

***Ambispora gerdemannii* and *Glomus badium*,  
two species of arbuscular fungi (Glomeromycota)  
new for Europe and Poland, respectively**

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Morphological characters of spores, as well as sporocarps and spores of *Ambispora gerdemannii* and *Glomus badium*, respectively, arbuscular fungi of the phylum Glomeromycota, are described and illustrated. Additionally, the known distribution of these species in both Poland and the other regions of the world is presented. *Ambispora gerdemannii* was not earlier reported from Europe, and *G. badium* is a new fungus for Poland.

**Key words:** Glomeromycota, occurrence, distribution

## INTRODUCTION

Analysis of collections of arbuscular-mycorrhizal fungi made over the last 27 years in Poland and other regions of the world included two unrecorded species, i. e., *Ambispora gerdemannii* (S.L. Rose, B.A. Daniels et Trappe) Spain, Oehl et Sieverd. and *Glomus badium* Oehl, Redecker et Sieverd. The former fungus has not so far been reported from Europe, and the latter species has not been reported to occur in Poland to date.

The aims of this paper are to describe and illustrate these species and present their distribution in both Poland and the world.

## MATERIALS AND METHODS

The methods of collection of soil samples, establishment of trap and one-species cultures, growth conditions, isolation and preparation of spores and the determination of properties of their subcellular structure, as well as the terminology of spore structure and colours, the nomenclature of plants and fungi, and the authors of the fungal names used are as those presented previously (Błaszowski, Czerniawska 2005). Microphotographs were recorded on a Sony 3CDD color video camera coupled to an Olympus BX 50 compound microscope equipped with Nomarski differential interference contrast optics.

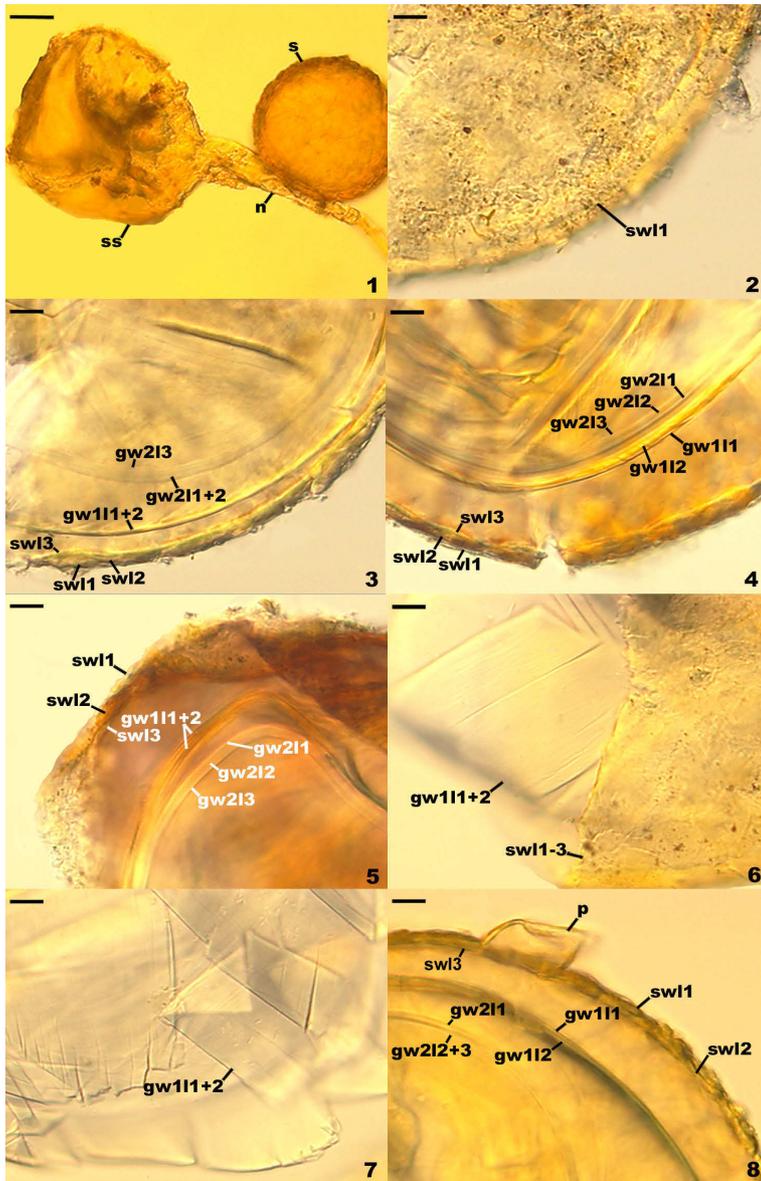
Voucher specimens were mounted in polyvinyl alcohol/lactic acid/glycerol (PVLG; Omar, Bollan and Heather 1979) and a mixture of PVLG and Melzer's reagent (1:1, v/v) on slides and deposited in the Department of Plant Pathology (DPP).

Colour microphotographs of spores of *Am. gerdemannii* and *G. badium* can be viewed at the URL <http://www.agro.ar.szczecin.pl/~jblaszkowski/>.

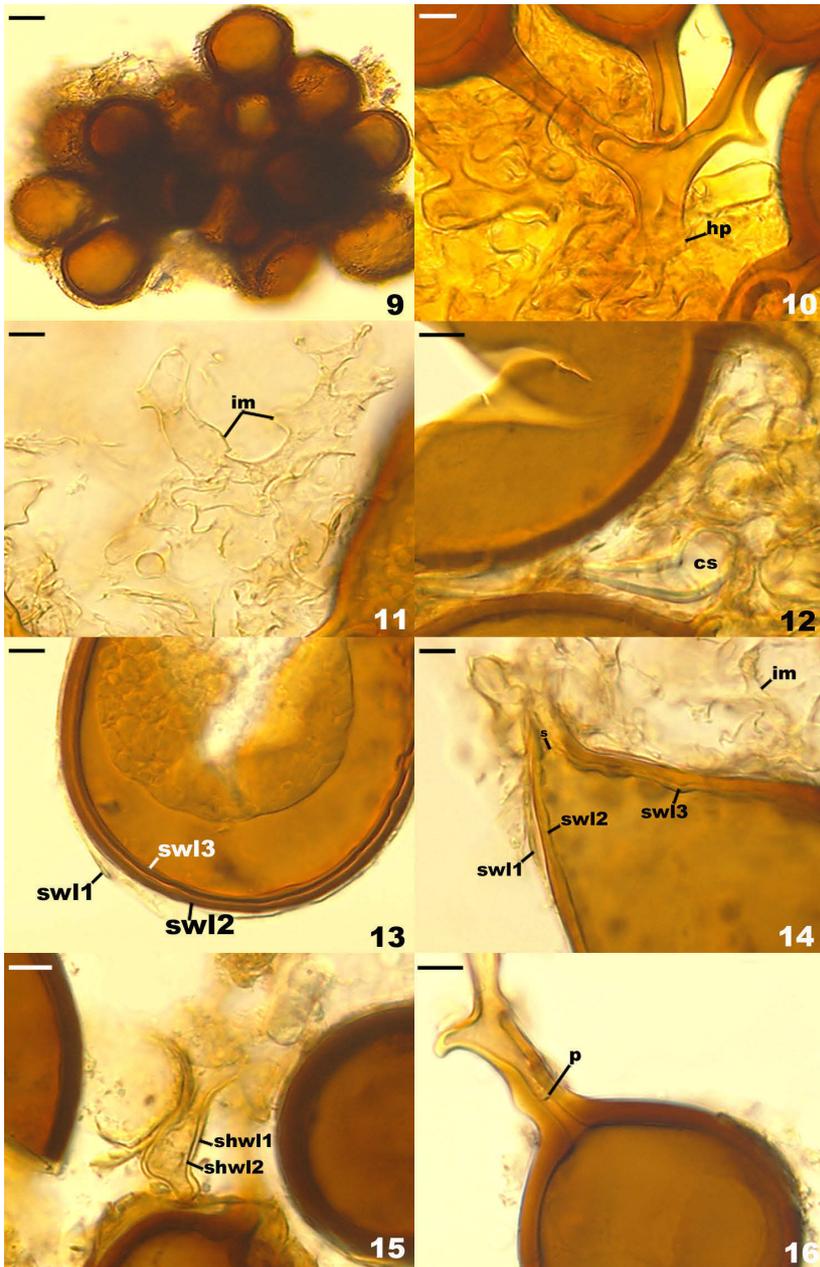
## DESCRIPTIONS OF THE SPECIES

*Ambispora gerdemannii* (S.L. Rose, B.A. Daniels et Trappe) C. Walker, Vestberg et Schuessler

Spores formed singly in the soil; arise blastically at the tip of a hyphal branch (pedicel) on the neck of a sporiferous saccule (Figs 1 and 8). *Spores* pale yellow (4A3) to maize yellow (4A6), globose to subglobose, (150-)210(-250)  $\mu\text{m}$  diam, sometimes ovoid, 150-190  $\times$  210-250  $\mu\text{m}$ . *Subcellular structure of spores* consists of a spore wall and two inner germination walls (Figs 3-6 and 8). *Spore wall* composed of three layers (layers 1-3). Layer 1, forming the spore surface, evanescent, pale yellow (4A3) to maize yellow (4A6), (1.7-)3.3(-5.6)  $\mu\text{m}$  thick when intact, usually with deep fissures due to sloughing with age (Figs 1 and 2). Layer 2 semi-flexible, smooth, hyaline (1.2-)2.5(-3.7)  $\mu\text{m}$  thick, continuous with the wall of the pedicel (Figs 3-6 and 8). Layer 3 flexible to semi-flexible, hyaline, 0.5-1.0  $\mu\text{m}$  thick, usually tightly adherent to the lower surface of layer 2 and, hence, difficult to see (Figs 3-5 and 8). *Germination wall 1* comprises two fragile, smooth, hyaline layers (layers 1 and 2), (0.5-)1.1(-1.6)  $\mu\text{m}$  and (0.6-)1.4(-2.1)  $\mu\text{m}$  thick, respectively, usually tightly adherent to one another and readily cracking to form line slits or polygonal pieces in crushed spores (Figs 3-8). *Germination wall 2* consists of three smooth, hyaline layers (layers 1-3; Figs 3-5 and 8). Layer 1 flexible to semi-flexible, 0.5-0.8  $\mu\text{m}$  thick, always tightly adherent to layer 2 and, thereby, very difficult to observe (Figs 3-5). Layer 2 semi-flexible, finely laminate, hyaline, (1.7-)2.8(-4.1)  $\mu\text{m}$  thick (Figs 3-5 and 8). Layer 3 flexible to semi-flexible, 0.5-0.8  $\mu\text{m}$  thick (Figs 3-5), rarely separating from layer 2. In Melzer's reagent, only spore wall layer 1 stains orange (6A6) to pastel red (8C5; Fig. 5). *Pedicel* 10-15  $\mu\text{m}$  long, 15-27  $\mu\text{m}$  wide at the spore base, positioned 80-120  $\mu\text{m}$  from the base of the sporiferous saccule, consisting of a hyaline wall continuous with the wall of the saccule neck, the spore wall, and layer 1 of germination wall 1 (Fig. 8). *Sporiferous saccule* hyaline to yellowish white (4A2), globose to subglobose, (185-)200(-275)  $\mu\text{m}$



Figs 1-8. *Ambispora gerdemannii*. 1. Spore (sp) associated with the neck (n) of sporiferous sacculus (ss). 2. Partly deteriorated spore wall layer 1 (sw1). 3-5. Spore wall layers 1-3 (sw1-3), layers 1 and 2 of germination wall 1 (gw111+2), and layers 1-3 of germination wall 2 (gw211-3). 6. Spore wall layers 1-3 (sw1-3) and layers 1 and 2 of germination wall 1 (gw111+2) with line splits in slightly crushed spore. 7. Disintegrated layers 1 and 2 of germination wall 1 (gw111+2) in vigorously crushed spore. 8. Spore wall layers 1-3 (sw1-3), layers 1 and 2 of germination wall 1 (gw111+2), layers 1-3 of germination wall 2 (gw211-3), and pedicel (p) with a wall continuous with spore wall layer 2. Fig. 1, spore in lactic acid. Figs 2-4 and 6-8, spores crushed in PVLG. Fig. 5, spore crushed in PVLG+Melzer's reagent. Fig. 1, bright field microscopy; Figs 2-8, differential interference contrast. Scale bars for Fig. 1=50  $\mu$ m, for Figs 2-8=10  $\mu$ m.



Figs 9-16. *Glomus badium*. 9. Sporocarp. 10. Hyphal plexus (hp). 11. Interspore mycelium (im). 12. Cystidium-like structure (cs). 13. Spore wall layers 1-3 (swl1-3). 14. Spore wall layers 1-3 and interspore mycelium (im); septum (s) of the subtending hypha formed by spore wall layer 3 is indicated. 15. Subtending hyphal wall layers 1 and 2 (shwl-2). 16. Plug (p) in the lumen of subtending hypha. Figs 9 and 11-16, spores crushed in PVLG. Fig. 10, spore crushed in PVLG+Melzer's reagent. Figs 9-16, differential interference contrast. Scale bars for Fig. 9=20  $\mu$ m, for Figs 10-16=10  $\mu$ m.

diam, occasionally ovoid, 160-200 × 210-260 µm, formed at the end of a funnel-shaped neck (Fig. 1). *Wall of sporiferous saccule* semi-flexible, semi-permanent, hyaline to yellowish white (4A2), 3.5-8.8 µm thick, smooth in young specimens, roughened because of a patchy sloughing of its outer surface, composed of two to three tightly adherent layers, usually difficult to observe. *Sacculi neck* hyaline to yellowish white (4A2), 200-250 µm long, 30-45 µm wide at the base of the saccule, 20-25 µm wide at the spore base, then gradually tapering up to 8-10 µm wide.

COLLECTIONS EXAMINED. Poland. Przelewiec (53°06'N, 15°05'E), under *Thuja occidentalis* L., 29 Sept. 1989, *Błaszowski J. 1722 and 1783-1801* (DPP); Truskaw (52°18'N, 20°46'E), from the root zone of *Juni-perus communis* L., 9 Aug. 1990, *Błaszowski J. 1802-1804* (DPP); Irzciel (52°22'N, 15°52'E), among roots of *Equisetum arvense* L., 13 Aug. 2004, *Błaszowski J. 1805-1806* (DPP); Romanówek (52°17'N, 15°22'E), from under *Achillea millefolium* L. and *Hypericum perforatum* L., 13 Aug. 2004, *Błasz. J., s.n.* (DPP); Lubrza (52°18'N, 15°27'E), under *H. perforatum*, 13 Aug. 2004, *Błasz. J. s.n.* (DPP); Tatra Mountains, among roots of *Campanula polymorpha* Witasek, *Cardaminopsis neglecta* (Schul.) Hayek, *Cerastium tatrae* Borbás, *Knautia kitaibelii* (Schult.) Borbás, *Leucanthemum waldsteinii* (Sch. Bip.) Pouzar, *Melampyrum herbichii* Woł., *Sesleria tatrae* (Degen) Deyl, and *Thymus* sp., *Błaszowski J. 2634-2643* (DPP).

DISTRIBUTION AND HABITAT. In Poland, spores of *Ambispora gerdemannii* were found in 19 samples of roots and rhizosphere soils of 14 species of uncultivated plants. None of the almost 1500 root and soil mixtures coming from cultivated sites of Poland contained spores of this fungus.

The average abundance of *Am. gerdemannii* spores in the samples examined was 4.7 and ranged from 1 to 29 in 100 g dry soil. The proportion of spores of this species in spore populations of all the arbuscular fungi recovered averaged 11.8% in a range of 2.1-66.7%. The average abundance of species of arbuscular fungi in samples in which spores of *Am. gerdemannii* occurred was 2.7 and ranged from 1 to 6 in 100 g dry soil.

The arbuscular fungi accompanying *Am. gerdemannii* in the field were *Acaulospora bireticulata* F.M. Rothwell et Trappe, *A. capsicula* Błasz., *A. koskei* Błasz., *A. lacunosa* J.B. Morton, *A. paulinae* Błasz., *Ar. trappei* (R.N. Ames et Linderman) J.B. Morton et D. Redecker, *Entrophospora infrequens* (I.R. Hall) R.N. Ames et R.W. Schneid., *G. caledonium* (Nicol. et Gerd.) Trappe et Gerd., *G. claroideum* N.C. Schenck et S.M. Sm., *G. constrictum* Trappe, *G. deserticola* Trappe, Bloss et J.A. Menge, *G. ? etunicatum* W.N. Becker et Gerd., *G. fasciculatum* (Thaxt.) Gerd. et Trappe emend. C. Walker et Koske, *G. geosporum* (Nicol. et Gerd.) C. Walker, *G. macrocarpum* Tul. et C. Tul., *G. mosseae* (Nicol. et Gerd.) Gerd. et Trappe, *G. pansihalos* S.M. Berch et Koske, an unrecognized *Glomus* sp., *Pacispora scintillans* (S.L. Rose et Trappe) Sieverd. et Oehl, *Scutellospora dipurpurescens* J.B. Morton et Koske, and *S. pellucida* (Nicol. et N.C. Schenck) C. Walker et F.E. Sanders.

Although *Am. gerdemannii* probably has a worldwide distribution, this species has been infrequently reported. Most reports of *Am. gerdemannii* come from the United States of America (Allen, MacMahon 1985; An et al. 1990, 1993; An, Guo and Hendrix 1993a; An, Quo and Hendrix 1993b; Bever et al. 1996; Koske, Gemma and Jackson 1977; Nicolson, Schenck 1979; Rose, Daniels and Trappe 1979). Additionally, spores of this fungus have been isolated in Brazil (Moreira-Souza et al. 2003), Colombia (Dodd et al. 1990), and Australia (Morton, Redecker 2001). In southern Poland, Turnau et al. (2001) recovered spores of a morphotype named *Glomus* sp. HM-CL4 of molecular properties close (71%) to those of *G. gerdemannii*, the basionym of *Am. gerdemannii* (Walker et al. 2007). However, the authors did

not show any morphological characters of the spores isolated and did not determine which of the two morphotypes of this fungus was found.

MYCORRHIZAL ASSOCIATIONS. Spores of *Am. gerdemannii* occurred among vesicular-arbuscular mycorrhizal roots of the plant species listed in the section “*Collection examined*”. Additionally, they were recovered from some trap cultures established from mixtures of roots and rhizosphere soils of these plants and with *P. lanceolata* as the plant host. Unfortunately, many attempts to produce one-species cultures of *Am. gerdemannii* failed.

According to Morton (2002) and Morton & Redecker (2001), mycorrhizae of *Am. gerdemannii* consisted of only arbuscules and intraradical hyphae; no vesicles were found. All the structures were patchily distributed along roots and stained weakly or not at all in trypan blue. Percentage mycorrhizal colonization always was very low, below 10%.

NOTES. *Ambispora gerdemannii* has originally been described as *Glomus gerdemannii* S.L. Rose, B.A. Daniels et Trappe from spores isolated from soils of Cascade Range and Siskiyou Mountains of Oregon, USA (Rose et al. 1979). Spain et al. (2006) transferred *G. gerdemannii* to the genus *Appendicispora* Spain, Oehl et Sieverd. gen. nov., and Walker et al. (2007) to the genus *Ambispora* C. Walker, Vestberg et Schuessler gen. nov. in the newly erected family *Ambisporaceae* C. Walker, Vestberg et Schuessler. The genus *Appendicispora* has been excluded because a nomenclatural error (Walker et al. 2007).

The distinctive morphological properties of *Am. gerdemannii* are the fragile bilayered inner wall 1 and the mode of differentiation of spores of this fungus. Additionally, *Am. gerdemannii* is a dimorphic fungus producing two morphotypes, acaulosporoid (as in *Acaulospora* spp.) and glomoid (as in *Glomus* spp.), a phenomenon rarely occurring in other species of arbuscular fungi.

Inner wall 1 of *Am. gerdemannii* resembles a hardened glass. In slightly crushed spores, linear cracks appear on the surface of this wall. However, in spores vigorously crushed, this wall almost always breaks into small pieces. Another characteristic of this wall is its glittering when seen in a polarized light.

When observed under a dissecting microscope, *Am. gerdemannii* spores may easily be confused with those of *A. spinosa*, *A. thomii*, *Am. appendicula* and *Am. fennica*. All the fungi form yellow brown and dull spores of a similar size range.

Spores of *Am. appendicula*, *Am. fennica*, and *Am. gerdemannii* differ mainly in the properties of layers of inner wall 1. In the latter two species, both layers of this wall are smooth on both sides (Spain et al. 2006; Walker et al. 2007). In contrast, in the former fungus, the lower surface of layer 1 is ornamented with hemispherical protuberances, which impress hemispherical concave depressions on the upper surface of layer 2 during its differentiation (Morton, Redecker 2001; Spain et al. 2006). Additionally, in vigorously crushed spores, inner wall 1 of *Am. fennica* and *Am. gerdemannii* usually disintegrates, and that of *Am. appendicula* remains its integrity. As concluded above (see comments on *Am. fennica*), *Am. fennica* and *Am. gerdemannii* probably are congeneric.

The subcellular structure readily separating *Am. gerdemannii* from *A. spinosa* and *A. thomii* is the beaded outer layer and the flexible to plastic, dextrinoid inner layer present in the innermost wall of spores of the latter two species (vs. no such structures have been found in spores of *Ambispora* spp.). Additionally, in *Am.*

*gerdemannii* the sporiferous saccule wall is continuous with spore wall layers 1–3 and layer 1 of inner wall 1, whereas in all known *Acaulospora* spp. the sporiferous saccule wall is continuous with only spore wall layer 1. Finally, only *Am. gerdemannii* is a dimorphic fungus, forming both acaulosporioid and glomoid spores. The glomoid morphotype of *Am. gerdemannii* has not so far been found in Poland and the only report of its existence is that of Morton and Redecker (2001).

***Glomus badium*** Oehl, Redecker et Sieverd.

Spores occur in dense sporocarps in the soil (Fig. 9) and on the surface of vesicular-arbuscular mycorrhizal roots. *Sporocarps* brownish orange (6C8) to reddish brown (8E8), mainly ovoid to irregular, 200–500 × 290–680 µm (Fig. 9), sometimes globose to subglobose, (250–)298(–320) µm diam, with 4–43 spores, radially originating from a hyphal plexus (Fig. 10) and separated by an interspore mycelium (Figs 11 and 14) and occasionally by cystidium-like structures (Fig. 12). *Interspore mycelium* consists of tightly interwoven, straight or branched, hyaline to pale orange (5A3) hyphae, (2.2–)5.8(–12.3) µm wide, with a wall (0.5–)1.1(–1.5) µm thick (Figs 11 and 14). *Cystidium-like structures* icicle-like, hyaline, 32.1–39.5 µm long, 9.6–12.0 µm wide at the base, with a wall (1.8–)2.0(–2.3) µm thick (Fig. 12). Both the interspore mycelium and the cystidium-like structures branch out from the hyphal plexus. Inside sporocarps frequently with sand grains and soil debris.

Spores formed blastically at the tip of hyphae developing from a hyphal plexus positioned in the centre of sporocarps (Fig. 10). *Hyphal plexus* composed of thick-walled, 6.9–10.3 µm thick, two-layered hyphae: a hyaline, evanescent, 0.5–0.8 µm thick outer layer, usually highly deteriorated and difficult to see in mature spores and pale orange (5A3) to brownish orange (6C8), permanent, (1.2–)2.3(–3.4) µm thick inner layer (Fig. 12).

*Spores* brownish orange (6C8) to reddish brown (8E8), usually ovoid, 35–55 × 60–70 µm, rarely globose to subglobose, (35–)55(–65) µm, usually with one subtending hypha (Figs 9, 10 and 14–16), occasionally with two. *Subcellular spore structure* consists of a spore wall comprising three layers (layers 1–3; Figs 13 and 14). Layer 1 evanescent, hyaline to pale orange (5A3), (0.7–)2.0(–3.4) µm thick, frequently highly or completely sloughed in mature spores (Figs 13 and 14). Layer 2 laminate, brownish orange (6C8) to reddish brown (8E8), (3.7–)4.5(–6.9) µm thick (Figs 13 and 14). Layer 3 flexible, pale yellow (4A3) to light brown (6D8), (0.5)1.7(–2.0) µm thick, usually tightly adherent to the lower surface of layer 2 (Figs 13 and 14). *Subtending hypha* brownish orange (6C8) to reddish brown (8E8), straight or recurved, cylindrical or slightly flared, rarely slightly constricted, (8.1–)9.5(–10.0) µm wide at the spore base (Figs 10, 15 and 16). Wall of subtending hypha brownish orange (6C8) to reddish brown (8E8), (2.9–)4.4(–7.4) µm thick at the spore base, continuous with spore wall layers 1 and 2 (Fig. 15). *Pore* 1.0–1.7 µm wide at the spore base, occluded by spore wall layer 3 inserted in the lumen of the subtending hypha up to 14.0 µm below the spore base (Fig. 14) or/and by thickening of spore wall layer 2 and wall layer 2 of subtending hypha, in which a hyphal plug occasionally forms (Fig. 16).

COLLECTIONS EXAMINED. Poland. Szczecin (53°26'N, 14°35'E), under *Glycine max* (L.) Merr., 5 Sept. 1985, *Błaszowski J. 2644–2646* (DPP); Przelewice, among roots of *Malus × purpurea* Rehder, 16 July 1985, *Błaszowski J. 2647–2649* (DPP); Pomierzyn (53°20'N, 15°51'E), in the roots zone of *Lupinus luteus* L., 9 Aug. 1985, *Błaszowski J. 2650–2652* (DPP); Szczecin, in the rhizosphere soil of *Anthriscus sylvestris* (L.) Hoffm., 18 Oct. 1985, *Błaszowski J. 2653* (DPP); Kolbacz (53°18'N, 14°49'E), under *Trifolium pratense*

L., 4 Aug. 1985, *Błaszczkowski J. 2654-2655* (DPP); Szczecin, from under *Allium schoenoprasum* L., 3 Sept. 1985, *Błaszcz. J. s.n.* (DPP); Międzyzdroje (53°56'N, 14°26'E), among roots of *Avena sativa* L., 14 July 1985, *Błaszcz. J. s.n.* (DPP); Przelewiec, in the roots zone of *Acer palamatum* Thunb., 15 May 1985, *Błaszcz. J. s.n.* (DPP); Żelistrzewo (54°41'N, 18°27'E), under *Triticum aestivum* L., 24 Aug. 1985, *Błaszcz. J. s.n.* (DPP); Hel (54°36'N, 18°49'E), in the rhizosphere soil of *Thuja occidentalis*, 21 Aug. 1985, *Błaszcz. J. s.n.* (DPP); Jarosławki (53°32'N, 15°01'E), under *Zea mays* L., 25 July 1985, *Błaszcz. J. s.n.* (DPP); Żelistrzewo, among roots of *Ficaria verna* Huds., 3 April 1989, *Błaszcz. J. s.n.* (DPP); Hel, in the root zone of *T. occidentalis*, 28 Sept. 1988, *Błaszcz. J. s.n.* (DPP); Szczecin, under *T. occidentalis*, 18 Oct. 1985, *Błaszcz. J. s.n.* (DPP); Żelistrzewo, near roots of *Festuca ovina* L., 25 June 1986, *Błaszcz. J. s.n.* (DPP); Jastrzębia Góra (54°50'N, 18°18'E), under *Crataegus monogyna* Jacq., 30 Oct. 1987, *Błaszcz. J. s.n.* (DPP); Żelistrzewo, from under *Rubus idaeus* L., 22 Aug. 1987, *Błaszcz. J. s.n.* (DPP); Płoty (53°48'N, 15°16'E), among roots of *Agrostis stolonifera* L., 22 Sept. 1987, *Błaszcz. J. s.n.* (DPP); Jastrzębia Góra, in the rhizosphere soil of *J. communis* L., *Błaszcz. J. s.n.* (DPP); Szczecin, under *Heracleum sphondylium* L., 22 Oct. 1987, *Błaszcz. J. s.n.* (DPP); Osłonino (54°42'N, 18°28'E), in the root zone of *Helictotrichon pubescens* (Huds.) Pilg., 22 June 1988, *Błaszcz. J. s.n.* (DPP); Chałupy, among roots of *Festuca arundinacea* Schreb., 28 Sept. 1988, *Błaszcz. J. s.n.* (DPP); Kuźnica (54°41'N, 18°34'E), associated with roots of *Ammophila arenaria* (L.) Link, 28 Sept. 1988, *Błaszcz. J. s.n.* (DPP); Władysławowo (54°47'N, 18°26'E), on roots of *Rosa rugosa* Thunb., 7 July 1989, *Błaszcz. J. s.n.* (DPP); Bolesław (50°00'N, 18°12'E), under an unrecognized grass, 17 Sept. 1989, *Błaszcz. J. s.n.* (DPP); Nowy Ujków (50°18'N, 19°26'E), among roots of *Agropyron repens* (L.) P. Beauv., 17 Sept. 1989, *Błaszcz. J. s.n.* (DPP); Leszna Góra (49°42'N, 18°43'E), associated with roots of *C. monogyna*, 8 Sept. 1989, *Błaszcz. J. s.n.* (DPP); Pieski (52°25'N, 15°26'E), under *Hordeum vulgare* L., 12 Aug. 2004, *Błaszcz. J. s.n.* (DPP); Połupin (52°03'N, 15°06'E), from under *Rumex acetosella* L., 12 Aug. 2004, *Błaszcz. J. s.n.* (DPP); Jemiołów (52°21'N, 15°16'E), in the root zone of *Cirsium arvense* (L.) Scop., 13 Aug. 2004, *Błaszcz. J. s.n.* (DPP); Trzciel (52°22'N, 15°52'E), among roots of *Corynephorus canescens* (L.) P. Beauv., 15 Aug. 2004, *Błaszcz. J. s.n.* (DPP); Łągow (51°59'N, 15°16'E), under *Silene latifolia* Poir. ssp. *alba* (Mill.) Greuter et Burdet, 13 Aug. 2004, *Błaszcz. J. s.n.* (DPP); Jemiołów, among roots of *H. perforatum*, 13 Aug. 2004, *Błaszcz. J. s.n.* (DPP); Zarzyń (52°23'N, 15°25'E), from under *E. arvense*, 13 Aug. 2004, *Błaszcz. J. s.n.* (DPP); Trzciel, in the rhizosphere soil of *Juncus effusus* L., 15 Aug. 2004, *Błaszcz. J. s.n.* (DPP).

**DISTRIBUTION AND HABITAT.** In Poland, *G. badium* was recovered from 39 field-collected mixtures of roots and rhizosphere soils. Of them, 15 came from under nine species of cultivated plants, and the others represented 20 species of wild plants.

The spore abundance of *G. badium* was much higher among roots of wild plants (av. 126.3; range 1-850 in 100 g dry soil) than cultivated plants (av. 5.2; range 1-20 in 100 g dry soil). The proportion of spores of this fungus in spore populations of all arbuscular fungi isolated also was higher in the root zone of wild plants (av. 45.2%; range 0.9-100%) than cultivated ones (av. 10.8%; range 0.9-40.7%). The species abundance in the root and soil samples taken from under cultivated plants averaged 5.0 with a range of 4-7 in 100 g dry soil, and that under wild plants averaged 3.7 and ranged from 1 to 9 in 100 g dry soil.

The arbuscular fungi co-occurring with *G. badium* were *A. polonica* Błaszcz., *A. capsicula*, *A. cavernata* Błaszcz., *A. gedanensis* Błaszcz., *A. lacunosa*, *A. mellea* Spain et N.C. Schenck, *A. paulinae*, an unrecognized *Acaulospora* sp., *G. aggregatum* N.C. Schenck et S.M. Sm. emend. Koske, *G. caledonium*, *G. constrictum*, *G. deserticola*, *G. ? etunicatum*, *G. fasciculatum*, *G. fuegianum*, *G. geosporum*, *G. microcarpum* Tul. et C. Tul., *G. macrocarpum*, *G. mosseae*, unrecognized *Glomus* spp., *Paraglomus occultum* (C. Walker) J.B. Morton et D. Redecker, *Scutellospora armeniaca* Błaszcz., and *Scutellospora dipurpurescens*.

Apart from Poland, *G. badium* has been found among roots of grasses and grassland plants growing in soils of pH 6-8 and located in Germany, France, Switzerland, and Italy (Oehl et al. 2005).

MYCORRHIZAL ASSOCIATIONS. The sporocarps of *G. badium* found by the authors of this paper were formed among and occasionally on vesicular-arbuscular mycorrhizal roots of the plant species listed in the section "Collection examined". In trap cultures with root and rhizosphere soil mixtures of the plant species sampled, *G. badium* rarely produced spores. All one-species cultures of this fungus established were unsuccessful. Oehl et al. (2005) also failed to obtain *G. badium* in one-species cultures and, hence, properties of mycorrhizae of this fungus remain unknown. However, phylogenetic molecular analyses showed *G. badium* to be a member of *Glomus* Group A (Oehl et al. 2005) *sensu* Schwarzott, Walker and Schüßler (2001), comprising fungi known to form vesicular-arbuscular mycorrhizae (Błaszkowski 2003).

The most distinguishing characters of *G. badium* are its small sporocarps lacking a peridium and composed of many, brownish orange to reddish brown, relatively small spores (Fig. 9). The innermost flexible to semi-flexible and coloured layer of the three-layered spore wall also is a diagnostic property of this species (Figs 13 and 14).

*Glomus badium* probably forms spores only in multispored sporocarps, and single spores occasionally recovered from field-collected soil samples represented their fragments. Examination of the ontogenesis of this species is needed to confirm this supposition. Unfortunately, all attempts to produce one-species cultures of *G. badium* made by the authors of this paper and by Oehl et al. (2005) failed.

The interspore mycelium of the specimens of *G. badium* found by the authors of this paper morphologically corresponds to that characterized by Oehl et al. (2005). However, the original description of this fungus does not inform of the cystidium-like structures occurring between spores of the Polish sporocarps of this fungus. The function of the cystidia-like structures in sporocarps of *G. badium* probably is similar to that of cystidia of Agaricales, in which they appear to serve as spacers between basidia (Ulloa, Hanlin 2000).

Of the three wall layers of spores of *G. badium*, the two outer ones are typical of most species of the genus *Glomus*, in which the outermost layer sloughs with age and adheres to a laminate structural layer (Figs 13 and 14). Spore wall layer 3 of *G. badium* is thin, pale yellow (4A3) to light brown (6D8), and usually tightly adheres to the lower surface of the brownish orange (6C8) to reddish brown (8E8) layer 2 in even vigorously crushed spores (Figs 13 and 14). Hence, it is difficult to see, especially in young and freshly matured spores. In older spores, this layer usually is slightly thicker and more frequently separates from the middle laminate layer. Additionally, this layer is most visible at the spore base where it forms a straight or curved septum of the subtending hypha continuous with its part adherent to the laminate spore wall layer 2 (Fig. 14).

Apart from *G. badium*, species of the genus *Glomus* forming small and compact sporocarps with small, brownish orange to reddish brown spores are *G. cuneatum* McGee et Cooper, *G. fuegianum* (Speg.) Trappe et Gerd., *G. invermaium* I.R. Hall, and *G. rubiforme* (Gerd. et Trappe) R.T. Almeida et N.C. Schenck. Compared with *G. badium*, sporocarps of *G. cuneatum* are much larger (2-12 mm vs. 200-500 × 290-680 µm in *G. badium*) and have a peridium (Fig. 9; vs. no peridium in *G. badium*; McGee and Trappe 2002). Additionally, the spore wall of the latter species consists of only one laminate layer lightening from black to hyaline towards their inside, whereas the spore wall of the former fungus comprises three layers, of which the laminate layer is dark- and uniform-coloured (Figs 10, 12 and 16).

According to Thaxter (1922), *G. fuegianum* spores coming from Spegazzini's original collection were reddish brown as are those of *G. badium*. In contrast, all *G. fuegianum* spores found by one of the authors (J. B.) of this paper in Poland, those loaned from Kew, United Kingdom (Błaszowski, Madej and Tadych 1998), and those revealed in Australia by McGee and Trappe (2002) were pale yellow to yellow brown. Moreover, the spores were frequently surrounded by branched and convoluted hyphae (Błaszowski 2003) that never occur on *G. badium* spores (Błaszowski, pers. observ.; Oehl et al. 2005). Finally, the radial arrangement of spores in sporocarps of *G. fuegianum* is regular, and irregular in *G. badium* sporocarps.

*Glomus badium* differs from *G. invermaium* in the formation of smaller (200-500 × 290-680 µm vs. up to 1 mm across) and more compact sporocarps with regularly distributed spores (Fig. 9; vs. loose sporocarps with randomly distributed spores in *G. invermaium*; Błaszowski, pers. observ.; Hall 1977). Other differences are the number and the phenotypic properties of the spore wall layers of these fungi. The spore wall of *G. badium* comprises three layers, of which the outermost one sloughs with age (Figs 13 and 14). In contrast, the outermost spore wall layer of *G. invermaium* spores is persistent and the spore wall of this species lacks spore wall layer 3 of *G. badium*.

The main difference between *G. badium* and *G. rubiforme* resides in the wall structure of their spores. The spore wall of *G. rubiforme* comprises only two layers similar in colour and phenotypic properties to layers 1 and 2 of the spore wall of *G. badium* (Błaszowski 2003; Gerdemann, Trappe 1974).

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## REFERENCES

- Allen M. F., MacMahon J. A. 1985. Impact of disturbance on cold desert fungi: comparative microscale dispersion patterns. *Pedobiologia* 28: 215–224.
- An Z.-Q., Grove J. H., Hendrix J. W., Hershman D. E., Henson G. T. 1990. Vertical distribution of endogonaceous mycorrhizal fungi associated with soybean as affected by soil fumigation. *Soil Biol. Biochem.* 22: 715–719.
- An Z.-Q., Guo B. Z., Hendrix J. W. 1993. Mycorrhizal pathogen of tobacco: cropping history and current crop effects on the mycorrhizal fungal community. *Crop prot.* 12: 527–531.
- An Z.-Q., Hendrix J. W., Hershman D. E., Ferriss R. S., Henson G. T. 1993. The influence of crop rotation and soil fumigation on a mycorrhizal fungal community associated with soybean. *Mycorrhiza* 3: 171–182.
- An Z. Q., Quo B. Z., Hendrix J. W. 1993. Populations of spores and propagules of mycorrhizal fungi in relation to the life cycles of tall fescue and tobacco. *Soil Biol. Biochem.* 25: 813–817.
- Bever J., Morton J. B., Antonovics J., Schultz P. A. 1996. Host-dependent sporulation and species diversity of arbuscular mycorrhizal fungi in a mown grassland. *J. Ecol.* 84: 71–82.
- Błaszowski J. 2003. Arbuscular mycorrhizal fungi (Glomeromycota), *Endogone* and *Complexipes* species deposited in the Department of Plant Pathology, University of Agriculture in Szczecin, Poland. <http://www.agro.ar.szczecin.pl/~jblaszkowski/>.
- Błaszowski J., Czerniawska B. 2005. *Entrophospora schenckii* and *Pacispora franciscana*, arbuscular mycorrhizal fungi (Glomeromycota) new for Europe and Poland, respectively. *Acta Mycol.* 40 (1): 11–18.
- Błaszowski J., Madej T., Tadych M. 1998. *Entrophospora baltica* sp. nov. and *Glomus fuegianum*, two species in the Glomales from Poland. *Mycotaxon* 68: 165–184.
- Błaszowski J., Tadych M., Madej T., Adamska I., Czerniawska B., Iwaniuk A. 1999. *Acaulospora mellea* and *A. trappei*, fungi new for Poland. *Acta Mycol.* 34 (1): 41–50.

- Dodd J. C., Arias I., Koomen I., Hayman D. S. 1990. The management of populations of vesicular-arbuscular mycorrhizal fungi in acid-infertile soils of a savanna ecosystem. *Plant and Soil* 122: 241–247.
- Gerdemann J. W., Trappe J. M. 1974. The Endogonaceae in the Pacific Northwest. *Mycological Memoir* 5: 1–76.
- Hall I. R. 1977. Species and mycorrhizal infections of New Zealand Endogonaceae. *Trans. Brit. Mycol. Soc.* 68: 341–356.
- Koske R. E., Gemma J. N., Jackson N. 1977. Mycorrhizal fungi associated with three species of turfgrass. *Can. J. Bot.* 75: 320–332.
- McGee P. A., Trappe J. M. 2002. The Australian zygomycetous mycorrhizal fungi. II. Further Australian sporocarpic Glomaceae. *Austral. Syst. Bot.* 15: 115–124.
- Moreira-Souza M., Trufem F. B., Gomes-da-Costa S. M., Cardoso E. J. B. N. 2003. Arbuscular mycorrhizal fungi associated with *Araucaria angustifolia* (Bert.) O. Ktze. *Mycorrhiza* 13: 211–215.
- Morton J. B. 2002. International Culture Collection of (Vesicular) Arbuscular Mycorrhizal Fungi. West Virginia University: <http://www.invam.caf.wvu.edu/>.
- Morton J. B., Redecker D. 2001. Two families of Glomales, Archaeosporaceae and Paraglomaceae, with two new genera *Archaeospora* and *Paraglomus*, based on concordant molecular and morphological characters. *Mycologia* 93: 181–195.
- Nicolson T. H., Schenck N. C. 1979. Endogonaceous mycorrhizal endophytes in Florida. *Mycologia* 71: 178–198.
- Oehl F., Redecker D., Sieverding E. 2005. *Glomus badium*, a new sporocarpic mycorrhizal fungal species from European grasslands with higher soil pH. *J. Appl. Bot. and Food Qual.* 79: 38–43.
- Omar M. B., Bollan L., Heather W. A. 1979. A permanent mounting medium for fungi. *Bull. Brit. Mycol. Soc.* 13: 31–32.
- Rose S., Daniels B. A., Trappe J. M. 1979. *Glomus gerdemannii* sp. nov. *Mycotaxon* 8: 297–301.
- Schwarzott D., Walker C., Schüßler A. 2001. *Glomus*, the largest genus of the arbuscular mycorrhizal fungi (Glomales) is nonmonophyletic. *Mol. Phylogen. Evol.* 21: 190–197.
- Spain J. L., Sieverding E., Oehl F. 2006. *Appendicispora*: a new genus in the arbuscular mycorrhiza-forming Glomeromycetes, with a discussion of the genus *Archaeospora*. *Mycotaxon* 97: 163–182.
- Thaxter R. 1922. A revision of the Endogonaceae. *Proc. Am. Acad. Arts and Sci.* 57: 291–351.
- Turnau K., Ryszka P., Gianinazzi-Pearson V., Tuinen D. van 2001. Identification of arbuscular mycorrhizal fungi in soils and roots of plants colonizing zinc wastes in southern Poland. *Mycorrhiza* 10: 169–174.
- Ulloa M., Hanlin R. T. 2000. *Illustrated Dictionary of Mycology*. APS Press. The American Phytopathological Society. St. Paul, Minnesota.
- Walker C., Vestberg M., Demircik F., Stockinger H., Saito M., Sawaki H., Nishimura I., Schüßler A. 2007. Molecular phylogeny and new taxa in the Archaeosporales (Glomeromycota): *Ambispora fennica* gen. sp. nov., Ambisporaceae fam. nov., and emendation of *Archaeospora* and Archaeosporaceae. *Micol. Res.* 111: 137–153.

*Ambispora gerdemannii* and *Glomus badium*, dwa gatunki grzybów arbuskularnych (Glomeromycota) nowe odpowiednio dla Europy i Polski

Streszczenie

Opisano i zilustrowano cechy morfologiczne zarodników oraz sporokarpów i zarodników odpowiednio *Ambispora gerdemannii* i *Glomus badium*, grzybów arbuskularnych z gromady Glomeromycota. Ponadto przedstawiono poznane rozmieszczenie tych gatunków zarówno w Polsce, jak i innych regionach świata. *Ambispora gerdemannii* nie była dotychczas notowana w Europie, a *G. badium* jest nowym grzybem dla Polski.