Additions to the rust fungi (Pucciniales) from northern Oman

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The first compilation of the rust fungi occurring in the Sultanate of Oman is presented based on historical records and numerous recent collections, primarily from agricultural hosts. The study compiles data for 16 species of Pucciniales in northern Oman, along with voucher and sequence data and presents new distribution data for three of these. Species are also listed by host plant family.

Keywords: Arabian Peninsula, arid regions, biodiversity, Hajar Mountains, Uredinales

Information on the species of rust fungi (Pucciniales) in the Sultanate of Oman is sparse. The first detailed survey of plant diseases in Oman was conducted as recently as 1974 (Bridge & Waller 1974). This was followed by a second survey in 1976 (Waller & Bridge 1976) and a combined report (Waller & Bridge 1978). In these surveys only two rust species were collected and identified: *Puccinia canaliculata* (identified as *P. conclusa* by Moghal 1993) on nut grass (*Cyperus rotundus* L.) and *Uromyces striatus* on alfalfa (*Medicago sativa* L.). Subsequently, the Ministry of Agriculture and Fisheries produced comprehensive survey data for crop diseases in the northern, Al Batinah region of the country (Moghal 1993). In addition to the species recorded by Waller and Bridge, Moghal (1993) identified *Puccinia cynodontis* on Bermuda grass (*Cynodon dactylon* (L.) Pers.), *Cerotelium fici* on fig (*Ficus carica* L.), *Puccinia graminis* on barley (*Hordeum vulgare* L.) and *Uromyces setariae-italicae* on bur bristle grass (*Setaria verticillata* (L.) P. Beauv.). In the years between the disease surveys, two additional reports of rust fungi in Oman were made. A new

species, *Ravenelia omanensis* was described on *Caesalpinia erianthera* Chiov. by Gjaerum & Reid (1983), and *Puccinia magnusiana* was reported on *Phragmites australis* (Cav.) Trin. ex Steud. by Gjaerum (1988). Both of these reports concerned collections made in the Dhofar region of southern Oman.

Most recently, the presence in northern Oman of several agriculturally important rusts has been reported: *Puccinia carthami* on safflower (*Carthamus tinctorius* L.), *Melampsora euphorbiae* on *Euphorbia heterophylla* L., *Tranzschelia discolor* on peach (*Prunus persica* (L.) Batsch), *Puccinia triticina* on wheat (*Triticum aestivum* L.) and *Puccinia sorghi* on maize (*Zea mays* L.) (Deadman *et al*. 2005, 2006a, 2006b, 2007a, 2007b).

Oman is situated on the south-eastern corner of the Arabian Peninsula and this study reports on Pucciniales collected from northern Oman, comprising the Al Batinah, Al Dhahera, Al Dakheliah, Al Sharqiah and Muscat regions where most agricultural activities are concentrated. In these regions date production predominates inland with vegetable cultivation concentrated in Al Batinah region along the northern coast. Natural vegetation is mostly dominated by *Acacia tortilis* (Forssk.) Hayne. The climate of northern Oman is hot and dry in summer and warm and dry in winter. Summer maxima can exceed 45 °C and winter minima rarely fall below 15 °C. Annual rainfall is usually less than 100 mm. The northern Al Hajar Mountain range has a more temperate climate with lower summer maxima, winter minima close to 0 °C and annual rainfall of approximately 300 mm. In the Hajar Mountains production is dominated by tree fruit crops, cereals, onion and garlic with wild olive and juniper and the higher peaks.

No systematic study has been made of the rust fungi in any of the countries of the Arabian Peninsula. Disease specimens from these countries are also lacking in any of the major world herbaria. Neither the U.S. National Fungus Collections (BPI) nor the Arthur Herbarium at Purdue University (PUR) —which contains the world's largest collection of rust fungi—contained any rust specimens from Oman prior to the present study. Because of Oman's position between northeastern Africa and northwestern Asia, a region that, for instance, just recently gave rise to a new, virulent strain of wheat rust, race Ug99 (Singh *et al*. 2007), the collection of baseline data on resident pathogens and their hosts fulfills a timely and critical need.

The current study compiles data for 16 species now known for northern Oman, including three new records––*Puccinia lapsanae, Phragmidium mucronatum,* and *Uromyces appendiculatus*. Furthermore, identities of species previously reported in northern Oman are confirmed using nuclear rDNA sequence data. A host-fungus list arranged by plant family is also provided for easy cross-reference.

Materials and Methods

Fresh collections were made across northern Oman including the Hajar Mountains between January 2005 and December 2006. The area is approximately enclosed by the coordinates 24°56'30"N, 56°25'05"E; 21°58'53"N, 55°40'47"E; 22°28'51"N, 59°49'38"E; 21°03'48"N, 58°50'11"E. The study area also includes the non-contiguous Omani territories of Musandam facing the straits of Hormuz and Madha lying within the borders of the United Arab Emirates. Field collections were transferred to Sultan Qaboos University for initial identification and then to the Systematic Botany and Mycology Laboratory of USDA/ARS, Beltsville, Maryland, USA for detailed examination and molecular characterization. Observations of microscopic features were made using a Zeiss Axioplan 2 microscope with bright-field illumination. Photographs and measurements of microscopic features were taken using a Spot 2 digital camera (Diagnostic Instruments, Inc., Sterling Heights, MI) and ImagePro software (Media Cybernetics, Silver Spring, MD). Pathogen identity was confirmed by nuclear ribosomal large subunit and internal transcribed spacer region-2 DNA analysis, following protocols outlined in Aime (2006). Voucher sequences were deposited in GenBank (http://www.ncbi.nlm.nih.gov/) and voucher specimens deposited in the U.S. National Fungus Collections (BPI, Beltsville, Maryland).

Authority names are based on Authors of Fungal Names (CABI): http://www.indexfungorum.org/Names/Names.asp. Roman numerals indicating rust stages observed on collections (0: spermogonial; I: aecial; II: uredinial; III: telial) are given after collection numbers.

Results and Discussion

This report brings together information on the 16 rust species that are now known to occur in Oman; three of these species are recorded in the country for the first time. The majority of collecting efforts thus far have been directed toward the northern agricultural regions of Oman and on hosts of agricultural importance. It is expected that collections made in the southern Dhofar region where climatic conditions are significantly different to those in northern Oman are likely to yield many additional species. In the following, species are treated alphabetically by genus and a list of specimens examined together with hosts and distribution are provided where available.

Cerotelium fici (Castagne) Arthur, *Bull. Torrey Bot. Club* 44: 509 (1917) – Figs. 2c-e.

Specimens examined. – District of Barka, on agricultural land, on *Ficus carica* L. (Moraceae), Y.M. Al Maqbali, 15 Dec 2004 (BPI 881122), II.

Hosts and distribution. – Known as the common fig rust, this species has been reported on *Ficus* spp. throughout the world under numerous synonyms (Farr & Rossman 2011). No spermogonial/aecial stage is known. First recorded in Oman as *Cerotelium fisci* by Moghal (1993).

Melampsora euphorbiae (Ficinus & C. Schub.) Castagne, *Observ. Uréd.* 2: 18 (1843) – Figs. 1e-g.

Specimens examined. – District of Mudhaibi, 100 km south of Muscat, on margins of agricultural land, on *Euphorbia heterophylla* L. (Euphorbiaceae), S Al Jahdhami, Apr 2005 (BPI 871135; 28S sequence GenBank #DQ351722), II.

Hosts and distribution. – *Melampsora euphorbiae* is an autoecious rust that occurs on *Euphorbia* and *Ricinus* spp. throughout the world. It was first reported in Oman in 2006 (Deadman *et al.* 2006b).

Phragmidium mucronatum (Pers.) Schltdl., *Fl. berol.* (Berlin) 2: 156 (1824) – Figs. 4g–h

Specimens examined. – District of Hail Al Mesibt on Al Jabal Al Akhdar within the western Al Hajar Mountain range, on agricultural land, on *Rosa* sp. (Rosaceae), M Al Ansari, Aug 2005 (BPI 881118; 28S sequence GenBank #HQ412646), II–III.

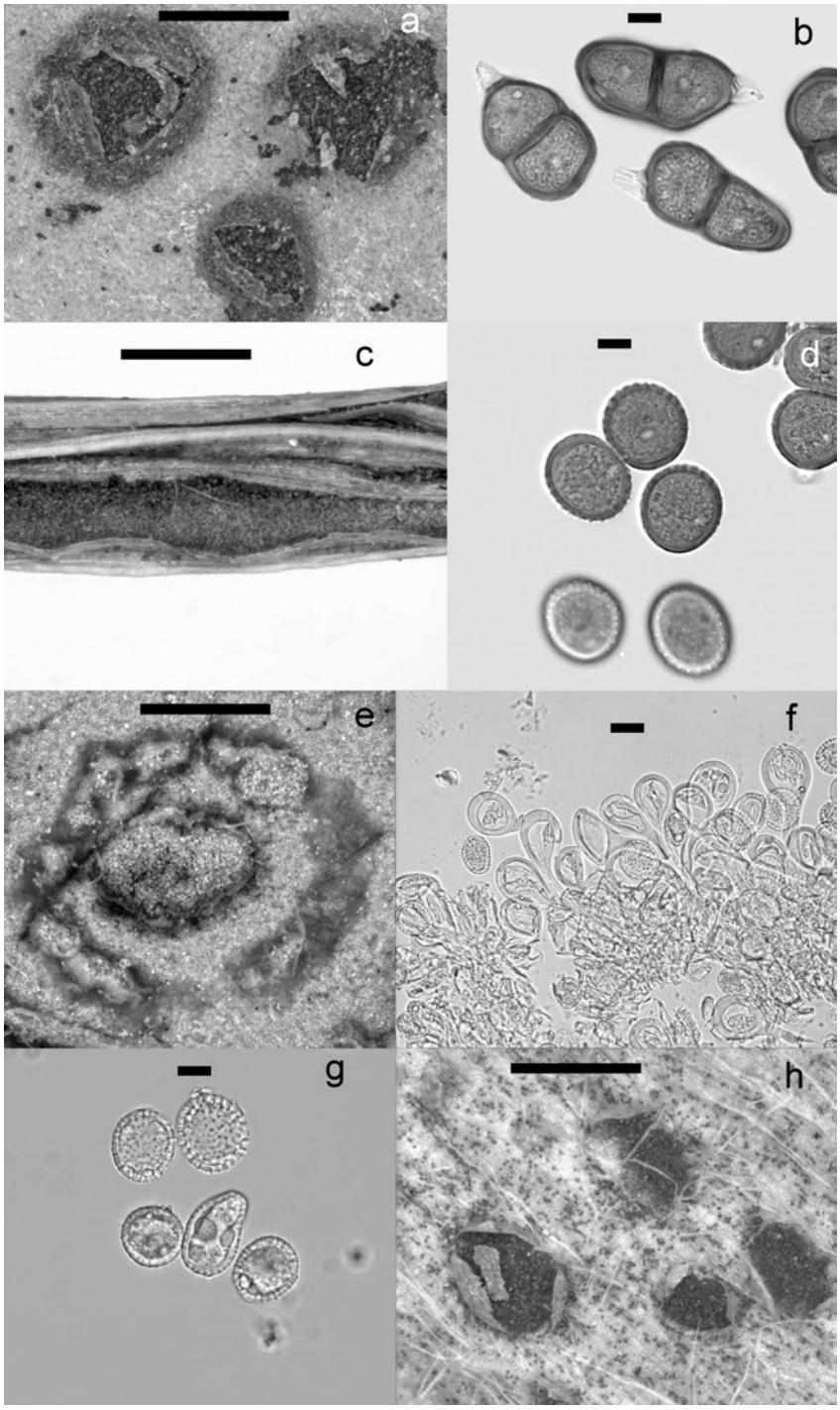
Hosts and distribution. – This autoecious rust is widely reported from Europe, North America, and parts of Asia on cultivated *Rosa* spp. (Farr & Rossman 2011). This is the first record of this rust for Oman and the Arabian Peninsula.

Puccinia canaliculata (Schwein.) Lagerh., Tromsø Mus. Aarsh. 17: 51 (1894) – Figs. 1c-d

Specimens examined. – Shinas, on agricultural land, on *Cyperus rotundus* L. (Cyperaceae), M L Deadman, Feb 2005 (BPI 881120a; 28S sequence GenBank #HQ412647), II.

Hosts and distribution. – The uredinial/telial stage of *P. canaliculata* is known on *Cyperus* spp. throughout the Americas and parts of Asia and Europe (Farr & Rossman 2011) and was first reported on nutgrass from Oman in 1978 (Waller & Bridge 1978). It is not known whether the spermogonial/aecial stage, which occurs on members of the Asteraceae, is also present on the Arabian Peninsula.

Fig. 1. – *Puccinia carthami* (BPI 863557): a. Telia (bar = 500 µm). b. Teliospores (bar = 10 µm). **c–d.** *Puccinia canaliculata* (BPI 881120a): c. Uredinia (bar = 500 µm). d. Urediniospores (bar = 10 µm). **e–g.** *Melampsora euphorbiae* (BPI 871135): e. Uredinia (bar = 500 µm). f. Paraphyses (bar = 10 µm). g. Urediniospores (bar = 10 µm). **h.** *Uromyces striatus* (BPI 878139) telia (bar = 500 µm).



Puccinia carthami Corda, *Icon. fung.* (Prague) 4: 15 (1840) – Figs. 1a-b

Specimens examined. – District of Mudhaibi, on agricultural land, on *Carthamus tinctorius* L. (Asteraceae), S Al Jahdhami, Apr 2004 (BPI 863557; 28S sequence GenBank #AY787782), III.

Hosts and distribution. – *Puccinia carthami* is part of a species complex of autoecious rusts on Cardueae that have been difficult to diagnose morphologically. It is globally distributed on *Carthamus* spp. and is known only from *C. tinctorius* in Oman (Deadman *et al*. 2005).

Puccinia cynodontis Lacroix ex Desm., *Pl. Crypt. Nord France*, Ser. 3: no. 655 (1859)

Hosts and distribution. – A widespread heteroecious rust with uredinial/telial stages occurring on Poaceae spp. and spermogonial/aecial stages reported on hosts in a number of families including Plantaginaceae, Ranunculaceae, Alliaceae, and Violaceae (Farr & Rossman 2011). Amongst the neighboring countries of Oman only the uredinial/telial stage has been recorded, on *Cynodon dactylon* (Poaceae) from Egypt (Baka & Gjaerum 1996) and the Himachal Pradesh area of India (Sharma & Sachan 1994). Elsewhere it is recorded on *Eragrostis barrelieri* Daveau in the Cape Verde Islands (Gjaerum 1984). It is reported as rare in Oman on *C. dactylon* (Moghal 1993).

Puccinia graminis Pers., *Neues Mag. Bot.* 1: 118 (1794) – Figs. 3a-b

Specimens examined. – Ad Dakhiliyah Region, Bahla, on *Hordeum vulgare* L. (Poaceae), Masoud Al Azri, Mar 2005 (BPI 881119; 28S sequence GenBank #HQ412648), II.

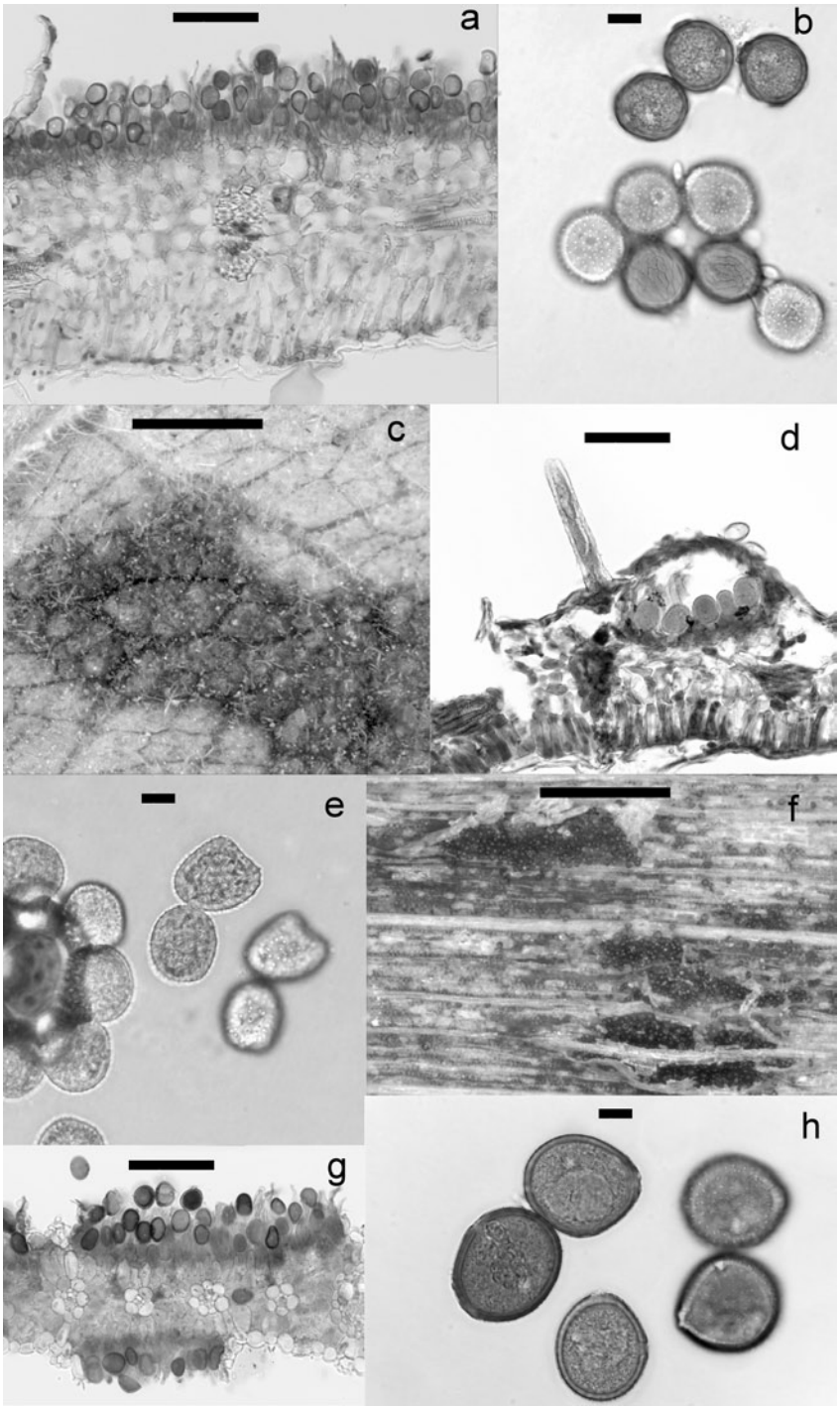
Hosts and distribution. – This is a cosmopolitan, heteroecious rust that infects wheat and other grasses in the uredinial/telial stage and species of *Berberis* (Berberidaceae) in the spermogonial/aecial stage. It was previously reported in Oman on *Hordeum vulgare* (Moghal 1993).

Puccinia lapsanae Fuckel, *Jb. nassau. Ver. Naturk.* 15: 13 (1860)

Specimens examined. – District of Dibba within Musandam Governerate, on margins of agricultural land, on *Lapsana* sp., A Al Subhi, Apr 2006 (BPI 881114; 28S sequence GenBank #HQ412649), II.

Hosts and distribution. – This rust is widely reported from northern temperate hemisphere on *Lapsana* spp. (Asteraceae) (Cummins 1978, Farr & Rossman 2011). This is the first record for Oman.

Fig. 2. – *Uromyces striatus* (BPI 878139): **a.** Uredinia (bar = 100 µm). **b.** Urediniospores (bar = 10 µm). **c–e.** *Cerotelium fici* (BPI 881122): **c.** Uredinia (bar = 500 µm). **d.** Uredinia cross section (bar = 100 µm). **e.** Urediniospores (bar = 10 µm). **f–h.** *Uromyces* sp. (BPI 881113). **f.** Uredinia (bar = 500 µm). **g.** Uredinia (bar = 100 µm). **h.** Urediniospores (bar = 10 µm).



Puccinia magnusiana Körn., *Hedwigia* 15: 179 (1876)

Hosts and distribution. – This circumglobal, heteroecious rust alternates between members of the Ranunculaceae in the spermogonial/aecial stage and *Phragmites* spp. (Poaceae) in the uredinial/telial stage. It is known in Oman only from the uredinial stage on *Phragmites australis* (Gjaerum 1988).

Puccinia sorghi Schwein., *Trans. Amer. phil. Soc.* Ser. 2, 4: 295 (1832) – Figs. 4b-c

Specimens examined. – Nizwa, on *Zea mays* L. (Poaceae), M L Deadman, Apr 2007 (BPI 881116; 28S sequence GenBank #HQ412650), II; Samail, 100km south of Muscat, on *Z. mays*, Masoud Al Azri, Apr 2005 (BPI 871134; 28S sequence GenBank #DQ345724), II-III.

Hosts and distribution. – *Puccinia sorghi* represents another circumglobal, heteroecious rust of agricultural crops, this species alternating between *Oxalis* spp. (Oxalidaceae) in the spermogonial/aecial stage and various grasses including *Zea mays* in the uredinial/telial stage. It has been previously reported in the Arabian Peninsula from *Z. mays* in Yemen, Saudi Arabia, and Oman (Deadman et. al 2006a, Farr & Rossman 2011). It is not known whether the alternate stage on *Oxalis* spp. exists on the Arabian Peninsula.

Puccinia triticina Erikss. *Annls Sci. Nat.*, Bot. Ser. 8, 9: 270 (1899) – Figs. 3e-h, 4a

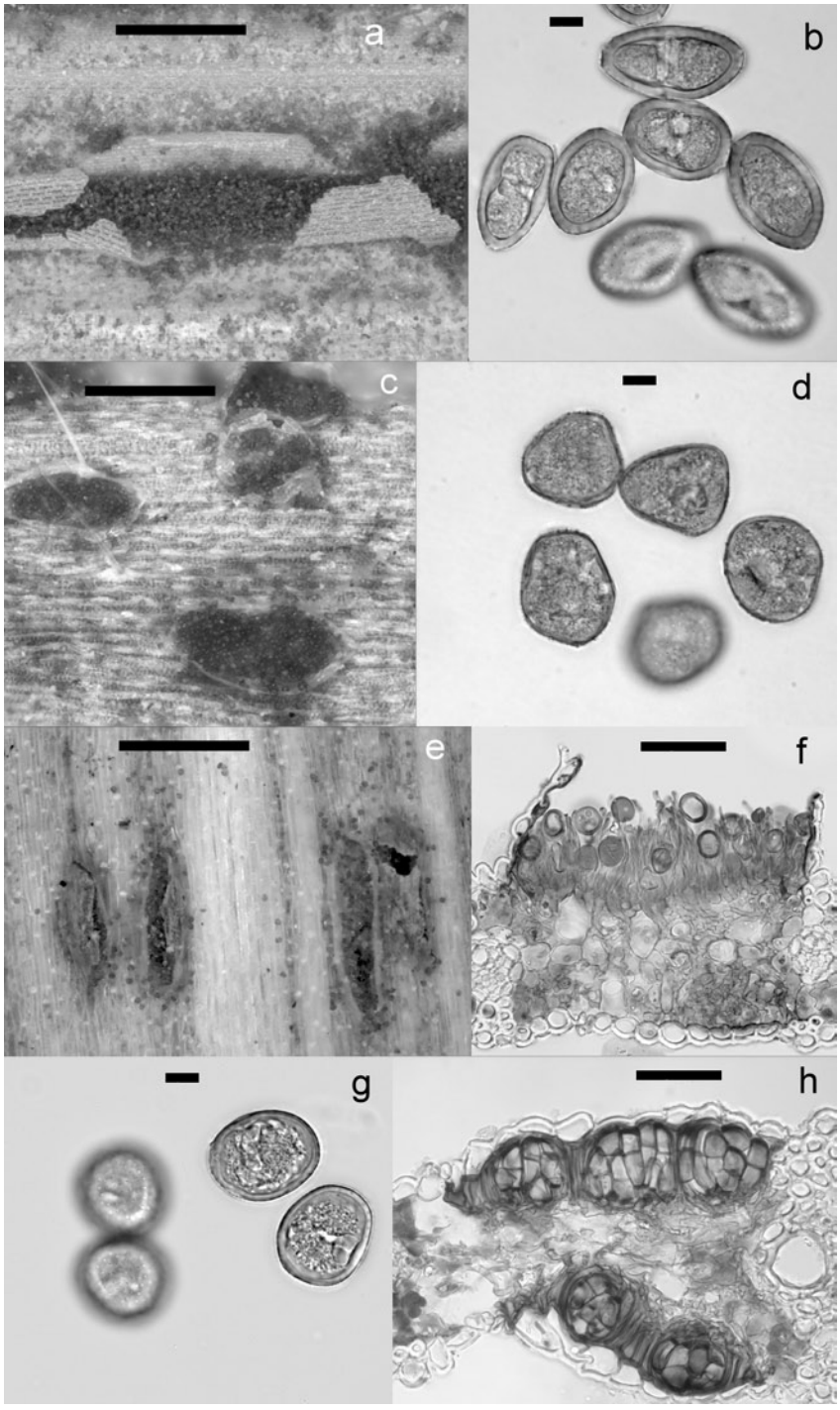
Specimens examined. – Rustaq, 100 km southwest of Muscat, on *Triticum aestivum* L., M L Deadman, Apr 2005 (BPI 872158; 28S sequence GenBank #DQ664194), II; Rustaq, 100 km southwest of Muscat, on *T. aestivum*, M L Deadman, Apr 2005 (BPI 872159), II-III.

Hosts and distribution. – *Puccinia triticina* is part of the *Puccinia recondita* species complex of circumglobal rusts that infect at least 37 genera of grasses in the uredinial/telial stage and hosts in at least four families (Balsaminaceae, Boraginaceae, Hydrophyllaceae, and Ranunculaceae) in the spermogonial/aecial stage (Cummins 1971). At present this pathogen is known only from wheat in Oman (Deadman *et al.* 2007a).

Ravenelia omanensis Gjaerum & D.A. Reid, *Trans. Br. Mycol. Soc.* 81: 653 (1983)

Hosts and distribution. – *Ravenelia omanensis* represents the only new species of rust fungus described from Oman to date,

Fig. 3. – *Puccinia graminis* (BPI 881119): **a.** Uredinia (bar = 500 µm). **b.** Urediniospores (bar = 10 µm). **c–d.** *Uromyces setariae-italicae* (BPI 881975): **c.** Uredinia (bar = 500 µm). **d.** Urediniospores (bar = 10 µm). **e-h.** *Puccinia triticina* (BPI 872159): **e.** Uredinia (bar = 500 µm). **f.** Uredinia (bar = 100 µm). **g.** Urediniospores (bar = 100 µm). **h.** Telia (bar = 100 µm).



where it was found to infect leaves of *Caesalpinia* cf. *erianthera* (Fabaceae) from the Dhofar region (Gjaerum & Reid 1983). Gjaerum & Reid (1983) reported that *R. omanensis* also occurred in South Yemen but no specimens were cited. Spermogonial, aecial, and uredinial stages are not known.

Tranzschelia discolor (Fuckel) Tranzschel & M.A. Litv. *J. Bot.,* Paris, 24: 248 (1939) – Figs. 4d-f

Specimens examined. – Balad Seet, 120 km southwest of Muscat, on *Prunus persica* L., M L Deadman, Feb 2006 (BPI 875341; 28S sequence GenBank #DQ9955341), II.

Hosts and distribution. – *Tranzschelia discolor* is a cosmopolitan pathogen of *Prunus* spp. (Rosaceae) in the uredinial/telial stage, alternating on Ranunculaceae spp. in the spermogonial/aecial stage. This pathogen was first reported from Oman on peach (Deadman *et al*. 2007b) where it has yet to be found on its alternate host.

***Uredo* sp.** – Figs. 2f-h

Specimens examined. – A'Suwaiq, on *Digitaria nodosa* Parl., Ali Al Subhi, Feb 2006 (BPI 881112; 28S sequence GenBank HQ412655), II; Ibra, on *Sorghum halepense* (L.) Pers., Mahmoud Al Ansari, Apr 2006 (BPI 881113; 28S GenBank HQ412656), II.

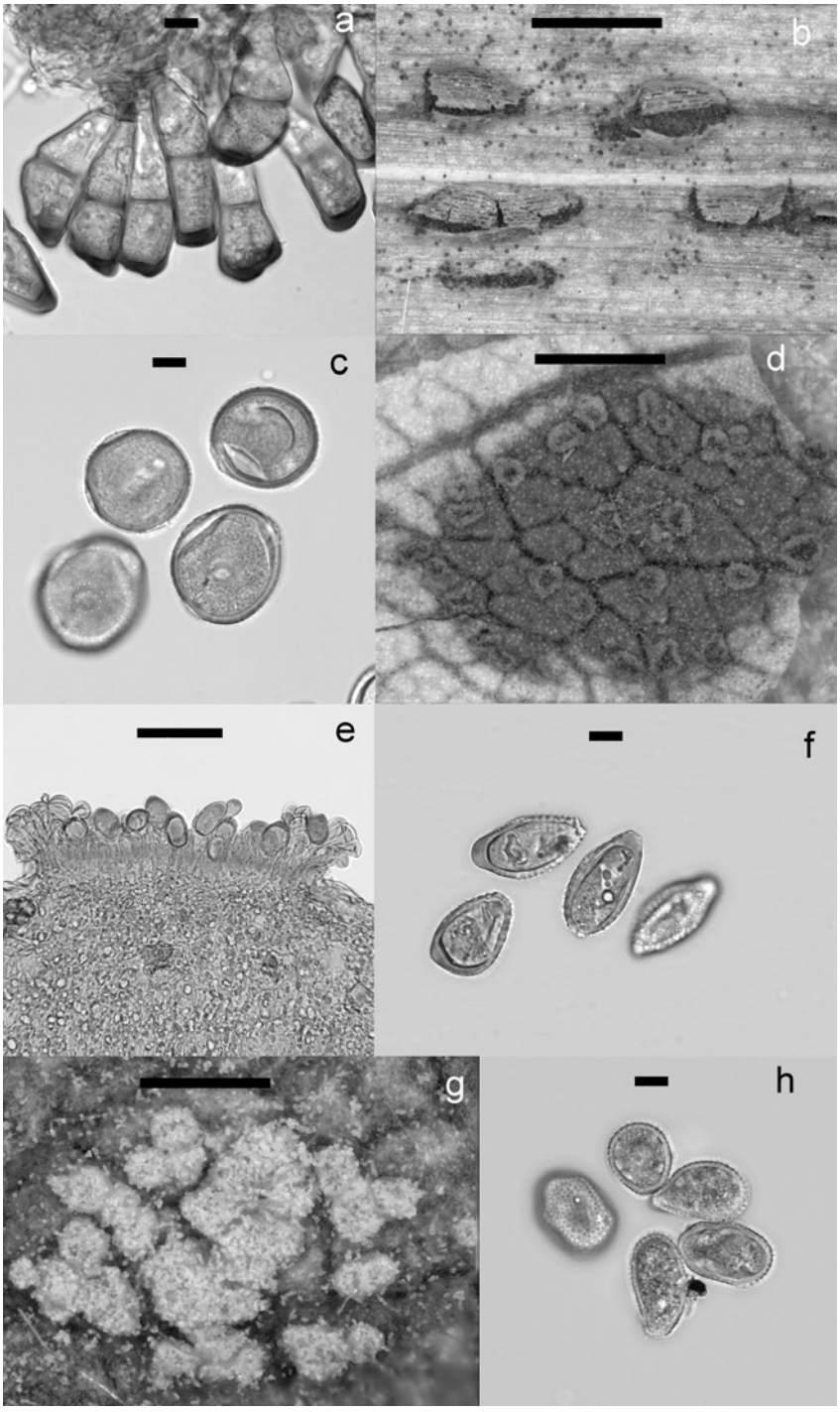
Hosts and distribution. – This species is known from two collections in Oman, one from *Digitaria nodosa* and one from *Sorghum halepense*. DNA sequence analysis—*Uredo* sp. shares 1081/1096 bp sequence identity with *Uromyces setariae-italicae* (GenBank #HQ412654) –places this species within the *U. setariae-italicae* species complex, which is consistent with urediniospore morphology (Figs. 2f-h). However, although *U. setariae-italicae* has a broad host range (see below), it has not yet been reported on species of either *Sorghum* or *Digitaria*. Efforts are underway to collect the teliospore stage of this rust in order to determine whether it represents either a new species or a new host record for *U. setariae-italicae*.

Uromyces appendiculatus (Pers.) Unger, *Einfl. d. Bodens* p. 216 (1836)

Specimens examined. – Salalah, on *Macroptilium atropurpureum* (DC.). Urb., Ali Al Subhi, Mar 2007 (BPI 881117), II.

Hosts and distribution. – *Uromyces appendiculatus*, the common rust of dry beans, is a circumglobal pathogen of *Phaseolus*

Fig. 4. – *Puccinia triticina* (BPI 872159) teliospores (bar = 10 µm). **b-c**. *Puccinia sorghi* (BPI 871134): **b.** Uredinia (bar = 500 µm). **c.** Urediniospores (bar = 10 µm). **d-f**. *Tranzschelia discolor* (BPI 875341): **d.** Uredinia (bar = 500 µm). **e.** Uredinia (bar = 100 µm). **f.** Urediniospores (bar = µm 10 µm). **g–h.** *Phragmidium mucronatum* (BPI 881118): **g.** Urediniospores (bar = 500 µm). **h.** Urediniospores (bar = 10 µm)



spp. and numerous other hosts in the Fabaceae (Cummins 1978). This rust is known previously from *Vigna unguiculata* (L.) Walp. (as *V. triloba* Walp.) in Saudia Arabia (Guyot 1957). This is the first known report from Oman.

Uromyces setariae-italicae Yoshino, *Bot. Mag., Tokyo* 20: 247 (1906) – Figs. 3c-d

Specimens examined. – Shinas, on *Setaria verticillata* (L.) P. Beauv., M.L. Deadman, Feb 2005 (BPI 881975; 28S sequence GenBank #HQ412654), II.

Hosts and distribution. – *Uromyces setariae-italicae* has a circumglobal distribution in warm regions on grass hosts in the genera *Brachiaria, Cyrtococcum, Eriochloa, Melinis, Ottochloa, Panicum, Paspalidium, Pennisetum, Setaria, Stenotaphrum,* and *Urochloa* (Cummins 1971). In Oman it is known only from *Setaria verticilliata* (Waller & Bridge, 1978). DNA sequence analysis (Aime unplublished) of *U. setariae-italica* collections from around the world on various hosts indicate this taxon most likely consists of a species complex.

Uromyces striatus J. Schröt., *Abh. Schles. Ges. Vaterl. Kult. Abth. Naurwiss* 48: 11 (1870) – Figs. 1h, 21-b

Specimens examined. – Masanaa, on *Medicago* sp., Mahmoud Al Ansari, Mar 2005 (BPI 878138; 28S sequence GenBank #HQ412651); Masanaa, on *Medicago* sp., Mahmoud Al Ansari, Mar 2005 (BPI 878139; 28S sequence GenBank HQ412652), II-III; Adan, on *Medicago sativa*, Mahmoud Al Ansari, Jul 2007 (BPI 881115; 28S GenBank HQ412653), III.

Hosts and distribution. – *Uromyces striatus* represents yet another cosmopolitan rust found worldwide on *Medicago* spp. (Fabaceae) in the uredinial/telial stage and infecting species of *Euphorbia* (Euphorbiaceae) in the spermogonial/aecial stage (Cummins 1978). It is a known pathogen of alfalfa in Oman (Moghal 1993, Waller & Bridge 1976, Waller & Bridge 1978).

List of Pucciniales of Northern Oman by host families

ASTERACEAE		**POACEAE**	
Carthamus tinctorius	***Puccinia carthami***	*Cynodon dactylon*	***Puccinia cynodontis***
Lapsana sp.	***Puccinia lapsanae***	*Digitaria nodosa*	*Uredo* **sp.**
CYPERACEAE		*Hordeum vulgare*	***Puccinia graminis***
Cyperus rotundus	***Puccinia canaliculata***	*Phragmites australis*	***Puccinia magnusiana***
EUPHORBIACEAE		*Setaria verticillata*	***Uromyces setariae-italicae***
Euphorbia heterophylla	***Melampsora euphorbiae***	*Sorghum halepense*	***Uredo* sp.**
FABACEAE		*Triticum aestivum*	***Puccinia triticina***
Caesalpinia erianthera	***Ravenelia omanensis***	*Zea mays*	***Puccinia sorghi***
Medicago sativa	***Uromyces striatus***	**ROSACEAE**	
MORACEAE		*Prunus persica*	***Tranzschelia discolor***
Ficus carica	***Cerotelium fici***	*Rosa* sp.	***Phragmidium mucronatum***

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