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Wrinkling instability taught by brown algae : Morphogenesis of a kelp blade

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ABSTRACT

Brown macroalgae, also known as kelp, consist of a holdfast that anchors them to the sea floor, a stipe that rises to the water surface, and leaf-like structures known as blades whose primary function is photosynthesis. A visual inspection of the blades' surface reveals complex and diverse geometrical features, from tiny wrinkles to large ruffles. It has been demonstrated that the edges of kelp blades grow faster than their midline, inducing a global plate instability known as ruffling. However, morphogenesis of the kelp blade could also be linked to the differential growth across the thickness of the blade. Indeed, the outer layers or meristoderm grow through cell proliferation while pulling on a passive inner core composed of the medulla and cortex. This incompatibility in growth across three layers eventually leads to a surface instability called wrinkling which has been characterized for bi-layers systems, but not tri-layer ones.

Here, we model the mechanics of the kelp growth. We use finite element simulations on a simplified tri-layer model to characterize the influence of material and geometrical parameters, e.g., layers' modulus, thickness, boundary conditions, on the wrinkling folds. Our results show that the realistic range of these parameters observable across kelp species leads to a diversity of surface patterns, arising from the same wrinkling mechanism. To further explore the mechanisms shaping kelp, we develop a realistic numerical model of the blade, that include complex growth patterns and 3D effects. Our work sheds light onto the close interaction between tissue mechanics and biological growth, focusing on the morphogenesis of brown algae.

Keywords: Kelp blade, morphogenesis, wrinkling instability, tri-layer model