

# Online identification guides for Australian smut fungi (*Ustilaginomycotina*) and rust fungi (*Pucciniales*)

Roger G. Shivas<sup>1</sup>, Dean R. Beasley<sup>1</sup>, and Alistair R. McTaggart<sup>1,2</sup>

<sup>1</sup>Plant Pathology Herbarium, Biosecurity Queensland, Department of Agriculture, Fisheries and Forestry, GPO Box 267, Brisbane 4001, Queensland, Australia; corresponding author e-mail: roger.shivas@daff.qld.gov.au

<sup>2</sup>Queensland Alliance for Agriculture and Food Innovation, The University of Queensland, Ecosciences Precinct, GPO Box 267, Brisbane, Queensland 4001, Australia

**Abstract:** Interactive identification keys for Australian smut fungi (*Ustilaginomycotina* and *Pucciniomycotina*, *Microbotryales*) and rust fungi (*Pucciniomycotina*, *Pucciniales*) are available online at <http://collections.daff.qld.gov.au>. The keys were built using Lucid software, and facilitate the identification of all known Australian smut fungi (317 species in 37 genera) and 100 rust fungi (from approximately 360 species in 37 genera). The smut and rust keys are illustrated with over 1,600 and 570 images respectively. The keys are designed to assist a wide range of end-users including mycologists, plant health diagnosticians, biosecurity scientists, plant pathologists, and university students. The keys are dynamic and will be regularly updated to include taxonomic changes and incorporate new detections, taxa, distributions and images. Researchers working with Australian smut and rust fungi are encouraged to participate in the ongoing development and improvement of these keys.

## Key words:

Australia  
Key  
Lucid  
Morphology  
*Uredinales*  
Taxonomy  
*Ustilaginales*

**Article info:** Submitted: 27 June 2014; Accepted: 31 October 2014; Published: 11 November 2014.

## INTRODUCTION

The smut fungi (*Ustilaginomycotina* and *Pucciniomycotina*, *Microbotryales*) and rust fungi (*Pucciniomycotina*, *Pucciniales*) in the *Basidiomycota*, together represent the most economically important and largest group of plant pathogens (Cummins & Hiratsuka 2003, Vánky 2011). A great diversity of smut and rust fungi occur on both agricultural and environmental species. Worldwide, there are about 1650 species of smut fungi (Vánky 2011) and almost 8000 species of rust fungi (Kirk *et al.* 2008). Economically important smut and rust species in Australia include wheat common bunt (*Tilletia caries*), sugarcane smut (*Sporisorium scitamineum*), wheat stem rust (*Puccinia graminis*), wheat stripe rust (*P. striiformis*), and barley leaf rust (*P. hordei*). *Puccinia psidii* appeared in Australia in 2010, and now threatens many susceptible, native species of *Myrtaceae* in natural environments (Pegg *et al.* 2014). Several species of smut and rust fungi that are absent from Australia pose serious biosecurity threats to agriculture if introduced, e.g. karnal bunt of wheat (*T. indica*), pine-gall rust (*Endocronartium harknessii*), coffee leaf rust (*Hemileia vastatrix*) and grapevine leaf rust (*Phakopsora euvitis*). Several rust fungi have been introduced to Australia as biological control agents of environmental weeds, with some having considerable success, e.g. *Puccinia chondrillina* on skeleton weed (Cullen *et al.* 1973), and *Maravalia cryptostegiae* on rubbervine (Tomley & Evans 2004).

Vánky & Shivas (2008) revised the Australian smut fungi, and a separate interactive Lucid key to 296 species with over 1000 images was developed to accompany the revision (Shivas *et al.* 2008). Despite the importance of rust fungi in Australia, the most recent monograph is over a century old and considered about 160 species (McAlpine 1906). The number of known smut and rust fungi in Australia has increased since these revisions through discoveries of new taxa, new incursions, and introductions of biological control agents.

The identification of smut and rust fungi has mostly been based on morphology and knowledge of the host species. Morphological identification of smut fungi is reliant on differences between sori and teliospores (McTaggart *et al.* 2012a, Vánky 2013). Rust fungi have up to five spore stages in their life cycles (Hennen & Hennen 2000, Cummins & Hiratsuka 2003). Morphological characters of the teliospore and urediniospore stages, such as size, apex shape and wall thickness, ornamentation, and germ pore position and number, are useful for species identification. Identification of a rust fungus may be challenging if a life cycle stage is absent on a specimen. Molecular identification based on sequence data from the Large Subunit (LSU) region or Internal Transcribed Spacer (ITS) region of nuclear ribosomal DNA, may identify species or genera of smut and rust fungi in cases where the host is unknown or morphology is inconclusive (Schoch *et al.* 2012). This approach is limited to fungi that have an available reference sequence on a public, nucleotide database.

© 2014 International Mycological Association

You are free to share - to copy, distribute and transmit the work, under the following conditions:

**Attribution:** You must attribute the work in the manner specified by the author or licensor (but not in any way that suggests that they endorse you or your use of the work).

**Non-commercial:** You may not use this work for commercial purposes.

**No derivative works:** You may not alter, transform, or build upon this work.

For any reuse or distribution, you must make clear to others the license terms of this work, which can be found at <http://creativecommons.org/licenses/by-nc-nd/3.0/legalcode>. Any of the above conditions can be waived if you get permission from the copyright holder. Nothing in this license impairs or restricts the author's moral rights.

## SMUT FUNGI OF AUSTRALIA

HOME ABOUT INTRODUCTION IDENTIFICATION KEY BROWSE SPECIES HOST INDEX


***Anthracocystis heteropogoncola*** (Mundk. & Thirum.) McTaggart & R.G. Shivas

## Synonyms

*Sorosporium heteropogoncola* Mundk. & Thirum.  
*Sporisorium heteropogoncola* (Mundk. & Thirum.) Vánky

## Description

Sori in some of the ovaries of an inflorescence, long-cylindrical or fusiform, 5-15 (-20) mm long, 0.7-1.0 mm wide, covered by an initially white, later pale yellowish brown peridium that ruptures from its apex exposing the black granular-powdery mass of spore balls and (1-) 2-3 filiform columellae of host and fungal origin.

Spore balls rather persistent, broadly ellipsoidal, elongate, or usually subpolyhedrally irregular, 45-180 (-260) × 30-140 μm, dark reddish brown, composed of tens to hundreds of spores that separate by pressure.

Spores subglobose, ellipsoidal to subpolyhedrally irregular, 8.0-13.5 × 8-12 μm, dimorphic. Outer spores reddish brown, prominently and densely verrucose on the free surface, finely punctate-verruculose to almost smooth on the contact surfaces; wall uneven, thickest at the angles and on the free surface, 1.0-2.5 μm thick (including warts). Inner spores subhyaline to pale yellow or pale yellowish brown; wall uniformly 0.5-0.8 μm thick, very finely punctate to smooth.

Sterile cells in chains or irregular groups, subglobose, subcylindrical or irregular, with flattened contact sides, 4-16 × 3-11 μm, subhyaline, smooth.

Spore germination resulting in septate basidia with lateral and terminal ovoid to ellipsoidal basidiospores and hyphae.

## Hosts

Host family: Poaceae

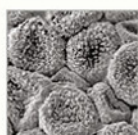
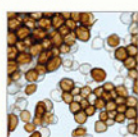
Host species: *Heteropogon contortus* (L.) P.Beauv. ex Roem. & Schult.

## Distribution

States & Territories: NT, QLD, WA

## Comments

*Anthracocystis heteropogoncola* produces fusiform sori in some ovaries of an inflorescence and is easily distinguished from the three other smut fungi that infect *Heteropogon contortus* in Australia. Although the earliest Australian collection dates back to 1940, *A. heteropogoncola* was first identified in Australia in 1997 (Shivas & Vánky, 1997).



**Fig. 1.** Fact sheet for *Anthracocystis heteropogoncola* from the *Smut Fungi of Australia* Lucid key.

Approximately 3% of rust fungi (310 LSU sequences and 210 ITS sequences) and 21% of smut fungi (346 ITS sequences) had reference sequences on GenBank when accessed on 18 March 2014.

We have developed interactive keys as contemporary online resources to aid the identification of Australian smut and rust fungi. The keys are freely available, dynamic, and will be upgraded to accommodate untreated or newly discovered taxa in Australia, as well as changes in taxonomy, host range and distribution.

## Methods

### Taxon selection

The taxa covered by the keys include all 317 known Australian smut fungi and 100 rust fungi. The initial 100 rust fungi were chosen from species that are agriculturally important, recently introduced, or endemic. All specimens have been lodged in the Plant Pathology Herbarium, Biosecurity Queensland (BRIP) or other herbaria. Specimens were also borrowed from Australian herbaria (DAR, MEL, PERTH and VPRI)

for examination. Biological and distribution data for many of these specimens can be accessed at <http://collections.daff.qld.gov.au>

### Morphology and image capture

Spores of smut or rust fungi were removed from host material with a scalpel and mounted in clear lactic acid (100 % v/v) on a microscope slide and gently heated to boiling. Slide preparations were examined with a Leica DM 2500 compound microscope using differential interference microscopy and images taken with a Leica DFC550 or DFC500 camera. Measurements of spore dimensions were made from a minimum of 20 spores, with values expressed as ranges and outliers given in parentheses. Composite images were constructed with image stacking software Helicon Focus (Helicon Soft, Kharkov).

Some of the images of spores were captured in two focal planes, one through the equator of the spores, and the other through the upper surface of the spores. A simple JavaScript was employed to allow users to toggle between

# Rust fungi of Australia

[about this key](#)
[identify a rust fungus](#)
[browse rust fungi](#)
[host index](#)
[records & references](#)

## *Puccinia stylidii* McAlpine

### Description

Uredinia on lower leaf surface, subepidermal, erumpent, round, up to 1.2 mm, yellowish brown, peridium present.

Urediniospores globose, subglobose or obovoid, apex obtuse, yellowish brown, 22–26 × 18–24 μm; wall 1.5–2.5 μm thick, echinulate to verruculose, with 1 equatorial germ pore.

Telia on stems and both leaf surfaces, erumpent, linear to dome-shaped, black.

Teliospores clavate, apex acuminate or rounded, 1 or 2 celled, reddish brown, 35–49 × 19–25 μm; wall 2–4 μm thick at sides, 6–10 μm thick at apex, smooth, with persistent pedicel, up to 31 μm.

### Hosts

Host family: Styliaceae

Host species: *Stylidium armeria*  
*Stylidium graminifolium*  
*Stylidium pycnostachyum*  
*Stylidium rigidulum*

### Distribution

TAS, VIC, WA

### Comments

*Puccinia stylidii* is an endemic Australian rust known only from species of *Stylidium* (Styliaceae). In a systematic study, *Puccinia stylidii* was shown to be closely related yet distinct from *P. lagenophorae*, which occurs on several genera of Asteraceae, and four species of rust on Goodeniaceae, namely *Puccinia dampierae*, *P. gilgiana*, *P. saccardoii* and *Uromyces scaevolae* (McTaggart et al. 2014). *Puccinia stylidii* differs further from these species by producing urediniospores.

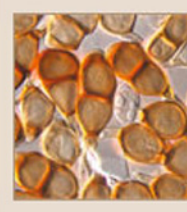
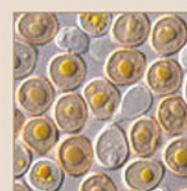
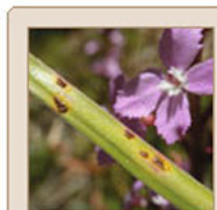


Fig. 2. Fact sheet for *Puccinia stylidii* from the *Rust Fungi of Australia* Lucid key.

the two different focal planes when viewing these spore images in the key. Host symptoms were captured in the field using an array of compact digital cameras and digital SLR cameras. In the laboratory, host symptoms were scanned using Epson Perfection V700 flatbed scanners, with a minimum resolution of 300 dpi. Close-up images of sori, especially aecia, uredinia and telia, were captured with a Leica DFC550 camera mounted on a Leica M165C stereo microscope. Images were selected based on quality and diagnostic potential.

### Key development

Lucid 3.5.16 ([www.lucidcentral.org](http://www.lucidcentral.org)) software was used to produce two interactive, multi-access keys, one for the Australian smut fungi, and the other for the Australian rust

fungi. The key to smut fungi uses 53 readily observable features (characters) and 334 character states that include host, distribution and morphology of the sori and spores. The Lucid guide for the rust fungi uses 92 features and 512 character states that also includes host, distribution and morphological features of all of the spore stages known to occur in Australia.

Lucid software was used to automatically generate natural language descriptions for all taxa included in the key to Australian rust fungi. Scores for the 92 features were used to provide uniform description formats for all species in the key. Fact sheets for each of the smut and rust taxa were authored using Adobe Dreamweaver CS5.5 software.

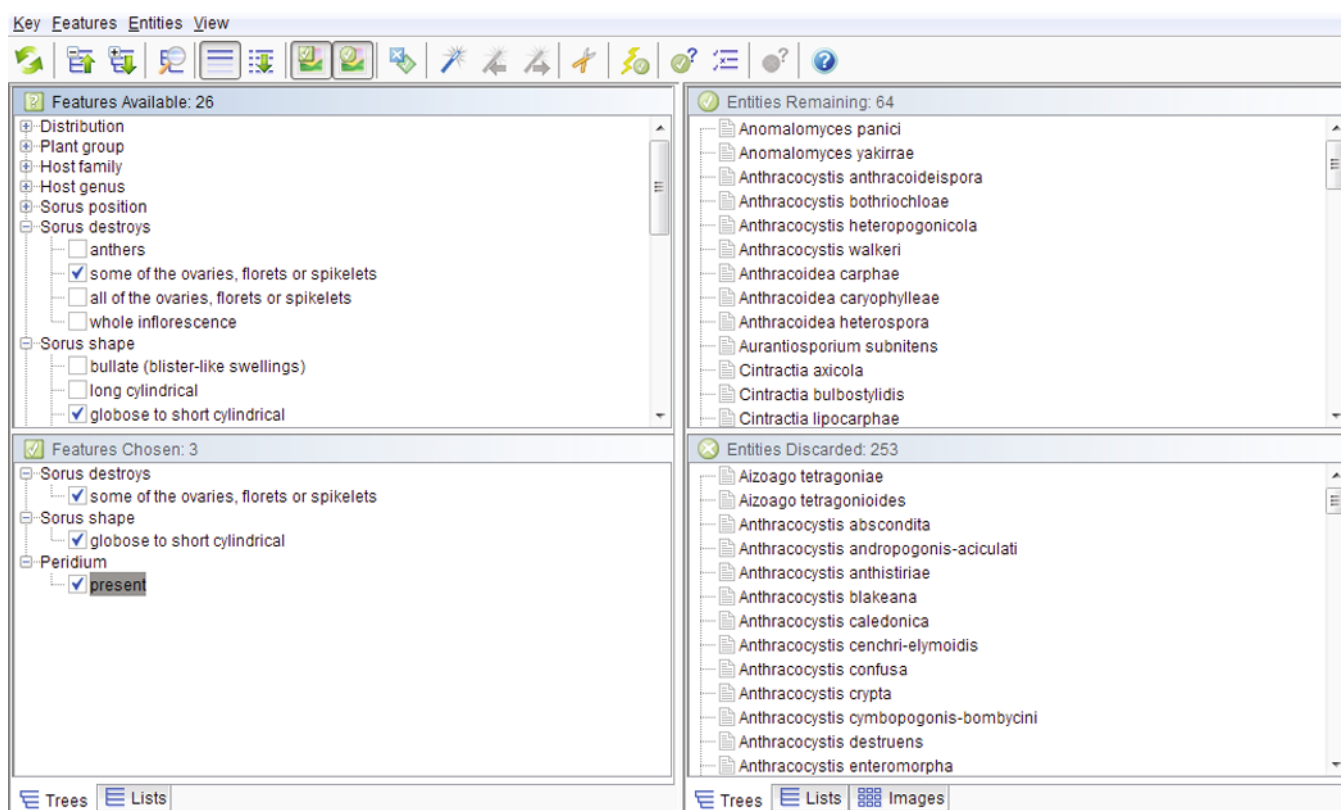


Fig. 3. Screenshot of the Lucid matrix key from *Smut Fungi of Australia*.

Table 1. New records of smut fungi in Australia since 2008.

Species	Host species	Reference
<i>Aizoago tetragoniae</i>	<i>Tetragonia diptera</i>	Ványkó & Shivas (2013)
<i>Aizoago tetragonioides</i>	<i>Tetragonia tetragonioides</i>	Ványkó & Shivas (2013)
<i>Anomalomyces yakirrae</i>	<i>Yakirra majuscula</i>	Shivas et al. (2013)
<i>Aurantiosporium subnitens</i>	<i>Scleria novae-hollandiae</i>	This publication
<i>Entyloma ageratinae</i>	<i>Ageratina riparia</i>	Morin (2012)
<i>Eriocortex eriocauli</i>	<i>Eriocaulon scullionii</i>	Ványkó et al. (2013)
<i>Macalpinomyces mackinlayi</i>	<i>Eulalia mackinlayi</i>	McTaggart & Shivas (2009a)
<i>Moreaua actinoschoeni</i>	<i>Actinoschoenus</i> sp.	Shivas et al. (2011)
<i>Moreaua chrysitricis</i>	<i>Chrysitrix distigmata</i>	Shivas et al. (2011)
<i>Moreaua peckii</i>	<i>Schoenus cruentus</i>	Ványkó (2009)
<i>Sporisorium andrewmitchellii</i>	<i>Enneapogon</i> aff. <i>lindleyanus</i>	Crous et al. (2012)
<i>Sporisorium warambiense</i>	<i>Xerochloa laniflora</i>	Piątek & Shivas (2011)
<i>Tilletia challinoriae</i>	<i>Panicum trachyrhachis</i>	McTaggart & Shivas (2009b)
<i>Tilletia geeringii</i>	<i>Eriachne festucacea</i>	Li et al. (2014)
<i>Tilletia mactaggartii</i>	<i>Eriachne burkittii</i>	Li et al. (2014)
<i>Tilletia majuscula</i>	<i>Yakirra majuscula</i>	Shivas & McTaggart (2009)
<i>Tilletia marjaniae</i>	<i>Eriachne pulchella</i> subsp. <i>dominii</i>	Li et al. (2014)
<i>Tilletia micrairae</i>	<i>Micraira dunlopii</i>	Barrett et al. (2009)
<i>Tilletia pseudoraphidis</i>	<i>Pseudoraphis spinescens</i>	Shivas & McTaggart (2009)
<i>Tilletia sehimicola</i>	<i>Sehima nervosum</i>	Shivas & McTaggart (2009)
<i>Ustanciosporium appendiculatum</i>	<i>Rhynchospora exserta</i>	Shivas et al. (2010)

**Table 2.** New species of rust fungi described from host plants in Australia since 1906.

Species <sup>†</sup>	Host species (family)	Type location	Reference
<i>Aecidium acanthocarp</i>	<i>Acanthocarpus verticillatus</i> (Lomandraceae)	Varanus Island, WA	Walker & van der Merwe (2009)
<i>Aecidium brachycomes</i>	<i>Brachycome</i> sp. (Asteraceae)	Mt Kosciusko, NSW	Petrak (1953)
<i>Aecidium gaubae</i>	<i>Arthrocnemum arbuscula</i> (Amaranthaceae)	Ourjen, Vic.	Petrak (1953)
<i>Atelocauda shivasii</i>	<i>Ormosia ormondii</i> (Fabaceae)	Noah Beach, Qld	Walker (2001)
<i>Bibulocystis gloriosa</i>	<i>Caesalpinia scortechinii</i> (Fabaceae)	Mt Glorious, Qld	Walker & Shivas (2009)
<i>Bibulocystis pulcherrima</i>	<i>Daviesia latifolia</i> (Fabaceae)	McKinnon's Corner, Vic.	Walker <i>et al.</i> (2006)
<i>Cystopsora notelaeae</i>	<i>Notelaea longifolia</i> (Oleaceae)	Pittwater, NSW	Sydow (1937b)
<i>Endoraecium parvum</i>	<i>Acacia</i> spp. (Fabaceae)	Caloundra, Qld	Berndt (2011)
<i>Endoraecium tierneyi</i>	<i>Acacia harpophylla</i> (Fabaceae)	Tambo, Qld	Walker (2001), Scholler & Aime (2006)
<i>Endoraecium violae-faustiae</i>	<i>Acacia</i> spp. (Fabaceae)	Kuranda, Qld	Berndt (2011)
<i>Endoraecium walkerianum</i>	<i>Acacia</i> spp. (Fabaceae)	Yass, NSW	Berndt (2011)
<i>Maravalia limoniformis</i>	<i>Austrosteenisia blackii</i> (Fabaceae)	Cooktown, Qld	McTaggart <i>et al.</i> (2008)
<i>Nyssopsora citriobati</i>	<i>Pittosporum multiflorum</i> (Pittosporaceae)	Salisbury, NSW	Sydow (1938)
<i>Puccinia argophyllae</i>	<i>Argophyllum nullumense</i> (Argophyllaceae)	Lost World Valley, Qld	Teakle (1959)
<i>Puccinia arthrocnemi</i>	<i>Arthrocnemum halocnemoides</i> (Amaranthaceae)	Eucolo Gorge, SA	Hansford (1954)
<i>Puccinia bassiae</i>	<i>Bassia</i> spp. (Amaranthaceae)	NSW, SA	Samuel (1924)
<i>Puccinia cygnorum</i>	<i>Kunzea glabrescens</i> (Myrtaceae)	Perth, WA	Shivas & Walker (1994), Makinson & Butcher (2014)
<i>Puccinia gastrolobii</i>	<i>Gastrolobium calycinum</i> (Fabaceae)	WA	Dietel (1922)
<i>Puccinia grevilleae</i>	<i>Grevillea mimosoides</i> (Proteaceae)	Almaden, Qld	McTaggart & Shivas (2008)
<i>Puccinia kenmorensis</i>	<i>Bothriochloa decipiens</i> (Poaceae)	Brisbane, Qld	Cummins (1945)
<i>Puccinia orellana</i>	<i>Senecio dryadens</i> (Asteraceae)	Brown Mountain, NSW	Sydow (1937a)
<i>Puccinia osbornii</i>	<i>Olearia rudis</i> (Asteraceae)	Kangaroo Island, SA	Sydow (1937a)
<i>Puccinia paspalina</i>	<i>Paspalum orbiculare</i> (Poaceae)	Brisbane, Qld	Cummins (1945)
<i>Puccinia scaevolincola</i>	<i>Scaevola aemula</i> (Goodeniaceae)	Weethalle, NSW	Petrak (1953)
<i>Puccinia sclerolaenae</i>	<i>Bassia biflora</i> (Amaranthaceae)	Roma, Qld	Massee (1910)
<i>Puccinia semibarbata</i>	<i>Bulbine semibarbata</i> (Liliaceae)	Eyre Peninsula, SA	Osborn & Samuel (1922)
<i>Puccinia ursinae</i>	<i>Ursinia anthemoides</i> (Asteraceae)	Perth, WA	Shivas (1991)
<i>Puccinia visci</i>	<i>Viscum angulatum</i> (Santalaceae)	Brisbane, Qld	Cribb (1955)
<i>Sphaerophragmium quadricellulare</i>	<i>Acacia pennata</i> (Fabaceae)	Cape York Peninsula, Qld	Alcorn & Walker (1996)
<i>Uredo xanthostemonis</i>	<i>Xanthostemon paradoxus</i> (Myrtaceae)	East Alligator River, NT	Walker (1983)
<i>Uredopeltis chevalieri</i>	<i>Grewia breviflora</i> (Tiliaceae)	Beverley Springs, WA	Walker & Shivas (2004)
<i>Uredopeltis euphaeus</i>	<i>Hypoxis glabella</i> (Hypoxidaceae)	Wiseman's Ferry, NSW	Sydow (1937b)
<i>Uromyces gaubae</i>	<i>Caltha introloba</i> (Ranunculaceae)	Mt Kosciusko, NSW	Petrak (1953)
<i>Uromyces lomandracearum</i>	<i>Lomandra longifolia</i> (Lomandraceae)	Northmead, NSW	Walker & van der Merwe (2009)
<i>Uromycladium naracoortensis</i>	<i>Acacia</i> spp. (Fabaceae)	Naracoorte Caves, SA	Berndt (2010)

<sup>†</sup> does not include subspecific taxa

## RESULTS

Both keys have been compiled for use on the internet, and are freely available at the following URLs:

- [collections.daff.qld.gov.au/web/key/smutfungi](http://collections.daff.qld.gov.au/web/key/smutfungi)
- [collections.daff.qld.gov.au/web/key/rustfungi](http://collections.daff.qld.gov.au/web/key/rustfungi)

The keys are wrapped in a web page, along with the applet version of the Lucid Player (Fig. 3). To access the keys, users require a web browser and the Java Runtime Environment, which can be downloaded for free from [www.java.com](http://www.java.com). Each taxon has its own web page (Figs 1–2), which is accompanied by additional resources including host index, glossary, references, and a tutorial on how to use the key.

Since the revision of Australian smut fungi by Vánky & Shivas (2008), a further 21 species of smut fungi have been described or recorded as new records (Table 1). Since the revision of Australian rust fungi by McAlpine (1906), 35 new species of rust fungi have been described in Australia (Table 2). There are also about 115 new records of rust fungi in Australia (including introduced biological control agents) that are provided in a comprehensive list, with references, on the website. At least another 50 undescribed species are represented in Australian herbaria (unpublished). Our current estimate of the number of Australian rust fungi is approximately 360 species.

## DISCUSSION

The Lucid guides to the Australian smut fungi and rust fungi simplify and promote accurate identification of taxa (genera and species), as the identification is made on available characters selected by the user. These characters are morphology, host range and distribution. Confirmation of specimen identity is enhanced by comparison with high quality images of authentic reference specimens taken in the field and in the laboratory.

Since the last revision of smut fungi in Australia (Vánky & Shivas 2008), six new generic names with type species from Australia have been established: *Aizoago* (Vánky & Shivas 2013), *Langdonia* (McTaggart et al. 2012b), *Shivasia* (Lutz et al. 2012), *Stollia* (McTaggart et al. 2012b), *Triodiomyces* (McTaggart et al. 2012b), and *Tubisorus* (Vánky & Lutz 2011). The genus *Anthracosystis* was resurrected (McTaggart et al. 2012b), and the first representative of *Aurantiosporium* from Australia was collected (Table 1).

McAlpine (1906) treated ten genera in the *Rusts of Australia*, and this number has more than tripled since his revision. McAlpine (1906) included several taxa that were later combined into new genera, such as *Ceratocoma* (*Cronartium*) *jacksoniae* (Cummins & Hiratsuka 2003), *Endoraecium* (*Uromyces*) *digitatum* (Scholler & Aime 2006), *Hamaspora* (*Phragmidium*) *acutissima* (as *longissima*), *Tranzschelia* (*Puccinia*) *discolor* and *Skierka* (*Uromyces*) *diploglottidis*. There are several additional genera that have been reported from Australia: *Atelocauda* (Walker 2001), *Bibulocystis* (Walker et al. 2006), *Cerotelium* (Simmonds 1966), *Coleosporium* (Anon. 2014), *Cystospora* (Sydow

1937b), *Dasturella* (Johnson 1985), *Diabole* (Burrows et al. 2012), *Goplana* (Langdon & Herbert 1944), *Kernkampella* (Walker et al. 2006), *Maravalia* (Tomley & Evans 2004), *Masseella* (Liberato et al. 2014), *Miyagia* (Cooke & Dube 1989), *Nyssopsora* (Sydow 1938), *Olivea* (Daly et al. 2006), *Phakopsora* (Weinert et al. 2003), *Prospodium* (Thomas et al. 2006), *Pucciniastrum* (Shivas 1989), *Ravenelia* (Walker 1983), *Sphaerophragmium* (Alcorn & Walker 1996), *Thekopsora* (McTaggart et al. 2013), and *Uredopeltis* (Walker & Shivas 2004).

The keys to the smut and rust fungi of Australia are the first online, taxonomically focused diagnostic tools created for the identification of Australian plant pathogenic fungi. A Lucid based identification key for smut fungi of Thailand has been released at the URL [collections.daff.qld.gov.au/web/key/thaismutfungi](http://collections.daff.qld.gov.au/web/key/thaismutfungi). A similar key for the rust fungi of south-east Asia is under development. We invite ustilaginologists and uredinologists to contribute to the construction of these keys. Protocols for the submission of images, morphological data, and specimens will be developed. In the future a BLAST database, based on vouchered herbarium specimens will be added to all keys to enable accurate molecular identification of taxa.

## ACKNOWLEDGEMENTS

This work was partly funded by the Australian Biological Resources Study, grant number RFL212-33.

## REFERENCES

- Alcorn JL, Walker J (1996) *Sphaerophragmium quadricellulare* sp. nov. (*Mycota*, *Uredinales*) on *Acacia* in Australia, with brief notes on some related rust genera. *Mycotaxon* **58**: 325–330.
- Anon. (2014) Fangipani rust. <http://www.daff.qld.gov.au/plants/lifestyle-horticulture/nursery/frangipani-rust>.
- Barrett MD, Barrett RL, Shivas RG, McTaggart AR (2009) *Tilletia micrairae*. *Persoonia* **22**: 170–171.
- Berndt R (2010) *Uromycladium naracoortensis*, a new species of rust fungi (*Uredinales*) from Australia, with new observations on described *Uromycladium* species. *Polish Botanical Journal* **55**: 299–308.
- Berndt R (2011) Taxonomic revision of *Endoraecium digitatum* (rust fungi, *Uredinales*) with description of four new species from Australia and Hawaii. *Mycological Progress* **10**: 497–517.
- Burrows NJ, Lukitsch BV, Liberato JR (2012) Rediscovery of the rust *Diabole cubensis*, released as a classical biological control agent against the invasive weed *Mimosa pigra* in Australia. *Australasian Plant Disease Notes* **7**: 171–175.
- Cooke RP, Dubé AJ (1989). *Host-Pathogen Index of Plant Diseases in South Australia*. Adelaide: South Australian Department of Agriculture.
- Cribb JW (1955) *Puccinia visci* sp. n. on *Viscum* in Queensland. *Papers, University of Queensland Department of Botany* **3**: 75–76.
- Crous PW, Summerell BA, Shivas RG, Burgess TI, Decock CA, et al. (2012) Fungal Planet description sheets: 107–127. *Persoonia* **28**: 138–182.

- Cullen JM, Kable PF, Catt M (1973) Epidemic spread of a rust imported for biological control. *Nature* **244**: 462–464.
- Cummins GB (1945) Descriptions of tropical rusts-VII. *Bulletin of the Torrey Botanical Club* **72**: 205–222.
- Cummins GB, Hiratsuka Y (2003) *Illustrated Genera of Rust Fungi*. St Paul, MN: American Phytopathological Society Press.
- Daly AM, Shivas RG, Pegg GS, Mackie AE (2006) First record of teak leaf rust (*Olivea tectonae*) in Australia. *Australasian Plant Disease Notes* **1**: 25–26.
- Dietel P von (1922) Einige neue oder bemerkenswerte Uredineen. *Annales Mycologici* **20**: 293–295.
- Hansford CG (1954) Australian Fungi. II. New records and revisions. *Proceedings of the Linnean Society of New South Wales* **79**: 97–141.
- Hennen JF, Hennen MMW (2000) Terminology applied to sori and life cycles of rust fungi (*Uredinales*) from 1729 to 2000. *Biológico, São Paulo* **62**: 113–126.
- Johnson GI (1985) Rust (*Dasturella divina*) of *Bambusa* spp. In Australia. *Australasian Plant Pathology* **14**: 54–55.
- Kirk PM, Cannon PF, Minter DW, Stalpers JA (2008) *Ainsworth & Bisby's Dictionary of the Fungi*. 10<sup>th</sup> edn. Wallingford: CAB International.
- Langdon RF, Herbert DA (1944) Records of Queensland fungi IV. *Papers, University of Queensland Department of Botany* **2**: 1–4.
- Li Y-M, Shivas RG, Cai L (2014) Three new species of *Tilletia* on *Eriachne* from north-western Australia. *Mycoscience* **55**: 361–366.
- Liberato JR, McTaggart AR, Shivas RG (2014) First report of *Masseëlla capparidis* in Australia. *Australasian Plant Disease Notes*: DOI: 10.1007/s13314-013-0121-y.
- Lutz M, Vánky K, Piatek M (2012) *Shivasia* gen. nov. for the Australasian smut *Ustilago solida* that historically shifted through five different genera. *IMA Fungus* **3**: 143–154.
- Makinson RO, Butcher R (2014) The type-host species of *Puccinia cygnorum* re-determined as *Kunzea glabrescens* (Myrtaceae). *Australasian Plant Disease Notes*: DOI: 10.1007/s13314-014-0141-2
- Massee GE (1910) Fungi exotici, X. *Bulletin of Miscellaneous Information, Royal Botanical Gardens, Kew* **3**: 1–6.
- McAlpine D (1906) *The Rusts of Australia*. Government Printer, Melbourne.
- McTaggart AR, Geering ADW, Shivas RG (2013) *Thekopsora minima* causes blueberry rust in south-eastern Queensland and northern New South Wales. *Australasian Plant Disease Notes*: DOI: 10.1007/s13314-013-0101-2
- McTaggart AR, Ono Y, Berndt R, Shivas RG (2008) *Maravalia* in Australia, including *Maravalia limoniformis* sp. nov. on *Austrostenisia blackii*. *Australasian Mycologist* **27**: 41–44.
- McTaggart AR, Shivas RG (2008) The rusts on *Proteaceae*, including *Puccinia grevilleae* sp. nov. from northern Australia. *Australasian Plant Pathology* **37**: 344–346.
- McTaggart AR, Shivas RG (2009a) *Macalpinomyces mackinlayi*. *Persoonia* **23**: 186–187.
- McTaggart AR, Shivas RG (2009b) *Tilletia challinorae*. *Persoonia* **23**: 184–185.
- McTaggart AR, Shivas RG, Geering ADW, Callaghan B, Vánky K, Scharaschkin T (2012a) Soral synapomorphies are significant for the systematics of the *Ustilago-Sporisorium-Macalpinomyces* complex (*Ustilaginaceae*). *Persoonia* **29**: 63–77.
- McTaggart AR, Shivas RG, Geering ADW, Vánky K, Scharaschkin T (2012b) Taxonomic revision of *Ustilago*, *Sporisorium* and *Macalpinomyces*. *Persoonia* **29**: 116–132.
- Morin L (2012) *Entyloma ageratinae*. *Australasian Plant Pathology Society, Pathogen of the Month – November 2012*. <http://www.appsnet.org/Publications/potm/pdf/nov12.pdf>
- Osborn TGB, Samuel G (1922) Some new records of fungi for South Australia, part II, together with a description of a new species of *Puccinia*. *Transactions and Proceedings of the Royal Society of South Australia* **46**: 166–180.
- Pegg GS, Giblin FR, McTaggart AR, Guymer GP, Taylor H, Ireland KB, Shivas RG, Perry S (2014) *Puccinia psidii* in Queensland, Australia: disease symptoms, distribution and impact. *Plant Pathology* **63**: 1005–1021.
- Petrak F (1953) Ein kleiner Beitrag zur Kenntnis der Uredineen Australiens. *Sydowia* **7**: 1–7.
- Piątek M, Shivas RG (2011) *Sporisorium warambiense* sp. nov., a fourth smut fungus on *Xerochloa* in Australia. *Mycological Progress* **10**: 57–60.
- Samuel G (1924) Some new records of fungi for South Australia part III. Together with a description of two new species of *Puccinia*. *Transactions and Proceedings of the Royal Society of South Australia* **48**: 149–161.
- Schoch CL, Seifert KA, Huhndorf S, Robert V, Spouge JL, Levesque CA, Chen W, Consortium FB (2012) Nuclear ribosomal internal transcribed spacer (ITS) region as a universal DNA barcode marker for *Fungi*. *Proceedings of the National Academy of Sciences, USA* **109**: 6241–6246.
- Scholler M, Aime MC (2006) On some rust fungi (*Uredinales*) collected in an *Acacia koa*–*Metrosideros polymorpha* woodland, Mauna Loa Road, Big Island, Hawaii. *Mycoscience* **47**: 159–165.
- Shivas RG (1989) Fungal and bacterial diseases of plants in Western Australia. *Journal of the Royal Society of Western Australia* **72**: 1–62.
- Shivas RG (1991) *Puccinia ursiniae* sp. nov. on *Ursinia anthemoides*. *Mycological Research* **95**: 379–381.
- Shivas RG, Beasley DR, Vánky K (2008) *Smut Fungi of Australia*. [Lucid CD-ROM. Melbourne: CSIRO Publishing].
- Shivas RG, McTaggart AR (2009) Three new species of *Tilletia* on native grasses from northern Australia. *Australasian Plant Pathology* **38**: 128–131.
- Shivas RG, Barrett MD, Barrett RL, Vánky K (2011) Two new species of *Moreaua* (*Ustilaginomycetes*), on *Actinoschoenus* and *Chrysitrix*, from Western Australia. *Mycologia Balcanica* **8**: 137–140.
- Shivas RG, Lutz M, McTaggart AR, Vánky K (2013) Emended description of *Anomalomyces* (*Ustilaginales*), including *Anomalomyces yakirrae* sp. nov. on *Yakirra pauciflora* (*Poaceae*) from Australia. *Mycobiota* **1**: 17–24.
- Shivas RG, McTaggart AR, Ryley MJ, Scharaschkin T, Gambley CF (2010) First report of the smut fungus *Ustanciosporium appendiculatum* in Australia. *Australasian Plant Disease Notes* **5**: 17–18.
- Shivas RG, Walker J (1994) *Puccinia cygnorum* sp. nov. on *Kunzea ericifolia* in Australia. *Mycological Research* **98**: 22–24.
- Simmonds JH (1966) *Host Index of Plant Diseases in Queensland*. Brisbane: Government Printer.
- Sydow H (1937a) Neue oder bemerkenswerte australische Micromyceten – I. *Annales Mycologici* **35**: 22–49.
- Sydow H (1937b) Neue oder bemerkenswerte australische Micromyceten – II. *Annales Mycologici* **35**: 350–361.
- Sydow H (1938) Neue oder bemerkenswerte Australische Micromyceten – III. *Annales Mycologici* **36**: 295–313.

- Teakle DS (1959) *Puccinia argophylli* sp. n. on *Argophyllum nullumense* in Queensland. *Queensland Journal of Agricultural and Animal Sciences* **16**: 91–92.
- Thomas SE, Ellison CA, Tomley AJ (2006) Studies on the rust *Prospodium tuberculatum*, a new classical biological control agent released against the invasive alien weed *Lantana camara* in Australia. 2. Host range. *Australasian Plant Pathology* **35**: 321–328.
- Tomley AJ, Evans HC (2004) Establishment of, and preliminary impact studies on, the rust, *Maravalia cryptostegiae*, of the invasive alien weed, *Cryptostegia grandiflora* in Queensland, Australia. *Plant Pathology* **53**: 475–484.
- Vánky K (2009) Taxonomic studies on *Ustilaginomycetes* – 29. *Mycotaxon* **110**: 289–324.
- Vánky K (2011) [“2012”] *Smut Fungi of the World*. St Paul, MN: American Phytopathological Society Press.
- Vánky K (2013) *Illustrated Genera of Smut Fungi*. St Paul, MN: American Phytopathological Society Press.
- Vánky K, Lutz M (2011) *Tubisorus*, a new genus of smut fungi (*Ustilaginomycetes*) for *Sporisorium pachycarpum*. *Mycologica Balcanica* **8**: 129–135.
- Vánky K, Shivas RG (2008) *Fungi of Australia. The Smut Fungi*. Melbourne: CSIRO Publishing.
- Vánky K, Shivas RG (2013) *Aizoago*, a new genus, and two new species of smut fungi (*Ustilaginales*) on *Tetragonia* (*Aizoaceae*) in Australia. *Mycobiota* **1**: 1–7.
- Vánky K, Shivas RG, Barrett MD, Lutz M (2013) *Eriocortex eriocauli*, gen. et sp. nov. (*Ustilaginomycetes*) from Australia. *Mycobiota* **1**: 9–16.
- Walker J (1983) Pacific mycogeography: deficiencies and irregularities in the distribution of plant parasitic fungi. *Australian Journal of Botany Supplementary series* **13**: 89–136.
- Walker J (2001) A revision of the genus *Atelocauda* (*Uredinales*) and description of *Racospermyces* gen. nov. for some rusts of *Acacia*. *Australasian Mycologist* **20**: 3–28.
- Walker J, Beilharz V, Pascoe IG, Priest MJ (2006) *Bibulocystis* gen. nov. (*Uredinales*) on *Daviesia* (*Fabaceae*) and *Albizia* (*Mimosaceae*) in Australasia, with comments on the genera *Cystomyces* and *Dicheirinia* and rust genera with teliospore cysts. *Australasian Plant Pathology* **35**: 1–22.
- Walker J, Shivas RG (2004) *Uredopeltis chevalieri* sp. nov., the rust of *Grewia* (*Tiliaceae*) formerly known as *Phakopsora* (or *Dasturella*) *grewiae*, its first record in Australia and a summary of the known rusts of *Grewia*. *Australasian Plant Pathology* **33**: 41–47.
- Walker J, Shivas RG (2009) *Bibulocystis gloriosa* sp. nov. (*Pucciniales*) on *Caesalpinia scortechinii* in Queensland, with comments on *Spumula caesalpiniae*. *Australasian Plant Pathology* **38**: 29–35.
- Walker J, van der Merwe M (2009) Two previously undescribed rusts of *Acanthocarpus* and *Lomandra* (*Lomandraceae*) in Australia. *Australasian Plant Pathology* **38**: 525–532.
- Weinert MP, Shivas RG, Pitkethley RN, Daly AM (2003) First record of grapevine leaf rust in the Northern Territory, Australia. *Australasian Plant Pathology* **32**: 117–118.