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The Wolffia effect: from biological to physical anchoring — meniscus engineering in a rootless duckweed

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The transition from land to water in Lemnaceae represents an extreme case of reductive evolution, culminating in the minute, rootless genus Wolffia. Aerenchyma explains buoyancy, but not how microscopic fronds remain upright, avoid rolling, and aggregate into cohesive colonies without any biological anchor. We addressed this in Wolffia globosa combining microscopy, surface metrology, histochemistry and mathematical modelling.

High-magnification and laser imaging revealed that the waterline around each frond is not flat: reflective points along the perimeter mark localised deformations of the air–water interface, while ESEM excluded any anatomical protrusion. Laser scanning profilometry showed alternating upward and downward menisci, with a bimodal distribution of contact angles (θup = 78.0 ± 3.0°, $\theta down$ = 96.1 ± 2.2°; n = 68). Neutral Red histochemistry mapped a matching wettability pattern: an undulated contact line between the unstained hydrophobic dorsal epidermis and the stained hydrophilic ventral one. Removing surface tension with a surfactant abolished the menisci and submerged the plants, showing that aerenchyma provides buoyancy while surface tension provides anchoring and orientation.

A finite-element model parameterised on these values reproduces the observed multipolar capillary field and predicts a short-range (<0.4 mm) attractive force between neighbouring fronds — the "Cheerios effect" — sufficient to drive passive self-assembly into stable rafts.

We propose that biologically patterned epidermal wettability functionally replaces the root system lost in derived Lemnaceae, with implications for colony dynamics, mat behaviour in cultivation systems, and bio-inspired interfacial engineering.

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