Physics

Explore–Journal of Research
ISSN 2278 – 0297 **(Print)**
ISSN 2278 – 6414 **(Online)**
UGC Approved List of Journals No. - 64404

http://www.patnawomenscollege.in/journal

Characteristics of Superhydrophobicity of the lotus plant

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Received **:** November 2017
Accepted **:** March 2018
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Abstract: *The present study was conducted to analyse superhydrophobic characteristics of the lotus leaf. This was compared with the rose petal and water lily leaf. Lotus leaf, rose petals and water lily leaf were analysed using XRD, XRF, FTIR, stereo-zoom microscope. A comparative study of the result was done. We report in this study the influence of micro- and nano-scale structures on the wetting behaviour of lotus leaves. The findings of this work may help in designing self-cleaning surfaces and improve our understanding of wetting mechanism.*

Keywords: *superhydrophobic, XRD, XRF, FTIR, stereo-zoom microscope.*

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Introduction:

The term Superhydrophobic means water heating at a high level. Superhydrophobic surfaces are extremely difficult to wet. Superhydrophobicity (https://en.m.wikipedia.org/wiki/Lotus_effect)is defined by the contact angle between a water droplet and the surface of another material. A superhydrophobic material (U Nimittrakoolchai et. al 2008) (https://www.teach engineering.org/lessons) will have a contact angle that is greater than 150 degree (https://arstechnica.com> science>2008/05).

Lotus: Lotus (Nelumbonucifera) is a semi-aquatic perennial plant growing up to the height of about 150 cm. It is the national flower of India and Vietnam. Lotus leaves which are as large as 60 cm possess remarkable water repellency as an adaptation to the aquatic environment. The upper epidermis of the leaves has the distinctive hierarchical structure consisting of papillae with a dense coating of agglomerated wax tubules, which is the basis of the superhydrophobicity (H J Ensikat et al 2011) (F Yang et al. 2015) (https://homeguides. sfgate. com/difference-water-lily-lotus-67046.html).

Water Lily: Water Lily (Nymphaeaceae) is an aquatic perennial herb found in temperate and tropical climates around the world. Water lilies grow from the muddy bottom of a body of water with leaves and flowers floating on or emergent from the surface. The leaves are round shaped and about 6 to 12 inches in diameter (https://en.m.wikipedia.org/wiki/Nymphaeaceae).

Rose: Rose is a woody perennial flowering plant known for its beauty and fragrance. A rose petal can be both "water hating " (hydrophobic) and water loving. If a water droplet is small, it will not roll off even when the petal is turned upside down but in a downpour it will remain fairly dry, with larger raindrops rolling off.

Objective:

- Study the influence of micro and nano scale structures on wetting behaviour of lotus leaves.
- Improve our understanding of wetting mechanisms in plant.
- The findings of this work may help design self-cleaning surfaces and improve our understanding of wetting mechanism overall.

Methodology:

Surface morphology, functional group of lotus leaf, water lily leaf and rose petal were studied using stereo-zoom microscope, FTIR, XRF and XRD.

Study Area:

- Lotus leaf was taken from Sanjay Gandhi Jaivik Udyan, Patna, Bihar.
- Water Lily leaf was taken from the pond of Patna Women's College, Patna, Bihar.
- Rose flower was taken from Sanjay Gandhi Jaivik Udyan, Patna, Bihar.

Instrumentation:

1. The surface morphologies were inspected on stereo-zoom microscope(Euromex,DC 5000C).
2. Functional group analysis was done using FTIR(Broker Alpha Eco-ATR)
3. Elemental analysis of the lotus, water lily leaves and rose petals was done by X-Ray Fluorescence (Elbatech 'ENax')
4. Chemical analysis and crystal structure analysis of the leaves and rose petal was done by X-Ray diffraction (RigakuUniflex 600)
5. Comparison of the results was done.

Results and Discussion:

1. Result of stereo-zoom microscope:- The study of papillae was performed using stereo-zoom microscope.

Lotus:

Fig. 1a. Lotus leaf (front side)

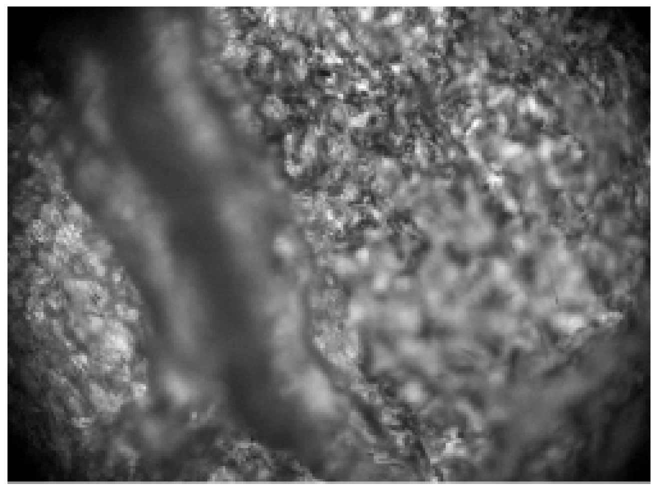


Fig. 1b. Lotus leaf (back side)

Figures 1(a) and 1(b) show that the front side of the lotus leaf contains papillae which helps in repelling water droplets. The rear surface of the lotus leaf does not possess similar structures.

Water Lily :

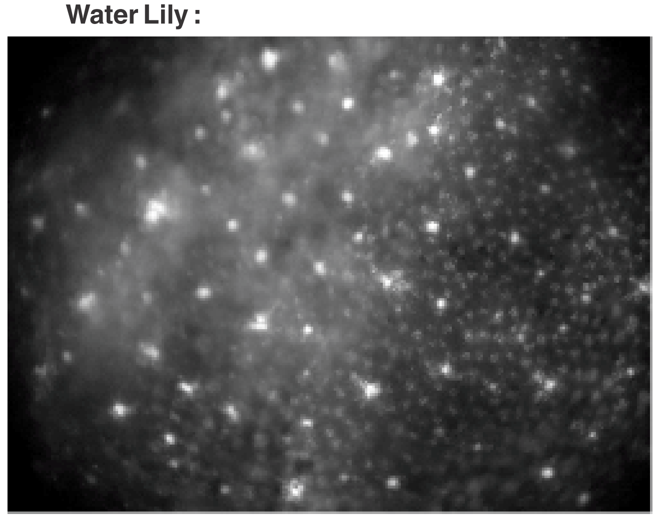


Fig. 2a. Water lily (front side)

Fig. 2b. Water Lily (back view)

Figures 2(a) and 2(b) shows that the pores present on the cells are sunken and hence can explain their hydrophilic response.

Rose:

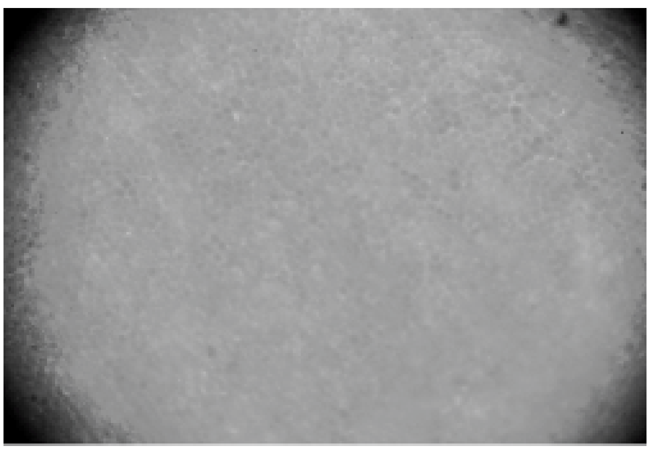
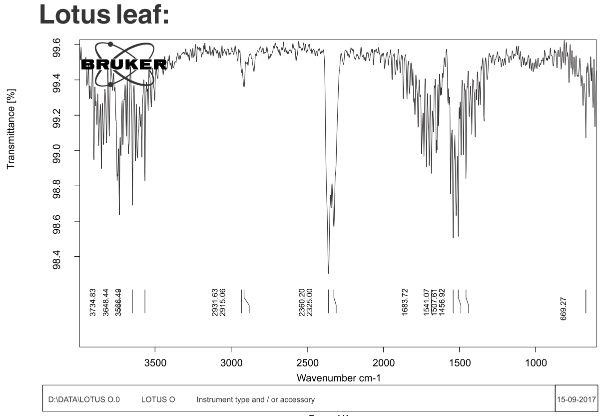


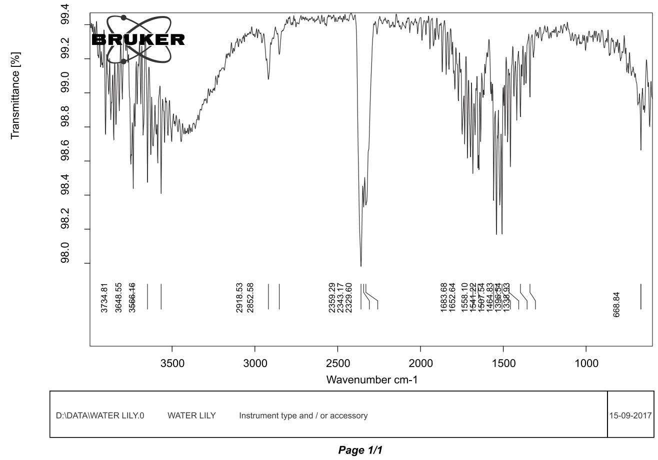
Fig. 3. Rose petal

Figure 3 shows that there were no papillae present on rose petals like those present in lotus leaves. Hence it can lead to less hydrophobic behaviour of lotus leaves.

2. Result of FTIR: The FTIR spectra studies were done to find wavelength resolved transmittance

Lotus leaf:

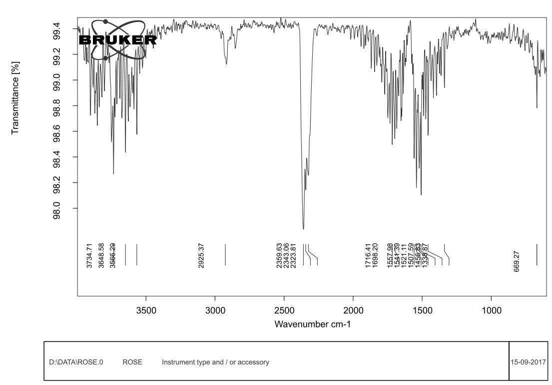




For lotus and water lily leaves the cuticle is common on the surfaces. The peaks ranging from 3600/cm to 3000/cm can be attributed to –OH groups affected by hydrogen bonding. The band around 2931.53/cm for lotus and 2918.53/cm for water lily are due to the –CH stretching vibrations of -CH , - CH_3, - CH_3 groups. The downward peak at 1683.72/cm for lotus and 1683.68/cm for water lily are assigned to the –CONH-, stretching from the amino acid dehydration synthesis of protein or keratin (1680/cm -1630/cm). The contents of N elements for lotus leaf and water lily leaf are confirmed. The fingerprint region(1500/cm-400/cm)mainly indicates the single bond of C-C, C-N, C-O, and various bending vibrations. Its peaks and bands are so dense that the identification for each one is hardly possible.The absorption peak at 1051.0/cm is ascribed to the vibration of carbon atoms in its backbone.

The main difference between lotus leaf and water lily are that the upward peak at 1197.6/cm and the wave spectral lines ranging from 1197.6/cm to 400/cm for lotus leaf. The upward peak at 1197.6/cm is due to the loss of –O-C $(CH_3)_3$and the wave spectral lines (876.3/cm to 400/cm) are partly assigned to the rocking vibration of $–(CH_2)_{n-}$ and the stretching vibration of naphthene.

Rose petal:



The peaks at 3566.29/cm, 3648/cm, 3734.71/cm indicated the presence of bonded OH group. The peaks at 2925.37/cm indicated the presence of sp3 Carbon-Hydrogen alkyl(C-H) group. The peaks at 2323.81/cm, 2343.66/cm, 2359.63/cm indicated the presence of CO and CN. The peaks at 1698.20/cm,1716.41/cm indicated the presence of aldehyde groups. The peaks at 1557.98/cm, 1541.39/cm, 1521.11/cm, 1507.59/cm indicated the presence of carboxylic group and NH bonding. The peaks at 1338.87/cm indicated the CO stretch.

3. Result Of XRF:

Elements	*Percentage*		
	Lotus	*Water lily*	*Rose*
Fe	1.6	1.3	1.4
Al	15	11	7
Si	4	3	1.6
Ti	4	3	2.0
Pb	1.5	1.4	0.6
Mn	1.0	1.3	0.6
Ga	0.5	0.3	0.5
Ni	0.7	0.7	0.3
Zr	1.2	1.0	0.5
Cu	0.5	–	–
Mg	–	–	40
Zn	0.6	0.5	0.3
Sb	–	–	10
Cr	–	1.0	–
Sn	–	–	5

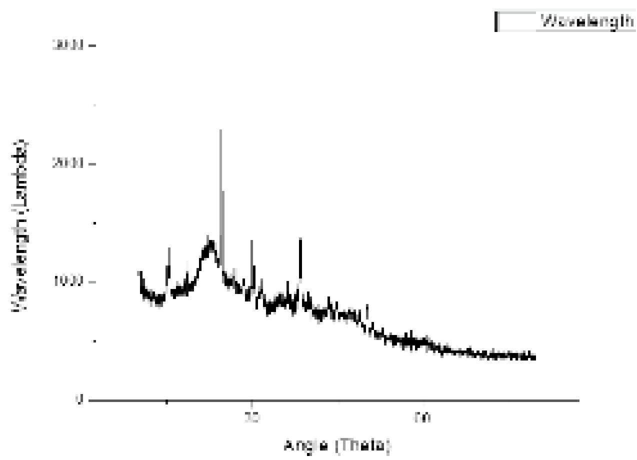
From the above data it can be seen that

- Fe is present in high amount in the lotus leaf, water lily leaf and rose petal.
- Cu is present only in lotus leaf.
- Only rose petal contains Mg. Since MgO is used for the treatment of Vitiligo and has huge benefits for skin, hence rose petal is commonly used in face packs

4. Result of XRD :

Given below are the XRD diagram of the pellets made from the lotus leaf, water lily leaf and rose petals.

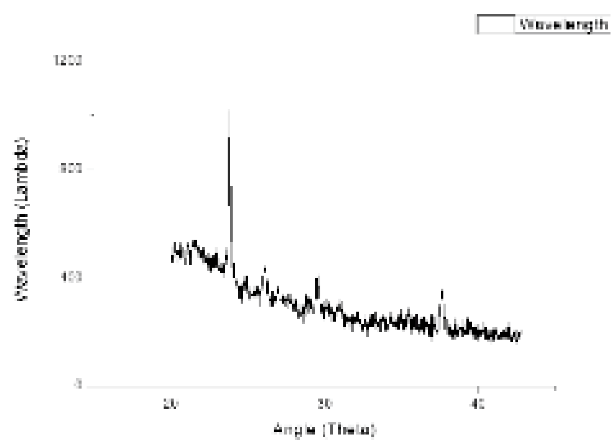
Lotus :



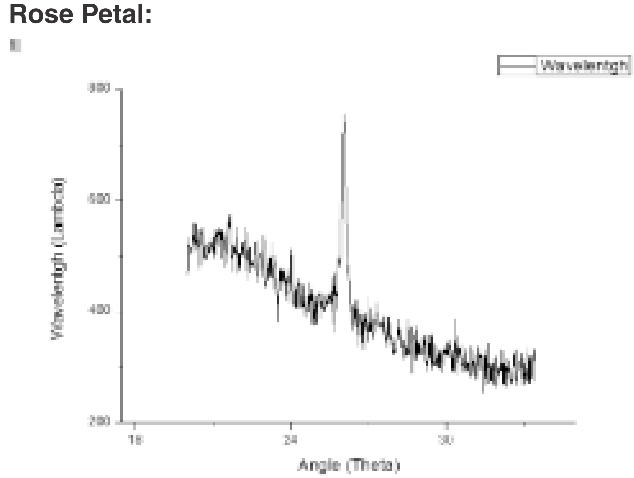
The long spacing peaks indicate a layer structure which is common in aliphatic waxes.

X-ray diffraction analysis of lotus leaf is in accordance with a layer structure model in which the –OH group are buried deep in the layer, while the layer surface consists of only non- polar methyl groups

Water Lily leaf :



Rose Petal:



Conclusion:

We have revealed the physics behind anti-dew superhydrophobicity, a vital property for water repellent materials to be deployed in the real world. These materials will be used in humid or cold environments where condensation will naturally occur.

The top surface of lotus leaves are covered with tiny irregular bumps spiked with even tinier hairs projecting upwards which forms the basis of superhydrophobicity.

The top surface of water lily leaf is textured with wrinkles and decorated with concave coin-shaped geometric structures. The wrinkles cause the appearance of many slits. No nanorods shaped or ellipsoid shaped protruding structure can be found.

The rear surface of lotus and water lily leaves show quite different morphologies.

FTIR, XRD and XRF were employed to analyse the hydrophobic wax-like materials and to determine surface chemical composition of the lotus leaf , water lily and rose petal.

The surface free energy determined by surface chemical composition also has great influence on wettabilities of lotus leaf and water lily.

FTIR spectra of lotus leaf and water lily are surprisingly similar, indicating that the chemical compositions of these two plant leaves are similar which is further proved by XRF result.

The results of this experiment show that the water droplets, spontaneously “jump” off a highly water-repellent or superhydrophobic surface. It will allow an engineer to employ man-made surface, much like the lotus leaf, in settings where the removal of condensation and transfer of heat are necessary.

Our findings point to a new direction to develop .water-repellent materials using chemical composition and surface morphologies of lotus leaves and have strong implications for a variety of engineering applications, including non-sticking textiles, self-cleaning optics and drag-reducing hulls.

Acknowledgement:

We extend our gratitude to our Supervisor Dr. Aprajita Krishna, Dr. Anamika Prasad, Prof., University of South Dakota, USA, and the team at Central Research Laboratory, Patna Women's College.

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