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Plant Membrane Dielectric as A Capacitive Biosensor

KEYWORDS: Dielectric, capacitance, hygroscopic, lipid bilayer, biosensor

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ABSTRACT *The plant leaf is working as a capacitive biosensor, because the water content creates pressure inside leaf, which changes the dielectric of leaf membrane. The dielectric capacitance is a result of molecular polarization, which carries random ion charge. The random dipoles of dielectric can be avoided by applying external small electrical potential for linear polarization. If there is a net charge in dielectric region near a membrane, an electrical difference exist from one region to another. The magnitude of such an electrical potential difference ΔE is related to the capacitive region but not affect the values of capacitance and dielectric. The measurement of dielectric values of Rajgira Sona (Amgranthus) plant using ECG electrodes, which varied as per the water contain in plant membrane. The value of membrane dielectric to be measured in the form of variable capacitance, due to change of water pressure inside the plant leaf. The capacitance of leaf observed 16 nF to 64.4 nF, which variable as the water content in leaf membrane. Due to above characteristic the plant leaf can be used as biosensor and useful for irrigation control system.*

INTRODUCTION

Plant membrane cells carry ion charges, which varies with water pressure during irrigation. The dielectric of plant leaf is used as a capacitor, where the capacitance of leaf changes with water supply to the plant. The plant leaf is sensitive to water content and its pressure inside leaf, which changes the dielectric value of leaf. The variable dielectric values of leaf due to water pressure working as a variable capacitor. It can be used as a biosensor. Any change in leaf capacitance is converted in to equivalent electrical signal for water control purpose.

The Rajgira plant used for measuring capacitance of leaf and dielectric. The dielectric of leaf varied due to water pressure inside leaf, therefore the effective capacitance due to water contents in nF range, which varied from 16 nF to 64.4 nF. The characteristic of dielectric and membrane capacitance is measured and calculated the effective dielectric values including environmental data's (humidity, temperature).

Electroneutrality and Membrane Capacitance

Another consequence of the relatively large magnitude of electrical effects is the general occurrence of electroneutrality, in most aqueous regions that are large compared with atomic dimensions, the total electrical charge carried by the cations is essentially equal in magnitude to that carried by the anions. If there is a net charge in some region, such as near a membrane, an electrical potential difference exist from one region to another.

To relate charges and ΔE's, we need to introduce capacitance (Fig. 1). Electrical capacitance is the coefficient of proportionality between a net charge and the resulting electrical potential difference. A high capacitance means that the region has the capacity to have many uncompensated charges separated across it without developing a large electrical potential difference across that region. The magnitude of such an electrical potential difference, ΔE, is related to the capacitance of the region.

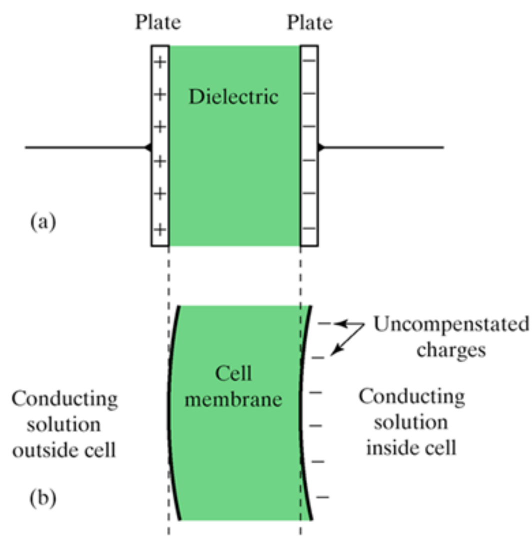

Figure 1: (a) A parallel plate capacitor (b) Cell membrane as a capacitor (membranes act as dielectric).

A parallel plate capacitance show in Fig. 1 (a), each plate represents as connectors between charges, can freely move between lipid bilayer, so each plate has a particular electrical potential. Region between the plates is called dielectric, charge cannot cross an electrical potential difference, therefore a small change in potential occurs across dielectric region. The cell membrane act as a dielectric separating the aqueous conductance phase on either side. As shown in Fig. 1 (b), electrical potential difference across dielectric due to conducting solution inside cell membrane.

Cell membrane capacitor, act as dielectric separating the aqueous conducting phases on either side; uncompensated negative charges accumulate on the inner side of a typical cell membrane. The higher the capacitance, the greater is the charge on the plates or the more uncompensated charges adjacent to the membrane for a given ΔE across the dielectric; (capacitance is proportional to dielectric).

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Characteristic of dielectric
The increase in capacitance due to dielectric presence is a result of molecular polarization. In water dielectric molecular have a dipole movement which carry ion charges. The plant membrane or leaf; contain cell and water, therefore the amount of water can be observed into the leaf. To avoid the random dipoles of dielectric, use small external electric potential across the dielectric of leaf, to maintain linear polarization of dipoles. Reduced electrical field leads to a smaller voltage across the capacitor.

$$v = \frac{V_0}{\varepsilon_r \, \varepsilon_0}$$

We can get an expression for the capacitor with a dielectric :-

$$C = \varepsilon_r \, \varepsilon_0 \frac{q}{V_0} = \varepsilon_r \, \varepsilon_0 C_0 \qquad (2)$$

Capacitor of parallel plate

$$C = \frac{\varepsilon_r \, \varepsilon_0 A}{d} \qquad (3)$$

$$C = \varepsilon_r \, \varepsilon_0 G \qquad (4)$$

Design of Capacitive BIOSensor Using Following Parameters:
1. Formation of Capacitor type:- Parallel Plate
2. Electrode Dimensions (both side):- 1936 mm^2
3. Spacer Material:- leaf membrane cell
4. Distance between electrodes:- 0.25 mm
5. Relative Humidity:- 19 % to 25 %
6. Leaf Temperature:- 12^0 C to 15^0 C
7. Value of Capacitor measured:- 16 nF to 64.4 nF
8. Dielectric value Varied (ε_r):- 233.5 to 939.67

The capacitance of leaf dielectric is effected by environmental changes like:- temperature variation, humidity and water contents in plant, therefore variation in temperature and humidity are compensated, and a net charge in capacitance of leaf is available, which varies with the water contents of leaf in the form of dielectric values.

Water contain in dielectric is effected; therefore the dielectric constant (ε_r) is changes due to water supply. In plants the leaf having the stomata pores through which water evaporate exit and intake therefore due to almost stable temperature it is working as a plant coolant, the temperature of leaf dielectric remain almost constant (12-15^0 C). Using plant leaf as a capacitive sensor, leaf dielectric and water present in leaf, work as hygroscopic material, it can absorb water molecules and change leaf dielectric constant (ε_r) accordingly. The change in capacitance can be measured and related to dielectric constant of plant leaf. Any change in water contents of leaf will indicated by capacitive and dielectric values. The dependence of such sensor is linear due to almost constant temperature; therefore such biosensors are able to generate a variable dielectric signal as per the water pressure inside plant leaf. Due to constant temperature and hygroscopic nature of plant leaf, the effects of environmental temperature and humidity not effect on the capacitance and dielectric of plant membrane.

Plant Membrane Capacitance
If there is a net change in capacitance of plant membrane, it indicates that water contents of membrane changes. The measurement of capacitance of plant recorded after water supply timing and converted into dielectric constants as per the water contents of leaf.

The capacitance of most biological membranes are approximately the same per unit area. The lipid bilayer of plant membrane represents the dielectric phase as per the water contents. The capacitance of plant membrane can be measured using capacitance meter. After applying water supply to plant, the capacitance measured with timing schedule, which indicate that as the water content of leaf reduced than capacitance and dielectric content of leaf decreases as shown in Fig. 2 and the measurement setup is shown in Fig. 3.

Conclusion
Plants can be used as a biosensor to observe the water contentsin leaf. Each plant has membrane cells, therefore when we measure the capacitance of plant leaf, than it shows the water contents in plant. When we are going to irrigate plants, then biosensory system of plant can be used to control the water supply of plant. If we are using plant as biosensor than it is very easy to automated water supply of plant.

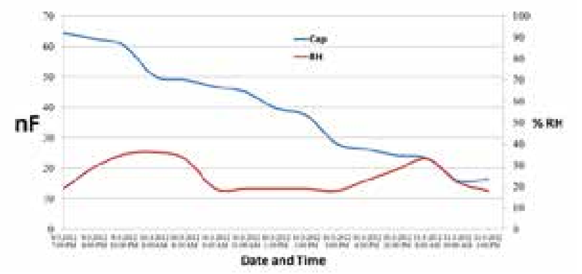

Figure 2: Transfer function of a capacitive sensor with time related to water contains in plant membrane (full water supplied at 6.00 AM on 9-3-2012).

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Figure 3: The leaf capacitance measurements using ECG electrode

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