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DIELECTRIC PROPERTIES OF LEAVES FROM SOME PLANT SPECIES

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Abstract

Dielectric properties of fresh leaves of *Ficus benghalensis, F. elastica, F. religiosa* and *Morus nigra* (Moraceae) and *Hibiscus rosa-sinensis* and *Gossypium hirsutum* (Malvaceae) were measured with time over a wide range of frequencies. The dielectric responses of different species belonging to the same family were qualitatively similar, whereas responses of samples belonging to different families were substantially different. The observed dielectric spectra were found to be a strong function of time. Although the overall effect of time was the reduction in sample conductance but the rate of reduction varied from species to species, which might be due to their anatomical and phytochemical properties.

Introduction

Dielectric spectroscopy is an analytical technique which offers a convenient and a suitable tool to understand the structure of various materials. There are several reports on the use of dielectric spectroscopy for the study of living material samples (Hart,1985). Broadhurst *et al.*, (1987) reported the dielectric properties of Jade plant leaves (*Crassula portulacea*) over a wide frequency range. Quantitative information about the charge transport and charge blocking in plant tissue can be obtained by the analysis of their dielectric spectra (Hill *et al.*, 1986). Glerum & Krenciglowa (1970) described the frequency-dependent impedance of various tissues in the young stems of 6 arboreal species. The dielectric properties of leaf samples from 34 different species at low frequencies showed three processes responsible for the charge transport (Hill *et al.*, 1987). Recently Hashmi *et al.*, (personal communication) measured the dielectric response of some algal species and the resulting spectra were found to be consistent with the taxonomic treatment of these species.

Under the influence of a time-varying stress, the flow of current through a sample depends upon its total impedance which is related to the capacitance and conductance of the sample. The capacitance and conductance of a given sample depend strongly upon its structure and composition. Dielectric studies are based on the measurements of sample capacitance and sample conductance as a function of frequencies. Thus the analysis of dielectric spectra of different materials gives an insight of the differences in structure and composition of the material.

The present paper describes the dielectric spectra of 4 arboreal plants of the family Moraceae (*Ficus benghalensis, F.elastica, F.religiosa* and *Morus nigra*) and 2

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shrubby to herbaceous plants of the family Malvaceae (*Hibiscus rosa-sinensis* and *Gossypium hirsutum*).

Materials and Methods

i) Analytical: Dielectric materials consist of an assembly of dipoles (positive and negative charges separated by some distance). Under the action of static (DC) electric field dipoles are aligned along the field direction which return to their original orientation when the field is removed. Alignment of dipoles in the field direction is called polarization whereas, the time delay in return back of dipoles to the original orientation after the removal of field is referred to as *Relaxation*.

Under the application of an alternating field, dipoles attempt to re-orient at the same rate as the frequency of the applied field and a current called *Polarization Current* is established. Idealy polarization current would be 90^{o} out of phase with the applied voltage, practically a phase difference less than 90^{o} is observed. The reduction in phase is due to the restricted orientation of dipoles, as a consequence, an in-phase current along with an out of phase current with respect to the field flows through the sample. The in-phase current is related to the conductance (*G*) of the sample and causes some energy loss (dielectric loss).

The study of conductance and relaxation requires the measurement of complex capacitance $C^{\sim}$ (w) where

$$C^{\sim}(w) = C'(w) - i\,C''(w) \quad (1)$$
$$G(w) = w\,C''(w) \quad (2)$$

Capacitance $C'(w)$ measures the energy stored and $C''(w)$ gives the energy lost. The variation of $C'(w)$ and $C''(w)$ with frequency gives the dielectric spectra of the material which was analysed to yield information about the sample material. The frequency dependence of $C^{\sim}(w)$ for dielectric materials characterised by the following two different type of responses depending on the nature of the polarising species (Hill *et al.*, 1983; Jonscher, 1991):

1) The dielectric response of polar materials is characterised by two fractional power laws in frequency respectively below and above the loss peak frequency (Jonscher, 1990)

$$C''(w) = C'(w) - C_{inf}\,(\cot n\,pi/2) \text{ proportional to } w^{(n-1)} \quad w >> w_p \quad (3\text{-a})$$
$$C''(w) \text{ proportional to } w^{m},\ C'(w) = \text{constant} \quad w << w_p \quad (3\text{-b})$$

Both exponents m and n lie between 0 and 1.

2) The behaviour of carrier-dominated systems at high frequencies is similar to that of dipolar ones (eq. 3-a) with $n = n_1$ close to unity. The low frequency behaviour below some critical frequency w is dominated by a second power law of the same form but with a much smaller value of the exponent $n = n_2$ close to zero (Bano, 1992).

Experimental Details Leaves from 6 different plant species viz., *Ficus benghalensis, F. elastica, F. religiosa* and *Morus nigra* of the family Moraceae and Hibiscus *rosa-sinensis* and *Gossypium hirsutum* of the family Malvaceae were used. Fresh mature leaves were collected , cleaned and cut into pieces of 5.8 cm diameter and placed in the sample holder. A parallel plate sample holder with circular electrodes (dia = 5.8 cm) of stainless steel was designed for this purpose. The lower plate of the sample holder was mounted on a block of Teflon (PTFE). The upper plate was movable so that the inter-electrode distance could be varied with the help of a fine thread screw attached to the upper plate. Two co-axial wires were connected to the electrodes which serve as leads to the measuring system.

The frequency response was measured on a fully automatic dielectric spectrometer. The system consists of a Solartron 1255 frequency response analyser (FRA), a Chelsea dielectric interface, an opus computer, a DXY 800 plotter and an Epson LQ-500 printer. Frequency range of the system was 10^{-4} to 10^{7} Hz which can measure the dielectric properties of any material provided the loss tangent lies between 10^{-3} and 10^{3}. All the measurements were computer controlled and stored in floppy.

The measurements were made on freshly collected living leaves with 0.1V rms and zero steady bias after 3, 6 and 24 h of picking. After each measurement the leaves were placed between duplicating papers and were kept in closed dessicator for the whole waiting period. Measurements after 3 h correspond to the response of fresh leaves as sample preparation took this period of time. Thirteen leaves for all samples were used except for *F. elastica* for which only 5 leaves were used. This gave same sample thickness in fresh condition for all samples (i.e. 4 mm). This was done to keep uniformity in sample dimensions. The results are presented in the form of logarithmic plots of $C'(w)$ and $C''(w)$ versus frequency.

Result

Dielectric properties of leaf samples from 6 different plant species belonging to two different families are shown on log scale (Fig.1). Both $C'(w)$ and $C''(w)$ are plotted on common axes and individual sets of data are displaced vertically by 3 decades to avoid overcrowding. All the samples were freshly measured after 3 h of picking. All samples gave dispersive behaviour particularly at low frequency and the whole spectra consist of two regions corresponding to low and high frequencies except for *F. elastica* (Fe) where the two regions could not be distinguished (Fig.1). Although the $C''(w)$ curves for all the 6 samples show an almost parallel variation but the spectral shapes of $C'(w)$ are significantly different for different families. Above 1 kHz $C(w)$ curves show small slopes which correspond to large values of n and a less dispersive behaviour. At low frequencies $C(w)$ shows large increase more than 3 decades for all samples except for Fe where this rapid rise was not observed. The frequency at which the response is changed from low dispersive to high dispersive (transition frequency) was different for different samples. In samples belonging to family Malvaceae, the transition frequency was relatively higher.

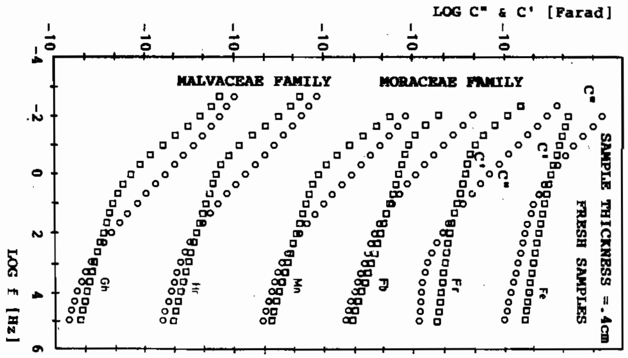

Fig.1. Variation of capacitance $C'(w)$ (squares) and dielectric loss $C''(w)$ (circles) with frequency on log-log scale for six different plant species. Both $C'(w)$ and $C''(w)$ are plotted on common axes and individual sets of data are displaced vertically by 3 decades for clarity. All the measurements were made on freshly picked samples with 0.1 V rms.

High frequency response of *Gossypium hirsutum* (Gh), *Hibiscus rosa-sinensis* (Hr), *Morus nigra* (Mn) and *Ficus benghalensis* (Fb) are almost identical (Fig.1). For Fe and Fr although the spectral shape was similar but the separation between $C'(w)$ and $C''(w)$ curves was relatively larger as compared to other samples.

The variation in $C^{\sim}(w)$ with frequency for Mn, Fb, Gh and Hr leaves are shown in Figs. 2 and 3 with time after picking as parameter. The individual sets of data is displaced vertically for clarity. For samples freshly measured after 3 h the response consists of two regions with different slopes at low and high frequencies. With the passage of time this division of spectra becomes less pronounced and after 24h the low frequency region almost disappears and the high frequency region (less dispersive) extends to low frequencies. At high frequency $C'(w)$ curves give parallel shift with time i.e., for a given sample the slope and hence the n value does not change with time, only the absolute magnitude is reduced.

Discussion

Both capacitance and conductance of all samples showed strong dependence on frequency which can be described by fractional power laws with different values of the exponent n at low and high frequencies. The value of exponent was related to the amount of dispersion in the sample, the larger the value of the exponent (close

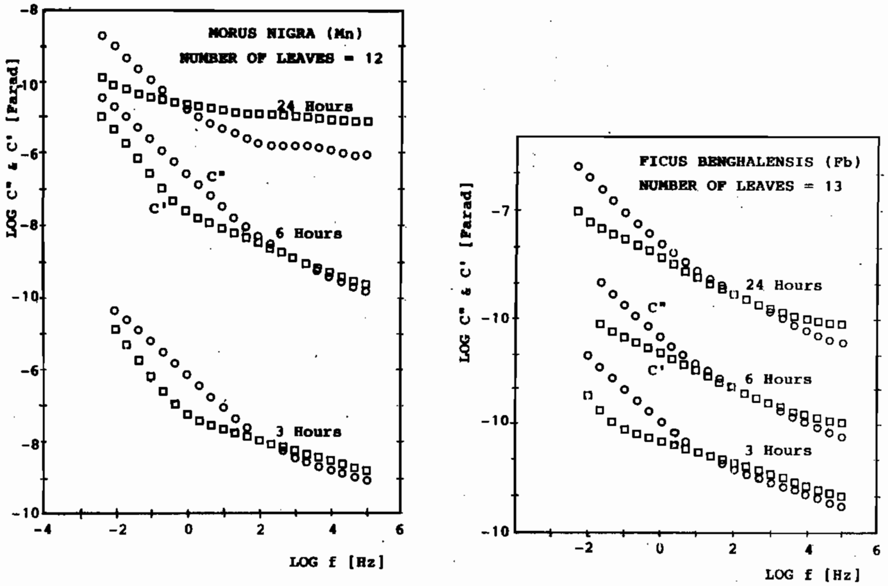

Fig. 2. Logarithmic plots of $C'(w)$ and $C''(w)$ for *Morus nigra* and *Ficus benghalensis* samples with time as parameter.

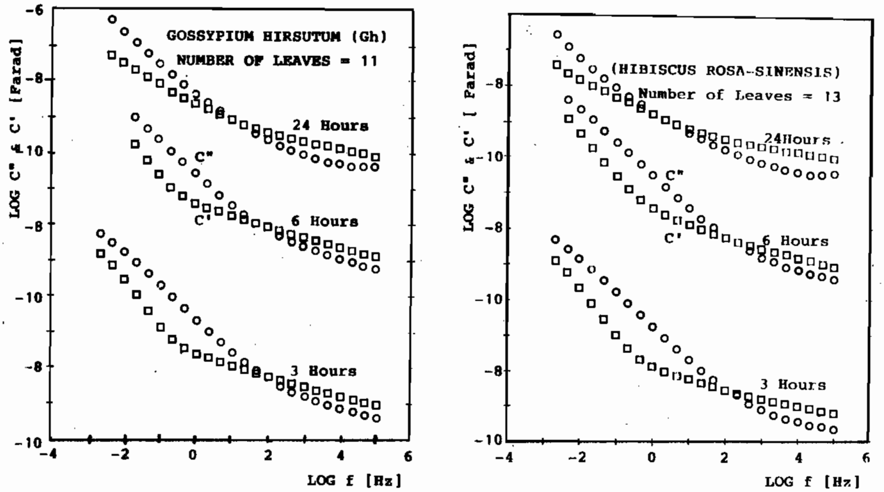

Fig. 3. Logarithmic plots of $C'(w)$ and $C''(w)$ for *Gossypium hirsutum* and *Hibiscus rosasinensis* samples after 3,6 and 24 h of picking.

to unity) the less dispersive the sample is and vice versa. Response of *F. elastica* was found to be the least dispersive (Fig. 1) which can be correlated with the low conductance of this sample as compared to other species. The conductance of 5 species at 4 different frequencies of the applied signal as reproduced in the form of bar chart with time as parameter (Fig.4) shows the largest conductance at all the four frequencies in Mn, whereas, conductance of Fe was almost negligible on that scale. To elaborate the behaviour of Fe, the variation in conductance of this plant with time is redrawn in Fig.5 on a magnified scale (100 times as compared to Fig.4) at two different frequencies.

Time seems to have significant effect on the dynamic response of leaves particularly at low frequencies where the dispersion is reduced with the passage

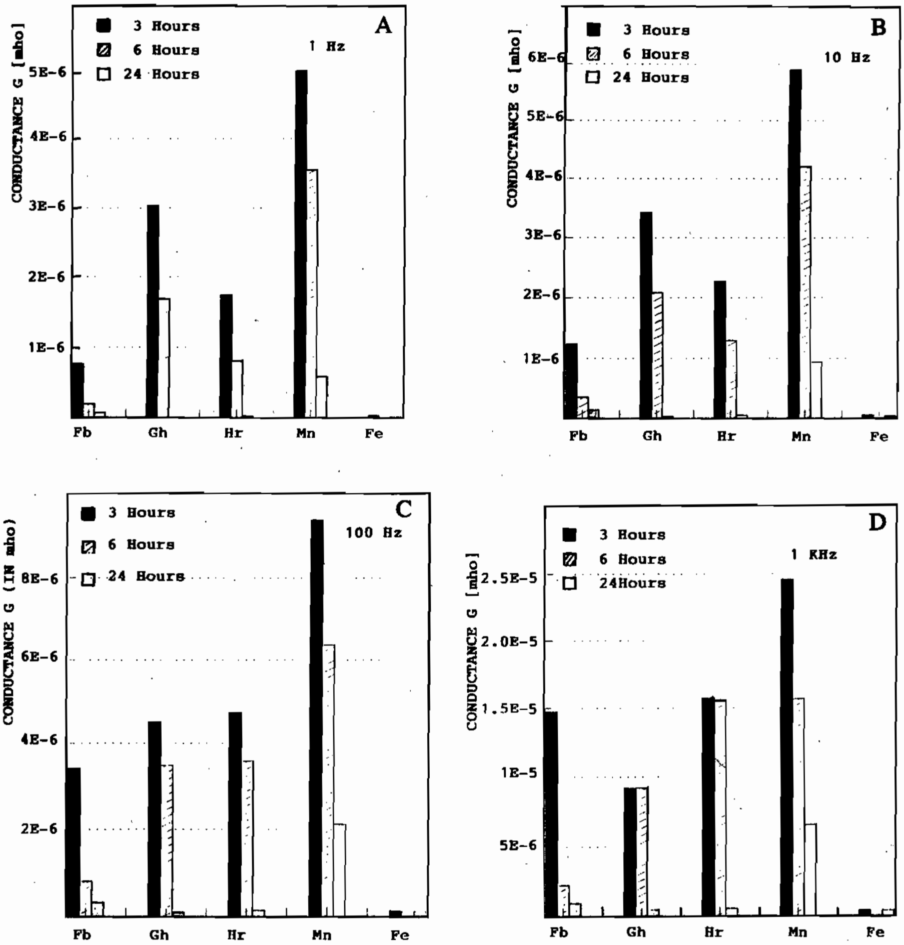

Fig. 4. Variation of conductance $G(w)$ with time for 5 different species at 1 Hz (a), 10 Hz (b), 100 Hz (c) and 1 kHz (d).

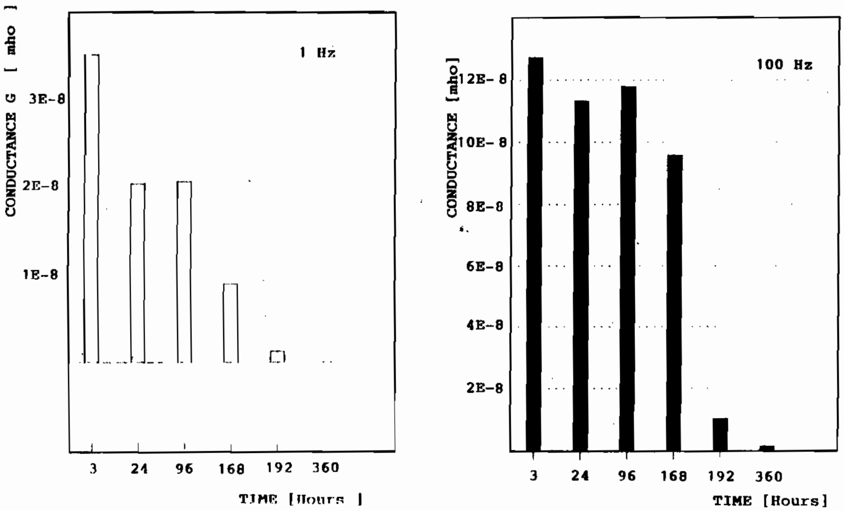

Fig. 5. Bar chart showing the change in conductance for *Ficus elastica* samples with time at 1 Hz and 100 Hz.

of time (Fig.2&3). One of the obvious reason for this change is the continued loss of water through transpiration. The rate of transpiration differs from species to species according to the anatomy of leaf and this affects the rate of change of conductance with time which is also evident from Fig.4&5.

Although there is a diurnal and seasonal variation in the water content of the leaf of a given plant according to the availability of moisture, atmospheric temperature humidity and wind velocity, the over all water content of one species differ from the other depending upon the detailed structure of the leaf. Those composed of large sized cells have greater amount of water, as the large cells have larger vacuole that contains most of the water of the cell. The total amount of cell-wall material would be lesser in leaves of larger cells as compared to leaves of smaller cells. This would result in different values of capacitance and conductance among the leaves of different plant species. According to Glerum & Krenciglowa (1970) the living tissue can be considered as a complex combination of series and parallel resistors and leaky capacitors where the cellular components of this combination are as follows:

i) the cell membranes, which have high capacitance and resistance (high impedance),
ii) the cell walls, which have low specific resistance and capacitance, and
iii) the cytoplasm and vacuoles, which have a very low resistance and negligible capacitance.

Thus the flow of current in plant tissue will depend strongly upon the amount of cell membrane and cell wall materials. Comparing tissues of similar dimensions, those composed of smaller cells have greater total amount of cell membrane and cell wall materials than those of larger cells. The greater the amount of cell membrane the lesser will be the current flow through the sample. Moreover, a leaf is not a homogeneous mass of cells. In cross section generally a leaf contains tissues made up of cells of different sizes and shapes, such as epidermal cells on either side, palisade tissue spongy panchyma and intervening veins which contain the vascular bundles. The relative amount of these tissues varies from species to species, and there could be one or more than one layers of palisade cells, or even the palisade tissues on both sides with spongy parenchyma sandwiched between them. Each type of tissue has its own impedance characteristics (Glerum & Krenciglowa, 1970) and it is not correct to propose a universal dielectric response of leaves on the assumption of a typical leaf structure and one has to correlate the dielectric response of different leaves with their actual anatomical features such as the thickness of cuticle, the comparative amounts of various types of tissues and average cell size in them.

Besides leaf anatomy, the chemical contents are also very important where cellulose and chlorophyll are the common substances in, all leaves, many other chemical constituents vary from species to species. The leaves of plants growing in saline habitats, such as the members of Chenopodiaceae, have much greater salt content than other plant species. Similarly some species have a tendency to accumulate any particular metal in their cells. The complex organic substances vary even to a larger extent. The presence of any particular substance can affect the viscosity of cytoplasm and cell sap. At the same time the concentration of various ions may be different in different species. All these factors may contribute to the differential charge binding abilities and hence different shapes of dielelctric responses for different species. Although there is a great diversity of anatomical features and chemical contents of the leaves of various plant species, the closely related species generally have relatively lesser differences both in their anatomy and chemical contents. The observed dielectric responses also reflect the similarities of related species where 4 species belonging to family Moraceae gave relatively similar spectra as compared to those of family Malvaceae. However, within same family, each species has its own characteristic spectrum slightly different from the other species. This may be due to anatomical and phytochemical differences among the leaves of related species. Dielectric spectroscopy, therefore, can provide additional information to plant taxonomist in combination with anatomical and phytochemical studies.

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