leg. J. Borovička (PRM 909940). – Praha: Divoká Šárka, on soil under *Larix decidua*, 30 Sep. 1994, leg. M. Svrček (PRM 882488). – Veselí nad Lužnicí, N of the village of Borkovice, site called Kozohlůdky, on peaty soil under *Pinus strobus*, 27 Oct. 2000, leg. F. Kotlaba (PRM 894155). – Western Bohemia, Český les, site called Pavlova huť, 19 Oct. 2012, leg. M. Kolařík (PRM 861414).

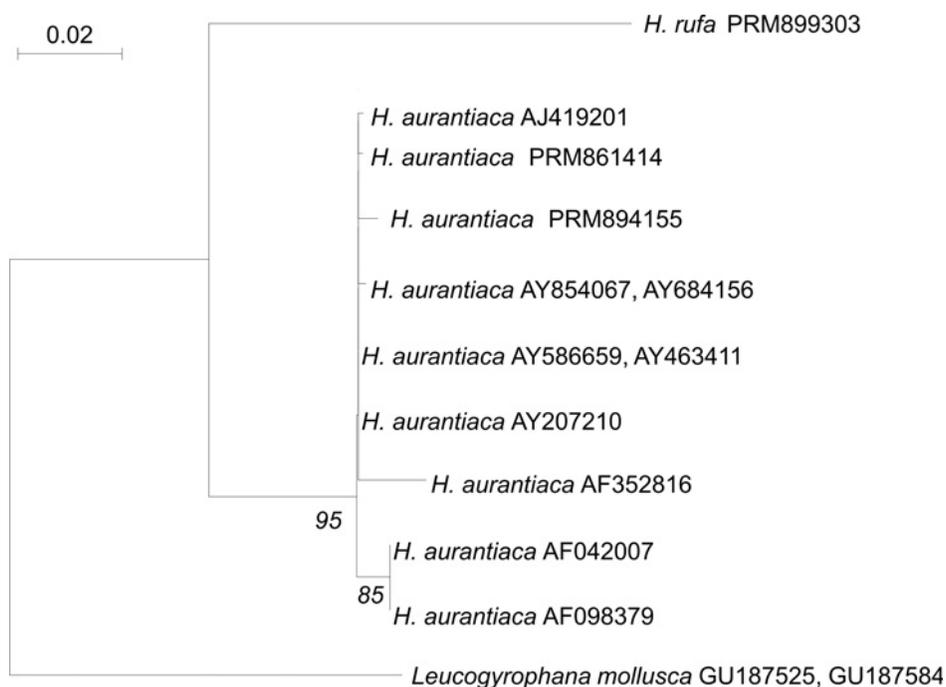


Fig. 1. Evolutionary relationships of *Hygrophoropsis aurantiaca* and *H. rufa* reconstructed using the maximum likelihood method. Sequences of collections printed in bold were obtained during this study. *Leucogyrophana mollusca* was used as an outgroup.

Tab. 1. Collections and sequences used for the DNA study.

Species	Country	Voucher	GenBank	Reference
<i>H. rufa</i>	Czech Republic	PRM 899303	HF951529	This paper
<i>H. aurantiaca</i>	Czech Republic	PRM 894155	HF951530	This paper
<i>H. aurantiaca</i>	Czech Republic	PRM 861414	HF951531	This paper
<i>H. aurantiaca</i>	Germany	AFTOL-ID 714	AY854067 (ITS), AY684156 (LSU)	Binder & Hibbett (2006)
<i>H. aurantiaca</i>	Germany	GLM 45936	AY207210 (LSU)	Walther et al. (2005)
<i>H. aurantiaca</i>	Germany	REG:HAM1	AF352816 (LSU)	Jarosch & Besl (2001)
<i>H. aurantiaca</i>	Germany	Ha1	AF042007 (LSU)	Binder et al. (1997)
<i>H. aurantiaca</i>	Germany	–	AF098379 (LSU)	Bresinsky et al. (1999)*
<i>H. aurantiaca</i>	Spain	MA-Fungi 47694	AJ419201 (ITS)	Martin & Raidl (2002)
<i>H. aurantiaca</i>	Sweden	EL42_99	AY463411 (ITS), AY586659 (LSU)	Larsson et al. (2004)

*Sequence present in GenBank together with a rich set of other sequences cited in the paper but omitted from the paper for unknown reasons.

RESULTS

Hygrophoropsis rufa (D.A. Reid) Knudsen, *Funga Nordica*: 913, 2008. Figs. 2, 3

Basionym. *Hygrophoropsis aurantiaca* var. *rufa* D.A. Reid, *Fungorum rariorum icones coloratae*, vol. 6: 5, 1972.

Selected descriptions/illustrations. Reid (1972: p. 5–6, pl. 41c, text-figs. 6b, 7), Knudsen & Taylor (2012: 196). On the Internet, there are numerous photographs looking almost identical with our collection, most probably representing *H. rufa*. As they lack complete documentation (especially data on microcharacters), they are not cited here for reason of precision.

Description

The description is based on 5 fruitbodies in optimal condition, both young and mature (Fig. 2).

Pileus 10–35 mm, slightly depressed to applanate, with conspicuously involute margin, dry, mat, tomentose to granulose-tomentose, dark brown with grey-brown margin when young, then brown to olive-brown with yellow-orange ground shining through. Lamellae moderately dense, low, thick, deeply decurrent, about 24–26 of them connected with stipe, forked towards the pileus margin, bright orange when young, then paler, yellow-orange. Stipe 30–40 × 8–12 mm, with lower half hidden in the substrate, cylindrical or slightly broadened towards base, dry, mat, granulose-tomentose in upper half, dirty ochre-brown, with olive tinge at maturity, covered with white tomentum in lower half. Context colour not recorded. Smell acidulous. Taste mild.

Basidiospores (5.2)5.6–6.4(6.8) × 3.6–4.4 μm, Q = 1.30–1.70, Q_{av} = 1.53, ellipsoid to ovoid, slightly thick-walled, with an indistinct hilar appendix, pale yellow in KOH, pale vinaceous brown to red-brown (i.e. dextrinoid) in Melzer's reagent. Basidia 26–36 × 7–8 μm, cylindrical to narrowly clavate, 4-spored, with basal clamp. Basidiolae 17–22 × 5.5–6.5 μm, narrowly clavate. True cystidia absent. Pseudocystidia (transformed terminal elements of hyphae protruding from subhymenium through hymenium) frequent, 14–36 × 5–7 μm, narrowly clavate to clavate with a low, broad, obtuse umbo. Lamellar trama regular to subregular, consisting of parallel to slightly interwoven hyphae 4–12 μm broad, cells cylindrical to slightly fusiform inflated, thin-walled, hyaline, non-dextrinoid. Pileipellis a trichoderm of loosely arranged, upraised, interwoven, branched hyphae 5–12 μm broad, cells cylindrical or slightly inflated, terminal cells slightly fusiform with obtuse apex to narrowly clavate, wall about 0.5 μm thick, yellow, cells filled with a homogeneous pale brown pigment, especially in the upper layer. Pileocystidia absent. Pileus trama of loosely arranged, branched, thin-walled, hyaline hyphae 5–12 μm broad, cells cylindrical to slightly inflated. Stipitipellis a trichoderm simi-



Fig. 2. *Hygrophoropsis rufa*, Czech Republic, České Švýcarsko (Bohemian Switzerland) National Park, Pryskyřičný důl gorge, 16 Aug. 2011, leg. J. Holec (PRM 899303). Photo by J. Holec.

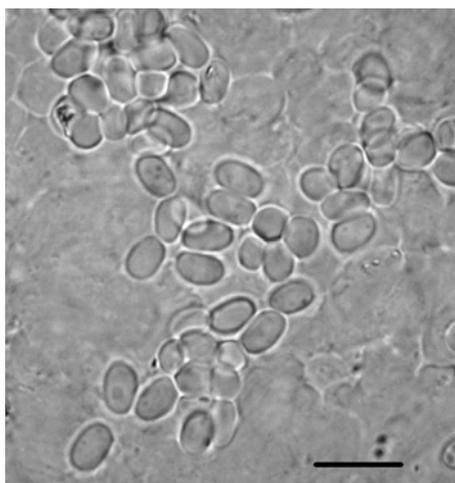


Fig. 3. *Hygrophoropsis rufa*, basidiospores (PRM 899303). Bar = 10 μ m. Photo by J. Holec.

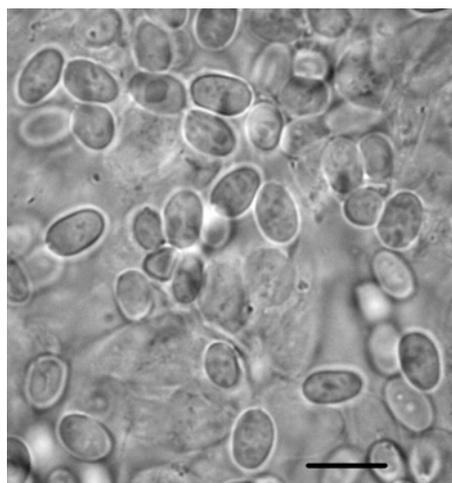


Fig. 4. *Hygrophoropsis aurantiaca*, basidiospores (PRM 882488). Bar = 10 μ m. Photo by J. Holec.

lar to the pileipellis, cells with infrequent, short, obtuse outgrowths. Caulocystidia absent. Clamp connections frequent, present in all tissues.

DNA study

Two *H. aurantiaca* collections in our study differed in 3 positions in the ITS rDNA sequence (0.38 % from 786 bp). The same variability was observed when other ITS rDNA sequences from the GenBank (AY854067, AJ419201) were included into the dataset. This dataset differed in 128 positions (17 %) from our sequence of *H. rufa*. A more conserved LSU rDNA sequence of *H. rufa* differed in 5–6 % positions from *H. aurantiaca* sequences in our study and GenBank (Tab. 1). The distant position of *H. rufa* is apparent from the phylogenetical analysis, which consistently places this species as a sister group to the homogeneous group of *H. aurantiaca* (Fig. 1).

DISCUSSION

Hygrophoropsis rufa versus *H. aurantiaca*

Reid (1972) characterised *H. aurantiaca* var. *rufa* as differing from the typical *H. aurantiaca* by a rufous colour (pileus “between Apricot Buff and Cinnamon-Rufous”, stipe similar but less bright) and “possibly also by its rather small spores”. His description was based on only one collection. The Czech find agrees well with the British one except for its larger basidia, slightly larger spores (Tab. 2) and narrower pileipellis hyphae. Moreover, we observed pseudocystidia, which are not mentioned by Reid.

Our data fully agree with the conclusion by Knudsen (in Knudsen & Vesterholt 2008: 913) and Knudsen & Taylor (2008, 2012) that *H. rufa* is not a mere variety of *H. aurantiaca* but a species of its own. The main character (orange-brown to dark brown pileus surface) is very distinctive, showing no transition to the yellow-orange to red-orange pileus in *H. aurantiaca*. The first published DNA sequence data of *H. rufa* (Fig. 1) differ considerably from those of *H. aurantiaca*, which clearly confirms the separate status of both species.

The second distinguishing character observed by Reid (1972) – small spores – is not stressed by Knudsen & Taylor (2008, 2012). They report almost the same spore size in *H. rufa* and *H. aurantiaca* (Tab. 2). However, our measurements based on one collection of *H. rufa* and three randomly selected collections of *H. aurantiaca* (Tab. 2) agree with Reid’s observation. There is an overlap in extreme values but the normal spore length values (10–90 percentile) are clearly separated and the width is slightly different as well: $5.6\text{--}6.4 \times 3.6\text{--}4.4 \mu\text{m}$ in *H. rufa* and $6.4\text{--}8.0 \times 4.0\text{--}5.2 \mu\text{m}$ in *H. aurantiaca*. Moreover, we observed that the spores

of *H. rufa* are rather thick-walled (a fact mentioned by Knudsen & Taylor 2008, 2012) whereas those of *H. aurantiaca* are thin-walled (Figs. 3, 4). A larger set of collections is necessary to confirm if these differences represent stable differential characters. We have to proceed with caution as the group of *H. aurantiaca* is known for its large variability in spore size. For example, a collection with a spore size of 8.0–11.0(13.0) × 3.0–4.5(5.0) µm was described as *H. aurantiaca* var. *macrospora* D.A. Reid (Reid 1972).

Tab. 2. Spore size in *H. rufa* and *H. aurantiaca* based on literature data and selected collections from the PRM herbarium. See also Figs. 3, 4.

Species	Source	Spore length (µm)	Spore width (µm)
<i>H. rufa</i>	PRM 899303 (this paper)	(5.2)5.6–6.4(6.8)	3.6–4.4
	Reid (1972)*	5.0–5.75	3.0–3.75
	Knudsen & Taylor (2008, 2012)	5.0–6.5(7.0)	3.0–4.0
<i>H. aurantiaca</i>	PRM 894155	6.4–7.2	4.0–4.8
	PRM 909940	6.4–8.0(8.8)	4.4–5.2
	PRM 882488	(6.0)6.4–7.6(8.8)	4.0–4.4(4.8)
	Knudsen & Taylor (2008, 2012)	5–7	3.5–4.5

* as *H. aurantiaca* var. *rufa*

Other dark-coloured taxa of the *H. aurantiaca* group

The group of *H. aurantiaca* is very variable and taxonomically unresolved. Besides pale-coloured taxa like *H. aurantiaca* f. *albida* (Fr.) Gillet and *H. pallida* (Peck) Kreisel (species having a rich synonymy, see e.g. Knudsen & Taylor 2008, 2012), there are darker forms as well:

(1) *H. fuscusquamula* P.D. Orton has a “whitish cream or pale yellowish ochraceous” pileus with “numerous olive-brown to sepia small fibrillose squamules” and spores measuring 6.0–8.0 x 3.5–4.5 µm (Orton 1960). Both the character of the pileus surface and larger spores show that *H. fuscusquamula* is not identical with *H. rufa*. Knudsen & Taylor (2008, 2012) place it into the synonymy of *H. pallida*.

(2) *H. aurantiaca* var. *nigripes* (Pers.) Kühner & Romagn. is characteristic by its black-brown stipe. However, its pileus is yellow like in the true *H. aurantiaca*. The combination by Kühner & Romagnesi (1953: 130) is invalid, as the basionym (*Merulius nigripes* Pers. 1801) is not cited.

(3) *Clitocybe aurantiaca* var. *atrotomentosa* J. Jaccottet is an enigmatic name representing a clear *Hygrophoropsis*. The name nor its author (John Jaccottet) are included in basic mycological databases (Mycobank, Index Fungorum, Authors of Fungal Names). The name was published by Jaccottet (1925: 92) in

French. It is validly published as Latin diagnosis and type designation was not necessary that time. The name is absent from an older book by Jaccottet (1922), containing black-and-white line drawings by Edouard Jaccottet. Unfortunately, we were not able to find in which publication *C. aurantiaca* var. *atrotomentosa* was transferred to *Hygrophoropsis* and if it was done validly. It is possible that the combination occurs in one of the nine editions of Jaccottet's book published in the period 1925–1973 (www.worldcat.org) by Delachaux & Niestlé, Neuchâtel. The only younger edition available to us was the third one (Jaccottet 1943), where the fungus is mentioned under *Clitocybe*. Bibliographic remark: the authorship of the book is ascribed either to John Jaccottet as the main author or to him and his co-authors (Paul-André Robert, colour plates; Edouard Jaccottet, line drawings; Charles-Ed. Martin, preface).

Clitocybe aurantiaca var. *atrotomentosa* was described (Jaccottet 1925: 91–92) as a fleshy fungus with dark brown pileus reaching up to 10 cm in diameter, red-orange lamellae, a 2–3 cm broad stipe concolorous with the pileus, and spores measuring $5\text{--}7 \times 4\text{--}5 \mu\text{m}$. In our opinion, it represents *H. rufa*. In the rank of variety, the name has priority over *H. aurantiaca* var. *rufa* D.A. Reid. However, at the species level *H. rufa* (D.A. Reid) Knudsen is the correct name.

Hygrophoropsis aurantiaca var. *atrotomentosa* is mentioned by e.g. Pilát (1952a: no. 78a; 1952b: p. 128, fig. 186, under *Clitocybe*), Herrmann (1983), Enderle (2004), and Besl & Bresinski (2009), mostly without illustrations. A photograph by Uzelac (2009) differs from our collection of *H. rufa* by its rusty brown pileus covering (not dark brown).

Ludwig (2001) considers *H. aurantiaca* var. *atrotomentosa* a different fungus, having an even darker brown pileus than *H. aurantiaca* var. *rufa*. We agree that more dark-coloured taxa may exist. Such collections should be carefully studied using both classical and molecular methods.

Distribution

Hygrophoropsis rufa is reported (as *H. rufa* or *H. aurantiaca* var. *rufa*) from e.g. Great Britain (Reid 1972, Legon & Henrici 2005), Denmark (Knudsen & Taylor 2008, 2012), Germany (Ludwig 2001) and Austria (Austrian Mycological Society 2009). In all cases it is characterised as a rare species. The possibly synonymous taxon *H. aurantiaca* var. *atrotomentosa* is reported from e.g. Germany (Herrmann 1983, Enderle 2004, Besl & Bresinski 2009), Austria (Austrian Mycological Society 2009) and Serbia (Uzelac 2009). Internet provides good photographs of *H. rufa* from e.g. France and Slovakia. The data show that *H. rufa* is rare but widespread in Europe.

CONCLUSIONS

The first published DNA sequence data of *H. rufa* (Fig. 1) differ considerably from those of *H. aurantiaca*, which clearly confirms their separate status. The macromorphological differences between *H. rufa* and *H. aurantiaca* observed in our material are summarised in Tab. 3. Spore size is rounded to 0.5 µm. The observed differences should be tested using a larger set of collections.

Tab. 3. Differences between *H. rufa* and *H. aurantiaca* based on this study.

Character	<i>H. rufa</i>	<i>H. aurantiaca</i>
Pileus surface colour	dark brown	yellow-orange, orange to red-orange
Normal spore size (10–90 percentiles) in µm	5.5–6.5 × 3.5–4.5	6.5–8.0 × 4.0–5.0
Spore wall	rather thick	thin

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