Experimental Study of Ice Formation Delay on Different Plant Leaves

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Abstract:

Ice adhesion and accumulation are well known to cause serious problems for different structures such as wind turbines, airplanes travelling in cold climates, and so on. Development of coatings resisting icing can solve many challenges in various areas of industry. This work was inspired by nature and ice-resistivity and superhydrophobicity of plants leaves. Kale is one of the little vegetables that can be harvested in winter. It shows superhydrophobic behavior, which is normally known as an advantage for cleaning the leaves, but we were able to show that its surface structure could delay the ice formation process making it a good candidate for an ice-repellent coating. We have performed in-depth experimental analyses on how different plants can prevent icing, and contact angle measurements and scanning electron microscopy (SEM) of the leaves were taken to further mimic their surface morphology.

Introduction:

The development of coatings that can resist icing can solve many challenges in various areas of industry. Even a small amount of ice can change the pattern of flow and streamlines around the airplanes causing a significant change in lift and drag while adding to the weight of the airplane (1). Ice can also extend to unprotected parts of the aircraft and form larger shapes. Ice accretion can also reduce the performance of wind turbines considerably by affecting the aerodynamic profile of the blade and finally the operational loading of the entire rotor leading to a significant energy loss and reduction of power production. Current de-icing methods require the machines to be stopped or get their power from the machine itself which decreases the proficiency by a considerable amount (2).

This work would mainly emphasis on in-depth experimental and study on how different plant leaves can prevent icing, which is of great potential to solve the issue of icing in different areas.

Experimental Procedure:

A series of experiments were performed to measure the rate of freezing of water droplets on different plant leaves. Freezing experiments were performed using the drop shape analyzer, Krüss DSA 100. This instrument is used for recording the droplet spreading dynamics and solidification process and provides accurate measurement of the dynamic contact angle of the droplet. In this device, the drop which is deposited on the leaves is illuminated from one side and a high speed camera at the opposite side records images of the droplet. Temperature of the solid targets can be adjusted by a Peltier element situated in DSA100 machine from -30 °C to 160 °C. The schematic of DSA100 is shown in figure 1. Experiments were conducted for three different substrate temperatures (-20 °C, -15 °C, and -10 °C) to acquire the correlation between leaf surface temperature and freezing delay time. For comparison water was also deposited on a smooth glass substrate which was rinsed successively in ethanol, methanol, and DI water. The volume of drop was set to 5μl for all the experiments in order to make sure the results are consistent and the size of the droplet is small enough to neglect the gravitational effects.

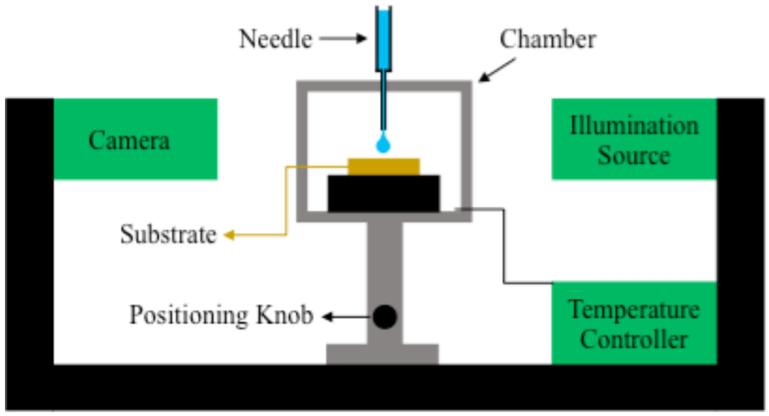

Figure 1: Drop Shape Analyzer (DSA100) by Krüss. This unit consists of a camera, illumination source, dosing unit, sample table, prism, peltier element, and temperature controller.

Results and Discussion:

The water drop on the glass substrate begins to freeze nearly instantaneously; however, the droplet on kale leaf shows 45 seconds delay in the start of freezing process (Fig.3). This observation suggests that plant leaves and in this case kale have the ability to prevent or delay icing. In order to understand the reason behind the icephobicity of kale, we have measured the contact angle of water on kale leaves and also analyzed the surface structure of the kale leaves using scanning electron microscopy to determine the micro pattern on the surface of the leaves.

Figure 2: The picture shows the left and right contact angle of water on kale leaf. The mean value of contact angle is 135.3°.

t= 0 sec
Deposition

t= 45 sec
Start of Freezing

t= 68 sec
Freezing Complete

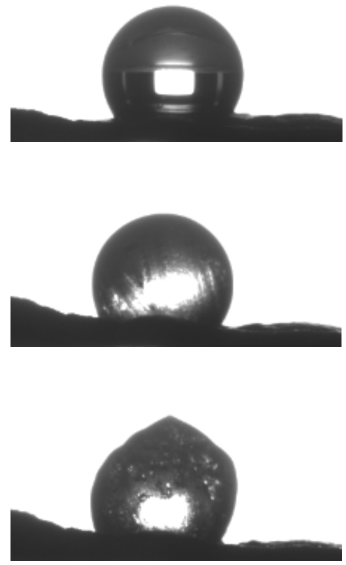

Figure 3: Video sequence of water freezing on kale at $-20°C$ temperature. The droplets were deposited on the solid target with the flow rate of 2ml/min and total volume of 5μl. The elapsed times as shown in the picture are 0 s, 45s, and 68s respectively.

A series of SEM (Scanning Electron Microscopy) images of the penguin feathers are taken using ZEISS SUPRA 40VP and the results are shown in Figure 4. The ZEISS SUPRA 40VP is a high resolution FE-SEM that allows surface examination down to nanometer scales in either High Vacuum or Variable Pressure (VP) modes and provides wide range of imaging voltage and examination of non-conducting samples.

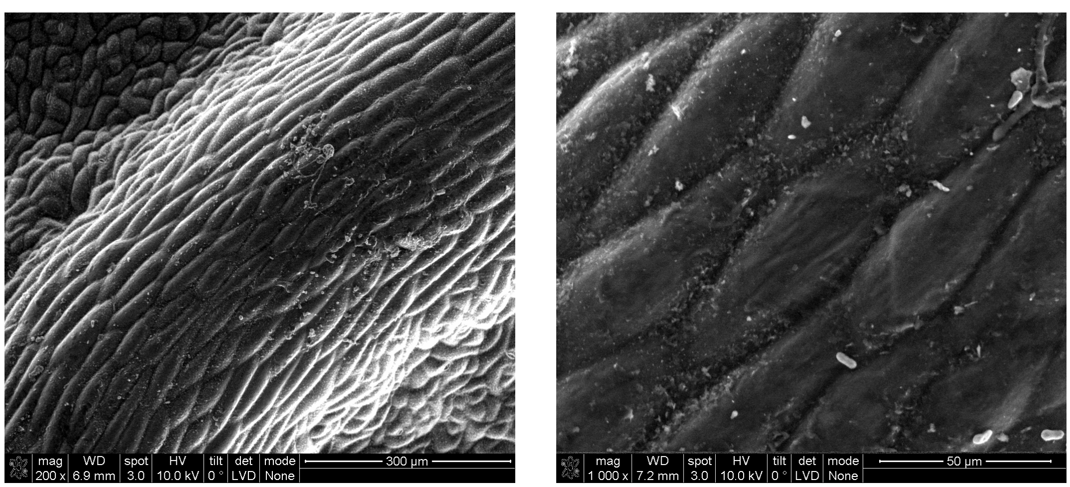

Figure 4: SEM images of kale leaf with different magnification.

The SEM images of the kale leaves reveal the micro-pattern on the surface which increases the contact angle of water on the leaves and delays the formation of ice. The high contact angle of water droplet on the kale leaves will change the profile of isotherms inside the drop and confine the heat flow to a smaller region and finally delay the heat transfer and subsequently the start of freezing.

References:

1. Cooper WA, Sand WR, Veal DL, & Politovich MK (1984) Effects of Icing on Performance of a research airplane. *Journal of Aircraft* 21(9):708-715.
2. Geer W, C (1939) An Analysis of the Problem of Ice on Airplanes. *Journal of the Aeronautical Sciences* 6(11):451-459.