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The relationship between the wettability and the density of stomata

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Abstract. stomata are channels for respiration of plants, and they are vital to keep it unblocked. In nature, in order to avoid the surface stomata being covered by water and ensure the normal respiration of stomata, plant leaves in nature are realized by a variety of methods, among which the difference surface wettability plays a crucial role in the distribution density of stomata. To explore the relationship between the wettability and the stomata density, this thesis investigates how the top and bottom density of stomata on plant surface affect the survivability of elm leaves (plant in the Ulmaceae family). Here, we find its lower surface with superhydrophobic function is covered by large amount of stomata. While the bottom surface with hydrophilic performance is smooth and covered by a small amount stomata. This research reveals the significant of waterproof function to the survival of leaf and has potential application in air exchange underwater.

Keywords: stomata, respiration, wettability, elm leaves, air exchange.

1. Introduction

Stomata is what plant use for respiration and gas exchange; therefore, it is important to make it thoroughly unblocked to increase the plant's survivability[1-4]. Plant as evolved and developed specific characteristics to adapt to different environment. For example, lotus (an aquatic plant) survives in an aquatic environment[5-7]. It has developed super-hydrophobic on bottom surface to make the surface uncontaminated. Even if the bottom surface of the lotus leaves is covered with water, its stomata can still respire at short notice. Therefore, the distribution of the stomata on the bottom surface are much denser than the bottom side. Another representative aquatic plant, Pistia stratiotes, both have the water-repellent function on their upper and lower surfaces. Therefore, their pores are distributed between the ultra-hydrophobic structures, which can also ensure their normal respiration in deep water[8]. Superhydrophobic can keep surface clean, but low surface energy surfaces are not suitable for all plants. For example, in crop application, the leaf surface is well wetted and covered by the drugs. It is conducive to drug absorption and avoid soil pollution[9]. The rose petals perform superhydrophobic and high adhesion performance, which is different from lotus leaf in nature[10]. However, not every leaf in nature world has a super-hydrophobic surface like the lotus leaf; elm leaf is an example. In raining environment, the bottom surface of the elm leaf can easily be wetted and covered by water layer, this causes the stomata on the plant's surface incapable of respiration. But how can the leaf survive in the nature world? During our investigation, we found out that the hydrophobicity of the lower side of the leaf is much

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higher than the bottom surface, and the distribution of the stomata is denser than the bottom surface. After experiments and data recording, our report describes the relationship between the distribution density of the stomata at the bottom and lower surface of elm leaf and how it survives in raining environment.

2. Experiment

2.1. Materials

Elm leaves (obtained on trees on the streets; experiment is performed and finished at the day of gathering); double-face adhesive tape; glass sheet; syringe

2.2. Equipment

Camera (Huawei ANG-AN00 phone camera-64m pixels); scanning electron microscope (S-4800 Hitachi scanning electron microscope).

2.3. Experiment procedure

Cut fresh elm leaves to 8cm by 15cm while keeping the vein in the middle, and then use the double-face adhesive tape to stick the leaf onto the glass sheet. Next, place it the scanning electron microscope (SEM) for observing the topography details of the leaf. A syringe is used to let-out a droplet while making sure it is at the height of 8cm and in a state of free falling. Last, use the camera to take a photograph of the droplet on the leaf with a contact angle. Repeat the procedure 10 times, 5 times each for front and back.

3. Analysis

3.1. Analysis on the exterior surface structure

In nature, physical structure and chemical composition have a decisive influence on function. Organisms have evolved for eons to improve their ability to survive in order to adapt to their living environment, and this evolution has never stopped. Any biological function cannot be completed by a single factor, but needs the synergistic action of many factors. For example, the self-cleaning function of lotus leaves is completed by the micro-nano structure and biological wax material on its surface. The elm leaf is a representative surface, and its special structure has an important influence on its wettability. The surface wettability plays a decisive role in stomatal arrangement.

To find the relationship between surface wettability, the details of topography are observed. Figure 1a-b are SEM photograph of the elm leaf's top surface; Figure 1c-d are SEM photograph of the elm leaf's bottom. From photograph 1a and 1c, we could find out both top and bottom surface of the elm leaf consist spherical micro protrusions that are like lotus leaf's protrusions which increase the roughness of the surface to make it more hydrophobic. In addition, there are lots of villus structure object on the surface of elm leaf, to protect the leaf from hostile environment and control the evaporation of water on the surface. The villus can ever support the droplet, which increase its hydrophobicity[11]. The larger size droplet could be suspended on the villus surface. There will be larger amount of pocketed air between the solid and liquid interface, which could ensure the air exchange of leaf[12].

By comparing figure 1a and 1c, bottom of the elm leaf has much more and longer villus and more micro protrusions than the bottom of the leave. Therefore, the hydrophobicity of the bottom is higher than the top. Figure 1b and 1d are magnified SEM photographs. According to figure 1b, there are no presence of nano protrusions and any stoma on the upper surface of the leaf, and there are even some substances stuck on top surface. Figure 1d shows a different image, the distribution of the spherical micro protrusions is very dense, and the roughness is higher than the bottom surface. Stomata are also very dense at the bottom, with about 20 micrometers in between each stoma. To conclude, we can speculate that the hydrophobicity of the bottom is higher than the top surface to protect the leaf during respiration. The enlarged view of the bottom, we find that the nano structures are surrounding the stomata, which could prevent to be wetted by the small droplets in nature.

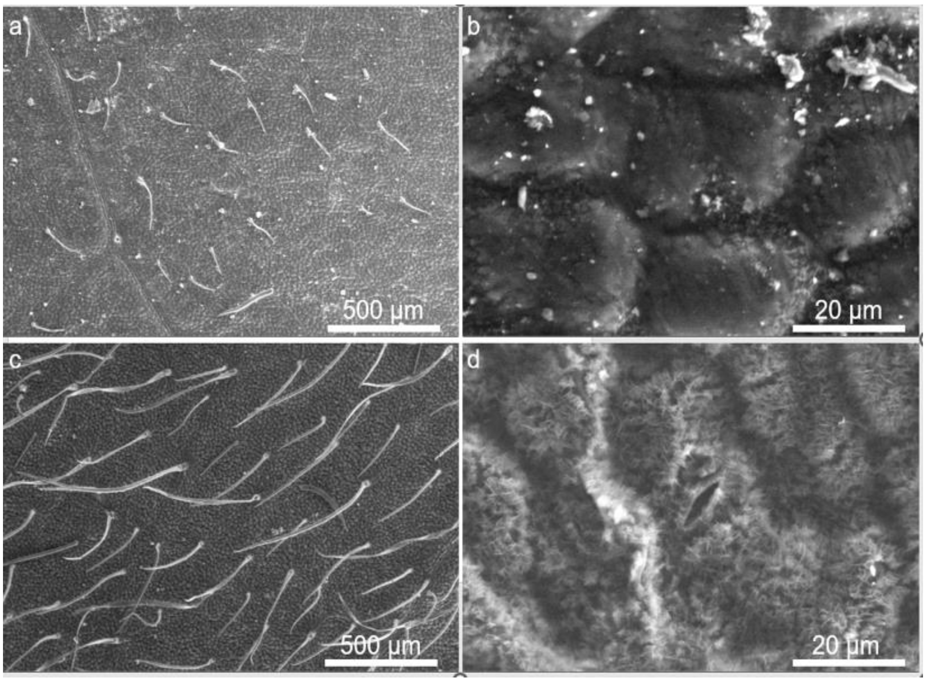

Figure 1. SEM photograph of bottom surface(a-b) and lower surface (c-d).

The top surface is composed by sparse array of villus and smooth micro protrusions (without stomata). The bottom side of leaf is composed by dense array of villus and rough micro protrusions.

3.2. Analysis on the experiment

After finishing experiment at 2.3, we obtained SEM photograph of the leaf's contact angle for both top and bottom surface. Figure 2a, 2c are photograph of elm leaf's top surface with a droplet and its contact angle (Wenzel status). Figure 2b, 2d are photograph of elm leaf's bottom surface with a droplet and its contact angle (Cassie status). Data is shown in table 1. From the average data, we can define that the top surface is hydrophilic, and the bottom is hydrophobic.

Table 1. The contact angle of the leaf surface.

Samples	bottom surface contact angle (°)	lower surface contact angle (°)
Leaf 1	106	130
Leaf 2	68	114
Leaf 3	81	123
Leaf 4	89	131
Leaf 5	88	124
Average	86	124

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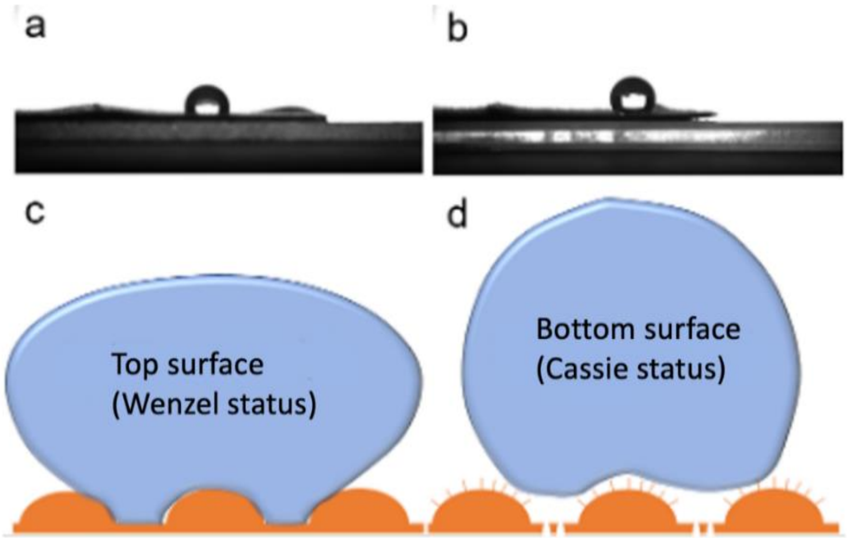

Figure 2. The different status of droplet on the top surface (a, c) and bottom surface (b, d).

After the experiment in 2.3, the hydrophobicity of the bottom of the elm leaf is higher than the top surface. The average contact angle of bottom surface is 124 degrees while the average contact angle of top surface is 86 degrees. Showing that the bottom surface of elm leaf is a hydrophobic state, and the top surface of elm leaf is a hydrophilic state. In sunny environment, the top surface of the elm leaf is exposed to sunlight, which allows photosynthesis to take place smoothly, providing energy for the trees to survive. In rainy environment, the top surface is impacted and wetted by rain. As the surface is covered with rain, the tip of the leaf sags and the water slips away in the direction of the leaf's incline. And the whole time, the bottom of the leaf is always hard to contact with the rain. Even under the synergistic effect of wind and rain, the raindrops touch the bottom of the leaf, the droplets roll off the surface without hysteresis due to the hydrophobic surface. This structure is designed not only for photosynthesis on the leaf surface but also for respiration in the natural environment, which has expected to be used in underwater breathing filters.

4. Conclusion

During the experiment we found out that the top and bottom of the elm leaf is hydrophilic and hydrophobic state, respectively. Since elm tree can survive in a large variety of environments, it requires ability to resist drought and moist conditions. This design can not only meet the photosynthesis of leaves, but also meet the respiration in different environments, to ensure the survival of plants in nature. Inspired by this, researchers could fabricate air filter in deep water environment.

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