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Figure 2 Dynamics of floral explosion. **a,** Coordinates x and y of positions of the filament tip (blue triangles) and anther tip (red circles), plotted at 0.1-ms intervals. Inset, a single stamen; points used to plot positions are indicated. Arrows, stamen positions just before pollen release. **b,** Coordinates x and y of velocity components of the anther (top) and filament (bottom) as a function of time, derived from the first six points in **a**. Arrows, velocity just before pollen release. Error bars represent uncertainty in measurements from **a**, propagated as random errors.
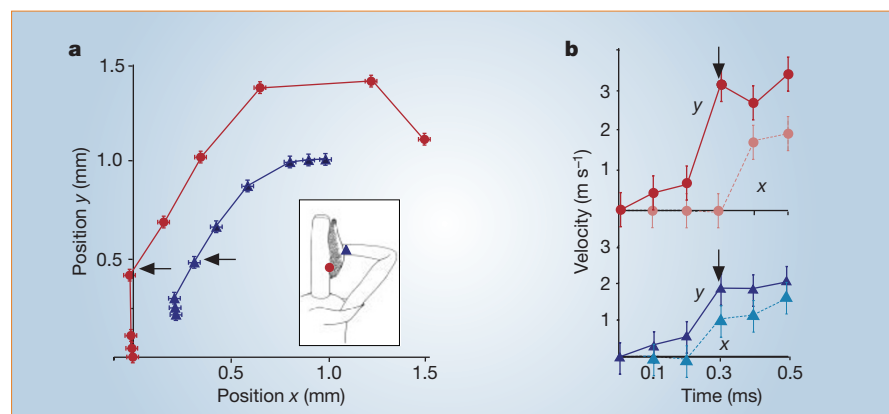
Botany

A record-breaking pollen catapult

The release of stored elastic energy often drives rapid movements in animal systems[1,2], and plant components employing this mechanism should be able to move with similar speed. Here we describe how the flower stamens of the bunchberry dogwood (*Cornus canadensis*) rely on this principle to catapult pollen into the air as the flower opens explosively[3–5]. Our high-speed video observations show that the flower opens in less than 0.5 ms — to our knowledge, the fastest movement so far recorded in a plant.

Cornus canadensis grows in dense carpets in the vast spruce-fir forests of the North American taiga. As bunchberry flowers burst open, their petals rapidly separate and flip back to release the stamens (Fig. 1). During the first 0.3 ms, the stamens accelerate at up to $24,000 \pm 6,000$ m s^{-2} ($2,400g$), reaching the high speed (3.1 ± 0.5 m s^{-1}) necessary to propel pollen, which is light and rapidly decelerated by air resistance (terminal velocity, 0.12 ± 0.03 m s^{-1} (mean ± s.e.m.); $n = 7$). The pollen granules are launched to an impressive height of 2.5 cm (range, 2.2–2.7 cm; $n = 5$), which is more than ten times the height of the flower: from this height, they can be carried away by the wind. (For methods and movies, see supplementary information.)

Petals open independently of stamen activity, moving out of their way within the first 0.2 ms (Fig. 1). Petals attain a maximum speed of 6.7 ± 0.5 m s^{-1}, accelerating at up to $22,000 \pm 6,000$ m s^{-2} (or $2,200g$). The process of petal opening and pollen launch

in bunchberry plants occurs faster than the opening of *Impatiens pallida* fruits (2.8–5.8 ms, $n = 3$, see supplementary information); the snap of venus flytraps (*Dionaea muscipula*; 100 ms)[6]; the leap of froghoppers (*Philaenus spumarius*; 0.5–1.0 ms)[1]; or the strike of the mantis shrimp (*Odontodactylus scyllarus*; 2.7 ms)[2].

As in these other organisms[1,2,6], rapid movements in bunchberry flowers rely on stored mechanical energy. Physiological processes, which take about a millisecond for each enzymatic reaction[7], are not required for the explosion itself. We find that the flowers will open even when the stamen filaments have been crippled by treatment with sodium azide. But the flowers do not open if their turgor is reduced: dehydration of flowers with sucrose decreases the extent of opening, although subsequent rehydration allows them to open fully (results not shown). Turgor pressure is therefore required in the production of mechanical energy for explosive flower opening.

Bunchberry stamens are designed like miniature medieval trebuchets — specialized catapults that maximize throwing distance by having the payload (pollen in the anther) attached to the throwing arm (filament) by a hinge or flexible strap (thin vascular strand connecting the anther to the filament tip). This floral trebuchet enables stamens to propel pollen upwards faster than would a simple catapult. After the petals open, the bent filaments unfold, releasing elastic energy. The tip

of the filament follows an arc, but the rotation of the anther about the filament tip allows it to accelerate pollen upwards to its maximum vertical speed, and the pollen is released only as it starts to accelerate horizontally (Fig. 2).

The rapid opening of the self-incompatible[8] bunchberry may enhance cross-pollination in two ways. First, when insects trigger flower opening, the pollen released sticks to their body hairs until it is transferred to an adhesive stigma. The force required to open flowers (0.1–0.5 mN) favours large pollinators (bumblebees, for example) that move rapidly between inflorescences; it effectively excludes smaller, less mobile visitors such as ants. Second, pollen from flowers that open by themselves may be carried by wind currents. Indoors, pollen is transported over 22 cm (more than 100 times the size of the flower) and outdoors, in the presence of a steady wind, pollen can move farther than a metre. Exploding flowers enhance insect pollination and may allow wind pollination, adding to growing evidence that flowers often use multiple pollination mechanisms[9,10].

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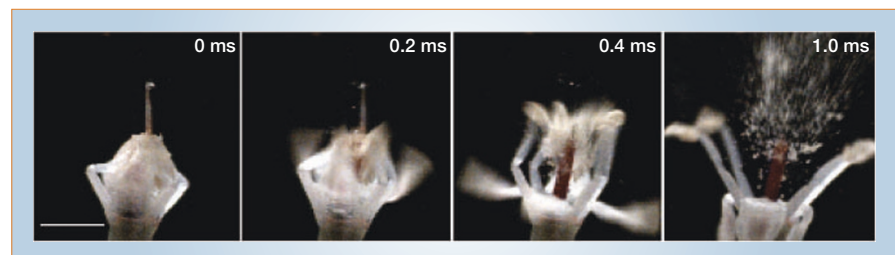
Figure 1 Bunchberry flower opening, recorded on video at 10,000 frames per second. Time elapsed is indicated. First frame shows a closed flower with four petals fused at the tip, restraining the stamens. Blur represents the distance moved in 0.1 ms. Scale bar, 1mm.