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Botany, uses, chemistry and bioactivities of mangrove plants V: *Acrostichum aureum* and *A. speciosum*

Norimi Kimura[1], Mami Kainuma[1], Tomomi Inoue[2], Eric W.C. Chan[3], Joseph Tangah[4], Karin Baba[1], Nozomi Oshiro[1] & Chika Okamoto[5]

[1] *Secretariat, International Society for Mangrove Ecosystems, c/o Faculty of Agriculture, University of the Ryukyus, Okinawa, 903-0129 Japan (e-mail: isme@mangrove.or.jp)*

[2] *Centre for Environmental Biology and Ecosystem Studies, National Institute for Environmental Studies, Onogawa, Tsukuba, 305-0053 Japan*

[3] *Faculty of Applied Sciences, UCSI University, Cheras 56000, Kuala Lumpur, Malaysia*

[4] *Forest Research Centre, Sabah Forestry Department, Sandakan 90009, Sabah, Malaysia*

[5] *Graduate School of Science, Nishi-Chiba Campus, Chiba University, Chiba, 263-8522 Japan*

Introduction

The genus *Acrostichum* comprises three species of mangrove ferns, namely, *Acrostichum aureum, A. speciosum* and *A. danaeifolium* (Adams & Tomlinson, 1979; Tomlinson, 1986). Of these species, *A. speciosum* is restricted to the Indo-West Pacific region, *A. danaeifolium* to the Atlantic East Pacific region and *A. aureum* occurs in both regions. In this short overview, the botany, uses, chemistry and bioactivities of *Acrostichum aureum* L. and *A. speciosum* Willd. are updated. Currently, *A. aureum* has only been reviewed by Raja *et al*. (2014).

Acrostichum aureum (Pteridaceae) grows up to 3–4 m in height (Giesen *et al*., 2007; Baba *et al*., 2013; Ragavan *et al*., 2014). Stalks of mature fronds are stout, erect and covered with scales. Fronds are pinnate, and produce 10–16 leaves with leathery texture, net-like venation and blunt tips when mature. Fertile leaves have undersides that are rusty-brown during spore release. Spores are large and tetrahedral in shape. In inland areas of mangrove forests that are cleared or disturbed, *A. aureum* grows in tall dense thickets (Figure 1) for new plants can easily sprout from rhizomes. Considered a mangrove weed, foresters have great difficulty in eradicating this fern when preparing the site for planting commercial species of *Rhizophora* (Chan, 1989).

Figure 1 *Acrostichum aureum* showing its dense thickets (left) and young fronds (right)

The fern *A. aureum* can be distinguished from *A. speciosum* by being taller, with young fronds having reddish leaves (Figure 1) and mature fronds bearing leaves with a blunt tip (Giesen *et al*., 2007; Ragavan *et al*., 2014). Plants of *A. speciosum* are shorter (1.0–1.5 m tall) and leaves have a papery texture and acuminate tips (Figure 2). In the Andaman and Nicobar Islands of India, a hybrid of *Acrostichum* has been reported (Ragavan *et al*., 2014). Leaves of the hybrid are leathery and have a pointed tip. Zhang *et al.* (2013) had earlier observed similar morphological intermediates of *Acrostichum* in China and affirmed their hybrid status by molecular analysis. They reported that the hybridization is unidirectional with *A. speciosum* being the maternal parent. Recently, 27 microsatellite markers have been developed and characterised for *A. aureum* (Yamamoto *et al*., 2016).

Figure 2 A cluster of *Acrostichum speciosum*

In the Sundarban mangroves of Bangladesh, *A. aureum* is called 'tiger fern' because the plant provides hiding places for tigers to prey on their victims including humans (Uddin *et al*., 2012). In their mangrove educational book, Baba *et al.* (2013) have included *A. aureum* as edible plants and as minor non-wood products. In Sri Lanka and Indonesia, young fronds are sold in the market as vegetable, sometimes consumed raw but more often, steamed or blanched (Batagoda, 2003; MAP, 2006). An interesting use of *A. aureum* was the harvesting of its stalks, which were sold to vegetable farmers as plant support in the Matang Mangroves, Malaysia (Chan and Salleh, 1987). In folklore medicine, the use of rhizomes and leaves of *A. aureum* for treatment of wounds and boils, and as worm remedy is most often reported (May, 1978; Mannan *et al*., 2008; Uddin *et al*., 2011a, 2012; Khan *et al*., 2013; Kale, 2015).

Chemistry

Phytochemical investigations on *A. aureum* are confined to the aerial parts. Early work by the Faculty of Pharmaceutical Sciences, Science University of Tokyo in Tokyo, Japan, led to the isolation of quercetin-3-*O*-β-D-glucoside and ponasterone (Tanaka *et al*., 1981). It took almost 30 years before scientists from the Institute of Tropical Bioscience and Biotechnology in Haikou, China, reported the occurrence of kaempferol, quercetin, ponasterone, pterosterone and 2-butanone in the fern (Mei *et al*., 2008). More recently, collaborative research between Griffith University in Queensland, Australia, and Khulna University in Khulna, Bangladesh, has led to the isolation of at least 14 compounds from *A. aureum* (Uddin *et al*., 2011b, 2011c, 2012, 2013). Recently, scientists from University of Science and Technology in Cochin, India, have isolated sterols of campesterol, cycloartanol, 24-methylene cycloartanol, γ-sitosterol and stigmasterol from the fern (Thomas *et al*., 2016). Compounds isolated from the aerial parts of *A. aureum*, comprising flavonoids, phthalates, sterols and terpenoids, are shown in Table 1. The chemical constituents of *A. speciosum* have not been studied.

Table 1 Compounds isolated from the aerial parts of *Acrostichum aureum*

Compound class and name	Reference
Flavonoids	
Kaempferol	(Mei *et al*., 2008; Uddin *et al*., 2012)
Quercetin	(Mei *et al*., 2008)
Quercetin-3-*O*-β-D-glucoside	(Tanaka *et al*., 1981; Uddin *et al*., 2012)
Quercetin-3-*O*-β-D-glucosyl-(6→1)-α-L-rhamnoside	(Uddin *et al*., 2011b, 2012)
Quercetin-3-*O*-α-L-rhamnoside	(Uddin *et al*., 2011b, 2012)
Quercetin-3-*O*-α-L-rhamnosyl-7-*O*-β-D-glucoside	(Uddin *et al*., 2011b, 2012)
Phthalates	
Di-(2-methylheptyl) phthalate	(Uddin *et al*., 2011b)
(2'*S*-Methylhexyl)(2"*S*-methyl-5'-acetylpentyl)phthalate	(Uddin *et al*., 2011b)
2"-(Methoxycarbonyl)-5"-methylpentyl -2'-methylhexylphthalate	(Uddin *et al*., 2013)
Sterols	
Campesterol	(Thomas *et al*., 2016)
Cycloartanol	(Thomas *et al*., 2016)
24-Methylene cycloartanol	(Thomas *et al*., 2016)
Ponasterone	(Tanaka *et al*., 1981; Mei *et al*., 2008)
Pterosterone	(Mei *et al*., 2008)
γ-Sitosterol	(Thomas *et al*., 2016)
Stigmasterol	(Thomas *et al*., 2016)
Terpenoids	
(2*S*,3*S*)-Pterosin C	(Uddin *et al*., 2011b, 2011c)
(2*R*)-Pterosin P	(Uddin *et al*., 2011b, 2011c)
(2*R*,3*S*)-Sulphated pterosin C	(Uddin *et al*., 2011b, 2011c)
(2*S*,3*S*)-Sulphated pterosin C	(Uddin *et al*., 2011b, 2011c)
Other compounds	
2-Butanone	(Mei *et al*., 2008)
Patriscabratine	(Uddin *et al*., 2012)
Tetracosane	(Uddin *et al*., 2012)

Bioactivities

Antioxidant

Out of 15 species of ferns screened for total phenolic contents and antioxidant activities, leaves of *A. aureum* ranked eighth under the moderate category (Lai & Lim, 2011). The ethanol leaf extract of *A. aureum* exhibited significant free radical scavenging activity with IC_{50} value of 42 μg/mL while that of ascorbic acid (used as standard) was 16 μg/mL (Khan *et al*., 2013).

Antibacterial

Tested against eight bacterial species of *Micrococcus luteus*, *Bacillus cereus*, *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Salmonella choleraesuis*, *Enterobacter aerogenes* and *Klebsiella pneumoniae*, the methanol leaf extract of *A. aureum* showed no antibacterial activity (Lai *et al*., 2009). When tested against *Serratia marcescens*, *S. aureus*, *E. coli*, *P. aeruginosa* and *M. luteus*, the petroleum ether and aqueous leaf extracts of *A. aureum* also showed no activity (Thomas, 2012). However, the methanol extract inhibited *S. marcescens* and *E. coli* while the acetone extract inhibited all bacteria tested except for *M. luteus*.

Anti-inflammatory

The anti-inflammatory activity of the ethanol root extract of *A. aureum* has been reported by Hossain *et al*. (2011). At 400 mg/kg, the extract displayed significant anti-inflammatory activity using the carrageenan-induced oedema test. After 24 h, the rats showed 66% reduction in paw volume, comparable to that of indomethacin (67%), the standard drug.

Analgesic
Results of an acetic acid-induced writhing test in mice showed that the ethanol extract of *A. aureum* at 250 and 500 mg/kg, exhibited significant analgesic activity in a dose-dependent manner (Khan *et al*., 2013). The writhing inhibition was 29% and 47%, respectively. Diclofenac sodium used as the standard had 69% inhibition at 25 mg/kg.

Cytotoxic
Medicinal plants from Hainan in China, screened for cytotoxic activity against HeLa human cervical cancer cells, showed that the ethyl acetate extract of *A. aureum* exhibited cytotoxic activity with an IC_{50} value of 6.3 µg/mL (Dai *et al*., 2005). No cytotoxic activity was observed with the aqueous extract. When medicinal plants from Bangladesh were screened for cytotoxic activity, the methanol leaf extract of *A. aureum* showed cytotoxicity against AGS gastric cancer cells with an IC_{50} value of 1.0 mg/mL (Uddin *et al*., 2011a), but not against HT-29 colon and MDA-MB-435S breast cancer cells. This finding led to a series of studies on the anticancer properties of *A. aureum*. Of the compounds isolated, (2*R*,3*S*)-sulphated pterosin C, tetracosane and patriscabratine displayed strong inhibitory activity against the cancer cells tested (Uddin *et al*., 2011b, 2011c, 2012).

Wound healing
Wound healing properties of *A. aureum* and *A. speciosum* have been reported by Herman *et al*. (2013). The healing efficiency of ethanol rhizome extracts in aqua cream (5% and 10%) was assessed in rats with inflicted inter-scapular wounds. Results showed that *A. speciosum* had stronger wound healing than *A. aureum*. Treatment with 10% *A. speciosum* exerted the greatest percentage wound contraction and shortest epithelization period. To date, wound healing is the only reported bioactivity of *A. speciosum*.

Anti-diarrhoeal
The ethanol root extract of *A. aureum* had anti-diarrhoeal effect on mice with castor oil-induced diarrhoea (Hossain *et al*., 2012). The extract at 400 mg/kg reduced the diarrhoea by 55% compared to loperamide, the standard drug, which displayed 66% reduction.

Other bioactivities
Other bioactivities of *A. aureum* include allergenic (Yasmeen *et al*., 1987), anti-fertility (Prakash *et al*., 1985; Dhar *et al*., 1992), tyrosinase inhibition (Lai *et al*., 2009) antiviral (Uddin *et al*., 2013) and anti-parasitic (Devi *et al*., 2015).

Conclusion

Of the two *Acrostichum* ferns reviewed, *A. aureum* occurs in both the Indo-West Pacific and Atlantic East Pacific regions, while *A. speciosum* is restricted to the Indo-West Pacific region. Compounds isolated from the aerial parts of *A. aureum* comprise flavonoids, phthalates, sterols and terpenoids. Pharmacological properties include antioxidant, antibacterial, anti-inflammatory, analgesic, cytotoxic, wound healing, anti-diarrhoea, allergenic, anti-fertility, tyrosinase inhibition, antiviral and anti-parasitic activities. On the contrary, no phytochemical analysis has been conducted on *A. speciosum* and only wound healing has been reported. With this open window, there is therefore a vast opportunity for research on the chemistry and bioactivities of *A. speciosum*.

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