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Translating the hygroscopic principles of explosively dehiscent fruits into bioinspired actuators

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Plants have evolved a range of reversible and irreversible, active and passive movements which are often triggered and/or driven by environmental cues such as light, temperature and humidity. Some of these movements rival the accelerations observed in the animal kingdom. Among the fastest plant movements is the explosive dispersal of seeds facilitated by the release of stored elastic energy previously built up by, and stored in drying lignified fruit tissues.
In this study, we investigate the dispersal mechanism of the sandbox tree (Hura crepitans, Euphorbiaceae), whose orange-sized fruits compose of up to 16 carpels that undergo pronounced deformations during drying. Initially constrained by their macroscopic arrangement, internal stresses are accumulated upon progressive tissue desiccation. Once a critical threshold is reached, rupture occurs at predetermined fracture sites, initiating explosive seed release.
We examined this mechanism across hierarchical structural levels (millimeter to nanometer scale) by combining multiple imaging techniques, including high-speed imaging, UV Micro-Spectrophotometry (UMSP), small-angle X-ray scattering (SAXS), micro-computed tomography (µCT), and nano-holotomography (nanoCT), combined with advanced 3D analysis tools such as digital volume correlation (DVC) and finite element analysis (FEA). Our multiscale analysis reveals how fruit geometry, cell orientation, anisotropic shrinkage, and the degree and composition of lignification together facilitate this rapid actuation.
Based on these insights, we translated the functional principle into a 4D-printed actuator composed of wood–plastic composite (WPC), which mimics the strain accumulation and release dynamics of the natural system. These bioinspired actuators demonstrate substantial movement and offer a platform for biodegradable seed dispersal devices aimed at reforestation, as well as novel autonomous material systems, going beyond biology, that can be tailored to respond to thermal, pneumatic, solar, or electrical stimuli.

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