Anti-attachment mechanisms help carnivorous plants to survive: Nepenthes singalana

Catching insects is a survival advantage for carnivorous plants. Insectivora try to catch their prey with mechanical traps, with sticky liquids or with anti-adhesion surfaces. The surface properties of the trap of a nepenthes species (nepenthes singalana) have been examined in this atomic force microscopy (AFM) and scanning electron microscopy (SEM) study.

Natural occurring adhesive or anti-adhesive surfaces are of great interest because nature can serve as a model for artificially made surfaces with completely new properties. One of the best known examples in this field called biomimetics is the “lotus effect”, which lead to easy-to-clean surfaces using surface structuring.

Some or the plants’ leaves meet in jug-like pitchers, which function as pit traps. Figure 1 shows the design of the pitcher, which consists of lid, collar, waxy area and digestion area.

Escape barriers on two levels
In addition to the shiny red color, the nectar’s flavor also attracts insects. The nectar is produced mainly in the lid and the collar region of the jar. Sometimes nectar-seeking insects fall into the inside of the jar. The collar is convex and bent. Its surface is not flat, but grooved. Between the grooves there are step like protrusions with anisotropic capabilities. They give foothold only in one direction.

Fig. 1 Pitcher (pit trap) of a nepenthes species, after [2]

Carnivorous plants are widely spread, occurring both in tropical and arctic regions. The round leaf sundew (drosera rotundifolia), for example, belongs to the well-known European carnivorous plants. It catches its prey with sticky fluid drops on its leaves.

The tropical carnivore nepenthes singalana is found in Sumatra’s humid mountain forests and lives on poor, not too sunny and acidic grounds. Therefore the plant’s survival depends on its ability to attract insects, and to catch and digest them [1].

In the scanning electron microscopy image in Figure 2, the surface looks like roof tiles [3]. The insect’s slipping is mainly caused by this structure.

Fig. 2 SEM-image of the pitcher’s collar region, scale bar 50 µm.

Wax glues adhesive hairs
If an insect tries to escape, its front legs are sliding continuously. The fly’s feet are covered with hairy structures (setae) on their attachment pads. The adhesion of the setae is mainly due to van-der-Waals and capillary forces [4].
If a fly tries to escape along the inner wall, it reaches the waxy zone of the pitcher. It is assumed that the fly’s setae are contaminated by the wax crystals [5], reducing the adhesion. Hence, the fly falls into the base of the pitcher, which is filled with liquid containing digestion enzymes.

Figure 3 is an AFM image showing the surface of the pitcher’s digestion zone. It has been imaged with a JPK NanoWizard® AFM, combined with an optical inverted microscope. During the experiment all the optical capabilities of the microscope remained available. Hence, it was possible to find a suitable area for AFM imaging prior to scanning. Due to the conditions inside the pitcher the AFM image was taken in air without further sample preparation.

The surface structure of the wax crystallites are shown in Figures 4 and 5. The SEM image in Figure 4 shows plate-like crystallites of around 2 µm in size, but the wax can also have a nodular shape. The sticky nodules shown in the AFM image in Figure 5 could easily be moved around with the AFM tip and have a diameter of 1 to 2 µm.

Under normal circumstances the sticky fluid and hairy structures keep the fly attached to nearly every surface. The adhesion force of setae of a spider has been measured by AFM and was found to be in the range of nanonewtons [7]. In their experiment the authors used the silicon AFM cantilever as a force sensor simulating the spider’s foot is attached to a silicon surface. They attached a group of setae to the tip of a cantilever and pulled it away from the surface. The adhesion causes the cantilever to
deflect as it is retracted, and from the deflection of the cantilever the adhesive force can be calculated. Scaled to human dimensions, a man (75 kg body weight) equipped with a fly’s adhesion system at his feet could keep himself and another 400 kgs (equivalent to 2 pianos) attached to the ceiling.

The question is, why the fly does not try to escape the pitcher using its wings. Movies shot with a high-speed camera show that the fly flaps with its wings when it falls. But wing movement does not seem to be well coordinated and not like the natural movements [8]. How the plant can succeed in preventing the fly’s escape is currently under investigation.

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This article has previously been published in German in Biospektrum (Elsevier) No. 3/2004, p. 325f.

Literature