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Records of slime molds (Myxomycetes) from deserts and other arid areas of Saudi Arabia

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Slime molds (herein limited to the myxomycetes) are fungus-like organisms associated with dead plant material in terrestrial ecosystems, with approximately 1000 species known worldwide. Slime molds are usually found in relatively moist habitats, so one might not expect them to occur in deserts and other arid areas. However, the number of species reported from this type of habitat is often surprisingly high. Very little is known about the slime molds of Saudi Arabia, including those regions of the country classified as deserts. The objectives of the present paper are (1) to review what is currently known about Saudi Arabian slime molds, (2) to report 15 species and four genera that are new records for the country, and (3) to discuss the need for additional studies.

Keywords: Asir Mountains, fruiting bodies, Saudi desert, sclerotia, Jazan.

Slime molds (herein limited to the myxomycetes) are fungus-like organisms associated with dead plant material in terrestrial ecosystems, with approximately 1000 species known worldwide (Lado 2005-2020). The slime mold life cycle consists of two very different trophic (feeding) stages, one consisting of uninucleate amoebae, with or without flagella (the term "amoeboflagellate" is used to refer to both types), and the other consisting of a distinctive multinucleate structure, the plasmodium (Martin et al. 1984). Under favorable conditions, the plasmodium produces one or more fruiting bodies containing spores, but when conditions are unfavorable, it can transform into a resistant structure called a sclerotium. The fruiting bodies produced by slime molds somewhat resemble those produced by higher fungi, although they are considerably smaller (usually no more than 1–2 mm tall).

Saudi Arabia is located in the southwestern corner of the continent of Asia. Most of the landscape territory is covered by extensive areas of arid deserts, with the exception of the southwestern portion of the country. The largest desert is the Empty Quarter (or Rub' al Khali), which dominates the southern part of the Arabian Peninsula and covers more than 650,000 km^2. Other important deserts are found in the north, including the An Nafud desert with an area of 57,000 km^2, and in the east of the country, including the Ad Dahna desert, with an area of 1,450 km^2. The climate of Saudi Arabia is one of the driest in the world, with an average annual precipitation of less than 100 mm. Temperatures can exceed 50 °C during the summer, but during the winter the average maximum temperature typically drops to 8–17 °C. Most precipitation occurs during the winter months, especially in the western and southern portions of the country. The central region of the country is relatively cold and dry during the winter months (Albugami et al. 2019).

Previous records of slime molds in Saudi Arabia appear to be limited to those reported in a single publication by Yamamoto and Hagiwara (2003), who listed 19 species in 10 genera from the Asir Mountains. The only other region of the Arabian Peninsula investigated to date appears to be the Sultanate of Oman, where Schnittler et al. (2015) carried out a survey for both slime molds and slime mold-like organisms. These authors reported a total of 50 species of slime molds, with all of the records represented by specimens obtained from moist chamber cultures or from agar cultures. The latter technique was not used in the present study nor has it been used in many other comparable studies of slime molds in arid regions of the world. However, the use of agar cultures typically yields specimens of the very small slime molds (e.g., species of *Echinostelium* and *Licea*) that do not always show up in moist chamber cultures.

Most of the species reported by Yamamoto & Hagiwara (2003) were represented by specimens that had fruited in the field. However, the last coauthor of the present paper processed a series of samples collected from a high-elevation locality near Abha (18° 14' 59" N, 42° 30' 38" E; elevation ca. 2270 m) in Aseer Province and a low-elevation coastal locality near the city of Jazan (16° 53' 06" N, 42° 34' 19"W; elevation ca. 5 m) (Fig. 1). These samples were collected during the summer of 2012 and sent to the Eumycetozoan Laboratory at the University of Arkansas for processing. All of the records obtained from these samples were based on specimens from moist chamber cultures.

Methods and materials

Slime molds can be collected as specimens that have formed fruiting bodies in the field as well by culturing specimens from samples of dead plant material collected in the field but placed in moist chamber cultures in the laboratory. For the former, the types of substrates (e.g., decaying wood and dead leaves on the ground) upon which fruiting bodies of these organisms typically occur are examined in an opportunistic manner as described by Cannon & Sutton (2004). However, in arid regions such as deserts, slime molds form fruiting bodies only under the special circumstances associated with a precipitation event, which can be exceedingly rare. As such, the majority of records of slime molds are obtained with the use of moist chamber cultures as described by (Stephenson & Stempen 1994). Types of dead plant material typically placed in moist chamber cultures include pieces of the dead outer bark of living trees and shrubs, dead leaves that have fallen to the ground and woody twigs.

Results

The samples collected from two localities in Saudi Arabia in 2012 yielded a total of 23 species. Fifteen species and four genera were new records for the country, whereas eight of the species recovered had been recorded previously by Yamamoto & Hagiwara (2003). This brings the total number of slime molds now known from Saudi Arabia to 34 species in 14 genera.

Annotated list of species

All species of slime molds now known from Saudi Arabia are arranged alphabetically. Species represented by specimens that developed in the field under natural conditions are marked with (f), whereas those that developed in moist chamber cultures are marked with (mc). The locality (either Abha or Jazan) where the sample material yielding the new records reported herein is provided. Collection numbers given in parentheses are those of the last coauthor.

Arcyria insignis Kalchbr. & Cooke (f)

Reported by Yamamoto & Hagiwara (2003), based on a specimen associated with plant litter.

Badhamia melanospora Speg. (f, mc)

Reported (as *Badhamia gracilis* [T. Macbr.] T. Macbr.) by Yamamoto & Hagiwara (2003), based on specimens associated with cactus debris. These authors recorded the species both in the field and in moist chamber cultures. In the present study, eight specimens (including 29209, 29239 and 3039) were recorded on bark and various types of plant litter from both Abha and Jazan.

Badhamia populina Lister & G. Lister (f, mc)

Reported by Yamamoto & Hagiwara (2003), based on specimens associated with plant litter. In the present study, this was one of the more common species recorded, with 15 specimens (including 29209, 29239 and 3039) recorded on bark and various types of plant litter from Abha. This species was not reported from Oman by (Schnittler et al. 2015).

Ceratiomyxa fruticulosa (O.F. Müll.) T. Macbr. (f)

Reported by Yamamoto & Hagiwara (2003), based on a specimen associated with decaying wood. On the basis of molecular genetic studies, members of the genus *Ceratiomyxa* are now considered to be a sister group to the other "true" slime molds, but traditionally this genus has been considered to be a slime mold and thus subject to being collected and recorded in the same manner. *Ceratiomyxa fruticulosa* was not collected in the present study nor was it reported from Oman by Schnitter et al. (2015).

Comatricha elegans (Racib.) G. Lister (mc)

This species was represented by a single specimen (29261) recorded on decaying wood from Abha.

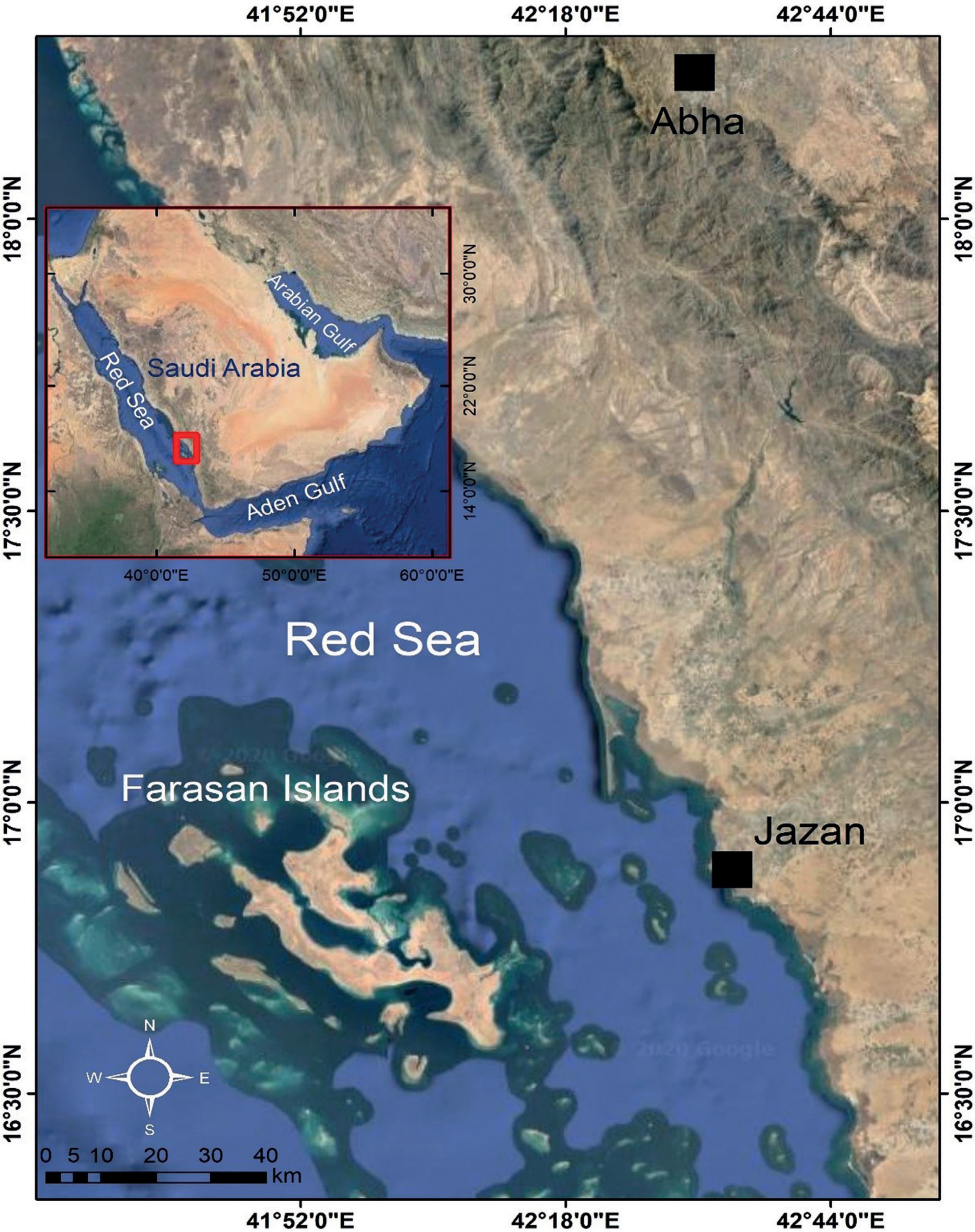

Fig. 1. Map showing the two localities from which samples were collected in the Saudi desert.

This specimen is somewhat problematic but appears to fit the description of *Comatricha elegans* better than any other morphologically similar species.

Comatricha laxa Rostaf. (mc)

This species was represented by two specimens (29196 and 29272) recorded on twigs from Abha.

Comatricha pulchella (C. Bab.) Rostaf. (f, mc)

Reported by Yamamoto & Hagiwara (2003), based on two specimens associated with plant litter. In the present study, this species was represented by three specimens (including 29196 and 29208) recorded on twigs and leaf litter from Abha. This species was not reported from Oman by Schnitter et al. (2015).

Craterium leucocephalum (Pers. ex J.F. Gmel.) Ditmar (f)

Reported by Yamamoto & Hagiwara (2003), based on specimens associated with plant litter and dead wood. These authors recognized the varieties *scyphoides* (Cooke & Balf. ex Massee) G, Lister and *cylindricum* (Massee) G. Lister of *Craterium leucocephalum*, but this distinction has not been made in most surveys carried out for slime molds. This species was not reported from Oman by Schnitter et al. (2015).

Dictydiaethalium plumbeum (Schumach.) Rostaf. (f, mc)

Reported by Yamamoto & Hagiwara (2003), based on a specimen associated with plant litter. This species is only rarely recorded from moist chamber cultures, but a single specimen (29276) was recorded on twigs in the present study. The twigs were from Abha.

Diderma hemisphaericum (Bull.) Hornem. (f)

Reported by Yamamoto & Hagiwara (2003), based on specimens associated with plant litter. This species was not reported from Oman by Schnitter et al. (2015).

Didymium anellus Morgan (mc)

This species was represented by three specimens (including 29258 and 30390), recorded on bark of an unidentified tree from Abha.

Didymium atrichum Henney & Alexop. (mc)

This species is represented by a single specimen (31006), recorded from a sample of litter from Jazan. *Didymium atrichum* appears to be restricted largely to acid regions of the world.

Didymium clavus (Alb. & Schwein.) Rabenh. (f)

Reported by Yamamoto & Hagiwara (2003), based on several specimens associated with plant litter. This species was not reported from Oman by Schnitter et al. (2015).

Didymium difforme (Pers.) Gray (mc)

Represented by six specimens (including 29215 and 30646), recorded on twigs and ground litter from Abha.

Didymium iridis (Ditmar) Fr. (f, mc)

Reported by Yamamoto & Hagiwara (2003), based on several specimens associated with plant litter. In the present study, three specimens (including 29205 and 29260) of this species were recorded on twigs and various types of plant litter from Jazan.

Didymium marineri G. Moreno, Illana & Heykoop (f)

Reported by Yamamoto & Hagiwara (2003), based on several specimens associated with plant litter. This species was not reported from Oman by Schnitter et al. (2015).

Didymium nigripes (Link) Fr.

Reported by Yamamoto & Hagiwara (2003), based on several specimens associated with plant litter. This species was not reported from Oman by Schnitter et al. (2015).

Didymium squamulosum (Alb. & Schwein.) Fr. & Palmquist (f, mc)

Reported by Yamamoto & Hagiwara (2003), based on a number of specimens associated with plant litter. This was one of the more common species reported in this previous study, but it was represented by only a single specimen (29244) in the present study. The latter was associated with ground litter from Jazan. This species was not reported from Oman by Schnitter et al. (2015).

Echinostelium coelocephalum T.E. Brooks & H.W. Keller (mc)

Represented by a single specimen (30395), recorded from the bark of an unidentified tree sampled in Jazan.

Echinostelium minutum de Bary (mc)

Represented by two specimens (both observed but not collected), recorded from the bark of an unidentified tree sampled in Jazan.

Licea kleistobolus G.W. Martin

Represented by a single specimen (29357), recorded on the bark from an unidentified tree sampled in Abha. This species was not reported from Oman by Schnitter et al. (2015).

Perichaena depressa Lib. (mc)

This species was represented by three specimens (including 29192 and 30647), recorded from ground litter and the bark from an unidentified tree sampled in Abha.

Perichaena vermicularis (Schwein.) Rostaf. (mc)

This species was represented by 10 specimens (including 29195, 30387 and 30399), recorded on bark and ground litter and from Abha.

Physarum bitectum G. Lister (f)

Reported by Yamamoto & Hagiwara (2003), based on a specimen associated with plant litter.

Physarum cinereum (Batsch) Pers. (f)

Reported by Yamamoto & Hagiwara (2003), based on a specimen associated with plant litter. One specimen (30388) that appears to represent this species was recorded in the present study. This species was not reported from Oman by Schnitter et al. (2015).

Physarum compressum Alb. & Schwein. (mc)

This species was represented by two specimens (29218 and 30643), recorded on ground litter from Abha.

Physarum decipiens M.A. Curtis (mc)

This species was represented by a single specimen (29210), recorded on twigs from Abha. This species was not reported from Oman by Schnitter et al. (2015).

Physarum leucophaeum Fr. & Palmquist (f)

Reported by Yamamoto & Hagiwara (2003), based on a specimen associated with plant litter. This species was not reported from Oman by Schnitter et al. (2015).

Physarum leucopus Link

Reported by Yamamoto & Hagiwara (2003), based on a specimen associated with plant litter. This species was not reported from Oman by Schnitter et al. (2015).

Physarum notabile T. Macbr. (mc)

This species was represented by a single specimen (29207), recorded on bark from an unidentified tree sampled in Abha. This species was not reported from Oman by Schnitter et al. (2015).

Physarum pusillum (Berk. & M.A. Curtis) G. Lister (f, mc)

Reported by Yamamoto & Hagiwara (2003), based on specimens associated with plant litter. In the present study, seven specimens (including 29199, 29203 and 30394) were recorded on twigs and ground litter from Abha and Jazan.

Physarum straminipes Lister (mc)

This species was represented by five specimens (including 29218, 30385 and 30636), recorded on bark and ground litter from Abha. It was not reported from Oman by Schnitter et al. (2015).

Protophysarum phloiogenum M. Blackw. & Alexop. (mc)

This species was represented by nine specimens (including 29266, 29269 and 30383), recorded on bark and ground litter from Abha. *Protophysarum phloiogenum* appears to be restricted largely to arid regions of the world (Schnittler et al. 2015), so its relative abundance in Saudi Arabia would not seem surprising.

Willkommlangea reticulata (Alb. & Schwein.) Kuntze (f)

Reported by Yamamoto & Hagiwara (2003), based on a specimen associated with plant litter. Stephenson et al. (2008) not indicated in literature cited suggested that woody twigs represent the primary microhabitat for this species. It was not reported from Oman by Schnitter et al. (2015).

Discussion

As indicted in the introduction, slime molds are seriously understudied in Saudi Arabia, but their occurrence in deserts and other arid areas has been established from the data generated from studies carried out in other regions of the world. For example, Blackwell & Gilbertson (1980) listed 46 species from the Sonoran Desert of Arizona in the southwestern United States, and Lado et al. (2007) reported 24 species from the Atacama Desert of northern Chile. The latter total is particularly noteworthy, since the Atacama Desert is one of the driest deserts in the world. Much higher totals have been reported in certain other studies, including 105 species from the Tehuacan-Cuicatlan Biosphere Reserve in Mexico (Estrada-Torres et al. 2009) identified from 1200 records from field and moist chamber culture collections. Two new species (*Didymium tehuacanense* and *Perichaena stipitata* and 158 species from desert and arid steppe in the Lowland Volga River Basin of Russia and adjacent areas of Kazakhstan (Novozhilov et al. 2006).

The occurrence of slime molds in deserts and other arid environments can be attributed to the fact that their spores and sclerotia are desiccation tolerant (Gray et al. 1968, Blackwell & Gilberston 1984). This allows these organisms to survive during periods when vegetative growth is not possible. Such periods occur in most types of ecosystems but are especially common in deserts and other arid areas. It seems likely that some of the slime molds associated with arid environments are more tolerant to desiccation than those found in non-arid environments, but this has never been examined in any detail. However, Blackwell & Gilbertson (1984) reported that slime mold sclerotia incubated at 70 °C still had significant survival rates, although survival differed among the species they examined. These authors also found that sporulation phenology in culture varied among species of desert slime molds, with some species displaying a different developmental time at 20 °C than at 30 °C, while this was not the case for others. It is widely known that pH is a major factor influencing the distribution of slime molds in nature (Stephenson 1994). Many of the substrates on which slime molds occur in deserts are characterized by a much higher pH (sometimes >10) than is typical for those found in most other environments (Blackwell & Gilbertson 1984, Stephenson 1989). All of this would suggest the possibility that the assemblage of species associated with arid areas is made up of a high proportion of particular ecotypes or biotypes (*sensu* Clark 2000) that have adapted to the special environmental conditions present. However, except for the few instances noted above, this phenomenon has not yet been investigated to any real extent.

In extremely dry deserts, the substrates suitable for the growth and development of slime molds are sparse or even completely lacking. However, wherever plant life exists, there is at least some plant detritus that can be colonized by slime molds. If there are trees and shrubs present, both bark and woody twigs represent possible substrates, and the same is true for any other type of plant-derived material (e.g., dead leaves, stems and old fruits and inflorescences). The amoeboflagellates of slime molds are sometimes abundant in soil containing at least some organic matter, but the cultural methods of studying slime molds in this microhabitat are not well-developed. Molecular genetic methods have been demonstrated but have yet to be used extensively. Some species of slime molds are associated with dung, but this substrate was not considered in the present study.

As already indicted, slime molds are seriously understudied in Saudi Arabia. However, the species reported in this paper do represent a potential starting point for more intensive efforts to characterize slime mold biota of this country. It is our hope that such efforts will be carried out in order to document more completely the occurrence of a truly fascinating group of microorganisms. Based on the results obtained from other studies, a considerable number of additional species almost surely have yet to be recorded in Saudi Arabia.

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