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Synoptic Keys to the Genera and Species of Zygomycetous Mycorrhizal Fungi

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Spore drawings are by Wendy Madar. Christopher Walker, Forestry Commission, Northern Research Station, Scotland, first detected and called to my attention the grammatical error of all past workers who have assumed a masculine gender for the generic name *Glomus*.

The literature on differential effects of zygomycetous vesicular-arbuscular (VA) mycorrhizal fungi on hosts is now ample. Given the same environment, different fungi may affect a host in different ways. Change the environment, especially the soil, and still different interactions can occur. To interpret results soundly, researchers need to know which fungi are involved in their experiments. Applications of mycorrhizal research to the improvement of crop productivity will succeed only if fungi that are right for the crop and the environment are selected with appropriate sophistication.

These concepts may be generally accepted, but researchers who must identify the VA fungi are confronted with monumental difficulties. The most recent monograph of the Endongonaceae (7) was published in 1974. It included all 31 zygomycetous mycorrhizal species recognized at the time, but detailed descriptions were provided only for those encountered in the region covered. Descriptions of the more than 50 new species described since 1974 are scattered in the mycological literature, and I am aware of more than 20 additional species soon to be described. As mycologists investigate mycorrhizae in other parts of the world, the total number of species that may be recognized by 1990 could approach 200. Concepts of species described earlier will occasionally be modified as new data emerge. With this projected rapid pace of discovery, updated monographs of endogonaceous genera will soon become outdated. Dichotomous keys, such as those of Hall and Fish (11), are extremely useful and can be rewritten and updated periodically, but their usefulness diminishes as new taxa are described.

The synoptic key, an alternative to dichotomous keys, provides each user with a key that can be expanded and corrected without rewriting. In contrast to the dichotomous key, in which the user is forced to use characters selected by the author of the key, the synoptic key permits the user to select characters that lead to the most efficient identification. The synoptic key arrays all characters useful for separating taxa in much the same way as for a computer-generated key (12). It can, indeed, be adapted directly to keysort or computer formats.

Synoptic keys for the genera of Endogonaceae plus genera that have affinity with or may be mistaken for Endogonaceae are presented below, along with keys for species of the genera known to include mycorrhiza formers. Space limitations preclude detailed descriptions or discussions of each of these taxa, but a reference to more complete treatment is cited for each taxon.

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USE OF SYNOPTIC KEYS

Procedures. The process is one of elimination: possible species names are eliminated through stepwise combining of the characters of the specimens in hand, until only one name remains. In some cases, a taxon can be keyed out immediately by recognizing one distinctive character. For example, of the described species of *Acaulospora*, only No. 4, *A. gerdemannii*, has cerebriform ornamentation of mature spores. In other cases (eg, in several of the species complexes within the genus *Glomus*) many steps may be needed to identify a specimen. Occasionally a synoptic key may not separate two taxa if the specimens are in poor condition, are closely similar, overlap in variation, or are imperfectly known. In these cases the specimens can be compared by referring to detailed descriptions of the two to determine the correct name. The synoptic key allows perception of close morphological similarities between related taxa, whereas the dichotomous key can often lead the user astray.

Readers should study the paper by Korf (14) on efficient use of the keys; I merely summarize the procedure here. The taxa included in each key are listed with an assigned number. The key includes several numbered major categories of structures (eg, for the *Acaulospora* key, **1. Spores**). Within each structural category are listed two or more numbered characters (eg, **1-1. Shape**). Within each character are listed several lettered descriptions (eg, a. globose). Each description is followed by a list of the numbers of all taxa that conform to that description. The number is in Roman type if a species conforms only to that descriptive choice and no other (eg, spores of No. 1, *A. bireticulata*, are always globose or nearly globose, never ellipsoid). The number is in italics if a species conforms to more than one descriptive choice (eg, spores of No. *2, A. elegans*, can be either globose or ellipsoid).

To use the key, begin with the character of your choice. Give special priority to unusual or distinctive features, such as spores exceptionally large or small, spore surfaces ornamented, walls unusually thick or thin (first browse through the key to see if opportunities exist for a quick and easy determination). If, for example, an *Acaulospora* collection has all spores less than 100 μm in diameter, you will find that only No. 8, *A. trappei*, conforms to that description in 1-1-a. Suppose, however, that some *Acaulospora* spores have reticulate ornamentation and that is used as the first descriptive choice. Jot down the numbers following descriptive choice 1-3-f. 1,2,4. Then it is noted that all spores in the collection have walls 2–3 μm thick (descriptive choice 1-6-b). Compare the numbers jotted down for reticulate-spored species with those for species with walls 2–3 μm thick: delete from the jotted list any number not represented in choice 1-6-b. In this case, number 2 is deleted, leaving 1 and 4 as the only species that combine reticulation with walls 2–3 μm thick. Then a grayish-green color in the spore wall is noted, so descriptive choice 1-5-e is used. Species 4 is not listed here, so delete it from the list, leaving species No. 1, *A. bireticulata*, as the only one having reticulate spores with gray-green walls 2–3 μm thick. Use of characters that are unique or distinctive increases efficiency, because more species drop out initially than if one starts with a character common to many species.

As new taxa are described, they can be added to the keys simply by assigning to them the next number in the sequence and adding that number to the appropriate descriptive listings. If concepts are changed for a previously described taxon through new research, the key can be corrected simply by adding its number to (or deleting from) the relevant descriptive listings. Additional characters valuable for species identification will become available, eg, reaction to Melzer's regent (now known for only some species, but sometimes quite distinctive). Each key user can add these as new data permit.

Precautions in identifying VA fungi. A high-quality research microscope with an oil-immersion objective is required for species identification of Endogonaceae. Colors described in the keys are for tungsten-filament, Köhler illumination with no filters. Single spores are often identifiable if in excellent condition and not parasitized (9). Dependable identifications, however, usually require numerous spores, so that variations within species can be assessed. Badly deteriorated spores cannot usually be identified. Wall structure of spores is often determined most reliably by observing crushed spores. This reduces artifacts from light refraction and reveals whether or not wall layers are separable. Potassium hydroxide, a common mounting medium in mycology, should be avoided in the study of Endogonaceae, because it often induces unnatural swelling of spore walls. Once a fungus has been identified by using a key, its features should always be compared to the species description to be sure they are all the same: undescribed species may sometimes key out in either dichotomous or synoptic keys.

Synoptic Key to Genera of Endogonaceae and Morphologically Similar Taxa

1. *Acaulospora* (7). **2.** *Complexipes* (28). **3.** *Endogone* (7). **4.** *Entrophospora* (2). **5.** *Gigaspora* (7). **6.** *Glaziella* (22). **7.** *Glomus* (7). **8.** *Modicella* (7). **9.** *Sclerocystis* (7).

1. Spores

1-1. Shape.
a. globose *1*, 2, *3, 4, 5, 6, 7*
b. ellipsoid, obovoid, reniform, or irregular *1, 3, 4, 5, 6, 7*, 8
c. broadly clavate *7, 9*
d. narrowly clavate with straight sides *9*

1-2. Longest dimension at maturity (both smallest and largest spores can be run through the key to define size ranges).
a. <20 μm *7, 8*
b. 20–100 μm *1, 2, 3, 7, 8, 9*
c. 100–300 μm *1, 2, 3,* 4, *5, 6, 7, 9*
d. 300–500 μm *1, 5, 6, 7*
e. >500 μm *5*

1-3. Surface configuration at maturity (all smooth in youth).
a. smooth to dull-roughened *1, 3, 5,* 6, *7,* 8, 9
b. surface layer flaking or sloughing away *7*
c. pits *1, 5*
d. warts *5, 7*
e. slender spines or rods *1,* 2, *5, 7*
f. polygonal projections *1*
g. crowded, erect tubes 4
h. reticulation *1, 5*
i. cerebriform folds *1*
j. spiralling ridges *3*
k. tightly enclosing mantle of *3, 7*

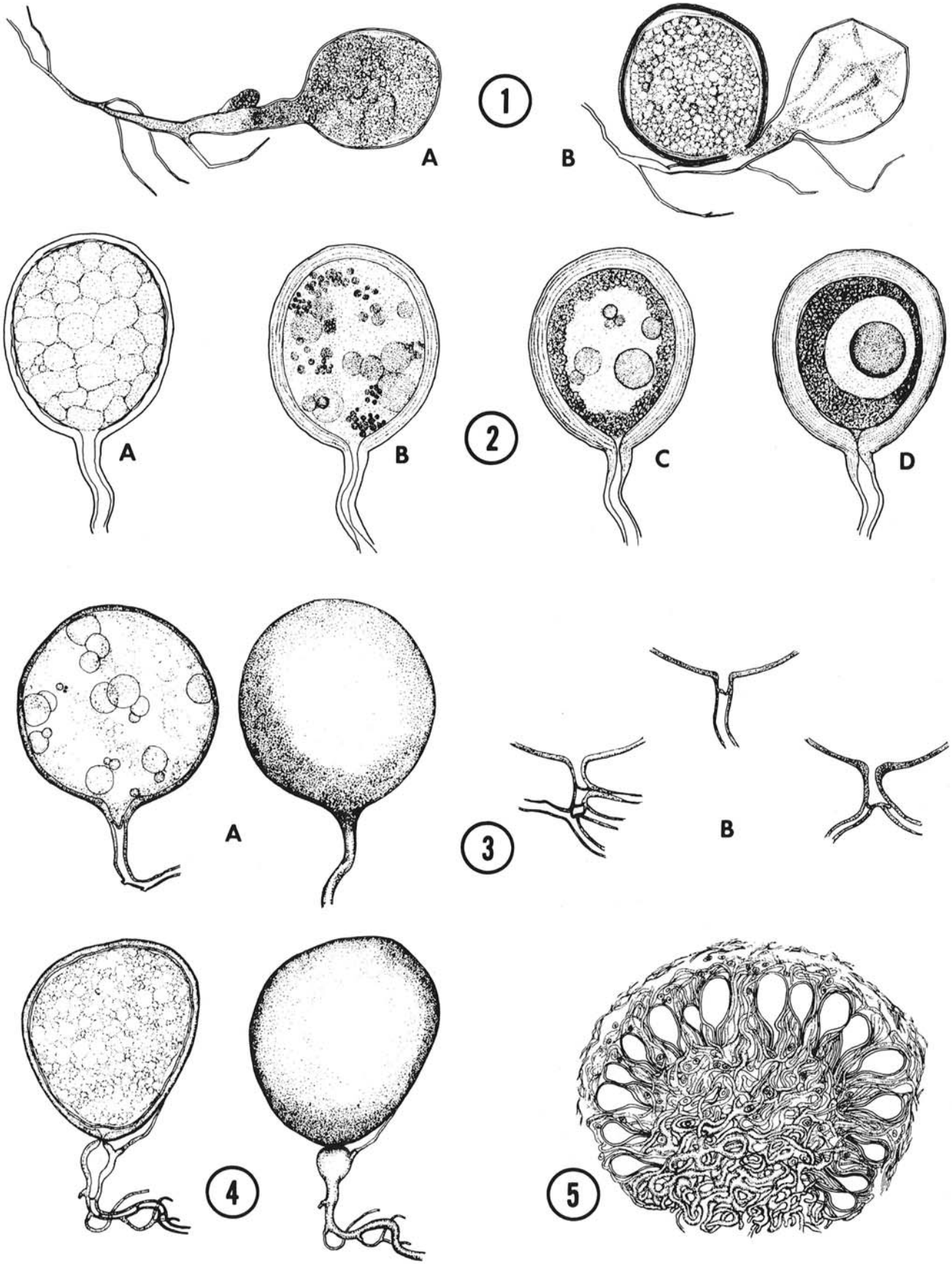
2. Attached hyphae or enclosing cell

2-1. Number (check numerous spores).
a. none perceptible *1, 3, 4,* 8
b. one *1,* 2, *4,* 5, 6, *7,* 9
c. two or more on at least some spores *3, 7*

2-2. Form of hyphae near attachment to spore, or enclosing cell.
a. Large, tapered hypha with inflated globose apex; spore budding from side of tapered hypha 1
b. Bulbous, suspensorlike cell usually with one to several emergent pegs; spore produced at tip or on side of cell 5
c. Mostly aseptate, cylindric to flaring, inflated, or constricted hypha, chlamydospore produced at apex 6, *7,* 9
d. Inflated hypha apex from which bud several chlamydospores *7*
e. Chain of ~isodiametric cells, spore produced from apical cell 2
f. Two gametangia; spore budding from gametangial union or from the tip of one of the fused gametangia *3*
g. Two suspensors with spore formed between *3*
h. Sporangia enclosing numerous sporangiospores 8
i. Large, thick-walled terminal cell with spore forming inside 4

3. Sporocarps

3-1. Presence.
a. present 3, 6, *7,* 8, 9
b. absent 1, 2, 4, 5, *7*



Figs. 1–5. Representative spores of vesicular-arbuscular (VA) mycorrhizal fungi: **1,** *Acaulospora laevis* in cross section (×100); **A,** tapered, globose-tipped hypha with a budding spore initial; **B,** cytoplasmic content of collapsing attached hypha streaming into the maturing spore. **2,** *Glomus fasciculatum* spores in cross section from **A,** young to **D,** mature stages (×500); fine lines in spore walls are successive deposits ("laminations") of wall material that by maturity occlude the opening into the attached hypha. **3,** *Glomus mosseae* (×200); **A,** cross-sectional and surface views of spores and characteristic hyphal attachment separated from spore contents by a protuding septum; **B,** variant forms of hyphal attachments. **4,** *Gigaspora calospora* spore formed at the tip of an inflated, suspensorlike cell with emergent pegs; cross-sectional and surface views (×200). **5,** *Sclerocystis coremioides* sporocarp in cross section (×100). (Drawings by Wendy Madar).

3-2. Form.
a. Amorphous to tightly packed aggregations of spores, spore clusters, or sporangia *3, 7,* 8
b. Spores radiating from base, but distributed throughout the sporocarp *3, 7*
c. Spores erect in a single layer around a central plexus of hyphae; numerous sporocarps often fused into crusts 9
d. Spores in walls of large, hollow, bright orange to red sporocarps 6

3-3. Longest dimension (both smallest and largest sporocarps can be run through the key to define size ranges).
a. <1 mm *7, 9*
b. 1–10 mm *3, 7,* 8, *9*
c. >10 mm *3,* 6, *7, 9*

3-4. Color of surface (at maturity in sun- or strong tungsten light).
a. white to gray *3, 7, 8, 9*
b. yellow *3, 7, 9*
c. brown *3, 7, 9*
d. orange to red 6
e. violet *8*
f. nearly black *9*

3-5. Peridium.
a. absent *3, 7,* 8, *9*
b. interwoven hyphae *3,* 6, *7, 9*
c. erect, emergent hyphae *7*
d. large, inflated cells *7, 9*

The following keys to species cover only the genera *Acaulospora, Gigaspora, Glomus,* and *Sclerocystis. Complexipes* forms ectendomycorrhizae with otherwise ectomycorrhizal hosts (28). Robert Danielson (*personal communication*) has confirmed that spores of *Complexipes* are produced by certain species of Pyronemataceae (Discomycetes). *Endogone* includes some species that form ectomycorrhizae and some that may be saprophytes or hyperparasites (7). *Entrophospora* is presently known only from the type species and has yet to be confirmed as a mycorrhiza former (2). Its relationship to the other Endogonaceae is uncertain. The nutritional habits of *Modicella* spp. are unknown and their relationship to other Endogonaceae remains unclear (7).

Synoptic Key to Species of *Acaulospora*

1. *bireticulata* Rothw. & Trappe (19). **2,** *elegans* Trappe & Gerd. (7). **3.** *foveata* Trappe & Janos (13A) **4.** *gerdemannii* Schenck & Nicol. (16). **5.** *laevis* Gerd. & Trappe (7). **6.** *scrobiculata* Trappe (23). **7.** *spinosa* Walker & Trappe (31). **8.** *trappei* Ames & Lind. (1). **9.** *tuberculata* Janos & Trappe (13A).

1. Spores

1-1. Shape.
a. globose 1, *2, 3,* 4, *5, 6, 7, 8,* 9
b. ellipsoid to reniform *2, 3, 5, 6, 7, 8*

1-2. Longest dimension at maturity (both smallest and largest spores can be run through the key to define size ranges).
a. <100 μm 8
b. 100–200 μm 1, *2, 5, 6, 7*
c. 200–300 μm *2, 3,* 4, *5, 6, 7, 9*
d. 300–400 μm *2, 3, 5, 7, 9*
e. >400 μm *5*

1-3. Surface ornamentation at maturity (all smooth in youth).
a. smooth to dull-roughened 5, 8
b. pitted 3, 6
c. rounded projections 9
d. polygonal projections *1*
e. spines or cylindrical rods *2,* 7
f. reticulation *1, 2, 4*
g. cerebriform folds *4*

1-4. Distinct wall layers (examine crushed spores).
a. single 8
b. double, both ~ equal 4
c. multiple, all ~ equal 1
d. multiple, thick outer layer over one or more thin layers 2, 3, 5, 6, 7, 9

1-5. Wall color in cross section at maturity with transmitted tungsten illumination (all hyaline in youth).
a. all layers hyaline *6,* 8
b. outer layer yellow, inner layers hyaline *6*
c. outer layer brown, inner layers hyaline 2, 3, 4, 5, 7
d. outer layer yellow, middle layer brown, inner layer hyaline 9
e. one or more layers grayish green 1, *6*

1-6. Composite wall thickness at maturity (excluding ornamentation).
a. < 2 μm *8*
b. 2–4 μm 1, 4, *5, 6, 7, 8*
c. 4–8 μm 3, *5, 6, 7*
d. 8–12 μm *7, 9*
e. >12 μm 2, *9*

Synoptic Key to Species of *Gigaspora*

1. *albida* Schenck & Smith (20). **2.** *aurigloba* Hall (10). **3.** *calospora* (Nicol. & Gerd.) Gerd. & Trappe (7). **4.** *coralloidea* Trappe, Gerd. & Ho (7). **5.** *erythropa* Koske & Walker (in preparation) **6.** *gigantea* (Nicol. & Gerd.) Gerd. & Trappe (7). **7.** *gilmorei* Trappe & Gerd. (7). **8.** *gregaria* Nicol. & Schenck (16). **9.** *heterogama* (Nicol. & Gerd.) Gerd. & Trappe (7). **10.** *margarita* Becker & Hall (4). **11.** *nigra* Redhead in Nicol. & Schenck (16). **12.** *pellucida* Nicol. & Schenck (16). **13.** *persica* Koske (in preparation). **14.** *rosea* Nicol. & Schenck (16). **15.** *alborosea* Ferr. & Herr. (5A). **16.** *minuta* Ferr. & Herr. (5A). **17.** *savannicola* Herr. & Ferr. (5A). **18.** *tricalypta* Herr. & Ferr. (5A).

1. Spores

1-1. Longest dimension at maturity (both smallest and largest spores can be run through the key to define size ranges).
a. <200 μm *1, 3, 9, 12, 15,* 16
b. 200–300 μm *1, 2, 3, 5, 7, 8,* 9, *10, 11, 12, 14, 15, 17*
c. 300–400 μm *1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12,* 13, *14, 15, 17, 18*
d. 400–500 μm *2, 3, 4, 5, 6, 8, 10, 11, 17, 18*
e. 500–600 μm *2, 5, 6, 11, 17*
f. >600 μm *6, 11*

1-2. Surface ornamentation at maturity (all smooth in youth).
a. smooth to dull-roughened 2, 3, 5, 6, 7, 10, 12, 14, 15, 17
b. pitted 1, *11*
c. warty 4, 8, 13, 16
d. minutely spinose 9, 18
e. reticulate *11*

1-3. Distinct wall layers (examine crushed spores).
a. single *10*
b. double, outer layer thicker than inner 12
c. double, outer layer thinner than inner 5, 6
d. multiple, all ~ equal or of varying thickness 1, *10,* 14
e. multiple, one thick layer over two or more thin, separable, inner layers 2, 3, 4, 18
f. multiple, two or more adherent outer layers over one to several thin, separable, inner layers 7, 8, 9, 11, 13, 15, 16, 17

1-4. Wall color in cross section at maturity with transmitted tungsten illumination (all hyaline in youth).
a. all layers hyaline to subhyaline 1, 7, *10,* 12, *14, 17*
b. outer layer hyaline, inner yellow to brown *6,* 13, 16
c. outer layer yellow 2, 3
d. one or more layers grayish green *6*
e. one or more layers pink near spore base *14,* 15
f. outer layer brown, inner hyaline 4, 5, *8, 9, 10*
g. all layers brown *8, 9*
h. outer layer dark-brown to black, inner brown 11, 18

1-5. Composite wall thickness at maturity (excluding ornamentation).
a. <5 μm 1, *3, 14*
b. 5–8 μm *1, 2, 3, 5, 6, 7, 9, 10, 12, 13, 14, 15,* 16, 17
c. 9–12 μm *1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15*
d. 13–20 μm *2, 4, 5, 7, 8, 10, 11, 15,* 18
e. >20 μm *10*

2. Bulbous attachment

2-1. Diameter.
a. <30 μm *1, 7, 9, 10,* 12, *14, 15,* 16, *18*
b. 30–50 μm *1, 2,* 3, *6, 7, 8, 9, 10, 11, 13, 14, 15,* 17, *18*
c. 50–60 μm *2, 4,* 5, *6, 8, 10, 11, 13*
d. >60 μm *2, 4, 8, 11, 13*

2-2. Wall color with transmitted tungsten illumination (all hyaline in youth).
a. hyaline *1, 2, 6, 10,* 12, 14, *15,* 17
b. yellow *1, 2,* 3, *6,* 13, *15*
c. yellowish brown to moderate brown 4, 5, 7, 8, 9, *10,* 11, 16, 18

3. Accessory soilborne vesicles

3-1. Largest dimension at maturity.
a. <30 μm *1,* 3, 5, *6,* 7, *8, 9, 10, 11, 12,* 13, *14,* 17
b. 30–40 μm *1, 2, 3,* 4, *6, 8, 9, 10, 11, 12, 14*
c. 40–50 μm *2, 8, 9, 11*
d. >50 μm *2*

3-2. Ornamentation at maturity (all smooth in youth).
a. smooth *3, 9*
b. rounded to irregular knobs or lobes *2, 3, 4,* 5, 7, 8, *9,* 10, *11,* 12, 13, 17
c. spines or cones, 1, *2,* 6, 14
d. digitate to coralloid projections *4, 11*
e. Unknown 15, 16, 18

3-3. Color at maturity with transmitted tungsten illumination (all hyaline in youth).
a. hyaline *1, 2,* 6, *10,* 13, 14
b. yellow *1, 2,* 3, *5*
c. brown 4, *5,* 7, 8, 9, *10,* 11, 12, 17
e. unknown 15, 16, 18

3-4. Clustering.
a. borne singly 3, 4, *10, 12*
b. 2–12 per cluster *1,* 2, *5, 6, 7, 8,* 9, *10, 11, 12,* 13, 14, *17*
c. >12 per cluster *1, 5, 6, 7, 8, 10, 11, 12, 17*
d. unknown 15, 16, 18

Synoptic Key To Species of *Glomus*

To correct a past error in Latin usage (26), endings of all adjectival species epithets listed below have been changed to neuter to conform to the gender of the neuter noun *Glomus.*

1. *aggregatum* Schenck & Smith (20). **2.** *albidum* Walker & Rhodes (30). **3.** *boreale* (Thaxter) Trappe & Gerd. (22). **4.** *caledonicum* (Nicol. & Gerd.) Trappe & Gerd. (7). **5.** *canadense* (Thaxter) Trappe & Gerd. (22). **6.** *claroideum* Schenck & Smith (20). **7.** *clarum* Nicol. & Schenck (16). **8.** *constrictum* Trappe (23). **9.** *convolutum* Gerd. & Trappe (7). **10.** *deserticola* Trappe, Bloss & Menge (25). **11.** *epigaeum* Daniels & Trappe (5). **12.** *etunicatum* Becker & Gerd. (3). **13.** *fasciculatum* (Thaxter sensu Gerd.) Gerd. & Trappe (7). **14.** *fecundisporum* Schenck & Smith (20). **15.** *flavisporum* (Lange & Lund) Trappe & Gerd. (15). **16.** *fragile* (Bk. & Br.) Trappe & Gerd. (22). **17.** *fuegianum* (Speg.) Trappe & Gerd. (8). **18.** *fulvum* (Bk. & Br.) Trappe and Gerd. (22). **19.** *geosporum* (Nicol. & Gerd.) Walker (29). **20.** *gerdemannii* Rose, Daniels & Trappe (17). **21.** *halonatum* Rose & Trappe (18). **22.** *intraradices* Schenck & Smith (20). **23.** *invermaium* Hall (10). **24.** *lacteum* Rose & Trappe (18). **25.** *leptotichum* Schenck & Smith (20). **26.** *macrocarpum* Tul. & Tul. (7,26,27). **27.** *magnicaule* Hall (10). **28.** *melanosporum* Gerd. & Trappe (7,26,27). **29.** *microcarpum* Tul. & Tul. (7,26,27). **30.** *monosporum* Gerd. & Trappe (7). **31.** *mosseae* (Nic. & Gerd.) Gerd. & Trappe (7). **32.** *multicaule* Gerd. & Bakshi (6). **33.** *occultum* Walker (29). **34.** *pallidum* Hall (10). **35.** *pubescens* (Sacc. & Ell.) Trappe & Gerd. (22). **36.** *pulvinatum* (Henn.) Trappe & Gerd. (22). **37.** *radiatum* (Thaxter) Trappe & Gerd. (7). **38.** *scintillans* Rose & Trappe (18). **39.** *segmentatum* Trappe, Spooner & Ivory (24). **40.** *tenue* (Green) Hall (10). **41.** *tortuosum* Schenck & Smith (20). **42.** *vesiculiferum* (Thaxter) Gerd. & Trappe (7). **43.** *reticulatum* Bhatt. & Muk. (4A).

Two species described by Tandy (21), *G. tenerum* and *G. tubaeforme*, are excluded because the descriptions do not conform well to the type collections.

1. Spores

1-1. Shape.
a. globose, often mixed with subglobose, ovate, ellipsoid, or irregular spores 1, 2, *4,* 6–14, 16, 17, 19–30, *31,* 32–36, 38–43
b. all or nearly all ellipsoid 3, 5, 15, 18, 37
c. pyriform or with projecting base *4, 31*

1-2. Longest dimension at maturity (both smallest and largest spores can be run through key to define size range).
a. <15 μm 40
b. 20–50 μm *29, 33, 34,* 35
c. 50–75 μm *1, 5, 6, 7, 10, 12, 13,* 16, *17, 18,* 23, *25, 29, 33, 34, 36, 37, 39, 42*
d. 75–100 μm *1, 2, 5, 6, 7, 9, 10–13, 17, 18, 25, 33, 34, 36, 37, 39, 42*
e. 100–125 μm *1, 2, 6, 7, 9–14, 18, 19, 22, 25, 26, 31, 33, 36, 37, 39, 41*
f. 125–150 μm *2,* 3, *4, 6, 7, 9–12, 14, 18, 19, 22, 25, 26, 27, 30, 31, 33, 41, 43*
g. 150–175 μm *2, 4, 6–9, 11, 12, 14, 15, 18, 19, 20, 24–28, 30, 31, 32, 33, 41, 43*
h. 175–200 μm *2, 4, 6–9, 14, 15, 19, 20, 24, 25, 26, 28, 30–33, 38, 41*
i. 200–225 μm *4, 7, 8, 14, 15, 19, 20, 21, 24, 25, 26, 28, 30, 31, 32, 38, 41*
j. 225–250 μm *4, 7, 8, 19, 20, 21, 25, 30, 31, 32, 41*
k. 250–300 μm *4, 7, 8, 19, 21, 25, 30, 31*
l. >300 μm *8, 30, 31*

1-3. Hyphal envelope enclosing individual spores.
a. absent—all numbers *except* 9, 28, 41
b. of interwoven hyphae 9, 28, *30, 31*
c. of sinuous hyphae 41

1-4. Surface ornamentation at maturity (all smooth in youth).
a. smooth to dull-roughened—all numbers *except* 25, 30, 38
b. coarsely roughened or sloughing off *2, 20, 21, 33*
c. pitted *32*
d. warty *7, 32,* 38
e. reticulate 25, *32, 43*
f. minute spines or fractures in hyaline matrix 30
g. cerebriform folds *7*

1-5. Distinct wall layers (rather than fused deposits of wall material within a single layer—examine crushed spores).
a. single 3, 5, *6, 8,* 9, 10, *12, 13,* 15, 17, 18, *22,* 24, 25, *26,* 28, 29, *31,* 32, 34–37, 40, 41, *42*
b. double, both ~ equal *1, 2, 4, 6, 8, 12,* 14, *21, 22, 33*
c. double, outer thicker than inner *1, 2, 4, 6,* 7, 27, *33*
d. double, outer thinner than inner 11, *12, 13,* 16, 19, *20, 21, 22,* 23, *26,* 30, *31, 33,* 39, *42,* 43
e. three or more layers *20, 22, 33,* 38

1-6. Wall color in cross section at maturity with transmitted tungsten illumination (all hyaline in youth).
a. all layers hyaline *2,* 5, *6, 7, 9, 16, 18,* 20, 24, *25, 29,* 33, 34, *35,* 36–40
b. all layers yellow *1, 6, 9, 13, 17, 18, 25, 29, 31, 35, 41,* 42
c. all layers yellowish brown to brown *1, 6, 8, 12, 13, 14,* 15, *17, 22, 26, 27, 31,* 32, *41*
d. all layers reddish brown to orange-brown 3, 10, *17,* 28
e. all layers brownish black to black *8, 14, 19, 28,* 43
f. outer layer hyaline, inner yellow to brown *2,* 4, *7,* 11, *12, 13, 16,* 19, 21, *22,* 23, *26,* 30, *31*
g. outer layer brown, inner hyaline *27*

1-7. Composite wall thickness at maturity.
a. < 3 μm *1, 2, 16, 25, 34,* 40, 41
b. 3–4 μm *1, 2,* 5, *10, 14, 16,* 18, *20, 22, 24, 25, 29, 31, 33–36*
c. 5–8 μm *2,* 3, *4, 6–15, 17, 19, 20, 22,* 23, *24, 25, 26, 28–36,* 37, *38,* 39, 42, 43
d. 9–12 μm *2, 4, 6–9, 11–15, 17, 19, 20, 22, 25–28, 30, 32, 38*
e. 13–20 μm *4, 7, 8, 12, 13, 15, 17, 19–22, 26, 27, 28, 32*
f. >20 μm *7, 21, 27, 32*

1-8. Contents of intact, healthy, mature spores.
a. white to hyaline globules or granules—1–5, *6,* 7, 8, 10–14, 16–21, 23, 24 *25,* 26–29, *30,* 31–36, *37,* 38–43
b. yellow globules or granules *6,* 9, 15, *22, 25*
c. brown globules *22*
d. hyaline hyphae *30, 37*

2. Subtending hyphae

2-1. Number.
a. single—all numbers
b. sometimes two *2, 12, 19, 24, 30, 31, 32, 34*
c. sometimes three or more *24, 32*
d. none perceptible *20, 28, 30, 31*

2-2. Shape.
a. cylindric or flared towards point of attachment 1, *2,* 3–7, *8,* 9, 10, *11,* 12–16, 18, 19, 20, *22, 23,* 24, 25, 26, *27,* 28–38, *39,* 40–43
b. cylindric but constricted at point of attachment *2, 8, 11, 21, 22, 23, 27, 39*
c. bulbous, constricted at point of attachment *8, 21*
d. bulbous, giving rise to several spores 17

2-3. Diameter at point of attachment.
a. <2 μm 40
b. 2–4 μm *2,* 35
c. 5–8 μm *1, 2, 3,* 5, *6, 9, 10, 11,* 12, *13, 14, 16, 17, 20,* 21, *23, 24, 29, 33, 34, 37, 38, 42, 43*
d. 9–12 μm *1–4, 6, 8–11, 13–18, 20, 22–26, 29,* 30, *31, 33, 34, 36–39, 41–43*
e. 13–20 μm *2, 4, 6, 7, 8, 13, 14, 15, 18, 19, 20, 22, 23, 25, 26,* 28, *31, 32, 34, 36, 38, 39, 41*
f. >20 μm *7, 8, 19, 22, 25,* 27, *32, 41*

2-4. Wall color at maturity with transmitted tungsten illumination (all hyaline in youth).
a. hyaline *1, 2, 3, 5, 6,* 7, 9, *11,* 12, 16, 18, 20, *21, 23,* 24, 25, 27, *28, 29, 31, 32,* 33–40, *41, 43*
b. yellow *1, 2, 4, 5, 6, 11, 13, 15, 17, 19, 22, 29–32,* 42, *43*
c. brown *1, 3, 4, 8,* 10, *11, 13, 14, 15, 17, 19, 21, 22, 23,* 26, *28, 30, 32, 41, 43*
d. brownish black to black *8, 14*

2-5. Wall thickness at maturity (all thin in youth).
a. <1 μm 40, *41*
b. 1–2 μm *1, 2, 3,* 5, *6, 9,* 11, *12, 15,* 16, 18, *22, 24, 27, 28, 31, 33, 34,* 35, 36, 39, *41, 43*
c. 2–4 μm *1–4, 6, 8, 9,* 10, *12–15,* 20, *22,* 23, *24–34, 37,* 38, *42, 43*
d. 5–8 μm *4, 7, 8, 13, 14, 17, 19,* 21, *22, 25, 26, 29, 30, 32, 37, 42*
e. >8 μm *7, 17, 19, 26, 32*

2-6. Alignment with spore axis.
a. straight—all numbers
b. recurved along spore surface *8, 30, 32, 33*

2-7. Closure at spore wall.
a. occlusion by spore wall thickening or plug 4, 6–9, 13, 14, *17, 19,* 21, 22, 23, *25,* 26, 27, *28,* 29, 30, 32, 35, 37, 39, *40,* 42, 43
b. septum or inner spore wall 1, *2,* 3, 5, 10, 11, 12, 15, 16, *17,* 18, *19,* 20, 24, *25, 28,* 31, 33, 34, 36, 38, 41
c. collapse of hypha *2, 40*

3. Sporocarps

3-1. Presence or absence.
a. absent *1,* 2, *4,* 6, 7, 8, 10, *11,* 12, *13,* 14, 19–22, *23,* 24, 25, *26,* 27, *29, 30, 31,* 32, 33, *34,* 38, 40, 41, 43
b. present *1,* 3, *4,* 5, 9, *11, 13,* 15–18, *23, 26,* 28, *29, 30, 31, 34,* 35, 36, 37, 39, 42

3-2. Shape.
a. round *1, 3,* 4, *5, 13, 15,* 16, 17, 18, *26,* 28, *29,* 30, 31, 36, *37,* 39
b. lobed or convoluted *1, 5,* 9, *11, 13, 15, 26, 29, 34, 37, 42*
c. flattened crusts or layers *42*
d. irregular aggregations *1, 3, 11, 13,* 23, *29, 34, 42*
e. elevated on a short stipe 35

3-3. Largest dimension (both smallest and largest sporocarps can be run through key to define size range).
a. <1 mm *1, 13, 23, 29,* 30, 31, *35*
b. 1–10 mm *1,* 3, 4, 5, 9, *11, 13,* 15–18, *23, 26, 28, 29, 34, 35,* 36, 37, 39, 42
c. 11–20 mm *11, 26, 28, 29, 34*
d. >20 mm *11*

3-4. Surface texture and configuration.
a. exposed spores 1, *3,* 11, 13, *23, 26, 28, 29, 34*
b. cottony, felty *3,* 4, 5, *9,* 15, 16, *17, 18, 26, 28, 29,* 30, 31, *34,* 36, *37*
c. pubescent with erect hyphal tips 35
d. subglabrous to glabrous *17, 18, 37, 39*
e. minutely warty from outer spore outlines or inflated cells *9, 23,* 42
f. subpolygons separated by grooves *39*

3-5. Surface color in sun or strong tungsten light (fresh, at maturity).
a. white to gray *1,* 4, 5, *15,* 16, 17, *18, 26, 28, 29, 34–37,* 39, *42*
b. yellow *1,* 9, *18, 34–37, 42*
c. brown 3, 11, 13, *15,* 23, *26, 28, 29,* 30, 31

3-6. Interior color at maturity in sun or strong tungsten light (fresh at maturity).
a. white to gray *1, 16, 18, 34, 36, 37, 39*
b. yellow *1, 4,* 9, *16, 18, 29, 34–37, 39,* 42
c. brown 3, *4,* 5, 11, 13, 15, 17, 23, 26, *29,* 30, 31, *35*
d. brownish-black to black 28

3-7. Gross morphology of interior.
a. undifferentiated—all numbers *except* 17, 39, 42
b. discrete clusters of spores separated by hyphae or soil 17, 42
c. separable segments radiating from base 39

3-8. Spore arrangment (section sporocarps vertically).
a. random—all numbers *except* 17, 42
b. discrete clusters 17, 42
c. radiate from sporocarp base *35, 37, 39*

3-9. Numbers of spores in sporocarps.
a. 1–5: 30, *31*
b. 6–10: *13, 23, 26, 29, 31, 34*
c. >10—all numbers *except* 30 and 31

3-10. Peridium.
a. absent 1, *3, 9,* 11, 13, 23, *26,* 28, *30, 34*
b. loosely interwoven hyphae *3, 4, 15, 16, 18, 26, 29, 30,* 31, *34, 36, 37*
c. tightly interwoven hyphae *4,* 5, *9, 15, 16,* 17, *18, 29, 30, 36, 37,* 39
d. erect hyphal tips over tangled hyphae 35
e. large, inflated hyphae *15,* 42

Synoptic Key to Species of *Sclerocystis*

1. *clavispora* Trappe (23). **2.** *coccogena* (Pat.) Höhn. (22). **3.** *coremioides* Bk. & Br. (7). **4.** *dussii* (Pat.) Höhn. (7, 22). **5.** *microcarpus* Iqbal & Bushra (13). **6.** *pakistanica* Iqbal & Bushra (13). **7.** *rubiformis* Gerd. & Trappe (7). **8.** *sinuosa* Gerd. & Bakshi (6).

1. Spores

1-1. Shape.
a. ellipsoid to obovoid or subglobose *2, 3, 4,* 7, *8*
b. broadly clavate *2, 3, 4, 5, 8*
c. narrowly clavate with straight sides 1, *5,* 6
d. ellipsoid-clavate within sporocarp, globose in peridium *2*

1-2. Length (both shortest and longest spores can be run through the key to define size ranges).
a. <50 μm *7, 8*
b. 50–100 μm *2,* 3, 4, *5, 6, 7, 8*
c. 100–150 μm *1, 2, 5, 6, 7, 8*
d. 150–200 μm *1, 6*
e. >200 μm *6*

1-3. Wall thickness at spore tip.
a. <5 μm 2, 3, 4, 6, 7, 8
b. >15 μm 1, 5

2. Sporocarps

2-1. Broadest dimension (both smallest and largest sporocarps can be run through the key to define size range).
a. <200 μm *5, 7*
b. 200–400 μm *3, 4, 5, 7, 8*
c. 400–600 μm *1, 2, 3, 4, 5, 6, 7, 8*
d. 600–700 μm *1, 2, 3, 6, 7*
e. >700 μm *1*

2-2. Surface texture and configuration.
a. warty from exposed spore tips 1, 5, 7, *8*
b. felty 3, 6, *8*
c. felty with small, globose chlamydospores 2
d. covered with giant cells 4

2-3. Surface color in sun or strong tungsten light.
a. white *2, 3, 4*
b. yellow *4*
c. brown *2, 3,* 5, 6, *7,* 8
d. brownish-black to black 1, *7*

2-4. Peridium.
a. absent 1, 5, 7
b. thin layer of sinuous, thick-walled hyphae 8
c. interwoven hyphae 2, 3, 6
d. giant cells overlaying interwoven hyphae 4

2-5. Gregariousness of sporocarps.
a. formed singly 1, *3,* 5, 6, 7, 8
b. fused into crusts 2, *3*
c. fused into crusts overlain by giant cells 4

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