Morphogenesis through mechanical instabilities: wrinkles and ruffles formation during the growth of kelp blades

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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 close 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 (i.e., the meristoderm) grow through cell proliferation while pulling on a passive inner core (i.e., the medulla and cortex). This incompatibility in growth eventually leads to a surface instability called wrinkling which has mostly been characterized for bi-layers systems. Here, we model the kelp blades as a tri-layer to study the influence of wrinkling instabilities on its morphogenesis. Using a combination of reduced-order models and finite element simulations, we characterize the influence of material and geometrical parameters (e.g., layers’ modulus, thickness, boundary conditions) on the wrinkling onset and the complex, post-instability deformation of the system. Our results shed light onto the role of wrinkling in the morphogenesis of kelp blade and could be extended to induce wrinkles and ruffles in artificial systems.

Keywords : Kelp blades, morphogenesis, wrinkling instabilities, ruffling instabilities, buckling analysis, tri-layer model