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Mechanical Character of Typica1 Plant Leaf Surfaces[1]

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Abstract: The hardness of typical plant leaves surfaces was investigated and analyzed by nano-hardness tester. Results show that the mechanical character of varied texture and varied surface morphologies shows regularity. The hardness of coriaceous fresh leaves (*Bambusa phyllostachys pubescens etc.*) and ligneous leaves is great. Waxiness leaves′ hardness (such as *Nelumbo nucifera Gaertn, Canna indica Linn* (*generalis*) is little. The hardness of convex morphology part is better than that of concave morphology part on non-smooth morphology leaf surfaces. And that the hardness of surface layer is better than that of internal layer in the same leaf. This study may be important biological foundation for design and fabrication of bionic engineering surface and composite materials.
Key words: engineering bionic; plant leaf; hardness; mechanical character

1. INTRODUCTION

Non-smoothness is a widely natural phenomenon in biological world, which has been formed during the long evolutionary process of living creatures as a stable self-adaptive system. There are non-smooth morphology surfaces including the aquatics, geobionts, plant leaves, insects and birds. However, it is a polymorphism character of non-smooth morphologies due to living creature diversity and complexity of nature surroundings, which have divers functions (such as hydrophobicity, anti-adhesion, visbreaking, wear-resistant, noise elimination etc.). Bathlott (University of Bonn, Germany) discovered the non-smooth lotus leaves with micrometer scale non-smooth morphologies have a self cleaning effect firstly and carried out a series of researches concentrating on relation between the morphology and hydrophobicity of plant leaves surfaces (Barthlott & Neinbus, 1997; Barthiott, 1990; Barthlatt et al., 1993). The researchers of key

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laboratory of bionic engineering (Jilin University, P.R.China) systematically researched on hydrophobicity and anti-abhesion character of non-smooth morphology on the biological surface, established"Theory of non-smooth surface anti-adhension" (REN et al., 1998; REN et al., 1999; REN et al., 2004; SHUN et al., 2004; DAI et al., 2006; REN, 2008), which screened the biological model of typical non-smooth surfaces and discussed quantitative relationship between non-smooth surface and characteristics of hydrophobicity and anti-abhesion (WANG et al., 2005; WANG et al., 2005; REN et al., 2007). This study discussed features of organization mechanics and nano-mechanics on non-smooth plant leaf surfaces firstly, attempted to analyse mechanical character of a few kinds of typical non-smooth plant leaves and provided an insight into design for bionic engineering surface and selection for biological composite materials.

2. MATERIALS AND METHODS

Samples collection: Some typical plant leaves in hearty growing period were chosed such as Bambusa phyllostachys pubescens, Nelumbo nucifera aertn, Ginkgobiloba Linn, Syringa oblate Linn(Var giraldii), Canna indica Linn(generalis), Calathea zebrine'Humilior', Begonia masoniana, Callistephus chinensis.

Hardness was measured by nano-hardness tester, which was Triboinddenter root position nano-mechanic testing system produced by Hysitron Company (U.S.). Resolving power of mechanics and displacement are 1 nm and 0.2 nm respectively. Maximal loading is 30mN and minimal loading is 100nN. Step length of displacement in longitudinal direction is 13 Nm, heat drifting is less than 0.05nN/sec, and have a capacity of root position photo and root position sound launching test.

Twenty indentation experiments were measured at sample' positions (0.075×0.01mm intraregional), the mean value was chosen as experimental intensity value.

3. RESULTS

3.1 Ascertainments of autofit heaped capacity

Trigonometry load method (no holding time) was adapted. Taking the case of *Nelumbo nucifera aertn* leaves, at first, depths of leaves were measured and leaves were cut into knobs, cleaned by ethanol, dried in the shade, and fixed on the table by using double sides adhesive tape. Hardness was determined by loading 200 micronewton force. Push deep of impression hemispherical convex: Hmax=719 nm, mean value of hardness (H) was 0.02 GPa. Push deep of concave (H) was 704nm, hardness value was 0.02 Gpa. Loaded a force of 100 micronewton, push deep of hemispherical convex: Hmax=204.2 nm, mean value of hardness (H) was 0.03 Gpa, push deep of concave (H) was 212.3 nm, hardness value was 0.02 Gpa. Loaded 50 micronewton, push deep of concave: Hmax=157.8 nm, hardness value was 0.03 Gpa, push deep of hemispherical convex: Hmax=157.3 nm, hardness value was 0.04 Gpa. Force-Displacement curve was showed in Fig.1 .The depth of folium multilayer was measured by nano-sclerometer and push deep was less than 10% depth of even chosen material according to literature[6]. Epidermic cells of *Nelumbo nucifera aertn* were multilayer. Maximal push deep depth of loutus leaf was much less than 10% thick layer of lotus leaf in this experiment, hence, nano-mechanical character of microcosmic layer composite structure of plant surfaces such as lotus can be determined by nano-sclerometer. Results showed that push deep become obviously with increasing load pressure, hardness values became small. However, hardness values of surface layer were large and inlayer′s were small, which were related with its tissue structures. Consequently, 50 micro newton was adopted to measure all kinds of samples′ surface hardness.

[6] ASTM standard test method E384. *Annual Book of Standards 3*. 01[S] .

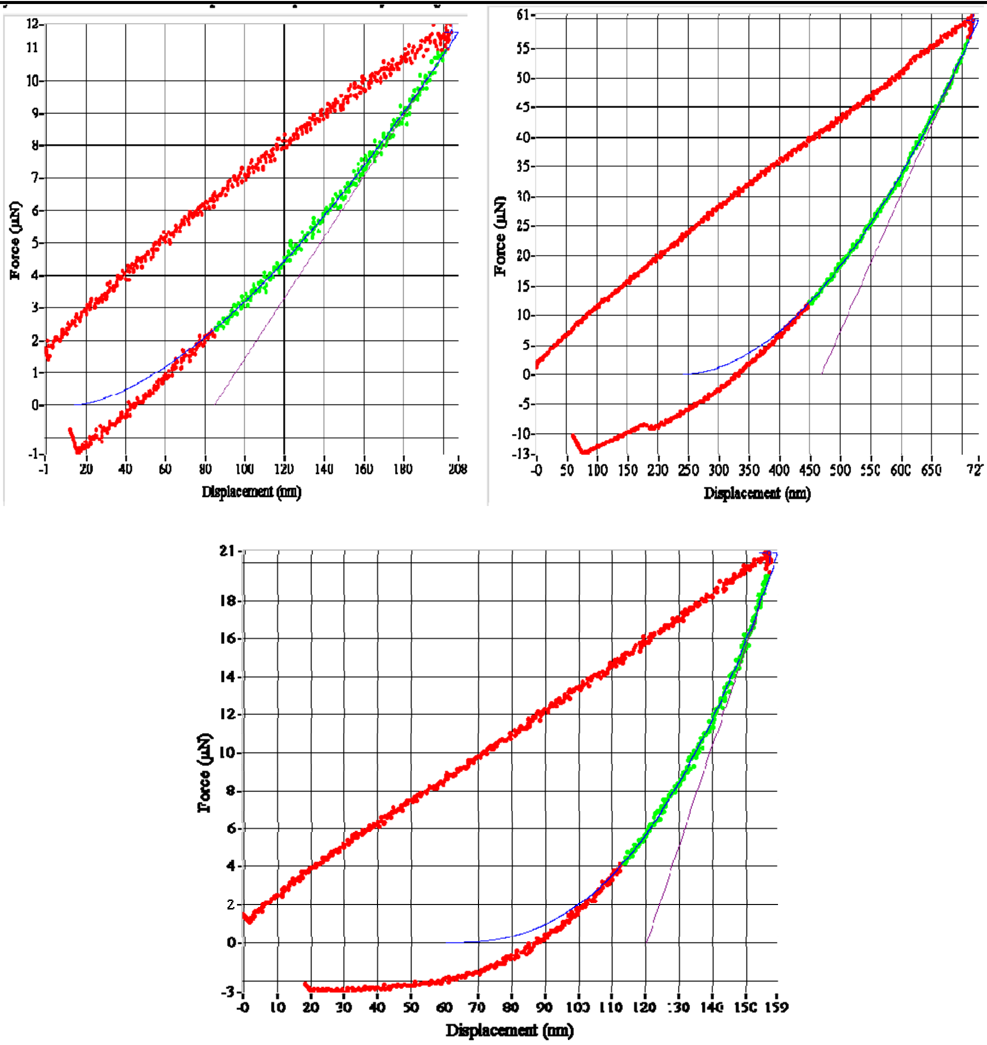


Fig. 1: Force-Displacement curves of lotus leaf under different conditions

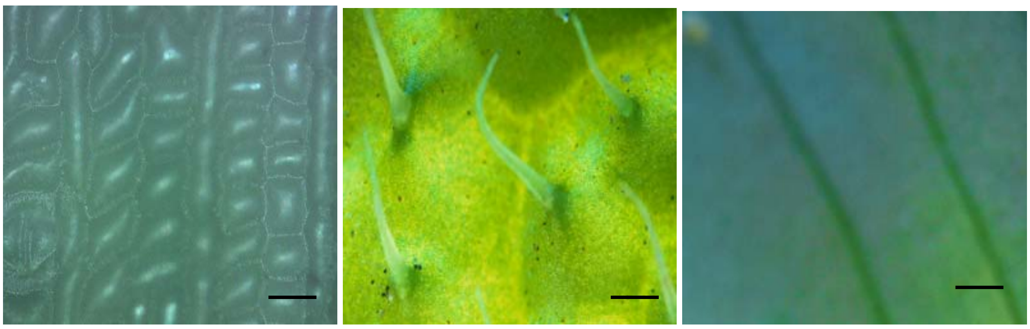
3.2 Comparative analysis on surface hardness of plant leaves

The hardness values (mean values of 10 to 20 times measurements of each processed sample) of different kinds of plant surfaces were measured and results were comparatively analyzed when loaded 50 micronewton. Surface hardness values were different with species of leaves as seen in Table 1, range of fresh leaves′ hardness was from 0.02 Gpa to 0.38 Gpa. The hardness of coriaceous *Bambusa phyllostachys pubescens* was great because of high content of fibers. Ligneous leaves (*Syringa oblate Linn(Var giraldii)*, *Ginkgobiloba Linn*, *Calathea zebrine'Humilior'*), which surface hardness was large as seen in Fig.2(c). Perennial plants leaves contained a less of fibers, which surface haudness was comparatively small as shown in Fig.2(e)and Fig.2(a). Annual herbs (*Callistephus chinensis*, *Begonia masoniana*) leaves contained a mass of water, which suface hardness was small as shown in Fig.2(f) and Fig.2(b). The surface hardness values of convex non-smooth morphology were larger than that of convave . The main causes are that leaf surface of non-smooth morphology let peak surface deformation only under the operation of comparatively great force, and then obtain some contact area. In other words, at the same force operation, contact area of hemispherical convex morphology is little, namely hardness of leaf surface is great. In contrast, deformation of smooth leaves is large under the operation of a certain force, and then obtain comparatively big contact area, namely hardnesss of leaf surface is little. The morphologies of *Canna indica Linn (generalis)* and *Ginkgobiloba Linn* leaf surfaces are smooth so that hardness values are similar.

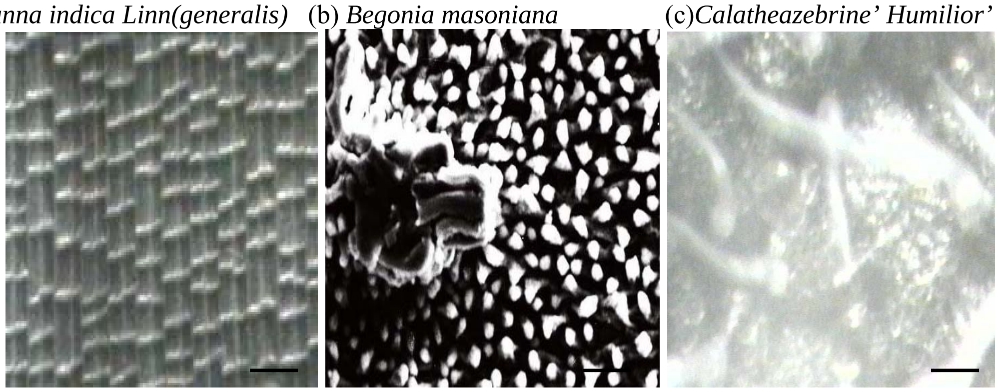
The hardness value was not be detected, which reasons were that water-contain of *Begonia masoniana*, *Callistephus chinensis* leaves was excessively high and epidermal hairs non-smooth structure of leaf surface disturbed badly.

Table 1: Hardness of different plant leaves

Plant(leaf) species	frontispiece convex depth (nm)	intensity (GPa)	frontispiece convex depth (nm)	intensity (GPa)	frontispiece convex depth (nm)	intensity (GPa)	Frontispiece convex depth (nm)	intensity (GPa)
Ginkgobiloba Linn	152.1	0.07	159.2	0.05	191.2	0.03	199.6	0.04
Calathea zebrine'Humilior'	215.4	0.015	218.8	0.01	166.8	0.02	233.4	0.03
Nelumbo nucifera aertn	157.2	0.04	151.8	0.03	212.3	0.02	204.2	0.03
Canna indica Linn (generalis)	215	0.02	213.2	0.02	201.1	0.03	192.1	0.03
Bambusa phyllostachys pubescens	94.5	0.160	92.6	0.150	70.1	0. 350	88.1	0.380
Begonia masoniana	—	—	—	—	—	—	—	—
Callistephus chinensis	—	—	—	—	—	—	—	—
Syringa oblate Linn(Var giraldii)	145.8	0.135	140.4	0. 110	190.4	0.040	192.4	0.050

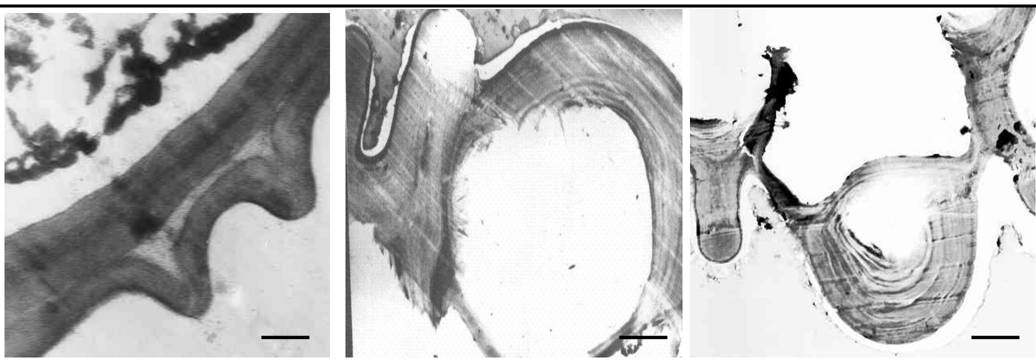


(a) *Canna indica Linn(generalis)* (b) *Begonia masoniana* (c)*Calatheazebrine' Humilior'*



(d) *Bambusa phyllostachys pubescens* (e) *Nelumbo nucifera aertn* (f) *Callistephus chinensi*

Fig. 2: Morphology of plant leaf surface



(a) *Nelumbo nucifera aertn* (b) *Bambusa phyllostachys pubescens* (c) *Bambusa phyllostachys pubescens*

Fig. 3: Epicuticular cells of *Bambusa phyllostachys pubescens* (3000X,scale: 2μm)

4. DISCUSSION

Cross-section of *Bambusa phyllostachys pubescen* is observed at optical microscope as shown in Fig.4, at the same time, it is seen that leaf structure consists of epicuticular、mesophyll and microtubule tissue. Epicuticular that is in the middle between two contiguous veins is made up of several special big thin wall cells with longitudinal array paralleling with vein, which cuticula of wall grows thick and have a big vacuole. The number of bullform cells is four to seven between every two contigous veins on the cross-section, which the biggest one is in the middle with reducing at two both sides and the cross-section area is ten times than that of epicuticular cells. Mesophyll tissue A: there is no differentiation of palisade tissue and spongy tissue in the mesophyll cells of bamboo plant leaf, moreover, cell wall folds inward and space among cells is small. Vein E: chief vein and lateral veins are parallel with each other, which are embedded in mesophyll cell and transverse veinlets connect with each other. Vein is made up of microtubule tissue and peripheral microtubule tissue sheath and bunchy or sheet thick walled fibers connect between veins and epicuticular or lower epidermis. Microtubule tissue sheath consists of internal layer and out layer. Cell wall of out layer is thin and that of internal layer is thick. Microtubule tissue consists of xylem and phloem. Xylem is in the side of epicuticular and phloem is in the side of lower epidermis. Epicuticular cells are amplified by STEM as shown in Fig.3(b) and Fig.3(c), which are covered by developed cuticula. Epicuticular cells are constituted by long cells and two kinds of short cells. The diameter of long cell is arrayed along longitudinal direction and cell wall becomes siliceous easily. Short cell that existed between two long cells is Shuan-cell, which cell wall is Shuan quality. Siliceous cells stand out outwards and make leaf surfaces hard. Anti-pulling intensity and surface hardness of bamboo leaf is maximal, which is dicided by its cell structure and composites of epicuticular cell.

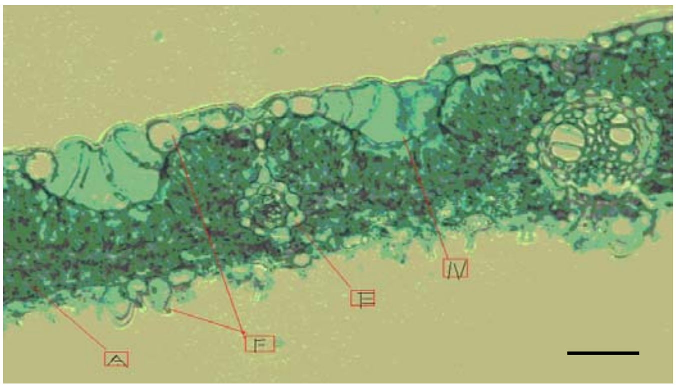


Fig. 4: Microscopic structure of cross-section of Bambusa phyllostachys pubescens leaf (A. mesopyll F. epicuticle E. vein vascular tissue N. bubble cell)

Nelumbo nucifera aertn is nymphaeaceous hydrophyte, which epicuticular cell wall with thin wax layer grows thick and keratinization is not occurred. Mechanical tissue is undeveloped, resulting from underdeveloped mesophyll tissue. Differentiation of mesophyll cells is unobvious and cell has a number of cavums. Epicuticular cell with waxiness and micron scale convex non-smooth morphologies is shown in Fig.3(a). There are a layer of long palisade cells in the mesophyll cells, spongy tissue is undeveloped and arranged loosely. Therefore, anti-pulling intensity and hardness of leaf is comparatively little.

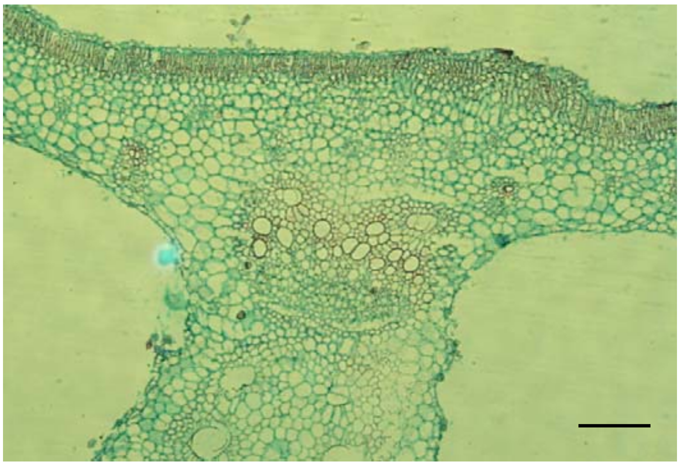


Fig. 5: Microscopic structure of cross-section of *Nelumbo nucifera aertn* leaf

The hardness of plant leaf is various due varied surface morphologies, organization structure and composites of surface material. Leaf surfaces contain cuticula such as *Syringa oblate Linn (Var giraldii)*, *Bambusa phyllostachys pubescens*, which surface hardness is greater than that of leaves with wax coat (such as *Ginkgobiloba Linn and Nelumbo nucifera aertn*). The main causes are that major composites of cuticula are fibers and lignin. However, wax coat is primarily made up of carbohydrates.

5. CONCLUSIONS

(1) Leaf surface material components influence surface hardness evidently. Leaves′ hardness is large, which surface layer contains much lignin and cellulose. Hardness of leaf surface with abundant wax and carbohydrates is little.

(2) In general, leaf surface hardness of convex part is greater than that of the concave. Leaf surface of non-smooth morphology character let peak surface deformation only under the operation of comparatively great force, and obtain some contact area. In other words, under the same force, contact area of convex part is small, the hardness is relatively large; on the other hand, smooth surface has a larger deformation and contact area in a certain force, which the hardness of the surface is small.

(3) Hardness of surface layer is larger than that of inlayer in the same leaf because cellular matters (cell wall) of surface layer are mainly made up of fiber、lignin and other high density substances.

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