

REFINED TAXON SAMPLING DISCLOSES NEW QUINONE PATTERNS AND
RELATIONSHIPS AMONG SUNDEWS (*DROSERA*, DROSERACEAE)

In Memoriam Allen James Lowrie (1948 - 2021),

without whom we would not even know about many species investigated in this study

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Abstract: In a screening of 43 accessions of predominantly Australian sundew species (*Drosera*), naphthoquinones were detected convincingly for the first time in *D.* section *Lasiocephala* (*D. petiolaris* group, or ‘wooly sundews’), where these metabolites remain restricted to a minority of four closely related species. Great chemical similarity across the large geographic range confirms a close phylogenetic affinity between taxa of the *D. peltata* species group (of *D.* section *Ergaleium*, from tropical and Eastern Asia to New Zealand). *Drosera barrettiorum* (*D.* section *Arachnopus*) is chemically confirmed as a close relative of *D. hartmeyerorum*. The recently described species *D. margaritacea* in the same section is chemically different from the morphologically close *D. finlaysoniana*. Quinone data for African and South American sundews (*D.* sections *Drosera*, *Ptycnostigma* and *Brasilianae*) shed further light on the affinities between these taxonomically challenging plants.

Introduction

The *Drosera petiolaris* R.Br. group (*D.* section *Lasiocephala* Planch.) of tropical Australasia is the last remaining speciose section in the genus *Drosera* L. that has hitherto resisted to yield appreciable amounts of naphthoquinones, although traces of plumbagin (**P**) have been detected in *D. banksii* R.Br. ex DC. (Schlauer *et al.* 2019a). Many closely interrelated taxa have been described recently (Gibson *et al.* 2012; de Salas 2018) in the polymorphic and widespread *D. peltata* Thunb. group (*D.* section *Ergaleium* Planch., from tropical and Eastern Asia to New Zealand), and an attempt is made here to test and compare the chemical profiles of as many of these segregates as possible. *Drosera* section *Arachnopus* Planch. has already been screened for naphthoquinones to some extent but *D. barrettiorum* Lowrie that is supposedly closely related to *D. hartmeyerorum* Schlauer, and *D. margaritacea* Krueger & A.Fleischm. that is morphologically similar to *D. finlaysoniana* Wall. ex Arn., have not been at our disposal for chemical investigation before. Similar comparisons are also due for a number of additional pairs of sister taxa from Australia, Africa, and America, of which cultivated material has now become available.

Materials and methods

All plants used in the present study were cultivated at Andreas Fleischmann’s greenhouse in southern Germany. Fresh leaf samples were investigated as reported previously (Schlauer *et al.* 2017).

Results

Naphthoquinones were detected in the investigated samples as summarized (together with previous results) in Table 1.

Table 1. <i>Drosera</i> taxa investigated and quinones found. P: plumbagin, M: ramentaceone, O: no quinone detected			
Section	Taxon	Quinone(s)	Comment
<i>Lasiocephala</i>	<i>D. brevicornis</i>	0	new data
<i>Lasiocephala</i>	<i>D. broomensis</i>	P	new data
<i>Lasiocephala</i>	<i>D. caduca</i>	P	new data
<i>Lasiocephala</i>	<i>D. darwinensis</i>	0	new data
<i>Lasiocephala</i>	<i>D. derbyensis</i>	P	new data
<i>Lasiocephala</i>	<i>D. dilatatopetiolaris</i>	0	new data
<i>Lasiocephala</i>	<i>D. falconeri</i> (2 different accessions tested)	0	new data
<i>Lasiocephala</i>	<i>D. fulva</i>	M	new data
<i>Lasiocephala</i>	<i>D. kenneallyi</i>	P	new data
<i>Lasiocephala</i>	<i>D. lanata</i> (Qld.)	0	new data
<i>Lasiocephala</i>	<i>D. aff. lanata</i> (NT)	0	new data
<i>Lasiocephala</i>	<i>D. paradoxa</i> (Arnhem Escarpment)	0	new data
<i>Lasiocephala</i>	<i>D. aff. paradoxa</i> (swamp form)	0	conf. Schlauer <i>et al.</i> 2019a
<i>Lasiocephala</i>	<i>D. aff. paradoxa</i> (orange form)	0	new data
<i>Lasiocephala</i>	<i>D. petiolaris</i> (Qld.)	0	conf. Culham & Gornall 1994?
<i>Lasiocephala</i>	<i>D. petiolaris</i> (NT)	0	conf. Culham & Gornall 1994?
<i>Ergaleium</i>	<i>D. macrantha</i> (<i>s.str.</i>)	P	conf. Culham & Gornall 1994?
<i>Ergaleium</i>	<i>D. moorei</i>	P-trace	new data
<i>Ergaleium</i>	<i>D. gracilis</i> (Papua New Guinea)	P, M-trace	new data
<i>Ergaleium</i>	<i>D. gunniana</i> (Tasmania)	P, M-trace	new data
<i>Ergaleium</i>	<i>D. hookeri</i> (Tasmania)	P, M-trace	new data
<i>Ergaleium</i>	<i>D. lunata</i> (Thailand)	P + M	new data
<i>Ergaleium</i>	<i>D. auriculata</i> (NSW)	P	conf. Culham & Gornall 1994
<i>Ergaleium</i>	<i>D. zigzagia</i>	P	new data
<i>Erythrorhiza</i>	<i>D. aberrans</i>	P + M	cf. Schlauer <i>et al.</i> 2019a (only M)
<i>Stolonifera</i>	<i>D. stolonifera</i> (<i>s.str.</i>)	0	cf. Culham & Gornall 1994 (P)
<i>Arachnopus</i>	<i>D. barrettiorum</i>	M	new data
<i>Arachnopus</i>	<i>D. margaritacea</i>	P, M-trace	new data
<i>Drosera</i>	<i>D. amazonica</i> (locus classicus)	M	new data
<i>Drosera</i>	<i>D. aff. amazonica</i> (Colombia)	P, M-trace	new data
<i>Drosera</i>	<i>D. biflora</i> (Colombia)	P	new data
<i>Drosera</i>	<i>D. biflora</i> × <i>D. ? (esmeraldae?)</i>	P + M	new data
<i>Drosera</i>	<i>D. esmeraldae</i> (Venezuela)	M	new data

Table 1. Continued

Section	Taxon	Quinone(s)	Comment
<i>Drosera</i>	<i>D. intermedia</i> (Gran Sabana, Venezuela)	P	conf. Culham & Gornall 1994
<i>Drosera</i>	<i>D. brevifolia</i> (Brazil)	P, M-trace	cf. Trevisan Ferreira <i>et al.</i> 2004 (P)
<i>Ptycnostigma</i>	<i>D. flexicaulis</i> (Zambia)	P	new data
<i>Ptycnostigma</i>	<i>D. madagascariensis</i> (Madagascar)	M	conf. Culham & Gornall 1994
<i>Ptycnostigma</i>	<i>D. madagascariensis</i> (Zambia)	M	conf. Culham & Gornall 1994
<i>Ptycnostigma</i>	<i>D. pilosa</i> (Zambia)	M	new data
<i>Brasilianae</i>	<i>D. graminifolia</i> (<i>s.str.</i>)	M	new data
<i>Brasilianae</i>	<i>D. magnifica</i>	M	new data
<i>Brasilianae</i>	<i>D. tentaculata</i>	M	new data

Discussion

After the detection of trace amounts of **P** in *Drosera banksii* (Schlauer *et al.* 2019a) the (more pronounced) occurrence of the same quinone in four additional species was not entirely unexpected in *D.* section *Lasiocephala*. Together with the fact that most other species of this section lack naphthoquinones, our results indicate a close relationship between *D. broomensis* Lowrie, *D. caduca* Lowrie, and *D. derbyensis* Lowrie. All of these are confined to the Kimberley region of northernmost West Australia and are possibly further linked to *D. kenneallyi* Lowrie, that occurs both in the Kimberley and in the Northern Territory and is morphologically a close relative of *D. falconeri* K.Kondo (endemic to the Darwin region of the Northern Territory, cf. Lowrie 2014), which is apparently devoid of naphthoquinones. The presence of the regio-isomer ramentaceone (**M**) in *D. fulva* Planch. (so far known only from the Northern Territory) indicates an isolated position in the section, possibly together with the morphologically very similar and geographically overlapping *D. brevicornis* Lowrie that lacks naphthoquinones.

P is doubtlessly the main quinone in *D.* sections *Ergaleium* DC. and *Erythrorhiza* Planch. (Culham & Gornall 1994) and this holds true for the close relatives of *D. peltata*, of which most also contain trace amounts of **M**, and *D. lunata* Buch.-Ham. ex DC. (at least in the specimen from Thailand that we investigated) even contains both quinones at comparable concentrations. Our discovery of **P** as an additional quinone in *D. aberrans* (Lowrie & Carlquist) Lowrie & Conran, in which an earlier study (Schlauer *et al.* 2019a) had identified only **M**, consolidates its position (makes it chemically less “aberrant”) in *D.* section *Erythrorhiza*. In this study we failed to detect **P** in *D. stolonifera* Endl. (in contrast to Culham & Gornall 1994), but as absence of metabolites does not constitute a reliable feature (especially if there is some deviating evidence), we abstain from drawing taxonomic conclusions from our result.

Once the detection of **M** in *D.* section *Arachnopus* was a surprise (Schlauer *et al.* 2017), and it remains less common there than **P**. It can thus be taken as further proof for the taxonomic significance of quinone patterns that **M** is the characteristic isomer in both *D. barrettiorum* and *D. hartmeyerorum*, that are jointly distinguished from all other relatives by emergences with exceptionally large heads at the leaf bases and that are morphologically similar and geographically overlapping (Lowrie 2014). The recently described species *D. margaritacea* (Krueger & Fleischmann 2021) is the first Australian member of *D.* section *Arachnopus* to produce both quinone isomers (with **M** at trace amounts but clearly detectable), a pattern previously identified in this section only in species outside Australia so far (*D. indica* L. and *D. serpens* s.l. (*D. makinoi* Masam.; Schlauer *et al.* 2019b)). The morphologically similar

D. finlaysoniana is apparently invariably characterized by formation of the **M**-precursor dihydroramantaceone while **P** is the main quinone with **M** remaining below detection (Schlauer *et al.* 2021).

D. sections *Drosera*, *Ptycnostigma* Planch., and *Brasilianae* Rivadavia, Gonella & A.Fleischm. constitute the widespread “crown group” of the genus that includes the vast majority of species outside Australia. **M** is generally the dominant quinone in all three sections. **P** is interestingly found in *D. flexicaulis* Welw. ex Oliv., which confirms its close relationship with *D. affinis* Welw. ex Oliv. (cf. Schlauer *et al.* 2019a). A plant morphologically similar to *D. amazonica* Rivadavia, A.Fleischm. & Vicent. clearly deviates from typical specimens, which may indicate the influence of another taxon (introgression?). A plant (containing both **M** and **P**) is suspected to represent a hybrid involving *D. biflora* Willd. in Roem. & Schult. (that contains **P**). The other parent may be *D. esmeraldae* (Steyerm.) Maguire & Wurdack (that has possibly contributed its quinone, **M**). These examples further demonstrate the utility of quinone patterns, especially in taxa of reticulate evolution, (Schlauer & Fleischmann 2016) where morphological comparison alone often does not yield unambiguous results.

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