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Polish Endogonaceae. 4. Gigaspora gigantea, Glomus deserticola, and Glomus globiferum

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B ł a s z k o w s k i J. : *Polish Endogonaceae. 4. Gigaspora gigantea, Glomus deserticola, and Glomus globiferum.* Acta Mycol. XXVI(2): 3-16, 1990.

Morphlogical features of three species of the *Endogonaceae* and their occurrences and distributions in Poland had been studied.

Morphological features of three species of the *Endogonaceae* are described and illustrated, and their occurrences and distributions in Poland are characterized and mapped on the ground of 176 soil samples taken from under both cultivated and natural plants. *Gigaspora gigantea* was found in 11 samples. It is probably a common symbiont of sand dune plants of the Hel Peninsula. However, its spore densities were were low, ranging from 1 to 6 spores per 100 g dry soil. *Glomus deserticola* occurred in 33 samples which contained from 1 to 218 spores per 10 g dry soil. On an average, its relative spore density was nearly two times higher among cultivated than natural plants. *Glomus globiferum* was isolated only from 2 samples. It is probably a rarely occurring species in Poland. Except for *G. globiferum*, the other two species treated in this paper occurred among both cultivated and natural plants.

Gigaspora gigantea (Nicol. et Gerd.) Walker et Sanders

Spores single in the soil, pale yellow (5Y 8/3-8/4, Munsel Color Company, INC., Baltimore, Maryland 1954), globose to subglobose, (480-) 510 (-520) μm in diam (Fig.1). Spore wall of two walls (walls 1, 2) in one group (group A)

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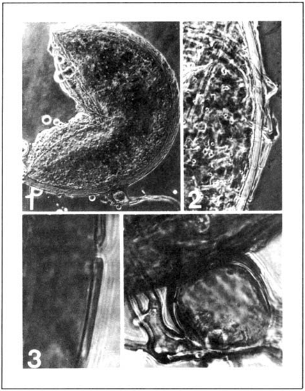
(Figs.2, 3); of a hyaline to pale yellow (5Y 8/3), (1,5-) 2,0 (-2,5) μm thick, unit outer wall (wall 1) and of a pale yellow (5Y 8/3-8/4), (8,8-) 15,5 (-19,9) μm thick, laminate inner wall (wall 2). Suspensor-like cell concolorous with the inner spore wall, bulbous, (43,0-) 49,8 (-53,0) μm in diam, with a wall (3,1-) 3,2 (-3,5) μm thick; one or two hyphal pegs, sometimes digitally branched, often develop from this cell (Fig. 4).
Material examined: see table 1; specimens deposited: 1176-1181 (Department of Plant Path., DPP).



Figs. 1-4. *Gigaspora gigantea*

1 – A crushed spore with bulbous suspensor-like cell, phase contrast (PC) x 205; 2-3 – Two-walled spore wall structure can be seen; the fragile nature of the outer wall is visible, PC and light microscope, x 750 and x 2250 resp.; 4 – Suspensor-like cell with the digitally branched hyphal peg, x 1105

Table 1
Frequency of occurrence of *Gigaspora gigantea* in Poland and chemical properties of soils from which this species was isolated

Plant species	No. of soil sample (Fig. 16)	No. of spores/100 g dry soil	pH	Chemical properties		
				NO_3	P	K
				mg/kg		
Cupressaceae						
Juniperus communis	98	2	5,1	10	14	9
Thuja occidentalis	102	2	5,1	38	11	29
Gramineae						
Triticum vulgare	108; 111; 149	1; 1; 1	5,3-6,0	27-50	14-114	9-161
Unknown grass	96	2	6,8	10	39	10
Rosaceae						
Crataegus monogyna	113; 121	1; 6	6,2; 6,0	160; 28	22; 17	25; 26
Rosa canina	118; 119; 123	1; 1; 2	4,5-4,8	24-32	8-24	11-28

D i s t r i b u t i o n a n d e c o l o g y . In Poland spores of this species were found in 11 of the 176 soil samples examined (Tab. 1, Fig. 16). Three of them were taken from the rhizosphere of winter wheat (nos. 108, 111, 149). *G. gigantea* was found in all samples representing sand dunes of the Hel Peninsula (nos. 96, 118, 119, 123), suggesting its common occurrence on this area. The spore densities of this species were generally low ranging from (1-6/100 g dry soil). In all the soil samples taken from under winter wheat only single spores were found. The relative spore densities ranged from 0,1 to 8,3 % (av. 1,5 %) for both cultivated and natural plants, and from 0,4 to 8,3 (av. 3,2 %) and from 0,1 to 1,4 % (av. 0,9 %) for cultivated and natural plants respectively. It is a new species to Poland.

G. gigantea has originally been described from cultivated soils of Illinois, although it had earlier been found in southern Indiana and in South Dakota (N.i c o l s o n, G e r d e m a n n, 1968). K o s k e and H a l v o r s o n (1981), B e r g e n and K o s k e (1984), and K o s k e (1987) stated it to be dominant species of vesicular-arbuscular mycorrhizal fungi in sand dunes of the south shore of Rhode Island, the New Jersey-Virginia transect, and Cape Cod, Massachusetts. Besides, *G. gigantea* has been found in soils from a New Zealand coniferous dicotyledonous forest (J o h n s o n, 1977), among roots of *Casuarina equisetifolia* L. growing on marine sand dunes of Florida (R o s e, 1980), and from undisturbed prairie soil and a winter wheat field soil in Kansas (H e t r i c, B l o o m, 1983). N i c o l s o n and S c h e n c k (1979) and S c h e n c k and K i n l o c h (1980) stated *G. gigantea* to be common among cultures of *Glycine max* (L.) Merr. in Florida, although its incidence gradually decreased in numbers when soybeans were grown in monoculture for 7 years.

There are poorly known factors regulating the occurrence and distribution of *G. gigantea* spores in nature. Koske and Halvorson (1981) found that the spore densities of this species were positively correlated with the cover degree of the studied areas by *Ammophila breviliqulata* Fern., although cover percentages of other three examined plant species showed no similar relationship. Koske (1987), basing on an Importance Value (calculated by summing relative frequency, relative spore density and relative spore biovolume) suggested that *G. gigantea* favores cooler soil temperatures what supported results obtained from sand dunes of Florida (Sylvia, 1987) but contradiced earlier results by Koske (1981), where *G. gigantea* spores germinated best at 30°C. Anderson et al. (1984) showed that *G. gigantea* may colonize plants of wet and relatively nutrient rich sites and suggested its ability to form ecotypically different populations. Although Ross and Ruttencutter (1977) belived that *G. gigantea* spores are relatively resistant to infections by soil fungal hyperparasites, Koske (1981) found that about 20 % of spores collected from a barrier dune at Moonstone Beach, Rhode Island contained spindle-cells of *Labyrinthula* sp., and later recorded (Koske, 1984) that *G. gigantea* was the most frequently occupied species by spores of other species of endomycorrhizal fungi in different dunes of the Atlantic Coast and Great Lakes of the U.S.. However, in the last case, it was not clear if some of the observed occupants preferred to sporulate within enclosed spaces whether they were capable of mycoparasitism. No spores of this species collected in Poland were occupied by inner spores, although their spore walls were sometimes perforated in a similar way like spores of an unknown *Gigaspora* sp. suggested to be destroyed by filamentous organisms (Taber, 1982).

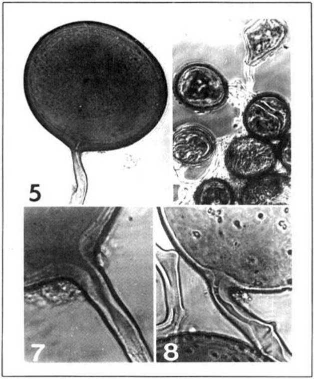
Taxonomic remarks. *G. gigantea* is an easily distinguishable species, mainly by its spore wall structure as well as by forming large and usually pale yellow spores. Spores from Poland generally fit well the conception of this species, however, they somewhat differ in thickness of the spore wall. Nicolson and Gerdemann (1968) give the range of the *G. gigantea* spore wall thickness from 2,5 to 7,5 μm, Gerdemann and Trappe (1974) characterized the inner wall as 5 to 7 μm thick, but later Trappe (1982) and Schenck and Smith (1982) placed *G. gigantea* among species forming walls from 5 to 12 μm and from < 6 to 12 μm thick respectively. Of other similar species of this genus, *G. margarita* Becker et Hall (1976) has a spore wall which is 5-25 μm thick, however, its spores are 1-walled and hyaline. *G. decipiens* Hall at Abbott (1984) also produces spores with one wall, but from 20 to 47 µm thick. *G. candida* Bhattacharjee, Mukerji, Tamari, Skoropad (1982) is described as forming white and 1-walled spores, and *G. albida* Schenck et Smith (1982) possesses smaller spores (av. 265 µm in diam) which are dull white with a light greenish-yellow tint. Spores freshly isolated from the soil samples collected in Poland were pale yellow, but after a few days storage in solutions containing lactic acid they always became reddish yellow (7,5 YR 7/8) to brown (7,5 YR 5/8). Morton (1988) ephasizes that *G. gigantea* spores are greenish-yellow to pale yellow and that they can grade to dark brown, probably because of oxidation of their contents or as a result of hyperparasitic activity.

An other known feature of *G. gigantea* is the ability to form auxiliary cells in the soil, occurring singly or in clusters which may be hyaline to pale yellow, 18-40 µm in diam, and are always covered with echinulations or narrow papillae (Nicolson, Gerdemann, 1968; Schenck, Smith, 1982). However, such structures were not found in Poland.

G. gigantea has several times been used in experimental studies. Generally, plants with *G. gigantea* infections grew better, had enhanced areas of the outer cortex and xylem, and contained more major and minor elements (e.g. Daft, Hacskaylo, 1977; Johnson, 1977), although Bierman and Linderman (1983) showed that such infections did not significantly increase growth of *Pelargonium* x *hortorum* L. H. V. Bailey and *Trifolium subterraneum* L. or even slightly decreased it. In Ross' and Ruttencutter's (1977) studies, *G. gigantea* inhibited sporulation and mycorrhizal infections by *G. geosporum* (Gerd. et Trappe) Walker. Koske (1981) stated that only low temperatures (below 15°C) and low water potentials (below -10 bars) may prevent or greatly delay *G. gigantea* spore germination.

Glomus deserticola Trappe, Bloss et Menge

Spores single in the soil or in loose clusters without a peridium (Figs. 5, 6); spores reddish yellow (5YR 6/8) to yellowish red (5YR 5/8), globose to subglobose (70-) 89 (-115) µm in diam, rarely prolate to pyriform, 70-100 µm. Spore wall of one, reddish yellow (5 YR 6/8) to yellowish red (5YR 5/8), laminate, (2,5-) 3,2 (-3,9) µm thick wall, became thicker (6,1-9,1 µm) at the spore base (Figs.5,7,8).Subtending hypha reddish yellow (5YR 6/8),straightor slightly funnel-shaped, (7,6-) 10 (-11,3) µm wide, with walls (2-) 3,4 (-4,7) µm thick, most often without a septum (Figs. 5, 7), rarely with 1-3 septa formed below the spore base (Fig. 8).
Material examined: see table 2; specimens deposited: 1160-1175 (DPP).



Figs. 5-8. *Glomus deserticola*

5 - An intact spore with the funnel shaped subtending hypha; the swelling of the spore wall near the spore base is seen, x 853; 6 - A cluster of spores, PC, x 242; 7 - An opened subtending hypha with the sinuous canal x 1800; 8 - Three septa in the subtending hypha x 1330

Distribution and ecology. In Poland *G. deserticola* was found in 33 soil samples (Tab. 2, Fig. 17). Fourteen of them were taken from under cultivated plants. Its spore densities ranged from 1 to 218 per 100 g dry soil. The relative spore densities of this taxon ranged from 1,9 to 92,3 % (av. 23,9 %) for both cultivated and natural plants, and from 2,5 to 92,3 % (av. 31,3 %) and from 1,9 to 75,2 % (av. 18,9 %) for cultivated and natural plants respectively. It is a new species to Poland. *G. deserticola* is probably widely distributed in the world, although it has formally been noted only from a few sites. This species has probably most often been reported under the name of *G. fasciculatum* (Thaxter) Gerd. et Trappe emend. Walker et Koske and at present it is practically impossible to determine its real distribution in the world. Trappe et al. (1984) recovered this species from sandy desert soils of southern California, Arizona, and Texas. Sylvia (1986) found it to be the most abundant species associated with *Uniola paniculata* L. in Florida foredunes. Bloss and Walker (1987) isolated *G. deserticola* spores from under unidentified grass in the Santa Catalina Mountains, Arizona. Graham et al. (1982) found that growth and colonization of *G. deserticola* were correlated with root exudation, the amound of which was changed by soil temperature and phosphorus level. Paulitz and Menge (1986) showed *Anguillospora pseudolongissima* Ranzoni to be a mycoparasite of *G. deserticola* spores; the former significantly reduced root colonization by the latter and growth response of onions as well as reduced the initial effective propagule density of the mycorrhizal fungus over 50 %.

Table 2

Frequency of occurrence of *Glomus deserticola* in Poland and chemical properties of soils from which this species was isolate

Plant species	No. of soil sample (Fig. 17)	No. of spores/100 g dry soil	Chemical properties			
			pH	NO_3	P	K
				mg/kg		
Compositae						
Petasites officinalis	168	23	5,9	85	30	44
Cupressaceae						
Juniperus communis	101	20	5,4	20	36	27
Thuja occidentalis	4; 37; 77; 90; 156	10; 28; 10; 18; 72	4,5-6,5	20-260	10-30	9-69
Gramineae						
Avena sativa	52	2	5,2	44	9	20
Calamagrostis arundinacea	89	24	4,8	21	16	14
Corynephorus canescens	32; 160	10; 2	6,1; 4,4	34; 25	30; 10	39; 10
Festuca ovina	64; 87; 97	2; 158; 40	4,5-7,2	20-130	18-40	17-44
Hordeum vulgare	24; 165; 169	11; 99; 1	4,8-6,8	35-70	28-37	35-45
Sorghum sunadense	8; 171	9; 49	7,0; 5,1	61; 70	24; 32	41; 38
Triticum vulgare	28	21	6,7	14	37	26
Zea mays	40; 44; 56; 91	39; 12; 40; 15	4,7-6,2	31-110	8-75	17-81
Unknown grass	83; 100	18; 6	5,6; 5,8	48; 20	26; 17	30; 20
Leguminosae						
Phaseolus vulgaris	48	13	6,7	71	57	62
Trifolim repens	7; 17	30; 40	5,1; 5,1	29; 54	15; 22	10; 19
Rosaceae						
Crataegus monogyna	113; 114	9; 18	6,2; 4,2	160; 56	22; 19	25; 24
Rosa canina	93	20	4,5	20	18	17
Umbelliferae						
Heracleum sphondylium	155	218	6,4	70	28	29

Taxonomic remarks. Compared with spores described by Trappe et al. (1984), specimens from Poland are slightly lighter (reddish yellow to yellowish red vs. reddish brown). Koske (1985, 1987) also mentioned the red-brown colour as distinguishing *G. deserticola* spores from those of *G. aggregatum* Schenck et Smith emend. Koske and *G. fasciculatum*, however, the black and white illustration by Bloss and Walker (1987) suggests that the colour of the presented *G. deserticola* spore is similar to that of spores found in Poland and is lighter than the reddish brown colour from the Munsell Soil Color Charts.

The spore wall of *G. deserticola* from Poland is of similar thickness on its almost whole girt except for the spore base where it usually became strongly thicker, forming a collar around the canal connecting the spore inside with the subtending hypha (Figs. 5-7). Trappe et al. (1984) stated that the collar is well developed only on quite mature spores and only then it appears to be closed by a membranous septum, which is not seen among Polish speciments. Berch (1985) studied *Rhizophagites acinus* Srivastava and stated it to be conspecific with *G. deserticola*, but she did not give any information on the presence of such a septum in the collar, which has also been formed. Most spores from Poland possess an opened subtending hypha. Its walls, thickening during spore maturation, narrow the canal of the hypha but do not close it completely. The inner surface of the hyphal walls is characteristically sinuous, causing the canal of the subtending hypha to be spiral (Figs. 7, 8). Sometimes, the subtending hypha possesses 1-3 septa, straight or and only among older spores, but both among those isolated singly from the soil and occurring in clusters. However, these septa differ from typical septa formed by other species of the genus *Glomus*, because they always occur considerably beneath the spore base and one can often find two to three septa situated one after another. Therefore, they more resemble septa formed in parent hyphae of many species of the genus *Glomus* and especially in hyphae connected with suspensor-like cells of spores of the genera *Gigaspora* and *Scutellospora*.

G. deserticola is the second species separated from the *Glomus fasciculatum* complex (Trappe et al., 1984). Earlier *G. aggregatum* Schenck et Smith (1982) emended by Koske (1985) and later *G. hoi* Berch et Trappe (Berch, Trappe, 1985) have also been excluded from this complex. Recently, Walker and Koske (1987) redescribed *G. fasciculatum* s. str. which differes from *G. denserticola* by possessing lighter spores [pale yellow to pale yellow-brown, which may be larger [(50-) 60-95 (-149) x 55-90 (-149) μm], are 3-walled and have a relatively broad subtending hypha (3,5-) 9-15 (-19) μm *G. hoi* is described as having light brown, 50-140 μm in diam spores with two distinct, separable walls, and their subtending hypha is 5-13 μm wide and occluded by a curved septum. *G. aggregatum* resembles *G. deserticola* spores in size and wall structure (of single-walled *G. aggregatum* spores), although spores of the former often exhibit a wide range of shapes (globose, pyriform to very irregular vs. globose to subglobose), form internal spores, and typically are yellow to yellow-brown (Koske, 1985; Błaszkowski, 1989).

Besides, as informed above, Berch (1985) stated *Rhizophagites acinus* to be conspecific with *G. deserticola*. Gerdemann and Trappe (1974) earlier synonymized the genera *Rhizophagites* Rosend. and *Rhizophagus* Dangeard with *Glomus*, and the trype species, *Rhizophagites butleri* Rosend. with *G. fasciculatum*. Berch (1985) concluded that since the type specimens of *R. butleri* and another species of this genus, *R. minnesotensis* Rosend. have apparent been lost, these two names are nomina dubia. However, Koske (1985) stated that *G. aggregatum* spores are formed by the same type of internal proliferation as described for *R. butleri* and that the *G. fasciculatum* redescription does not conform to the latter taxon as well.

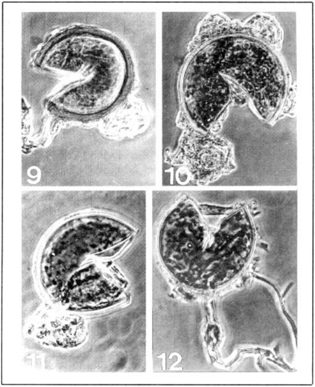
Glomus globiferum Koske et Walker

Spores single in the soil or in sporocarps with 2-4 spores placed randomly and tightly side by side (Fig. 13). Spores olive yellow (2,5Y 6/8), reddish yellow (7,5YR 7/8) to yellowish red (5YR 5/8), globose to subglobose, (120-) 136 (150) µm in diam, covered with a hyaline to yellow (2,5Y 8/6) peridium (Figs. 9-12, 14). Peridium composed of loosely interwoven, prolate, 10-15 µm wide and up to 120 µm long hyphae (Fig. 12) with vesiculate sweellings. Vesiculate swellings hyaline to yellow (2,5Y 8/6), globose, subglobose to prolate or irregular, 16,4-41,6 µm in diam, with 1-2 walls, (1-) 1,3 (-2) µm thick (Figs. 9-11, 14).

Spore wall of three walls (walls 1-3) in one group (group A); of a hyaline to pale yellow (5Y 8/4), (0,7-) 1,5 (-2) mm thick, unit outermost wall (wall 1), tightly adhering to a reddish yellow (7,5YR 6/8) to yellowish red (5YR 5/8), (5,4-) 8,3 (-9,8) µm thick, laminate middle wall (wall 2), and of a hyaline, ± 0,5 µm thick, membranous innermost wall (wall 3).

Subtending hypha (Fig. 15) yellow (5Y 8/6) to reddish yellow (7,5YR 7/8), straight or slightly funnel-shaped, (15-) 17,4 (-19,6) µm wide with a wall (3,7-) 6,7 (-9,1) µm thick at the spore base, closed by thickening of the laminate wall 2 and by a granular plug. Germination by regrowth of the germ tube through the subtending hypha.

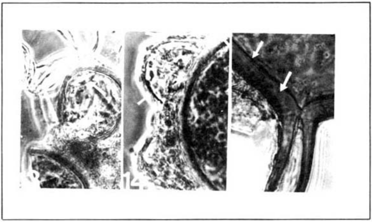
Material examined: see table 3; specimens deposited: 1135-1159 (DPP).



Figs. 9-12. *Glomus globiferum*
9-11 - Crushed spores with the peridial vesiculate swellings, all PC, x 371, x 381, and x 365 respectively;
12 - A crushed spore with prolate hyphae, PC, x 368

Table 3
Frequency of occurrence of *Glomus globiferum* in Poland and chemical properties of soils from which this species was isolated

Plant species	No. of soil sample (Fig. 16)	No. of spores/100 g dry soil	Chemical properties			
			pH	NO_3	P	K
				mg/kg		
Gramineae						
Agrostis alba	131	1	4,0	70	22	35
Rosaceae						
Rosa canina	134	34	4,9	41	10	12



Figs. 13-15. *Glomus globiferum*

13 - A fragment of a sporocarp; the wrinkled wall 3 is arrowed, PC, x 360;

14 – The two walls of the vesiculate swelling are arrowed; the unit spore wall is seen (arrow), PC, x 1100;

15 - Subtending hypha of a spore; the three spore walls are arrowed, x 1250

Distribution. In Poland *G. globiferum* was isolated only from two soils samples taken from under two natural plant species (Tab. 3, Fig. 16). Its relative spore densities amounted 0,2 % and 17,3 % respectively. Its a new species to Poland and is so far known only from the U.S..

16

17

Figs. 16-17. Maps of distribution of the *Endogonaceae* in Poland

16 – *Gigaspora gigantea* and *Glomus globiferum* in Poland. The numbers indicate the numbers of soil samples.

17 – *Glomus deserticola* in Poland

G. globiferum has been found originally in only one sample from more than 500 taken from dunes of the North and Middle Atlantic coast, but has later been discovered in sand dune samples from Virginia and Michigan (K o s k e, W a l k e r, 1986). K o s k e (1987) stated its occurrence to be low along the New Jersey--Virginia dune transect. Despite *G. globiferum* has been among the most abundant species in Florida foredunes, however, it has not affected growth of the most common plant species of these dunes, *Uniola paniculata* L., has remained unchanged P concentration in shoots of this plants, and has colonized its roots poorly in pot experiments (S y l v i a, B u r k s, 1988).

Taxonomic remarks. Spores from Poland are generally very similar to those described by K o s k e and W a l k e r (1986), especially by possessing the peridial hyphae with vesiculate swellings, the most striking feature of this species, as well as by their spore wall structure, although these spores are slightly lighter (olive yellow to yellowish red *vs.* orange-brown, rarely fuscous black) and attain only the bottom limit of dimensions of orginal *G. globiferum* spores. The peridium is seen on almost all spores, however, it is sometimes very poorly developed and without vesicules (Fig. 12), forming prolate hyphae which are usually noticeable only by using a phase contrast microscope. According to K o s k e and W a l k e r (1986), the wall of vesiculate swellings is composed of a hyaline, thin, unit outer wall and a slightly coloured, thicker, laminate inner wall, whereas in Polish specimens the outer wall (if present) is sloughing (Fig. 14), and the inner one is rigid and no laminae are seen. These structures are olso sometimes filled with yellow (2,5Y 8/6) granular material, although there occur no septa closing this content, but present among spores of *G. globiferum* from the U.S.. The swellings are visible on the whole surface of spores, however, they occur especially often near the point of hyphal attachment (Figs. 10, 11).

The spore wall structure of *G. globiferum* is characterizad as 3 or 4-walled in 1 or 2 groups. The outer two walles are similar to those presented in Polish specimens (Fig. 11, 14, 15). The walls 3 and 4 are orginally described as membranous, arranges in the some group (group A) as the walls 1 and 2 or in a separate wall group B as attached to each other by a thin, amorphous cement-like layer. When spores have three walls, the third wall may also by coriaceous, 2-3 μm thick. The third wall of Polish speciments is thin (± 0,5 μm thick) and usually thightly adhered to the middle wall and may sometimes be difficult to determine, although it wrinkles in polyvinyl alcohol lactophenol (Fig. 13). W a l k e r (1983, 1986) described two types of elastic walls, membranous and coriaceous, of which the letter, of similar properties as the former, is usually thicker (M o r t o n , 1988).

The subtending hypha differs only slightly from that described by Koske and Walker (1986). It is also thick-walled with the wall thickness rapidly diminishing from the point of connection a thin-walled parent hypha, but it is not constricted at the spore base.

REFERENCES

Anderson R.C., Liberta A.E.., Dickman L.A., 1984. Interaction of vascular plants and vesicular-arbuscular mycorrhizal fungi across a soil moisture-nutrient gradient. Oecologia 64: 111-117.

Becker W.N., Hall I.R., 1976. *Gigaspora margarita*, a new species in the *Endogonaceae*. Mycotaxon 4: 155-160.

Berch S.M., 1985. The nomenclatural fate of *Rhizophagites acinus*. Mycotaxon 23: 405-407.

Berch S.M., Trappe J.M., 1985. A new species of *Endogonaceae, Glomus hoi*. Mycologia 77: 654-657.

Bergen M., Koske R.E., 1984. Versicular-arbuscular mycorrhizal fungi from sand dunes of Cape Cod, Massachusetts. Trans. Br. Mycol. Soc. 83: 157-158

Bhattacharjee M., Mukerji K.G., Tewari J.P., Skoropad W.P., 1982. Structure and hyperparasitism of a new species of *Gigaspora*. Trans. Br. Mycol. Soc. 78: 184-188.

Biermann B., Linderman R.G., 1983. Use of vesicular-arbuscular mycorrhizal roots, intraradical vesicles and extraradical vesicles as inoculum. New Phytol. 95: 97-105.

Bloss H.E., Walker C., 1987. Some endogonaceous mycorrhizal fungi of the Santa Catalina Mountains in Arizona. Mycologia 79: 649-654.

Błaszkowski J., 1989. Polish *Endogonaceae*. 2. *Acaulospora rugosa, Glomus aggregatum, Glomus etunicatum, Glomus fasciculatum*, and *Glomus occultum*. Karstenia (in press).

Daft M.J., Hackaylo E., 1977. Growth of endomycorrhizal and nonmycorrhizal red maple seedlings in sand and anthracite soil. Forest Sci. 23: 207-216.

Gardemann J.,W., Trappe J.M., 1974. The *Endogonaceae* in the Pacific Northwest. Mycologia Memoirs 5: 1-76.

Graham J.H., Leonard R.T., Menge J.A., 1982. Interaction of light intensity and soil temperature with phosphorus inhibition of vesicular-arbuscular mycorrhiza formation. New Phytol. 91: 683-690.

Hall I.R., Abbott L.K., 1984. Some *Endogonaceae* from south western Australia. Trans. Br. Mycol. Soc. 83: 203-208.

Hetrick B.A.D., Bloom J., 1983. Vesicular-arbuscular mycorrhizal fungi associated with native tall grass prairie and cultivated winter wheat. Can. J. Bot. 61: 2140-2146.

Johnson P.N., 1977. Mycorrhizal *Endogonaceae* in a New Zealand forest. New Phytol. 78: 161-170.

Koske R.E., 1981. *Gigaspora gigantea*: observations on spore germination of a VA-mycorrhizal fungus. Mycologia 73: 288-300.

Koske R.E., 1981. *Labyrinthula* inside the spores of a vesicular-arbuscular mycorrhizal fungus. Mycologia 73: 1175-1180.

Koske R.E., 1984. Spores of VAM fungi inside spores of VAM fungi. Mycologia 76: 853-862.

Koske R.E.,1985. *Glomus aggregatum* emended: a distinct taxon in the *Glomus fasciculatum* complex. Mycologia 77: 619-630.

Koske R.E., 1987. Distribution of VA mycorrhizal fungi along a latitudinal temperature gradient. Mycologia 79: 55-68.

Koske R.E., Halvorson L., 1981. Ecological studies of vesicular-arbuscular mycorrhizae in a barrier sand dune. Can. J. Bot. 59: 1413-1422.

Koske R.E., Walker C., 1986. *Glomus globiferum*: a new species of *Endogonaceae* with a hyphal peridium. Mycotaxon 26: 133-142.

Miller D.D., Domoto P.A., Walker C., 1985. Mycorrhizal fungi at eighteen apple rootstock plantings in the United States. New Phytol. 100: 379-391.

Morton J.B., 1988. Taxonomy of VA mycorrhizal fungi: classification, nomenclature, and identification. Mycotaxon 32: 267-324.

Nicolson T.H., Gerdemann J.W., 1968. Mycorrhizal Endogone species. Mycologia 60: 313-325.

Nicolson T.H., Schenck N.C., 1979. *Endogonaceous* mycorrhizal endophytes in Florida. Mycologia 71: 178-198.

Paulitz T.C., Menge J.A., 1986. The effects of a mycoparasite on the mycorrhizal fungus, *Glomus deserticola*. Phytophatology 76: 351-354.

Rose S.L., 1980. Mycorrhizal associations of some actinimycete nodulated nitrogen-fixing plants. Can. J. Bot. 58: 1449-1454.

Ross J.P., Ruttencutter R., 1977. Population dynamics of two vesicular-arbuscular mycorrhizal fungi and the role of hyperparasitig fungi. Phytopathology 67: 490-496.

Schenck N.C., Kinloch R.A., 1980. Incidence of mycorrhizal fungi on six field crops in monoculture on a newly cleared woodland site. Mycologia 72: 445-456.

Schenck N.C, Smith G.S., 1982. Additional new and unreported species of mycorrhizal fungi *(Endogonaceae)* from Florida. Mycologia 74: 77-92.

Sylvia D.M., 1986. Spatial and temporal distribution of vesicular-arbuscular mycorrhizal fungi associated with *Uniola paniculata* in Florida foredunes. Mycologia 78: 728-734.

Sylvia D.M., Burks J.N., 1988. Selection of a vesicular-arbuscular mycorrhizal fungus for practical inoculation of *Uniola paniculata* Mycologia 80: 565-568.

Taber R.N., 1982. *Gigaspora* spores and associated hyperparasites in weed seeds in soil. Mycologia 74: 1026-1031.

Trappe J.M., 1982. Synoptic keys of the genera and species of Zygomycetous mycorrhizal fungi. Phytopathology 72: 1102-1108.

Trappe J.M., Bloss E., Menge J., 1984. *Glomus deserticola* sp. nov. Mycotaxon 20: 123-127.

Walker C., 1983. Taxonomic concepts in the *Endogonaceae*: spore wall characterisics in species descriptions. Mycotaxon 18: 443-455.

Walker C., 1986. Taxonomic concepts in the *Endogonaceae* 2. A fifth mirphological wall type in endogonaceous spores. Mycotaxon 25: 95-97.

Walker C., Koske R.E., 1987. Taxonomic concepts in the *Endogonaceae* 4. *Glomus fasciculatum* redescribed. Mycotaxon 30: 253-262.