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The dual face of a duckweed frond

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Author Note

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KEYWORDS

- Cuticle
- duckweed
- frond
- *Lemnaceae*
- permeabilization
- phytochrome B
- reactive oxygen species
- shade avoidance

The cuticle of duckweeds (*Lemnaceae*) has to fulfil contrasting roles depending on its anatomical position: while the water-repellent upper adaxial layer is exposed to the atmosphere and protects these fragile plants from UV radiation, mechanical damage, pathogens, and other adverse impacts, the lower abaxial layer is water-permeable and mediates

nutrient uptake from the medium. However, the remodelling of the cuticle with distinct desired traits in different parts of the duckweed frond was until now unexplored. In their multi-approach study, Kim *et al.* (2026) revealed that dynamic cuticle restructuring in developing fronds was a response to the light conditions and mediated by reactive oxygen species.

Life at the water–air frontier: fight on two fronts for duckweed

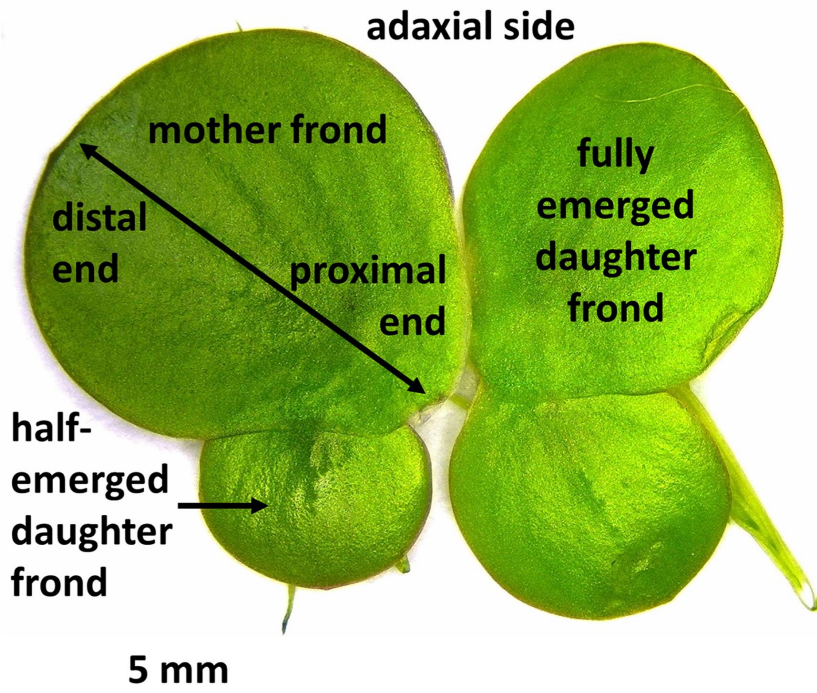
Duckweeds (*Lemnaceae*) are free-floating aquatic plants that had returned to freshwaters ~63–65 million years ago, after an ancestral detour in their evolution to the terrestrial ecosystem (Fang *et al.*, 2025). The current worldwide distribution of *Lemnaceae* proves that the transition from land to water was successful. This re-adaptation involved extreme size reduction and anatomical simplification, resulting in the smallest angiosperms on Earth that can produce vegetative offspring every other day in suitable environments (Acosta *et al.*, 2021; Fig. 1).

Fig. 1.

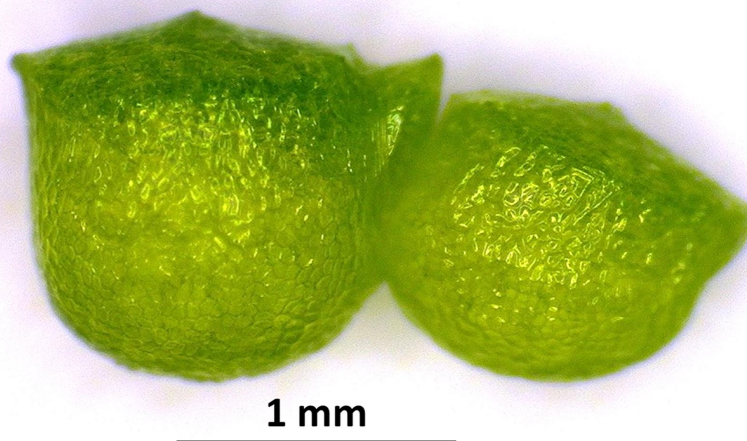
Janus-faced duckweeds: The impermeable adaxial (upper image) and permeable abaxial (central image) sides of the same colony of a rooted duckweed species, *Spirodela polyrhiza*, and side-view of the rootless *Wolffia arrhiza* mother and daughter fronds with impermeable and permeable cuticles on the top and in the bottom, respectively (bottom image).

Alt text: Three close-up photos arranged below each other that depict duckweed colonies. The upper image shows the top view of a representative colony of the rooted species *Spirodela polyrhiza* featuring the waxy, impermeable adaxial cuticle. The colony consists of four fronds, that are ramets, at different developmental stages: the largest one is the mother frond. On the proximal end of the mother frond, a developing daughter frond has emerged halfway, with the distal end visible, while its proximal part is still inside the meristematic pocket of the mother frond. On the other side of the mother frond, another fully emerged daughter frond can be seen, which already has a partly emerged daughter frond on its own. The central image depicts the abaxial, lower, side of the same *Spirodela polyrhiza* colony featuring the thin, permeable cuticle, multiple roots emerging from the node of each frond, and a slight anthocyanin accumulation that results in purple pigmentation on this side of the fronds. The bottom image depicts a side-view of a two-frond colony of the rootless duckweed species, *Wolffia arrhiza*. The mother and the fully emerged daughter frond feature a dark green, flat, and waxy adaxial cuticle, and a pale green, globular abaxial side with a permeable cuticle.

Spirodela polyrhiza



Wolffia arrhiza



As part of this re-adaptation process, these minimalist plants faced the dual challenge of living at the water–air interface. Consequently, they had to redesign their cuticle—a fundamental tool in terrestrial plants to control water loss, defend against pathogen attack, and filter UV irradiation ([Khan *et al.*, 2026](#)). Duckweeds developed two distinct types of cuticle: the cuticle on the adaxial side provides sufficient

defence from even the highest intensity UV radiation in tropical regions, while the abaxial side is permeable to nutrients, enabling duckweeds to have the fastest known biomass production by higher plants on Earth (Borisjuk *et al.*, 2018; Ziegler *et al.*, 2025). This latter structure allows highly efficient nutrient supply and makes roots dispensable even in rooted duckweed species (Ware *et al.*, 2023).

These plants are not only fundamental members of lentic communities but have practical applications too. Plant biology and ecotoxicology research relies on the fact that duckweed fronds can easily take up various inorganic and organic substances from the aqueous medium through their lower cuticle. In this way, duckweed provides a suitable and easy-to-modulate platform that is widely used as a plant model. In a similar fashion, from a further applied aspect, duckweeds are also extensively utilized in wastewater management, where they efficiently take up nutrients (N, P) and micropollutants (metals and metalloids, pesticides, drug residuals, and so on) through their lower epidermis, and produce valuable biomass for applications such as bioenergy production (Piyachon *et al.*, 2026). Duckweeds grown under suitable hygienic conditions are also increasingly gaining popularity as food and feed components (Acosta *et al.*, 2024; Dutta *et al.*, 2026; Jahreis *et al.*, 2026; Yadav *et al.*, 2026).

The ability of duckweeds to take up substances through the abaxial surface is a major basis for these practical applications. Therefore, deciphering the cuticle structuring on the duckweed frond surface, which is in contact with the atmosphere on one side and the hydrosphere on the other, is crucial to understand the functioning of plant life at the air–water juncture.

Duckweed cuticle is not a fixed structure

Kim *et al.* (2026) found that duckweed cuticle organization was more dynamic than one would have expected. Based on the results, these plants still carry an evolutionary heritage of impermeable cuticles on both frond sides at the early developmental stage. This pattern changes only after the new frond protrudes from the meristematic pocket and becomes in direct contact with the external environment. From that point, the abaxial cuticle becomes water-permeable progressively from the distal emerging end until the maturing frond is capable of exchanging materials through its entire abaxial lower epidermis.

In addition, Kim *et al.* (2026) revealed that this transformation happens in response to environmental signals. The signal, however, does not come from below—such as getting in direct contact with water—as may seem plausible. Instead, developing fronds look up, and use light quality as a signal. The results of the study support the assumption that shade avoidance-related regulation, another legacy from the earlier terrestrial lifestyle (Franklin and Whitelam, 2006), was the main driver of cuticle restructuring. The shade-avoidance response describes the response of terrestrial plants under a leaf canopy, where the ratio between red and far red light (R:FR) is lower than in open spaces because red light is efficiently absorbed by the shading leaves. Terrestrial plants respond to this light signal by excessive linear growth to reach open areas with better conditions for photosynthesis, namely higher red light portions. The shift in R:FR ratio, registered by the photoreceptor phytochrome B (with a minor contribution from phytochrome D and E in *Arabidopsis thaliana*; Franklin and Whitelam, 2006) marks the beginning of exposure to the external environment for the protruding frond, and induces a chain of events that result in permeabilization of the abaxial cuticle. Inside of the mother frond, the daughter frond receives light that passes through cell layers of the mother frond containing chlorophylls. Consequently, the R:FR ratio is low but increases after emergence of the daughter frond. This signal is mediated by reactive oxygen species (ROS) as secondary messengers. Based on their findings, Kim *et al.* (2026) hypothesized that phytochrome B could be the general signalling hub for cuticle remodelling in duckweeds by supposedly integrating various environmental signals (e.g. mechanical sensations, humidity, temperature, etc.) and modulating developmental and physiological responses of the protruding frond via ROS and plant hormones. Thus, whereas the signalling part is inherited from terrestrial plants, signal transduction via ROS and the final response (enhanced permeability of the abaxial cuticle) were necessary adaptations after returning to the aquatic environment (Fang *et al.*, 2025). Analogously, phytochrome B was found to mediate cuticle development in maize (*Zea mays*) albeit in an opposite direction and pattern (Qiao *et al.*, 2020). In expanding leaves of this terrestrial species, differential gene expression and accumulation of longer-chain alkanes, wax esters, and cutin monomers showed a proximodistal gradient in response to light.

Important results were obtained by transcriptomic analyses comparing the internal (inside the mother plant) and external (emerged) parts in half-emerged daughter fronds. Unexpectedly, cutin biosynthesis occurs essentially without region-specific differences. Structural specificity was mediated by differentially more highly expressed genes for the transport of wax and cutin components in the external part of the frond.

Perspectives

The results reported by Kim *et al.* (2026) set the basis for, and will indeed inspire further research on, this aspect of duckweed ontogenesis. Some of our views are presented here.

When and how the development of upper and lower cuticles diverged and led to contrasting traits during frond ontogenesis have not yet been studied in detail.

Most of the *Lemnaceae* species are floating on the water surface, except for a few species, for example *Lemna trisulca*, which are submerged, leading to their fronds being oriented in different angles underwater. It would be interesting to learn whether the adaxial and abaxial cuticles of these water-submerged daughter fronds also behave in a similar manner to those afloat.

Duckweeds tend to form thick floating mats in suitable habitats with multiple overlapping frond layers. Under these conditions, a slight shift in the R:FR ratio due to emergence from the meristematic pocket of the mother frond seems insignificant compared with the light-screening effect of several other canopied fronds. Hence, modulation of cuticle restructuring by regulators other than light quality also seems highly likely. Similarly, the vertical R:FR gradient throughout the frond cross-section can be hypothesized to have an effect on diverging development of abaxial and adaxial cuticles.

The authors investigated three species, *Spirodela polyrhiza*, *Landoltia punctata*, and *Lemna minor*—all being rooted species from the family *Lemnaceae*. It would be interesting to know whether similar cuticle patterning and maternal pouch characteristics exist in the rootless duckweed species of the genera *Wolffiella* and *Wolffia*.

The fact that duckweeds acquire nutrients predominantly through their lower epidermis raises the follow-up question of whether the abaxial cuticle can be dynamically restructured throughout the life span of the frond to become more permeable, for example under nutrient-limited conditions. Understanding the regulation of cuticle development in duckweeds and maybe modifying its traits, for example through tailored light environments, may help in the removal of pollutants from wastewaters such as PAHs (polycyclic aromatic hydrocarbons), PBDEs (polybrominated diphenyl ethers), and microplastics, where cuticle permeability or hydrophobic/hydrophilic interactions play important roles in adsorption and uptake.

From a wider perspective, duckweeds could find just one more way to support agricultural production as plant models. Threatened by climate change, weather extremes, new pests, and pathogens, better understanding of the regulatory network of cuticle development and remodelling in duckweeds can also contribute to breeding of more resilient crop cultivars.

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Conflict of interest

The authors declare no conflicts of interest.

Note: Please provide information related to Funding (Optional).

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