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Cordyceps rouxii (Ascomycetes, *Clavicipitales*) in Slovakia and Czech Republic, with notes to distribution, ecology and taxonomy

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Cordyceps rouxii, a new species for Slovakia and Czech Republic was recorded in 2004. Revision of herbarium collections revealed that this species has been often misidentified as *C. capitata* and is more common than was expected. After revision of the type material the authors propose an epitype based on a Slovak collection.

Key words: *Cordyceps capitata*, *Cordyceps longisegmentis*, epitype

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Cordyceps rouxii bol v roku 2004 nájdený ako nový druh pre Slovensko a Česko, nezávisle na viacerých lokalitách. Revízia položiek druhu *Cordyceps* v herbároch ukázala, že tento druh bol v minulosti často nesprávne určovaný ako *C. capitata* a je oveľa hojnejší ako sa predpokladalo. Po revízii typového materiálu autori ustanovili epityp, ktorý predstavuje položka zo Slovenska.

INTRODUCTION

The genus *Cordyceps* includes several hundred species of fungi parasitizing as anamorphs and teleomorphs on various species of insects and spiders. Only a few of them – about 18 species – parasitize on fungi of the genera *Elaphomyces* and *Claviceps* (Mains 1953, Candoussau 1976, Kobayashi and Shimizu 1982, Kovaľ 1984, Ginns 1988). Six species of *Cordyceps* parasitizing on *Elaphomyces* are known from Europe and three species (*C. capitata*, *C. longisegmentis* and *C. ophioglossoides*) have to date been recorded in Slovakia and Czech Republic (Holec 2001, Holec and Suková 2002, Kautmanová 1998, Lizoň and Bacigálová 1998). In 2004, 2005 and 2006 further species, *C. rouxii*, was recorded in both of

these countries. Further study of herbarium specimens in Slovak, Czech and later in some other European collections revealed that this species was collected in the past, but was not distinguished and was treated mostly as *C. capitata*. This, together with the possibility of a detailed study of the variability of the species thanks to an extremely rich population at one of the Slovak sites (counting more than 170 individuals) stimulated our interest in ecology, distribution as well as taxonomy of the species.

MATERIAL AND METHODS

Macromorphological characters were observed in fresh material. Micromorphological structures were observed in dried material using a light microscope with an oil immersion lens. Fragments of material were examined in 5 % KOH, Melzer's reagent, and a solution of Congo Red in ammonia (1 ml of 25 % ammonia dissolved in a filtrated solution of 1.5 g of Congo Red and 50 ml of distilled water). Extreme values of micromorphological characters were estimated as average plus and minus standard deviation of 15 measurements. Descriptions were made according to our specimens collected in Slovakia (field collections) and revised herbarium material (herbarium collections). The ultrastructure of segments was observed under JEOL JXA 840 scanning electron microscope, using JEOL JFC-1100 ion sputtering device for fine gold coating.

Exsiccatae collections were dated according to Pfister (1985). Abbreviations of herbaria follow Index Herbariorum (Holmgren et al. 1990):

BP – herbarium of the Hungarian Natural History Museum, Budapest, Hungary; BRA – herbarium of the Slovak National Museum, Bratislava, Slovakia; BRNM – herbarium of the Moravian Museum, Brno, Czech Republic; CB – herbarium of the Jihočeské Muzeum, České Budějovice, Czech Republic; CUP – Cornell Plant Pathology Herbarium, Cornell University, Ithaca, United States; KRA – herbarium of the Institute of Botany, Jagiellonian University, Cracow, Poland; KRAM – herbarium of the W. Szafer Institute of Botany, Polish Academy of Sciences, Cracow, Poland; M – Staatsherbarium München, Germany; PC – herbarium of the Natural History Museum, Paris, France; PRM – mycological herbarium of the National Museum, Prague, Czech Republic; W – herbarium of the Natural History Museum, Wien, Austria; WU – herbarium of Wien University, Austria.

Other abbreviations: N – ARON, Ascomycete Research Team, Dept. of Biology, University of Oslo, Norway; HD – herbarium H. Deckerová, OP – herbarium of the Orava Museum, Oravský Podzámok, Slovakia; PVDK – herbarium D. Karasiński, PVK – herbarium V. Kautman.

STUDIED SPECIMENS

Cordyceps rouxii Candoussau

Field collections

Slovakia: Nízke Tatry Mts., Malužiná, Michalovo valley, northern slope of Hradisko Mt., alt. 780 m, in young cultivated spruce (*Picea abies*) forest, calcareous soil, two localities ca. 200 m apart, 9 Aug. 2004, on *Elaphomyces muricatus*, leg. J. Ripka, det. V. Kautman, BRA CR8030; 20 Aug. 2005, on *Elaphomyces* sp., leg. et det. V. Kautman, PVK 109. – Orava region, Západné Tatry Mts., Zuberec, "Mačie diery" Nature Reserve, alt. 1000 m, old spruce (*Picea abies*) forest, with intermixed fir (*Abies alba*), pine (*Pinus sylvestris*) and maple (*Acer* sp.), undergrowth with mosses and blueberries (*Vaccinium myrtillus*), with a great number of *Cordyceps ophioglossoides*, limestone underground, on *Elaphomyces muricatus*, 18 Sept. 2004, leg. et det. I. and V. Kautman, PVK 100, 101, 102, 103, BRA CR8031; 22 July 2005, leg. et det. I. and V. Kautman, PVK 104, 105, 106, 107, 108, BRA CR8028 (EPITYPE); 19 Aug. 2005, leg. et det. I. and V. Kautman, PVK 110, 111, 112, 113, 114, 115, BRA CR8027; 16 Aug. 2006, leg. et det. I. and V. Kautman, PVK 124; 24. Aug. 2006, leg. et det. V. Kautman PVK 126, 127, 129, 130, 131; 10 Sept. 2006, leg. et det. V. Kautman, PVK 133, 134. – Orava region, Oravská Magura Mts., Zabava hill, Drevená, 3 km W of Hruštín, alt. 780 m, N slope in young (20 years) spruce forest (*Picea abies*), intermixed with fir (*Abies alba*) and maple (*Acer* sp.), undergrowth with blueberries (*Vaccinium myrtillus*), horsetails (*Equisetum sylvaticum*), *Plagiomnium* sp. and other mosses, near spring, 16 July 2006, leg. et det. V. Kautman, PVK 116, 117, 118, BRA CR8179; 16 Aug. 2006, leg. et det. I. and V. Kautman, PVK 119, 120, 121, 122, 123; 24 Aug. 2006, leg. et det. V. Kautman, PVK 125.

Czech Republic: Šumava Mts., Lenora, Malá niva Nature Reserve, alt. 750 m, coniferous forest (*Pinus sylvestris*, *Picea abies*) with intermixed birch (*Betula* sp.), undergrowth with *Sphagnum*, mosses and blueberries (*Vaccinium myrtillus*), 7 Oct. 2004, leg. et det. I. Kautmanová, BRA CR8029.

Herbarium collections

Slovakia: Slovenský Raj Mts., Novoveská Huta (Iglófüred), in forest on *Elaphomyces cervinus*, July 1910, leg. et det. F. Filarszky as *C. capitata* BRA CR4858, BRA CR4859, BRA CR4860, PRM 11702, PRM 169288, W 18967, W 9870, W 12844, WU 2618, PC 0090839, BP 71665, BP 1720. – Malá Fatra Mts., Hôrky, near the stream Bystrička, 3 km west of Bystrička village, alt. 700 m, 15 July 1982, leg. et det. L. Hagara as *Tulostoma fimbriatum*, rev. by V. Zíta as *C. capitata* BRA CR8042. – Orava region, Skorušinské vrchy hills, Blatná valley, Pod Skorušinou, above gamekeeper´s cottage, alt. 860 m, six specimens on *Elaphomyces muricatus* in mixed forest, by the stream bank, 30 July 2004, leg. J. Červenka and H. Deckerová OP 219. – Nízke Tatry Mts., Kráľova hoľa, Pod Škútovou, in peat bog in spruce forest, alt. 1150 m, 8 Sept. 2006, leg. et det. H. Deckerová HD 252/4210.

Czech Republic: Šumava Mts., Kdyně, Svah kozáků, 29 Aug. 1927, leg. et det. A. Hilitzer as *C. capitata*, PRM 169282. – Jičínská pahorkatina highlands, Turnov-Nebákov, 15 July 1948, leg. J. Kubička as *Cordyceps* sp. PRM 622915. – Šumava Mts., peat-bog Cikánská slať, by stream valley, ca. 2.8 km from Modrava, humid spruce forest, alt. 1070 m, in *Sphagnum*, 9 Oct. 1998, leg. et det. J. Holec as *C. capitata*, PRM 897594. – Žďárské vrchy, Radostín u Vojnova Městce, forest Doubravník, on *Elaphomyces* in soil, alt. 630 m, 16 July 1999, leg. et det. V. Antonín as *C. capitata* BRNM 648473.

Poland: S Poland, Western Tatra Mts., Sarnia Skala massif, Dolina Spadowiec valley, eastern slopes – western exposure, alt. 1000 m, *Dentario glandulosae-Fagetum*, on carphophores of *Elaphomyces muricatus*, 20 Aug. 2001, leg. et det. (Sept. 2006) A. Ronikier KRAM 51598, BRA CR 8433. – N Poland, Kaszuby region, Przewóz forestry, 28 July 2004, leg. et det. D. Karasiński as cf. *C. rouxii*, PVDK 040728. – N Poland, Kaszuby region, vicinity of Kartuzy, Zamkova Góra Nature reserve, under *Fagus*, 24 July 2005, leg. et det. D. Karasiński as *C.* sp. cf. *capitata* PVDK 050724.

Austria: Waldgebiet near Barnan, summer 1942, leg. Pfalz, det. H. Lohwag as *C. capitata* W 02352. – Göstling/Ybbs, Hochtel, Leckermoor, 5 Sept. 1984, leg. et det. Mrasch as *C. capitata* WU 3547. – Göstling/Ybbs, Leckermoor, alt. 900 m on *Elaphomyces muricatus*, 22 July 1989, leg. et det. W. Ulofer as *C. capitata*, rev. Ell. z Evech. as *C. canadensis* WU 8060.

France: Pyrénées, Pau region, Bois de Haouquère near Plas des Asphodèles, on *Elaphomyces* sp. under leaves of *Fagus*, 3 July 1976, leg. G. Roux, det. F. Candoussau CUP 54937, HOLOTYPE. – Pyrénées atlantiques, Pau, Bois de Haouquère, alt. 1000 m, on *Elaphomyces variegatus*, July 1974, leg. G. Roux, det. F. Candoussau CUP 54948, PARATYPE. – Basses Pyrénées, Chemin de Eaux – Chaudes aux Eaux Bonnes, alt. 1000 m, on *Elaphomyces* sp. under oak, 22 June 1975, leg. G. Roux, det. F. Candoussau CUP 54934, PARATYPE.

Germany: Dorfhalden, Oct. 1946, PC 0090822. – leg. et det. Wolgs as *Xylaria capitata* = *Sphaeria capitata* PC 0090819. – Bayern, Wald bei ..., 25 July 1854, ... as *C. capitata* M 0125526. – Bayern, Oberammergau, Waldung am Fulse der Noth, on *Elaphomyces*, Aug. 1894, leg. et det. Allescher as *C. capitata* M 0125528. – Scht. Park Rothenhaus, on *Elaphomyces cervinus*, Oct. 1916 (Pilzherbarium Kupka) as *C. capitata* M 0125533. – Bayern, Augsburg, 6 Sept. 1919, comm. Zinsmeister M 0125520. – Bayern, Sauerbach, Munich, on *Elaphomyces*, 18 July 1945, leg. I. Losch, det. Messenguth as *C. capitata* M 0125523. – *Cordyceps capitatus* Peyl M 0125530.

Norway: Sogn a Fjordane, Hornindal, Sept. 1998, leg. B. Bjørseth, det. O. Stensrud as *Cordyceps* sp., N 3002. – Oslo, Maridalen (at Sandermosen railway station); 15 Sept. 1999, leg. A. Holst-Jensen, leg. T. Vrålstad det. O. Stensrud as *Cordyceps* sp. N 3083.

Cordyceps capitata (Holmsk.: Fr.) Link

Field collections

Slovakia: Nothern Slovakia, Orava region, Čapica hill, 1 km W of Zázrivá, Picetum with *Corylus*, alt. 650 m, 6 Oct. 2006 leg. M. Burian, J. Červenka, J. Šuvada, V. Kautman, det. V. Kautman BRA CR 8484, PVK 153, 155; 13 Oct. 2006, leg. J. Červenka, V. Kautman, det. V. Kautman BRA CR8489, BRA CR8490, BRA CR8491, PVK 182, 183, 184, 186, 187, 188; 21 Oct. 2006, leg. I. and V. Kautman, det. V. Kautman BRA CR8493, BRA CR8494, BRA CR8495, PVK 194, 195, 197, 198. – North Slovakia, Orava Region, Terchová-Horná Tižina, on Vojenné hill, near Nogovci, alt. 860–900 m, 9 *Elaphomyces* with stromata, under the *Corylus*, *Pinus*, *Picea* and *Fagus*, 6 Oct. 2006, leg. J. Červenka, J. Šuvada, M. Burian, V. Kautman, det. V. Kautman BRA CR8485, BRA CR8486, PVK 157, 158, 159, 160, 163; 8 Oct. 2006, leg. B. Kuzmová, det V. Kautman PVK 169, 170; 13 Oct. 2006, leg. V. Kautman, J. Červenka, det. V. Kautman BRA CR8488, PVK 171, 172, 173, 174, 175, 176, 178; 21 Oct. 2006, leg. I. and V. Kautman, det. V. Kautman PVK 192. – Kubínska hoľa Mt., Bucľov, 3 km up from Beňova Lehota, spruce forest, alt. 900 m, 14 Oct. 2006, leg. J. Šuvada, det. V. Kautman PVK 190.

Herbarium collections

Czech Republic: Velké Meziříčí, near Netín, in "Jedlovec" forest, Sept. 1910, leg. R. Picbauer as *Torrubia parasitica* = *Sphaeria ophioglossoides* BRNM 130261. – Kuřim, in silva Šiberná on *Elaphomyces cervinus*, in oak forest, 9 Aug. 1940, leg. et det. F. Šmarda as *C. capitata* BRNM 224238.

Poland: Beskid Sądecki, between Tylicz and Krynica on *Elaphomyces asperulus*, in fir forest, 23 Oct. 1960, leg. et det. B. Lubelska-Gumińska as *C. capitatus* KRA 1960–4. – Polonia meridionalis, Carpati occidentales, in Kościełska valley – Tatri occidentales, on *Elaphomyces granulatus*, 14 Sept. 1909, leg. et det. K. Rouppert, matrix – rev. A. Skirgiełło KRAM 881. – Western Tatra Mts., forest towards Dolina Bialiego valley on *Elaphomyces* sp., Aug. 1909, leg. et det. K. Rouppert KRAM 1429.

Austria: Göf. Wald on *Elaphomyces cervinus*, Sept.– Oct. 1897, leg. et det. Rick W 09214. – Nadelwald plateau near Frojach, Rosseg in Ramten, Oct. 1898, leg. et det. Tobsich W 01407. – Tirol, Iglerwald, in coniferous forest, on *Elaphomyces*, 3 Oct. 1948, leg. Chaida, det. M. Moser M 0125529. –

Bezau, Sibratsgfäll, Q8526, 2 Sept. 1995, leg. et det. I. Krisai WU 14587. – Sehenlingwald near Mayrhofen in Zilbertal, alt. 650 m, leg. K. Walde, det. H. Lohwag W 03338.

France: Vosges, on *Elaphomyces granulatus*, autumn 1813, leg. et det. Mougeot W 379. – Vosges, in fir forest, on *Elaphomyces cervinum*, autumn 1823, leg. Mougeot et Nestler W 763 (neotype series). – Vosges, in fir forest, on *Scleroderma cervinum*, 1830, leg. et det. Mougeot as *Sphaeria agariciformis*, PC 0090833. – Gheluvelz, 1848, leg et det. Wolgs as *Xylaria capitata* PC 0090820. – Vosges, leg. et det. Mougeot as *Sphaeria capitata* PC 0090816. – Vosges, leg. et det. Mougeot as *Sphaeria capitata* PC 0090817. – in forest near Borvyleré, parasitic in *Sclerocium cervinum* PC 0090818. – in *Elaphomyces granulatus*, 1879, leg. et det. Salaise as *Torrubia ophioglossoides* PC 0090837. – in *Elaphomyces granulatus* parasitica, as *Torrubia ophioglossoides* PC0090838; – Forêt de Levisy, Calvados, under *Pinus silvestris* on *Elaphomyces granulatus*, Oct. 1910, leg. et det. N. Maire W 5508, PC 0090814, BP 71664, M 01255534. – Beluz, bois de Montsille, Nov. 1953, leg. et det. G. Métrod as *C. ophioglossoides* PC 0090811. – Le Mans, Sarthe, Oct. 1958, col. R. Heim, leg. et det. as *C.* cf. *capitata* PC 0090812. – in *Elaphomyces granulato*, as *Torrubia ophioglossoides* PC 0090836.

Germany: near Pruswitz, on *Elaphomyces granulatus*, labelled as *Sphaeria capitata* M 0125535. – Isterheimer Wald near Rastatt in Baden, Nov. 1877, leg. et det. Dr. Schroeter as *Torrubia capitata* M 0125532; Dec. 1877, leg. et det. Dr. Schroeter as *Torrubia capitata* M 0125531. – Bayern, Dosenhofen, Oct. 1919, leg. et det. Soehner M 0125524. – Bayern, Schwetelquelle near Agstetten, Augsburg, 1 Nov. 1957, leg. et det. A. Bresinski M 0125521. – Bayern, Pfronten (Allgäu) Vilstalsäge, 15 Nov. 1966, leg. Bresinski M 0125527. – Bayern, forest near Drösling, Seefeld am Pisensee, MTB 7933, 7 Nov. 1982, leg. Dr. Saveletti, det. A. Einhellinger M 0125522.

Norway: Buskerud, Øvre Eiker, Vestfossen (Gommerud/Røkebergtjern), 10 Oct. 1999, leg. B. Krømer, det. O. Stensrud N 3085 (now BRA CR8180 – gift), N 3086, N 3087. – Akershus, Frogn, HÍøya, 1998 leg. J. Stokland, det. O. Stensrud N 3001.

Cordyceps longisegmentis Ginns

Field collections

Slovakia: Western Slovakia, Záhorie, Borská nížina, Jasenácke near Studienka, in Pineto on *Elaphomyces granulatus*, alt. 200 m, 9 Sept. 1998, leg. et det. I. Kautmanová as *C. capitata*, rev. J. Holec as *C. longisegmentis* BRA CR3124; Oct. 2000, leg. H. Kautmanová, det. V. Kautman PVK 99. – North Slovakia, Vysoké Tatry Mts., Liptovská kotlina, 8 and 9 km NE of Hybe, on old outgrown pasture, on *Elaphomyces* sp., alt. 850 m, 12 Sept. 2006, leg. V. Kučera, det. I. and V. Kautman, leg. et det. I. and V. Kautman BRA CR 8520, BRA CR 8521, BRA CR 8522, PVK 137, 138, 140, 141, 142, 144, 145 146.

Herbarium collections

Czech Republic: Sušice (Schuschitz) near Chrudim, leg. et det. Peyl as *C. capitata*, rev. J. Holec as *C. longisegmentis* PRM 169286, PRM 169278. – Kačina, 1844 leg. et det. Peyl as *C. capitata*, rev. J. Holec as *C. longisegmentis* PRM 169284, PRM 169285. – Čáslav, 1854, leg. et det. Veselský as *C. capitata*, rev. J. Holec as *C. longisegmentis* PRM 169290. – Hranice, Uhřínov (Mähr. Weiskirchen: Ungersdorf), on *Elaphomyces* sp., Sept. 1921, leg. F. Petrak as *C. capitata* W 24300. – Žarošice, mixed broadleaved forest dominated by *Quercus*, on *Elaphomyces*, Sept. 1940, leg. et det. V. Vacek as *C. capitata*, rev. J. Holec as *C. longisegmentis* PRM 169289. – Šumava, Bohemian Forest, Povydří Protected Area, about 2.3 km SEE of Srní, alt. 850 m, in relict pine wood, on *Elaphomyces* sp. among mosses, 19 Sept. 1998, leg. et det. J. Holec PRM 897286. – Šumava, Bohemian forest, Povydří Protected Area, about 1.9 km NNE of Srní, in relict pine wood on stony ground with mosses, 9 Oct. 2000 leg. et det. J. Holec PRM 897871. – Bohemia, Mokré, 1km NW of Mokré, Mlázina, 7052a, *Pineto-Picetum* with *Quercus*, on *Elaphomyces granulatus*, 24 Sept. 1981, leg. J. Schneider, det. Z. Kluzák as *C. capitata* CB 3328, 20 Aug. 1989, leg. et det. J. Schneider as *C. capitata* CB 5645.

Poland: Pieniński National Park, PPN Kurnikovka, edge of the meadow, on *Elaphomyces* sp., without *Elaphomyces*, 20 Aug. 1970, leg. et det. Lagowska as *C. capitata* KRA 1970–308. – S Poland, vicinity of Tarnów, Lasy Radłowskie Nature Reserve, Tarnowa, 28 Aug. 2005, leg. et det. D. Karasiński PVDK 050828.

France: Bois de Thury-en-Valois, Sept. 1849, leg. et det. Abbé Questiér as *C. capitata* PC 0090815. – Natalios (Satory), Oct. 1853, as *Sphaeria capitata*, PC 0090831. – Chaville, on *Elaphomyces variegatus*, herb. Tulasne, as *Sphaeria capitata*, Aug. 1851, PC 0090825, PC 0090828; Aug. 1853, PC 0090830; Aug. 1860, PC 0090824. – Bois de Ville d'Avray, on *Elaphomyces variegatus* and *Elaphomyces asperulus*, Nov. 1906, leg. et det. Ludwig as *C. capitata* PC 0090821. – Fontainebleau, Oct. 1915, leg. et det. D. Joachim as *C. capitata* PC 0090827.

Germany: Zehlendorf near Berlin, on *Elaphomyces variegatus*, leg. et det. P. Sydow as *C. capitatus*, Oct. 1881 W 356174; Sept. 1882 W 9, PC 0090829; Oct. 1891, W 2449, WU 2950, BP 71668; Sept. 1892, BP 71667; 25 Sept. 1896 BRA CR4861. – Brandenburg, Königl. Forst Grünauer h. Rathenaur, in mosses under spruce on *Elaphomyces cervinus*, 1912, W. B. (herb Petrak), as *C. capitata* W 1753. – Bayern, Bayer. Alpen, South Bayern, Regensburg, Bayer. Wald, in spruce forest, Jura, Offenbach/Main, Oct. 1939, leg. et det. S. Killermann as *C. capitata* M 0125525.

Denmark: Denmark, island Fyn, in forest, carpophore on *Elaphomyces cervinum*, 20 Sept. 1968, leg. F. Kotlaba, det. H. Dissing as *C. capitata*, rev. J. Holec as *C. longisegmentis* PRM 672023.

Ukraine: Kiev, 22 Sept. 1923, leg. G. Borysevicz as *Cordylia capitata*, BP 1721. – Kiev, Brovary, parasitizing on *Elaphomyces cervinus*, 1 Oct. 1925, leg. V. Bondartseva, det. Monteverde as *C. capitata* W 19789.

Lithuania: Primitz, Kr. Oppek, Oct. 1877, leg. Silwebel as *C. capitatus* W 365873.

United States: on *Elaphomyces*, Nov. 1903, leg. S. Mast as *C. capitata* W 15476. – Eastern Tennessee, Burbank, parasitizing on *Elaphomyces* sp., alt. 1100 m, 20 Aug.–5 Sept. 1887, leg. et det. R. Thaxter as *C. capitata* BRA CR4857, W 13964.

RESULTS AND DISCUSSION

ECOLOGY

The first find of *Cordyceps rouxii* in Slovakia was made by Filarszky in 1910 near Iglófüred, now Novoveská Huta, in Eastern Slovakia. No other characteristics of the habitat are available. In 1982 Hagara found the species in Bystrička at Malá Fatra Mts. In 2004–2006 it was recorded by the present authors at three localities in Central and Northern Slovakia (Mačie diery, Michalovo, Zábava). In 2004 it was collected also by Červenka and Deckerová at Blatná valley, situated ca. 2 km from the locality Mačie diery, and the following year Líška (2005) published picture of *Cordyceps* found at the locality Lazisko near Liptovský Mikuláš. He did not collect the specimen, but the picture was undoubtedly *C. rouxii*. In 2006 Deckerová collected the species at Kráľova hoľa in the Nízke Tatry Mts.

Type specimens were collected in beech (*Fagus*) forests (Candoussau 1976). This was confirmed by Polish records (Karasiński 2005). However, all of the recorded specimens of *C. rouxii* in Slovakia were found in spruce *(Picea abies)* forest, sometimes with admixture of other trees (*Pinus sylvestris*, *Abies alba*, *Acer pseudoplatanus*, *Sorbus aria* and *Betula* sp.), most of them were waterlogged

spruce woods of the association Eu-Vaccinio-Piceenion (Michalko et al. 1986). The undergrowth of these forests was species poor, often dominated by *Vaccinium myrtillus*. Occurrence of mosses, mainly *Plagiothecium undulatum*, *Dicranum scoparium* and *Plagiomnium* sp. is characteristic, although carpophores of *Cordyceps* were frequently observed also in bare soil covered only by a layer of spruce needles. The bedrock was mostly made up of limestone, the soil was acid. Most of the localities were situated within protected areas and although the forests were often strongly influenced by human activities, they retained their semi-natural character.

In the Czech Republic *C. rouxii* was collected for the first time in 1927 by Hilitzer in the Šumava Mts., later in 1948 by Kubička in the Jičínská pahorkatina highlands and more recently in 1998 by Holec at Cikánská slať in the Šumava Mts. and in 1999 by Antonín in the Žďárské vrchy. Fellner (2004) published a find of *Cordyceps*, later identified by authors as *C. rouxii*, from Farské bažiny at Český les and Kautmanová found it in 2004 at Malá niva in Šumava. Although it is not possible to characterize historical sites, it seems that most of the Czech localities are also wet or waterlogged. Cikánská slať, Malá niva and Farské bažiny nature reserves are peat bogs overgrown by native forest with spruce, pine and birch, surrounded by spruce forest with undergrowth of *Vaccinium myrtillus*.

All of the localities visited by the authors were situated near springs, streams or were simply moist. *C. rouxii* did not grow directly in these wet places, but in their vicinity, often together with *C. ophioglossoides*. We noticed that *C. rouxii* preferred small elevations while *C. ophioglossoides* grew in depressions; they were never very close to each other.

Carpophores of *C. rouxii* were long lasting, the same specimens were observed at Mačie diery from July 22 untill Sept. 18, 2005. The fruiting period of the species is still longer – at the time of our first visit at the end of July 2005 we recorded several old carpophores with mature perithecia. At the end of September most of the carpophores were old, however some young and immature ones were also observed. Studied herbarium specimens were dated from June 22 in 1975 (France – type material) to Oct. 9 in 1998 (Czech Republic). The earliest record is probably from Poland (Pszonka 2006), where this species was presented at an exhibition on June 22, 2006, which means it must have been collected earlier. *C. capitata* and *C. longisegmentis* probably fructify later. Studied herbarium specimens were labelled from Aug. 9 in 1940 to Nov. in 1906 (*C. longisegmentis*) and from Aug. in 1909 to Dec. 1877 (*C. capitata*). We recorded *C. longisegmentis* from Sept. 9 in 1998 to Nov. 2 in 2000 and *C. capitata* from Sept. 16 to Oct. 21 in 2006.

C. rouxii probably prefers higher altitudes. According to accessible data from Europe it occurs from 630 m to 1150 m above sea level. The distribution of *C. capitata* is similar, *C. longisegmentis* probably prefers lowland forests at alti-

tudes about 200 m (Denmark, Germany, Ukraine, Slovakia), although some Slovak, Czech and American localities are situated higher.

MACROCHARACTERS

Fruitbodies of *C. rouxii* grew solitarily or in clusters (up to 9) directly from the *Elaphomyces* ascocarps buried 2–7 cm in soil (Fig. 2). A find of *C. rouxii* with a stroma length of 16 cm, without reaching *Elaphomyces* (Holec, PRM 897594) was exceptional, as well as our find of *Cordyceps* growing from *Elaphomyces* only half-buried in the soil (collection from Zábava hill, 2006). Although the stipes grew directly from *Elaphomyces*, they were often twisted, especially at the base, pointing to various directions underground, bearing young, pure white, immature stromata (Figs. 1, 3). In dry conditions, when the soil was hard, we found fruitbodies of *C. rouxii* growing almost completely underground, only one or two from the cluster protruded the soil surface and were short, resembling the type specimens.

From the closely related species *C. capitata* and C. *longisegmentis* with straight stipes, *C. rouxii* differs by more delicate and fragile stromata (especially in underground parts), with stipes contorted and often very long (Fig. 1, 3, 4, 5). Kobayashi and Shimizu (1960) and Candoussau (1976) put these three species into the section *Directae* growing directly from *Elaphomyces*, differing from the section *Rhizomatae* attached to *Elaphomyces* sometimes as much as 20 cm deep by rhizomorphs (e.g. *C. ophioglossoides*).

In older descriptions of *C. capitata* (Mains 1957, Kobayashi and Shimizu 1960) characters typical for *C. rouxii* are often mentioned, as this species was not separated. Therefore sometimes it is not easy to tell what a "typical" *C. capitata* is. However Ginns (1988) used a specimen from Mougeot´s series 763 as a neotype and we used another specimen of the same series as a voucher specimen. Also specimens treated for DNA sequences (Stensrud et al. 2005) fit well to Ginns' description (Fig. 4). Typical *C. capitata* is described and depicted also in Dennis (1968), Breitenbach and Kränzlin (1981), Kovaľ (1984) and Imazeki et al. (1988).

One of the most conspicuous characters separating *C. rouxii* from the other two species is the colour of the stroma, which is dark grey or almost black at the head, fading to olive grey at the stipe, and pure white underground, lacking yellow colouring (Figs. 1, 3). Candoussau (1976) described the cap as brown-black, brilliant and viscid and the stipe grey to olive. Macrocharacters of *C. capitata* and *C. longisegmentis* are almost identical: the fertile head is natal-brown or olive-brown and the stipe orange-yellow, ochre-yellow to olive-buff. Yellow and brown colours are visible also on dried specimens. The shape of the head is oblong, hood-like, protruding to the stem (Ginns 1988) (Figs. 4, 5). In *C. rouxii* the fertile

Fig. 1. Variability of *Cordyceps rouxii*, collection from the locality Mačie diery, 19 Aug. 2005. (Photo: J. Kautman)

Fig. 2. Cluster of 9 carpophores of *Cordyceps rouxii* growing from one *Elaphomyces*, locality Mačie diery, PVK 107. (Photo: I. Kautmanová)

Fig. 3. Carpophores of *Cordyceps rouxii* often grow underground and remain white, PVK 111. (Photo: I. Kautmanová)

Fig. 4. Typical specimen of *Cordyceps capitata* from Norway. (Photo: Ø. Stensrud)

Fig. 5. *Cordyceps capitata* from Horná Tižina in Northern Slovakia, PVK 173. (Photo: V. Kautman)

part of the stroma is globose to flattened, involuted and distinctively separated from the stipe (Fig. 1, 2).

Fruitbodies of *Elaphomyces* are filled with white mycelium of *C. rouxii* protruding through crevices to the vivid orange surface (Fig. 1). The white colour of the mycelium persists also in dry state. Fruitbodies of *Elaphomyces* parasitized by *C. capitata* and *C. longisegmentis* are filled with mycelium of yellow-brown colour, which darkens after drying. The variability of *C. rouxii* is shown on Fig. 1.

MICROCHARACTERS

Kobayashi and Shimizu (1960) divided *Cordyceps* species growing on *Elaphomyces* into two groups according to the tissue structure of the cortical layer of the fertile part. The cortex of the type specimen of *C. rouxii* was "dark and pseudoparenchymatous, covered with a paler superficial layer ca. 20 µm thick, clearly differentiated" (Candoussau 1976); typical of the *Valliformes* group of Kobayashi and Shimizu (1960). This character is common for *C. longisegmentis* and *C. rouxii*, their stromal epidermis (outer part of the cortex) is made up of short parallel hyphae palissade-like in section. In *C. longisegmentis* it is rather conspicuous and clearly visible, in *C. rouxii* it is not so obvious, but it could be observed as a distinct pale band over the darker inner layer (Fig. 6). The cortex of *C. capitata* consists of interwoven pseudoparenchymatous hyphae showing no palissade-like structure (Mains 1957, Ginns 1988) and Kobayashi and Shimizu (1960) put it into the group of *Evalliformes*. Combination of short ascospore parts of average length 17–22 µm and palisade-like epidermis is therefore a good character separating *C. rouxii* from *C. capitata* and *C. longisegmentis*.

Ascospore segments of *C. rouxii* are cylindrical, thin-walled, very similar to those of *C. capitata*, only pictures taken by electron microscope show that they are more spindle-like than the latter ones (Figs. 9, 10). Candoussau (1976) in the type description of *C. rouxii* indicated that ascospore parts measured (13–)16(–21) × 2.5–3 µm, which is in correspondence with our observations. However, we frequently observed very long (up to 42 µm) segments besides the "normal" ones of the average length of about 17–22 µm. The number of ascospore segments is 16 (Fig. 11), the same as in *C. capitata* according to Stensrud et al. (2005). In some cases, however, the two neighbouring segments do not divide and the result is a segment of doubled length (32–42 µm) and lowered number of segments. We have even observed several ascospores with only 8 segments of doubled lengths. The total lengths of ascospores remained unchanged (Figs. 12, 13). We have never observed this character in *C. capitata*. Candoussau (1976) did not mention it, but this could be caused by the fact that she had only 3 specimens (coll. 1974, 1975 and 1976) at her disposal and this character is best visible on

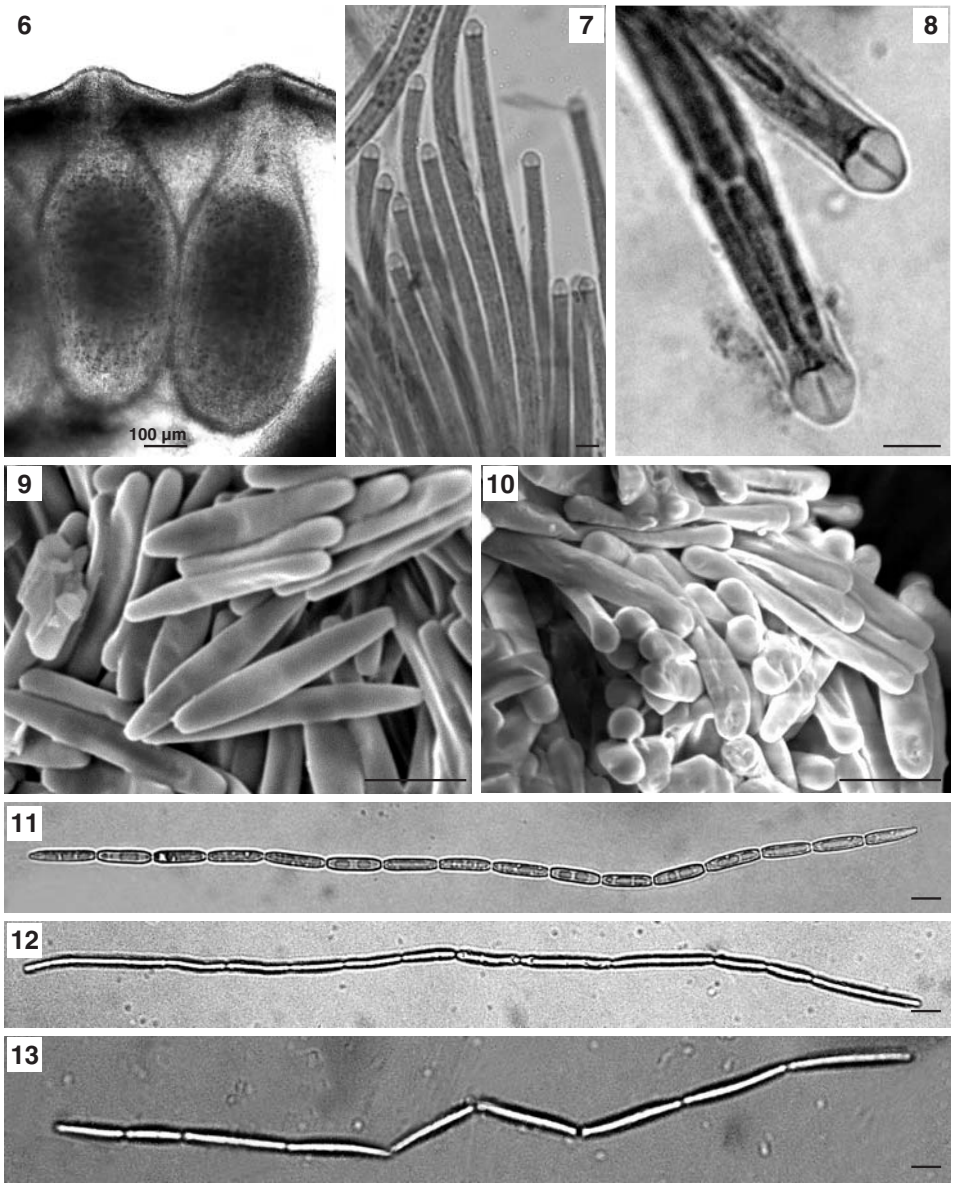

Fig. 6. Perithecia of *Cordyceps rouxii*, BRA CR8028 – epitype.
Fig. 7, 8. Asci of *Cordyceps rouxii* with distinct ascoapical apparatus, BRA CR8028 – epitype.
Fig. 9. Spore segments of *Cordyceps rouxii*, BRA CR8031.
Fig. 10. Spore segments of *Cordyceps capitata*, BRA CR8180.
Fig. 11. Normal spore of *Cordyceps rouxii* breaking to 16 segments, BRA CR8179.
Fig. 12, 13. Spores of *Cordyceps rouxii* with non-divided segments of doubled length, BRA CR8179. Bar = 10 µm

well-developed mature stromata. We have revised the holotype and two paratype specimens from the Plant Pathology Herbarium at the Cornell University. The holotype (CUP 54937) is macroscopically most typical, but it is almost immature specimen with only a few differentiated ascospore segments that could be measured 15–19(28) × 2–3 µm long. The first recorded specimen (CUP 54948) collected by Guy Roux in July 1974 consisted of two young, not well developed carpophores, and originally was described as *C. japonica* (Candoussau 1975). No mature ascospores were observed. Only the paratype (CUP 54948) has well developed asci with ascospores breaking into segments 15–20(28) × 2–3 *µm*, however the specimen contains only a fragment of one carpophore and macrocharacters are not obvious. Therefore we designate an epitype here.

Stensrud et al. (2005) analysed ITS nrDNA sequence data of 72 taxa of *Cordyceps* and related genera, amongst others also 4 specimens of *C. capitata*, 1 specimen of *C. longisegmentis* and 2 specimens of *Cordyceps* sp. (No. 3002, 3083). In their analyses these three species branched off basally to the rest of the taxa in subclade IV-J (70 % bootstrap support) showing *Cordyceps* sp. as a well-defined separate species closely related to *C. capitata*. Later we checked spec. no. N 3002 and N 3083 and identified them as *C. rouxii*, species new to Norway.

EPITYPE

Slovakia, Západné Tatry Mts., Zuberec, "Mačie diery" Nature Reserve, alt. 1100 m, 22 July 2005, I. Kautmanová and V. Kautman (BRA CR8028), designated here.

Holotype: CUP 54937, France, Pyrénées Atlantiques, Région Pau, Bois de Haouquère near Plas des Asphodèles, July 3, 1976, leg. G. Roux, det. F. Candoussau. (Candoussau 1976).

Epitype: Stromata growing in clusters of 2–3 in various stages of development, or solitarily, from ascocarps of *Elaphomyces* sp. buried 4–6 cm in soil. Stromata 4–8 cm high, with long and thin stipitate part and upper globose to subglobose fertile part. Fertile part 0.5–1 cm in diameter, folded and distinctively separated from the stipe, shiny and slightly viscid when fresh and wet, greyish-black, sometimes with bluish tinge in old, or olivaceous to olivaceous-brown in young fruitbodies. Fertile parts of old specimens powdered with white spore dust. Surface verrucose by the ostioles of the perithecia. Ostioles often fused, forming mounds. Stipe 4–6 × 0.3–0.5 cm, cylindrical, contorted at the base, longitudinally striate and finely granulose, ash-grey to dark grey in upper part, in young specimens sometimes with olive tinge, fading to pure white at the basal underground part growing out from *Elaphomyces*. Part of the stipe emerging from *Elaphomyces* fragile, thin and densely contorted, with white mycelial cords. If more fruitbodies of *Cordyceps* growing from a single *Elaphomyces*, stipes some-

times fused together. On underground parts of mature fruitbodies develop young ones which are pure white, sometimes greyish white. Ascocarps of *Elaphomyces* outgrown by white mycelium of *Cordyceps* in older specimens broken down, so that only remnants of outer peridium can be observed. Surface of *Elaphomyces* ascocarps often vividly orange contrasting with the white mycelium filling the inner part of the fungus.

Cortical layer of the fertile part 25–30 µm thick, brown to black, covered with pale gelatinous substance. Outer part of the cortex made up of short palisade-like parallel hyphae c. 10 µm long. Perithecia with ostiolum embedded, ellipsoid to ovoid, (550–)600–750 × 200–300(–380) µm (Fig. 6). Asci cylindrical, (300–)350–500 × 8–10(–15) µm, thin-walled, non-amyloid, with distinct, non-refractive ascoapical apparatus (Figs. 7, 8). Ascospores are smooth, filiform, narrow, multiseptate, in maturity breaking to segments (12–)15–20(–24) × 2–3 µm (terminal parts distinctly shorter than others), cylindrical, slightly tapered at the ends. Occasional occurrence of very long (twice the normal length) segments is rather typical (Figs. 11, 12, 13). Content granulose when young, homogenous in maturity.

CONCLUSIONS

Though *Cordyceps rouxii* was described in 1976, it was not reported until 1994 (Mornard 1994) and later only occasionally from France (Hertzog 2001, 2005), Poland (Karasiński 2004) and Belgium (Ghyselinck 2002). This was probably caused by the fact that the type specimens described and depicted by Candoussau (1976) were immature and not very typical in macrocharacters. Moreover, microcharacters separating this taxon from *C. capitata* are not very distinctive, unless a very large collection is available.

Until the second half of the 20th century *C. capitata* was the only known representative of capitate *Cordyceps* species growing on *Elaphomyces* in Europe (*C. ophioglossoides* being clavate). Maas Geesteranus (1963) revised many European collections of this species and assigned those with long and broad segments to *C. canadensis* as recognized by Mains (1957) from North American collections. Later Ginns (1988) lectotypified this name in agreement with its protologue as a synonym of *C. capitata* and ascribed collections with very long ascospore parts (up to 40–60 µm) to the new species *C. longisegmentis*. Already Maas Geesteranus (1963) and Læssøe (1982) stated that *C. canadensis* (i.e. *C. longisegmentis* in their concept) was more common in Europe than *C. capitata* itself. This was later confirmed also by Holec (2001) and Holec and Suková (2002), as well as by our observations.

Holec (2001) and later Holec and Suková (2002) published finds of *C. capitata* from the Bohemian Forest in the Czech Republic in 1998 (PRM 897594). In both

articles they described the stipe as being very long (up to 18 cm without fruitbodies of *Elaphomyces* being observed), the upper part greyish-yellowish and underground part white and segments (15–)17–20(–23) µm long. After revising this specimen we realized that it was *C. rouxii*, as well as other two specimens labelled as *C. capitata* and *C.* sp., held at PRM. This means that probably only two collections of *C. capitata* from the Czech Republic exist at present (BRNM 130261, BRNM 224238). Kautmanová (1998) described the find of *C. capitata* from Slovakia (BRA CR3124) which was later revised by Holec as *C. longisegmentis*, what means that there was no record of *C. capitata* from Slovakia until September 2006, when the numerous populations of *C. capitata* were recorded at three localities in Kysuce and Orava regions.

Besides 90 specimens from our own collections we have studied 114 herbarium specimens of capitate *Cordyceps* species growing on *Elaphomyces*. Out of 98 herbarium specimens labelled as *C. capitata* 26 were in fact *C. rouxii* and 37 of them were *C. longisegmentis*. Only 35 were *C. capitata*. That means that there is an urgent need to revise all *C. capitata* specimens held in herbaria not only in Europe.

However, the problems of *C. capitata* group are still not solved and although Ginns (1988) stated that "...in some *C. capitata* stromata most spore segments were 15–20, in others they were 20–27 and in still others 17–24. When a number of stromata are examined the segment length form an overlapping series and to me represent one species." this may not be true. We have observed similar differences in *C. longisegmentis*, where the ascospore parts were from 26–35 µm to 41–83 µm long.

Candoussau (1979) and Ghyselinck (2002) reported *C. intermedia* from France and *C. japonica* from Austria. Future research may reveal also some new *Cordyceps* species growing on *Elaphomyces* in Europe.

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