A Morphological Study of *Padina australis* (Dictyotales, Phaeophyceae) from Hainan Island, China

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*Padina australis* was collected from Hainan Island of China. Both sporophyte and gametophyte were found. The gametophyte is monoecious. This study is the first report on the gametophyte of *P. australis* in the Northern Hemisphere. Morphological and anatomical studies were carried out. Concentric hairlines alternately grow on both surfaces of a thallus, and reproductive structures occur along the upper side of dorsal hairlines. Sporangia are larger in size than gametangia, and oogonia and antheridia mix in the latitudinal direction of a thallus. Reproductive cells show the same sex in the longitudinal direction of a thallus, though some exceptions exist. The positional relationship between reproductive structures and hairlines is considered as a valuable taxonomic characteristic to classify species in *Padina*.

**Key words**: Dictyotales, monoecism, *Padina*, Phaeophyceae, reproductive structures.

The *Padina* species, belonging to the Zonarieae (Dictyotales, Phaeophyta) (Womersley 1987), occur widely in tropical to temperate waters throughout the world. The members of the genus can be easily distinguished from other dictyotalean species, in having fan-shaped thallus with apical margins rolled. In *Padina* 55 names are listed in Algaebase (http://www.algaebase.org), of which 32 names are taken as valid ones (Guiry and Guiry 2008). Although some taxonomic characteristics are used to classify species in *Padina*, e.g., tallness of a fan-shaped thallus, number of cell layers, and quantity of calcium carbonate deposited on surfaces, identification of *Padina* species remains difficult. In particular, species with distromatic thallus are notoriously confused. Sporophytes are predominant in the populations of species of *Padina*, while gametophytes of most species are still unknown (Womersley 1987, Yoshida 1998).

*Padina australis* Hauck is a common species in tropical waters, which possesses two cell layers throughout a thallus. Hauck (1887) first described its sporophyte from Queensland in Australia, and Farrant and King (1989) reported its gametophyte in New South Wales with a rough sketch. Tseng (1984) described sporophyte of *P. australis* from China, but made no mention of its gametophyte. We collected both sporophyte and gametophyte of *P. australis* from Hainan Island of China. This study is the first report on its gametophyte in this region. The morphologies of both vegetative and reproductive structures of this species are described in detail. The principal aim of
this study is to discuss available taxonomic characters in Padina.

In the present paper, we use the term “ventral surface” for the side where the apical margin of the thallus is inrolled, “dorsal surface” for the other side, and “hairline” for a line of phaeophycean hairs that are arranged in a concentric row (Fig. 1a).

Materials and Methods

The collections were made by skin diving at Tianyahaijiao, Sanya City, Hainan Province (18°30′N, 109°34′E), China (Fig. 2). The specimens were fixed with 10% formalin seawater solution soon after collected. Sections were made from the liquid-preserved specimens by a freezing microtome (Yamato Koki, Wako), stained with 1% aqueous cotton blue solution, and mounted in 20–30% corn sugar syrup solution. Photographs were taken with a light microscope (BH-2 Olympus) and a digital camera (C-4100 Olympus). Voucher herbarium specimens were lodged in the Tokyo University of Marine Science and Technology, Laboratory of Phycology (MTUF-AL).

Result

Padina australis Hauck


Type locality: Cape York, Queensland, Australia.

Distribution: tropical waters of the Pacific Ocean and the Indian Ocean.

Specimens examined: Tianyahaijiao, Sanya City, Hainan Province, 15 January 2003, Z. Sun s.n. (MTUF-AL-23141); the same site, 16 February 2005, Z. Sun s.n. (MTUF-AL-23142).
Fig. 2. Map of the collecting site. Tianyahaijiao, Sanya City, Hainan Province, China.

Figs. 3–5. *Padina australis*. Fig. 3. Mature thallus (MTUF-AL-23142). Fig. 4. Dorsal surface of an immature thallus, showing the first dorsal hairline (d1), the second one (d2) and so on. Fig. 5. Ventral surface of the same thallus, showing the first ventral hairline (v1) and the second one (v2). Scale bar = 2 cm (Fig. 3), 5 mm (Figs. 4, 5).
Plants are erect from a matted rhizoid holdfast without stick-like blade at the basal part (Fig. 3). Fan-shaped thalli are soft and robust, 10–15 cm high and 10–20 cm wide. Thalli look translucent in the sea, and become somewhat reddish in color after steeped in formalin seawater. Both surfaces are slightly calcified, ventral surface is upward. Two cell layers are present through out a thallus, and dorsal cells are smaller in size than ventral ones. The thickness of a thallus is 80–100 µm in the middle part, 100–120 µm in the basal part.

Hairlines alternately occur on both surfaces (Fig. 1), and the distance between neighbor hairlines is 4–7 mm. Concentric

Figs. 6–8. Structures of hairlines of *Padina australis*. Fig. 6. Vertical section of the upper part of a thallus, the first dorsal hairline (d1) and the third dorsal hairline (d3) observed clearly. Fig. 7. Surface view of the third dorsal hairline, showing undeveloped hairs (arrows) and hair scars existing at the underside (arrowheads’ region). Fig. 8. Surface view of the fourth dorsal hairline (arrowheads), showing developed transparent hairs stretching out. Scale bar = 500 µm (Figs. 6, 8), 100 µm (Fig. 7).
hairlines divide a thallus into many bands (Figs. 4, 5). The first hairline originates on the dorsal surface near the apical margin (Figs. 4, 6), consisting of 6–8 hairs in latitudinal direction of a thallus. Hairs of the first hairline are transparent, 15–20 µm in diameter. As the apical margin grows, the hairs break and the scars remain, and the new hairline develops again at the top of the thallus. So that, the second hairline deriving from the previous first hairline becomes a line of scars of hairs. The third hairline originates along the upper side of the scar zone (hair loss zone), and the immature hairs are short (Fig. 7). The fourth hairline has developed, and the hairs are long and transparent (Fig. 8). The fifth hairline subsequently arises similarly to the third one. New hairlines always occur on the upper side of scar zones. In these ways, more than 10 hairlines form on the dorsal surface of a well-developed thallus. On the ventral surface, each hairline occurs between two dorsal hairlines and more near to the elder dorsal one. The first ventral hairline can be observed between the third and fourth dorsal hairlines, and the second ventral hairline is developed between the fourth and fifth dorsal hairlines.

Sporangial sori initiate along the upper side of dorsal hairlines (Fig. 9), and indusia on young sori break accompanying the growth of sporangia. Occasionally, a few small reproductive sori are disposed on the upper side of ventral hairlines. A well-

Figs. 9–11. Sporophyte of Padina australis. Fig. 9. Surface view of sporangial sori borne along the upper side of dorsal hairlines (arrows). Fig. 10. Surface view of a sporangial sorus. Fig. 11. Transverse section of a sporangial sorus. Scale bar = 2 mm (Fig. 9), 200 µm (Figs. 10, 11).
developed sporangial sorus consists of 6–10 sporangia in the longitudinal direction of a thallus (Fig. 10). Young sporangia originate from surface cells, and later grow to protrude from the surface (Fig. 11). Well-developed sporangia are 100–120 µm high and 100–110 µm broad. All gametophyte plants collected were monoecious, and gametangial sori are broader than sporangial ones (Fig. 12). Unilocular oogonia and plurilocular antheridia mix among a gametangial sorus (Figs. 13, 14), and oogonia occupy more area than antheridia on each gametangial sorus. Although some exceptions are present, the cells situated in the same longitudinal direction of a thallus in gametophyte do not change sex as a general rule. Gametangia originate from surface cells that are 20–25 µm × 40–50 µm in surface view. Developed oogonia and antheridia protrude from the surface (Figs. 13, 14). Young oogonia and antheridia are in the same size, but developed oogonia are larger than antheridia. Developed oogonia are 50–65 µm high and 40–60 µm broad. Developed antheridia are 40–50 µm high, consisting of 4 × 8 × (ca.) 10 small loculi.

Figs. 12–14. Gametophyte of Padina australis. Fig. 12. Surface view of gametangial sori borne along the upper side of dorsal hairlines (arrows), never exceeding ventral hairlines. Fig. 13. Surface view of gametangial sori, cells in the same longitudinal direction hardly changing sex, a few exceptions existing (arrows). Fig. 14. Transverse section of gametangial sorus, oogonia and antheridia (arrowheads) mixing with one another. Scale bars = 2 mm (Fig. 12), 200 µm (Figs. 13, 14).
Discussion

Most species in Dictyotales are dioecious, and Padina is the only genus in which some species are monoecious. Reinke (1878) firstly reported monoecious gametophyte of Padina pavonica (L.) Thivy in the Bay of Naples. Later, other authors described the presence of the dioecious gametophyte (Williams 1904, Ramon and Friedman 1966, Littler and Littler 2000). Ramon and Friedman (1966) suggested the depth and the temperature of water affect the ratio of monoecism of P. pavonica. Studies on the monoecious gametophyte of P. australis were limited, and the monoecious specimens were reported only from the Southern Hemisphere. Farrant and King (1989) reported a monoecious gametangial plant from New South Wales in Australia, however, after one century, Verheij and Prud’homme van Reine (1993) reported monoecious gametophyte from the Spermonde Archipelago in Indonesia. Dioecious gametophyte was never found in P. australis in the earlier and the present studies. The present study gives the first evidence that monoecious gametophytes of P. australis occur on the Pacific coast of the Northern Hemisphere.

The two monoecious Padina species can be easily distinguished from each other: P. pavonica consists of 3–4 cell layers, while P. australis is 2 cell layers exist throughout. Padina pavonica is mainly distributed on the north Atlantic coasts and the Mediterranean region; on the contrary, P. australis mainly occurs in the tropical Pacific (Guiry and Guiry 2008). Therefore, we identified the distromatic monoecious species from Hainan Island to be P. australis.

Padina australis never possesses the Vaughaniella stage, differing from many Padina species, e.g., P. japonica and P. minor. The absence or presence of the Vaughaniella stage is an available taxonomic characteristic to identify some species in Padina. Immature reproductive structures are covered by observable indusia, which are broken later as reproductive structures grow. The presence or absence of such indusium on young reproductive structure is determined by the robustness of cortical membrane. We suggest this character is not available to rank species in Padina. Farrant and King (1989) described reproductive sori of P. australis on the ventral surface of a thallus, however, Verheij and Prud’homme van Reine (1993) mentioned that reproductive sori of their specimens only occur on the dorsal surface. The present result agrees with the latter authors, though a few sporangial sori are present on the ventral surface occasionally. Perhaps the geographical separation results in the morphological variation of P. australis.

Sun et al. (2008) suggested the relative position of reproductive structures and hairlines to be available as a taxonomic characteristic at the rank of species in Padina. The present study indicates that P. australis is distinguished from some distromatic Padina species, e.g., P. japonica, by the reproductive structures borne only along the upper side of each hairline in contrast with other species, whose reproductive structures are borne along both sides of each hairline. Abbott and Huisman (2003) described a new species P. moffittiana Abbott & Huisman, however, we consider they misidentified the species, because their specimen is very similar to P. australis especially in the position of reproductive structures and hairlines. Although they illustrated the difference between P. moffittiana and P. australis in a diagram, the reproductive structure of their P. australis might be mistaken in the position occurring along the lower side of hairlines. It is impossible that the reproductive structure of Padina species occurs at the lower side of hairlines instead of the upper side.

All the species of Padina possess hairs on their surfaces, especially near apexes, where many long hairs form the first hairline. Each
cortical cell can form hair only once, and new hairs grow nearby after the old ones fell. In *P. australis*, the dorsal surface is separated into reproductive and sterile zones by the ventral hairlines, and each reproductive zone occurs between elder dorsal hairline and younger ventral hairline (Fig. 1b). It is assumed that the ratio of reproductive and sterile zones of a thallus is modulated by the hairlines. The function of the sterile zones may be to produce photosynthate for growth and reproduction.

In the latitudinal direction of a thallus of a gametophyte of *Padina australis*, the oogonial area is broader than antheridial area on each reproductive zone. It is assumed that the investment to female is more than to male. In the longitudinal direction, the cells that are considered as the cognate ones do not change sex as general rule. However, some cells were observed to change sex in the same longitudinal line, thus we suggest that the sex determination on a thallus is non-genetic in this species. A further work should be carried out to clarify the mechanism for the determination of sex in species of *Padina*.

**References**


