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Multiscale modelling of Leaf

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Abstract: Visualization of a leaf reveals distinct patterns, primarily comprised of vein architecture and mesophyll distribution. An attempt is made to model the vein and mesophyll arrangements. Drawing an analogy between the diagram of leaf veins enclosing the mesophyll region, a configuration of resistors arranged in a closed loop, with an additional series arrangement of inductors is made. This geometry provides a conceptual framework for understanding food transport in leaf. Based on the architectures a model is proposed with RL networks. From UV-visible spectroscopy two absorption bands are observed and attributed to two bandgaps.

Keywords: Leaf, Venation architecture, RL networks, UV-visible spectra.

1. INTRODUCTION

Leaf, the natural kitchen prepares food for trees and creepers. The features and properties of leaf has puzzled many and motivated the curious minds. The physical structure of leaf consists of vein architecture, chlorophyll, and the margin [1-3]. The two functions of the leaves are (a) photosynthesis and (b) transpiration. The above two processes occur at the chlorophyll part of the leaf. The vein, carries the food, gives the mechanical strength to the leaf. The structure of leaf consists of (i) cuticle (typical polymer/wax protecting the skin), (ii) epidermis (behaves as plant skin), (iii) mesophyll cells (retains the chlorophyll) (iv) xylem, phloem (stays inside the vein) and vein as shown in Figure 1.

Many researchers tried to model the leaf in various aspects. Ciorita *et.al.* have investigated the morphological and anatomical traits of certain leaves. They have shown that stomatal index is related to trichome density, cuticle, spongy and palisade parenchyma thickness [4]. Yun. *et.al.* have investigated leaf anatomy and corelated to solar cells [5]. Fahmy investigated leaf anatomy and its relation to the ecophysiology of some non-succulent desert plants [6]. The water flow through leaves have investigated by Sack [7]. The transport network of leaf have investigated by Katifori [8, 9]. So, more investigation is required for further understanding. We, on this aspect put our efforts to re-investigate it.

2. EXPERIMENT

The optical images of the leaf are taken with the help of smart phone. Before photograph, the leaves were washed with ordinary water. For Field Emission Scanning Electron Microscope (FESEM) images, the leaves were washed with water and rectangular size of 5mm x 5mm were cut and fixed on a stub with carbon tape. Gold coating was carried out in a sputtering chamber for 2 minutes. Then the samples were put in chamber. FESEM, (JSM-7610F) was used for electron micrographs.

For UV-visible spectra, the samples were washed and rinsed with DI water. Then appropriate size of the sample was cut and grinded in the agate mortar and pestle till the liquid slurry was formed. The slurry was filtered in Whatman filter paper and mother liquor was taken for measurement. A rectangular quartz crucible was rinsed in DI water before experiment. Plain DI water was taken as reference. 10 micro liter was added to the DI water for measurement for the absorption mode.

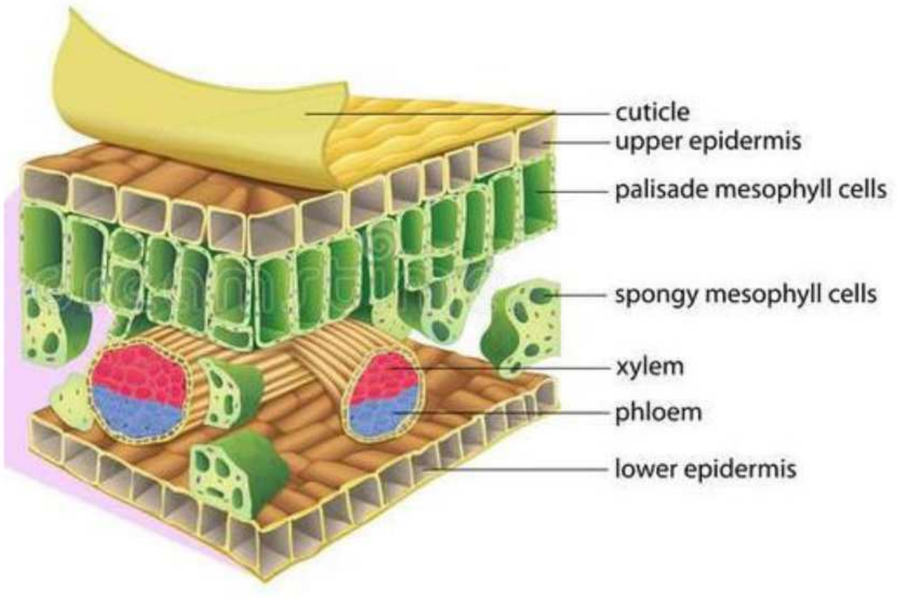

Figure 1. Anatomy of the leaf.

3. RESULTS

3.1 Surface morphology (Optical image)

The optical image of banana leaf (Musa acuminata) is shown in Figure 2. For clear surface morphology, certain region was chosen and images were taken. The leaf is patterned with vein structures. The networks of vein (white lines in the image) enclose the chlorophyll region (green patches in the image). Figure 3 shows the surface morphology of guava leaf (Psidium guajava). Like banana leaf, guava leaf also shows patterned vein structures. Here also the networks of vein (white lines in the image) enclose the chlorophyll region (green patches in the image), but the two dimensional patterns are different.

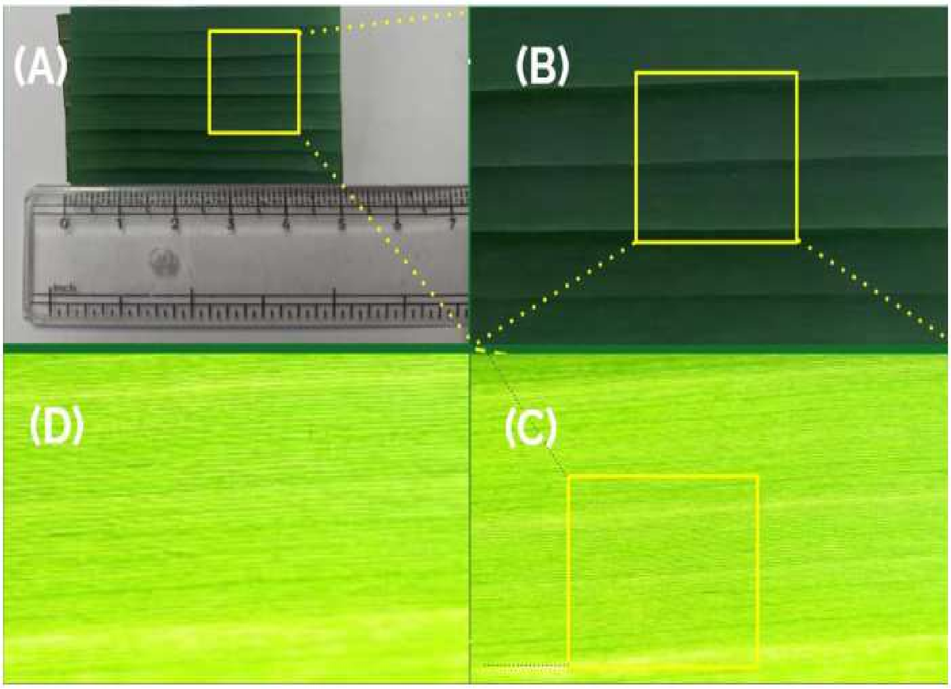

Figure 2. Optical images of banana leaf.

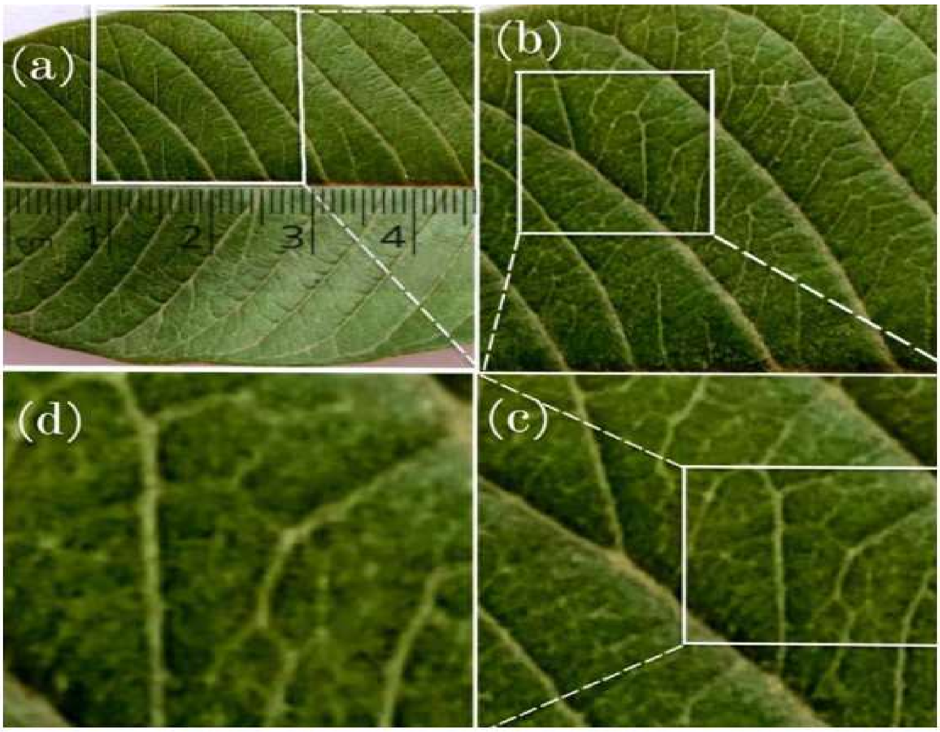

Figure 3. Optical images of guava leaf

3.2 Surface Morphology (SEM image)

For clear surface features, SEM images were taken as shown in Figure 4 & 5. Figure 4 (a) shows the overall surface morphology (@50X) of the banana leaf. It shows the clear rectangular venation pattern. Figure 4 (b) shows the distorted localized part of rectangular venation structure (@5000X). The higher magnification images (@10KX and @20KX), show bulging and wavy in the localized region (distorted epidermis and mesophyll). We observe these distorted features are formed due to the high energy beam of electron (5.0 kV).

Figure 5(a) shows the overall surface morphology (@50X) of the guava leaf. The curly parts are polymeric part (cuticle) that has been damaged by the electron beams while taking images. Figure 5(b) shows the localized part of rib structures on the localized hill structures (@5000X). We attribute these parts are the joints/connecting parts of the veins (underneath). The higher magnification images (@10KX and 20KX), show crack in the localized region. We confirm they are formed due to the high energy beam of electron (5.0 kV).

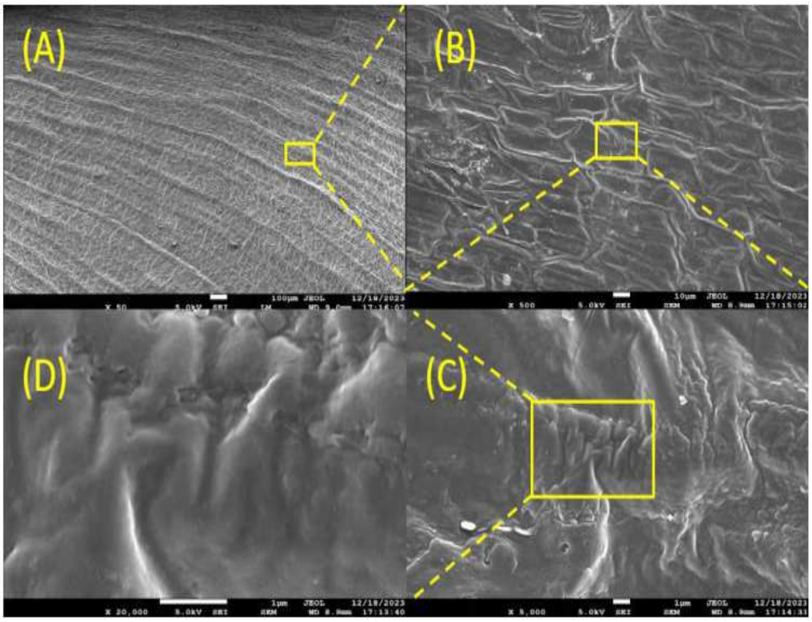

Figure 4. SEM images of banana leaf.

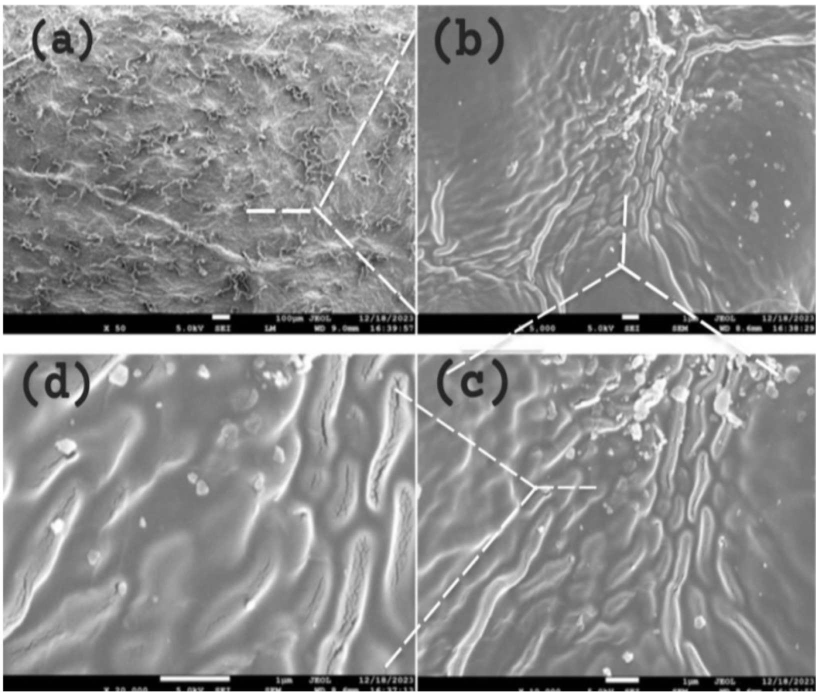

Figure 5. SEM images of guava leaf.

3.3 UV Visible Spectroscopy

For UV Visible Spectroscopy, only guava leaf is considered. Figure 6 (a) illustrates the absorption spectra in the UV-visible range (350–850 nm). It is observed that, the leaf has an absorption band at ≈ 550 nm and ≈ 730 nm respectively. The corresponding calculated bandgaps are at 1.69 eV and other at 2.25 eV respectively (Figure 6 (b)). These two band gaps can be correlated with the two parts of the leaf *i.e.*, the fiber part and the green (mesophyll) part. (Details investigation under progress).

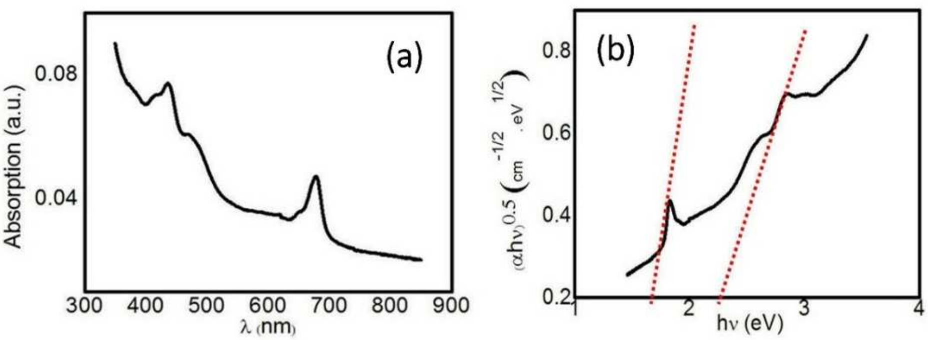

Figure 6. UV-Visible spectra. (a) Absorption band (b) Calculated bandgap.

4. MODEL

We divide the leaf mainly into two parts i.e., the vein part and chlorophyll part.

4.1 Vein architecture

The vein of the leaf is a tube structure that encloses xylem and phloem. This tubular structure is the main part that transport the food to/fro the leaf. We propose this vein to act as an electric equivalent to resistor (R). For more clarity of venation architecture, we have considered the SEM image of banana leaf (Figure 7(b)), and optical image of guava leaf (Figure 7(c)). Similar features are also observed for Gloeospermum sphaerocarpum leaf (Figure 7 (d)) [3]. Other venation architecture is clearly observed in all our cases and for others also [8, 9]

Following the features, equivalent resistor networks are considered. In the present case, the four veins are met at one point and similar four different resistor network circuit is constructed (Figure 8).

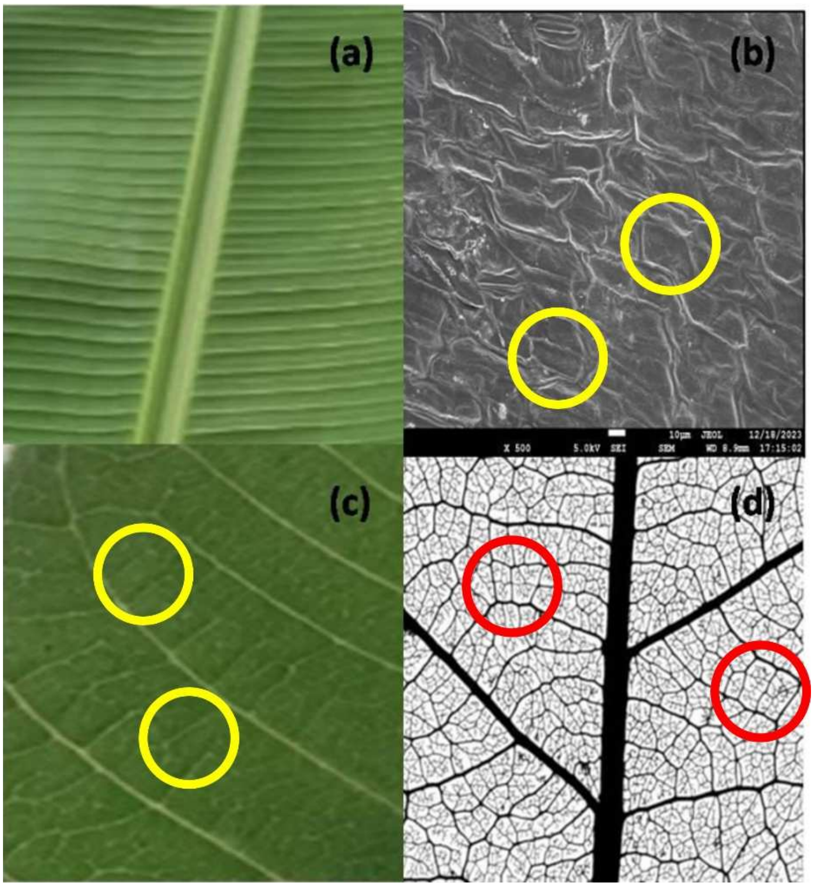

Figure 7. Venation architechture of different leaves. (a) Optical image of banana leaf, (b) SEM image of banana leaf, (c) optical image of guajava leaf, (d) optical image of Gloeospermum sphaerocarpum leaf [3].

4.2 Mesophyll and epidermis architecture

The green patch contains the mesophyll and epidermis. Epidermis is a protective skin of the leaf covering the mesophyll. We assume that, the mesophyll gets the food from the vein through semi-permeable membrane owing to the diffusion process, supported with transpiration. We also propose these can act as inductor (equivalent to secondary coil in electrical circuit of mutual inductance) (see Figure 8).

4.3 Proposed RL Network

We propose a RL network system existing in a fluid/food flow network. It may not be exactly the same network but somehow similar to it [10].

Considering the work of every component of RL network (resistor and inductor), we assume the parameter to the flow can be considered as a resistor. Similarly, the permeability of food from the vein networks to the mesophyll cells can be considered as inductor.

Figure 8 shows the proposed equivalent R-L networks. The above circuit diagram represents a theoretical proposed model based on certain assumption and parameters. Here we have considered input signal in one end corner and output signal from an opposite end corner. Here resistor R1 and R2 are connected in series and R3 and R4 are connected in series ((see Figure 8).). The above circuit diagram resembles a Wheatstone bridge. So, the equivalent resistance of the circuit can be calculated as follows:

$$R_{eq} = \frac{(R1+R2)(R3+R4)}{(R1+R2)+(R3+R4)} \qquad (1)$$

The inside inductors (L1, L2, L3 and L4), are connected in series of the circuit and can be calculated as:

$$L_{total} = L1 + L2 + L3 + L4 \qquad (2)$$

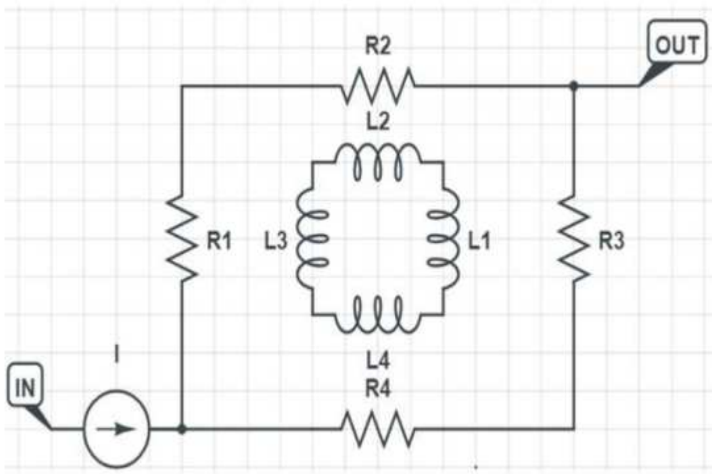

Figure 8. Proposed equivalent R-L networks, based on the observation.

In our proposed model, foods are flowing from certain corners of vein to other corners. For the simplicity of the circuit, we have only chosen a pair of opposite end. Passage of food from vein to mesophyll is equivalent to inductors adjacent to resistors. (A point to note that in our model the resistors are not directly connected to inductors. So the phenomenon equivalent to mutual inductance can be considered).

It is known that, whenever a current is passed through a conductor, it produces a magnetic field according to amperes law. And when these wires or conductors are coiled into number of turns, the magnetic field intensity get stronger and a strong magnetic field is set up inside the loop of coil. Now, if the current in the coil is changed, a voltage is developed inside the same circuit which opposes its change. This is known as self inductance. Faraday's Law states that the amount of induced voltage is proportional to the number of turns in the coil and the rate of change of the magnetic flux. Lenz's law states that an induced current has a direction such that its magnetic field opposes the change in magnetic field that induced the current, This means that the current induced in a conductor will oppose the change in current that is causing the flux to change. Now, if we place another rounded coil near to a current carrying loop, there will be an induction of emf in the non-current carrying loop. This is the phenomenon of mutual inductance. Similarly, in the leaves as we have assumed that the circuit diagram of the veins enclosing the mesophyll region is similar to that of a four resistor connected in a square like fashion and inside it a series arrangement of inductors are present. So for our reference, we can consider the resistor an equivalent loop of wire carrying food. So this induces an emf to the inductors present inside it as a result due to concentration gradient food from the loop wires or veins get induced inside the chlorophyll region. This way we assume that the coefficient of mutual inductance is somehow related with the coefficient of concentration gradient. (The details computation is under investigation).

5. CONCLUSION

The morphological structures of banana leaf and guava leaf are investigated. From the optical images and SEM images, it is revealed that the leaf consists of vein part and mesophyll part. The architectures are investigated experimentally and a model is proposed with RL networks. We attribute the vein mimic as resistor. We compare the mutual inductance (in electrical circuits) with the concentration gradient of the leaf from vein to mesophyll region. Our approach can be a guide lines to investigate generalized procedure to venation architecture mimicking the RL networks. For other architectures, similar concepts can be applied and can be improved with approximations. From UV-visible spectroscopy two absorption bands are observed and attributed to two bandgap.

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