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FRACTIONAL-ORDER MODELS FOR VEGETABLE TISSUES

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Abstract: We use electrical impedance spectroscopy to determine the impedance spectra of vegetable leaf samples. We fit fractional-order empirical models into the experimental data. We verify that a 4-parameter model characterizes assertively the leaf specimens.

keywords: Nonlinear Fractional Dynamics and Applications, System Biology, Modeling, Numerical Simulation and Optimization.

1. INTRODUCTION

Leaves are most responsible for food production in vascular plants. They exhibit a large variety of shapes and sizes, and often are classified according to their form, or based on the arrangement of their veins [1]. The study of individual leaves can reveal important characteristics of the whole plant, namely the nutrient concentration, the presence of diseases, tissue damage and rooting ability, among others [1-2].

Electrical impedance spectroscopy (EIS) has been widely used for studying vegetable tissues [1-5]. EIS measures the electrical impedance of a specimen across a given range of frequencies, producing a spectrum that represents the variation of the impedance versus frequency [1-2].

In practical terms, EIS involves exciting the specimen under study by means of electric sinusoidal signals and registering the system response. This technique has the advantage of avoiding aggressive examinations. A considerable volume of research addresses this topic when dealing with vegetable materials, namely roots, leaves, stems, vegetables and fruits [1-9].

2. PURPOSE AND METHODS

Given an impedance spectrum of experimental data, the main question is to find a mathematical model that fits well to the data and has minimum number of parameters [10-11]. As biological tissues are complex systems characterized by dynamic processes that occur at different lengths and time scales, we need models that adequately describe the behavior of such materials by considering the interactions among the various relaxing phenomena and memory effects. Different empirical models, developed in the context of the so-called dielectric relaxation phenomena have been used to achieve that purpose, namely the Cole-Cole (CC), Cole-Davidson (CD) and Havriliak-Negami (HN) models [12-14]. Even though the original formulations are empirical and do not use fractional derivatives or integrals, explicitly, they may be regarded as pioneer applications of fractional calculus (FC). Such connection has been addressed by several authors [15-16].

In this paper the impedance spectra of leaf samples from two distinct plants are determined by means of EIS. FC empirical models are then fitted into the experimental data. The chosen plants, namely the Bracken (*Pteridium aquilinum*) and the Anthurium (*Anthurium andraeanum*) have leaves with very different shapes.

2. RESULTS

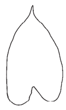
We start by measuring the electrical impedance in the frequency range $f = 10$ Hz up to $f = 1$ MHz, at $N = 30$ logarithmically spaced points. We then fit the FC models into the experimental data in order to minimize a distance criterion, J, between the experimental and model impedance polar diagrams. A standard genetic algorithm (GA) is adopted, with elitism, crossover within all population and 5% mutation probability [17].

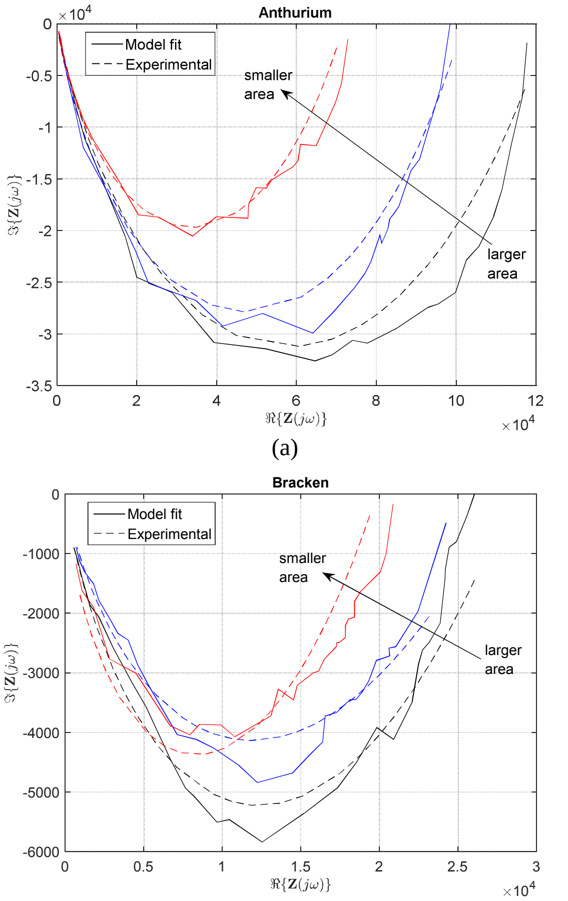
Experiments demonstrated that the HK model of equation (1) leads to the best fit.

$$G(j\omega) = \frac{K}{\left[1+\left(\frac{\omega}{\omega_p}\right)^{\alpha}\right]^{\beta}} \quad (1)$$

Table 1 summarizes the optimal parameters obtained for six specimens analyzed. The experimental and approximated curves are depicted in Figure 1 in the form of polar plots. We verify that the values of K and ω_p vary with the leaf size, while α and β remain almost invariant. On the other hand, we observe that α and β characterize assertively the plant species.

Table 1 – FC model parameters calculated by the GA algorithm.

Leaf specimen		Area (mm^2)	K	ω_p	α	β	J
Bracken *Pteridium aquilinum*		22848	28395.56	30190.56	0.376	2.109	0.178
		14184	27929.71	43807.77	0.297	2.551	0.142
		4857	19839.88	267357.11	0.432	2.456	0.326
Anthurium *Anthurium andraeanum*		11591	122965.77	1742.80	0.558	1.296	0.191
		4878	101670.76	2957.08	0.593	1.314	0.271
		2281	71862.53	3350.45	0.593	1.314	0.415



(b)

Figure 1 – Polar plot of the impedance Z($j\omega$) for two leaves with three different sizes for: (a) Bracken; (b) Anthurium

3. CONCLUSION

We used EIS to determine the electrical impedance spectra of leaf samples and we adopted FO models to describe the experimental data. We showed that 4-parameter FO transfer functions describe adequately the data. Further research will investigate the correlation between the impedance parameters and additional characteristics of the specimens.

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