Origami-like unfolding of hydro-actuated ice plant seed capsules

Abstract

Actuated plant materials are a source of inspiration for the design of adaptive materials and structures that are responsive to specific external stimuli. Hydroresponsive, metabolismindependent plant movements are particularly fascinating, because the extracted concepts are more amenable to transfer into engineering than those dependent on cellular activity. Here we investigate the structural and compositional basis of a sophisticated plant movement mechanism—the hydration-dependent unfolding of ice plant seed capsules. This reversible origami-like folding pattern proceeds via a cooperative flexing-and-packing mechanism actuated by a swellable cellulose layer filling specialized plant cells. Swelling is translated into a bidirectional organ movement through simple geometric constraints embedded in the hierarchical architecture of the ice plant valves. Extracted principles from this reliable and reversible actuated movement have relevance to the emerging field of 'programmable matter' with applications as far-reaching as the design of satellites and artificial muscles.

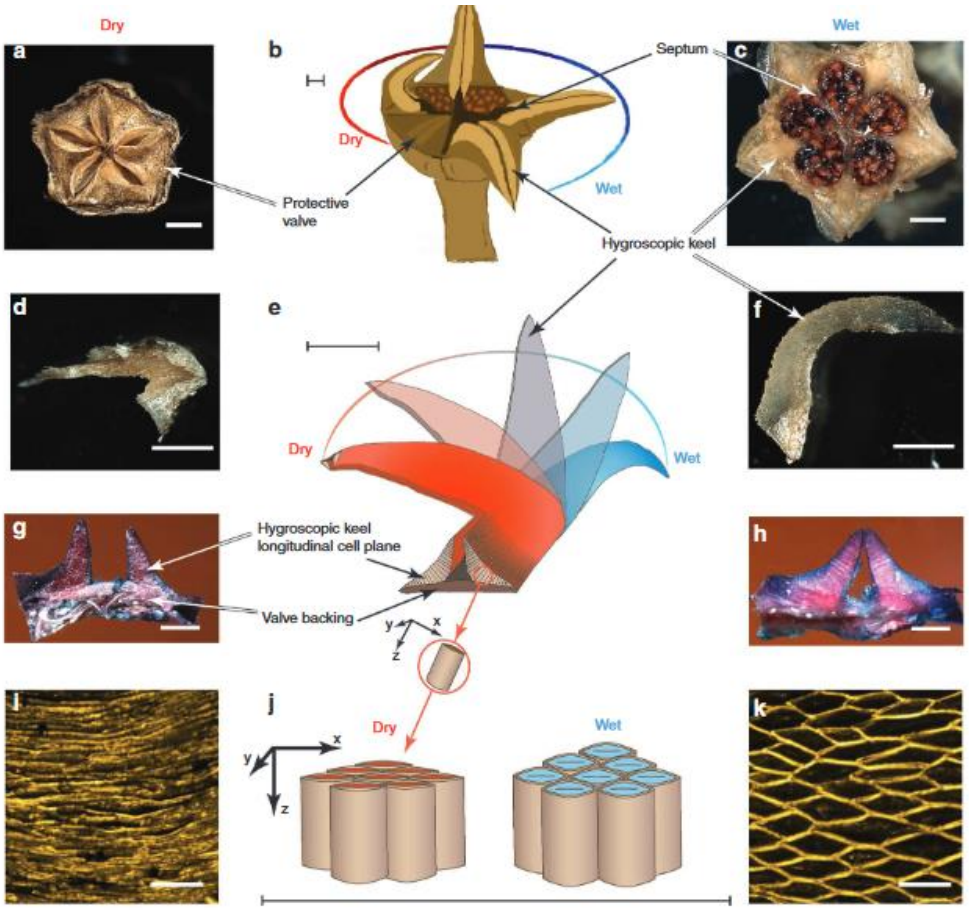

Figure 1 | Ice plant seed capsule hierarchical morphology. Light and confocal microscopy images depict the morphology of the ice plant capsule and the hygroscopic keel tissue at different hierarchical levels (**a**–**k**). For each hierarchical level, an illustrated schematic provides a simplified representation of structures and the progressive movements that occur during water-dependent actuation. Cell longitudinal images (**g**, **h**) were stained with FCA to provide contrast. Contrast in confocal images (**i**, **k**) originates from lignin autofluorescence. Scale bars are defined as follows: **a** and **c** = 2 mm; **b**, **e** and **j** = 1 mm; **d** and **f** = 1 mm; **g** and **h** = 0.5 mm; **i** and **k** = 0.1 mm.