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# Anti-adhesive Property of Maize Leaf Surface Related with Temperature and Humidity

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## Abstract

The anti-adhesive surfaces have always aroused great interest of worldwide scientists and engineers. But in practical applications, it often faces the threat and impact of temperature and humidity. In this work, the excellent anti-adhesive performance of maize leaf under high temperature and humidity were investigated in detail. Firstly, the adhesion forces of the maize leaf surface under different temperature and humidity were measured by using Atomic Force Microscopy (AFM). The temperature of the substrate was varied between 23 ˚C to 100 ˚C, and the ambient relative humidity is from 18% to 100%. It was found that the adhesion force of maize leaf decreased with the increase of temperature and humidity. The mechanism of its excellent anti-adhesive performance of maize leaf under high temperature and relative humidity was revealed. The transverse and longitudinal ridges on maize leaf surface interlace with each other, forming small air pockets, which reduces the actual contact area between the object and the maize leaf. With the increase of humidity, the liquid film will be formed in the air pockets gradually and so much water vapor is produced with increase of temperature. Then the air flow rate increases though the wavy top of transverse ridges, inducing the dramatic decrease of adhesion force. Inspired by this mechanism, four samples with this bionic structure were made. This functional "biomimetic structure" would have potential value in the wide medical equipments such as high frequency electric knife with anti-adhesion surface under high temperature and high humidity.

**Keywords:** maize leaf, anti-adhesion, temperature, relative humidity, bionic surface



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## 1 Introduction

Nature has been always a best source for human beings to create our ideal life[1]. After billions of years of evolutionary development, various species have experienced a long natural selection and present their best to the world[2]. Nature has provided scientists with a lot of special microstructures which are potentially applicable for new materials and technologies[3–7]. Recently, among many excellent features of the organisms, the property of anti-adhesion has been one of the most hot spots and attracted great interest of many scientists and researchers[8–11]. The biological community provides us with a lot of anti-adhesion models such as lotus leaf[12,13], *Nepenthes* species[14–16], gecko spines[17], some insect wing cuticles[18] and so on. It was found that the particular micro and nanostructures of surface play a very significant role in the property of anti-adhesion. The lotus leaf exhibits the the property of self-cleaning due to the cooperation of hydrophobic epicuticular wax and multiscale structures with randomly distributed micropapillae covered by branch-like nanostructures. Little water drops, which fall onto the lotus leaf and bead up, can roll in all directions freely and pick up the dust[1,19,20]. This is the famous "Lotus effect"[21]. According to previous research for *Nepenthes* species, however, there are four theoretical hypotheses in total: roughness-hypothesis; fluid-absorption-hypothesis; wax-dissolving-hypothesis; contamination-hypothesis[10,22,23].

It is well known that adhesive property of biological surfaces are greatly affected by several factors, such as surface topography[22,24], hydrophobicity[19], temperature and humidity. Most researchers, however, have focused their attention on the first two factors. Only a few studies concerning the influnce of temperature and

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humidity on the adhesion force were carried out[25]. Tambe and Bhushan found that the adhesion force decrease with the increase of temperature with a range from 20 ˚C to 125 ˚C[26]. However, Cappella *et al*. discovered that the adhesion force increases, with temperature increasing[27]. Shavezipur *et al*. concluded that the adhesion force notably reduced with the lack of electrostatic and capillary forces as temperature increases[25]. It is apparent that the relationship between adhesion force and temperature of substrate is still not conclusive.

In our daily life, when people cook pasta, they often lay a layer of fresh maize leaves between the pasta and the holder to prevent the adhesion of pasta. In fact, this method is more effective than traditional practice in reducing the adhesion between pasta and holder. This phenomenon is very interesting and has attracted our attention all the time. It is well known that cooking pasta is a process of increasing temperature and humidity. What does it mean? There is no doubt that the fresh maize leaf is anti-adhesive under high temperature ($T \leq$ 100 ˚C) and Relative Humidity ($RH \leq$ 100%). In this paper, the adhesion force of maize leaf under varying temperature (23 ˚C – 100 ˚C) and relative humidity (18% – 100%) was studied in detail. In order to explain the problem clearly, two stainless steel samples and two plastic samples were made inspired by the surface microstructures of maize leaf. A probe with a flat tip was used to measure the adhesion force of maize leaf and four samples. In order to obtain accurate data relatively, each sample was automatically measured 64 times by Atomic Force Microscopy (AFM), and the average adhesion force was recorded. The test results of adhesion force were investigated in detail, and the behaviours of adhesion force depending on temperture and relative humidity were also analyzed further. We also discussed the reason that adhesion force changes according to the obtained trend. Our findings might be helpful to design and manufacture micro-/nanostructure functional materials and devices working in some environments of high temperature with a certain humidity.

## 2 Materials and methods

### 2.1 Material preparation

The maize, named Zheng Dan 958 (validated in 2000, Henan Academy of Agricultural Sciences, China), is one of the most common types in China since 2000. In order to obtain relatively accurate experimental results, maize leaves were obtained from two ways. The maize seeds were purchased from Chinese Academy of Agricultural Sciences in March. We simulated the living environment of maize in the field. We sowed in April, cultivated carefully and obtained maize leaves in September. Meanwhile, another set of maize leaves were collected from farmers' field in autumn. Two kinds of maize leaves were used in experiments.

### 2.2 Surface characterization

The multiscale 2D morphologies and structures of maize leaf were inspected on a Scanning Electron Microscope (SEM, EOV-18). All the samples of maize leaves were cut into 5 mm × 5 mm in size and stored in closed boxes for subsequent experiments. We selected ten samples for freezing and drying randomly. To confirm the cleanliness, the samples were cleaned in the ultrasonic for half an hour. After cleanliness, they will be frozen in the freezer for 24 hours at −20 ˚C and dried for 12 hours at −50 ˚C immediately. Before the scan, the maize leaves were sprayed with a thin layer of gold for better conductivity and clearer topography relatively. The Confocal Laser Scanning Microscope (CLSM, LSM-800) was also used to determine the height difference between different regions on maize leaf surface.

### 2.3 Wettability test

In order to investigate the wettability of maize leaf surface, the static Contact Angle (CA) measurement was carried out by sessile droplet method (OCA20). The liquid used in the test is deionized water. No treatment of maize leaf surface was required before the measurement in order to not affect the hydrophobicity. The droplet volume is 5 μL. We chose three samples randomly. Each sample was measured 8 times. The value of *CA* is the average result of multiple measurements to reduce the deviation.

### 2.4 Design and fabrication of maize leaf-inspired surfaces

Based on the analysis of the microstructure of maize leaf surface, we chose two different materials to make four kinds of samples. One material is 304 stainless steel with good corrosion resistance and high temperature resistance. Laser engraving method was