

Research Article

## The Fluctuation Studies on Dielectrical Properties of Quail Eggs Depend on Storage Duration

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### ABSTRACT

An increasing of public attention to the quality of food has been increasing, recently. One type of food that consumed is quail eggs (QE). In this study, QE were tested by Electrochemical Impedance Spectroscopy (EIS) method with some parameters such as complex impedance, dielectric constant, and loss tangent analysis. Several interesting results showed that dielectric properties of QE experience a fluctuation phenomenon if the test is influenced by storage duration, qualitatively. Therefore, we approximately prove that QE quality can be tested via EIS to obtain fine results.

## Introduction

Each material has unique electrical properties and their magnitude is determined by the internal conditions of the material, such as electric dipole moment, chemical composition, water content, acidity and other internal properties. Materials that have electrical properties and are able to store electrical energy are called dielectric materials.<sup>1</sup> The use of dielectric materials is increasingly being applied in industry and agriculture. Its application is based on the material's ability to absorb electromagnetic wave radiation and convert it into heat. Apart from that, the dielectric method can also be used for non-destructive measurement of water content at low energy levels. Most materials used as dielectrics come from non-biological materials, such as air, noble gases and metals. These materials have relatively low dielectric constant values.

However, the knowledge of dielectric properties of such biological materials is a requirement for the investigation of the heating characteristics of such materials, especially at radio frequencies.<sup>2</sup> Dielectric constant, loss angle, and dissipation factor are some interesting dielectric properties necessary for biological materials such as eggs that have not a non-comprehensive analysis still found if the fresh eggs collected within a day of laying.<sup>2</sup>

Eggs are a food source that many people like because they taste delicious, are relatively cheap and can be processed into new food products. Apart from that, eggs also contain unsaturated fats, protein, vitamins, selenium, lutein and minerals that the body needs. But, the internal quality of eggs can change during storage including loss of water and CO<sub>2</sub>, as well as

diffusion of fluids between different parts of the egg. Water is lost by evaporation through the shell and its loss together with loss of CO<sub>2</sub> and increases in acidity results in the liquefaction of albumen.<sup>3</sup> Gas exchange through the shell can cause changes in two of the albumen proteins, ovomucin and lysozyme, which then affects the thickness of albumen layer and can be used as a measure of their freshness. External appearance of an egg gives no indication of its freshness,<sup>3</sup> so we have to try a non-destructive assessment of eggs via dielectric parameters.

Previous work on non-destructive assessment of eggs have used dielectric detection in the range of radio frequency of 40 kHz to 20 MHz,<sup>4</sup> visible (UV/VIS 200-800 nm) transmittance spectroscopy and proton NMR relaxation. Hyper-spectral imaging is a non-destructive technique which integrates the conventional spectroscopy and image processing for quality evaluation of samples. Conventional NIR spectroscopy can only provide a spectrum while hyper-spectral imaging can provide both spectrum and spatial information of the composition of samples.<sup>5</sup> In this research, we tried a simple method to detecting the freshness of quail eggs via Electrochemical Impedance Spectroscopy with some analytical parameters such as complex impedance, dielectric constant and loss tangent.

## Methodology

### Materials

In this research, several quail eggs were obtained from Aruna Farm Desa Koleang, Jasinga, Bogor City. It stored in room temperature (20 °C - 25 °C) for 18 days and will be tested every 2 days. A chamber, multi-tester probe cable, computer, and LCR meter Hioki (3532-50) were used for experimental and data analysis.

### Research Methods

Quail eggs that have been stored are placed in the chamber that has been made, then parallel plate capacitive sensors, multi-tester probe cables, LCR meters are assembled in such a way that everything is connected as in Figure 1. The measurement is conducted at 50 Hz – 100 MHz for 100 points with the quantities measured including impedance (Z), electrical conductivity (G), and reactance (X).

### Data Analysis

In this stage, the impedance, dielectric constant and loss tangent values of the quail eggs will be measured, each of which is measured using equations (1), (2), and (3).

$$\varepsilon' = \frac{z''}{\omega C_0(z'^2 + z''^2)} \quad (1)$$

$$\varepsilon'' = \frac{z'}{\omega C_0(z'^2 + z''^2)} \quad (2)$$

$$\tan \delta = \frac{\varepsilon'}{\varepsilon''} \quad (3)$$

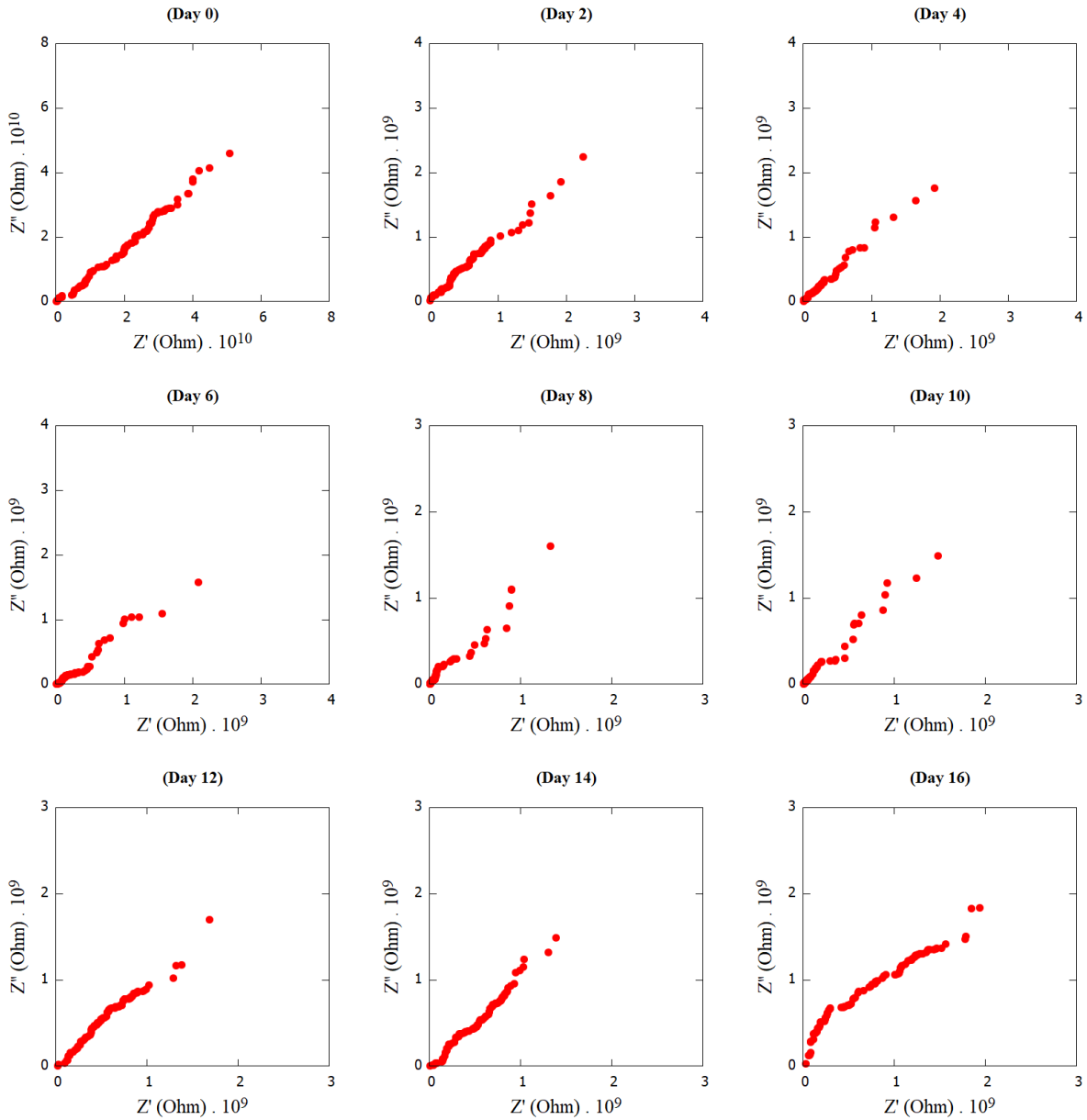
Where,  $\varepsilon'$ ,  $\varepsilon''$ , and  $\tan \delta$  are real dielectric, imaginary dielectric, and loss tangent, respectively. Whereas  $\omega$  and  $C_0$  are angular frequency and vacuum capacitance.

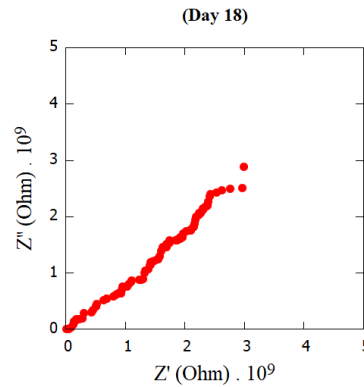
## Results and Discussion

The results showed several outputs about electrical properties such as complex impedance plots, real and imaginary dielectric and also loss tangent analysis. The frequency dependent of dielectric properties was studied at room temperature in the frequency range 50 Hz – 100 MHz.

Complex Impedance Plots

The study of complex impedance plots is a powerful tool to investigate the phase lag of charge carrier's movement under ac voltage.<sup>6</sup> It is an outstanding informative on demonstrating the resistances of quail eggs. Nyquist plot displayed with imaginary ( $Z''$ ) and real ( $Z'$ ) parts of the complex impedance as shown in Fig. 1.



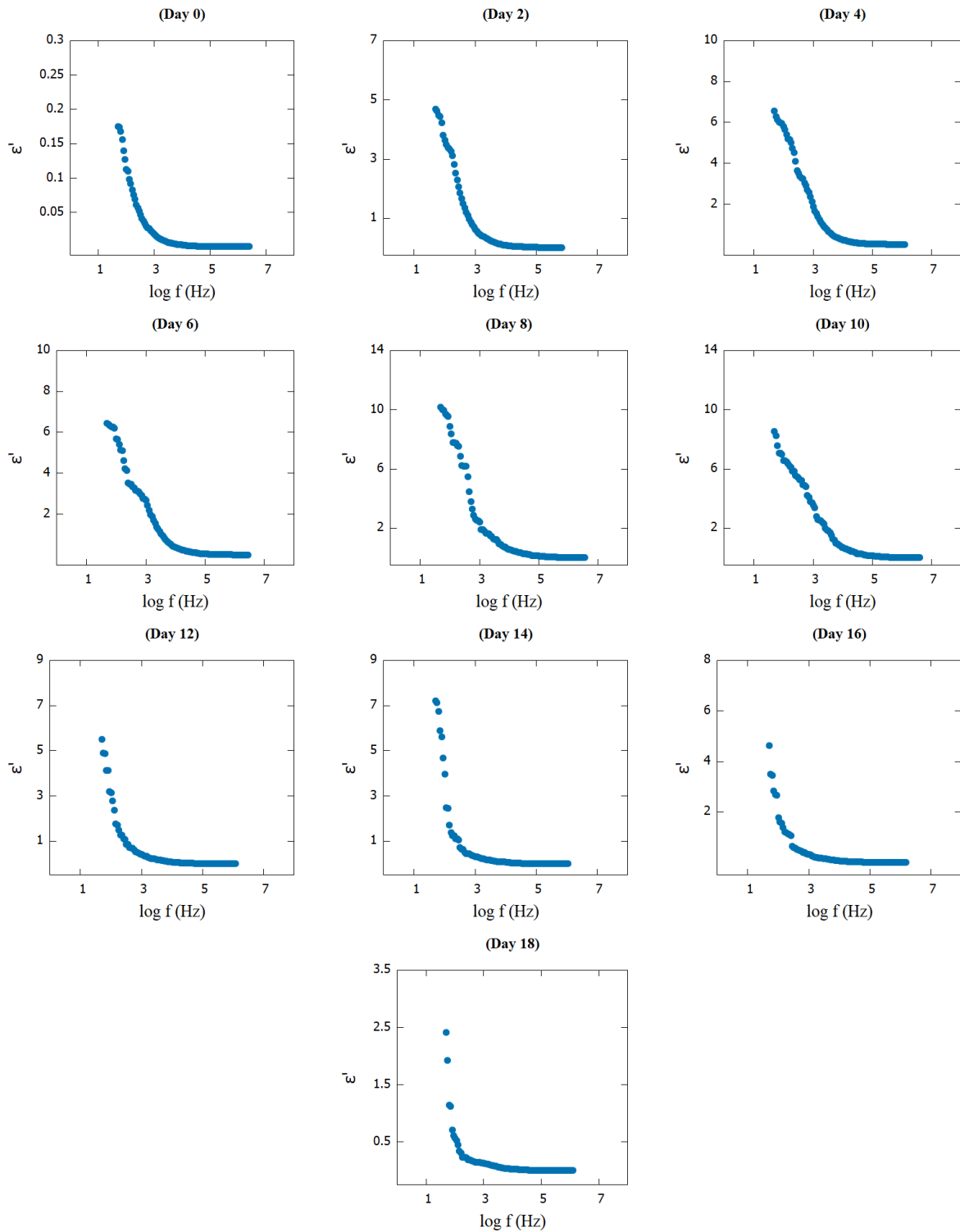


**Figure 1.** Complex Dielectric Spectra of Quail Eggs from Day-0 to Day-24

The resistance values were obtained begin from day-0 to day-8 where QE has an increment on its bulk resistance due to the enhancement of ions activity, where they have a high mobility following with higher frequency, then on days 10 to 24 it slowly increases again. This caused by microscopic changes in the QE which indicate a decrease in ion concentration in the eggs. The decrease in these ions is indicated by the evaporation of water in the egg white and the activity of incoming microbes, so that ion mobility decreases and the egg tends to act as an insulator. Improved electrical performance is indicated by reduced resistance as storage time progresses. In this case, ions from the egg white are indicated to diffuse towards the egg yolk.<sup>7</sup> Therefore, the observed pattern of this analysis explain that the fluctuation of complex impedance spectra was influenced by QE condition. Microscopically, QE will decrease or increase its bulk resistance due to water evaporation in white egg following with ion activity.

### *Real and Imaginary Dielectric*

Real dielectric analysis and frequency for the analyzed QE samples is illustrated in Fig 2. It can be observed that the dielectric pattern of each QE samples exhibits decrease in values with increasing frequency. It is due to polarization effect between electrode-QE interface.<sup>2</sup> The real dielectric pattern obtained in this study forms an exponential pattern, where the dielectric constant value is large at low frequencies and decreases at high frequencies. This is because the greater frequency given, the greater wave transmitted every second and the charge orientation occurs on the capacitor plates, so that at frequencies less than 1000 Hz the insulator area is dominant, where in this condition the voltage distribution channel is large and in these conditions the voltage distribution line with the supporting poles is isolated.<sup>8</sup> Built upon on real dielectric values that we obtained from each samples, it has increase on day 0 to day 8, then decrease gradually on day 10 to day 18. It can be observed that the increase of real dielectric values of each samples possible due to re-orientation of dipole in QE, whereas the decrease of dielectric values are possible to polarization effect.



**Figure 2.** Dielectric Real Spectra of Quail Eggs from Day-0 to Day-24

Imaginary dielectric analysis and frequency for the analyzed QE samples is illustrated in Fig 3. When observing the dielectric spectrum, the real dielectric value increased gradually from day 0 to day 8. This is line with the decrease in resistance that occurred previously. The relationship between ion activities that occurs in the egg has a direct effect on the dielectric results that appear, where the interaction between the electrode and the quail egg shell causes ion polarization at low frequencies, thus causing high dielectric values at low

frequencies in all dielectric measurement results. Furthermore, the dielectric value decreases gradually at higher frequency because of changing the direction of charge on the electrode to run faster but are not accompanied by adjustments to the movement of charge on the egg shell.<sup>7</sup> The imaginary dielectric value also represents the ability of the material, namely QE to store charge. Electricity or called capacitance, the greater the capacitance of the material, the greater the dielectric value.

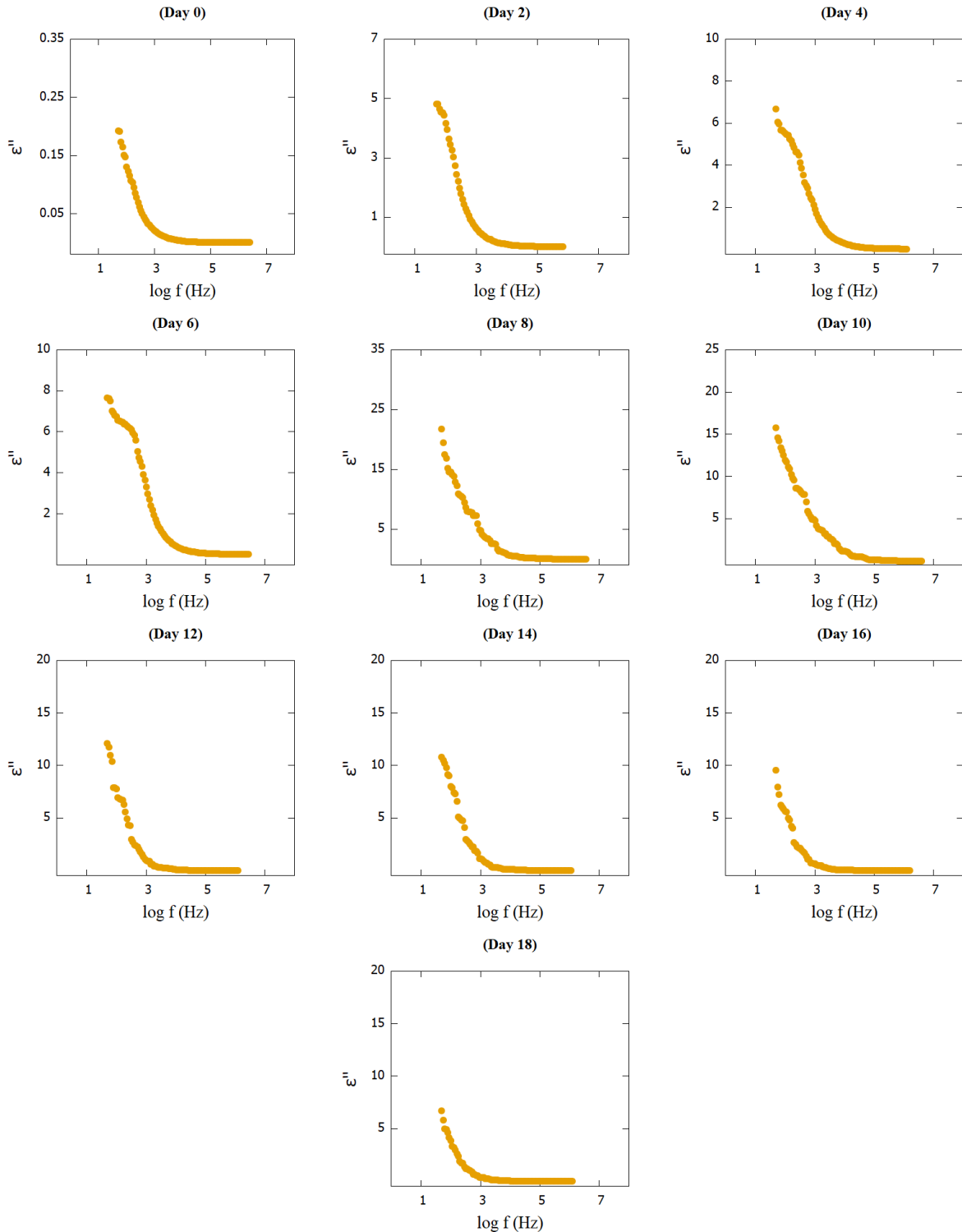
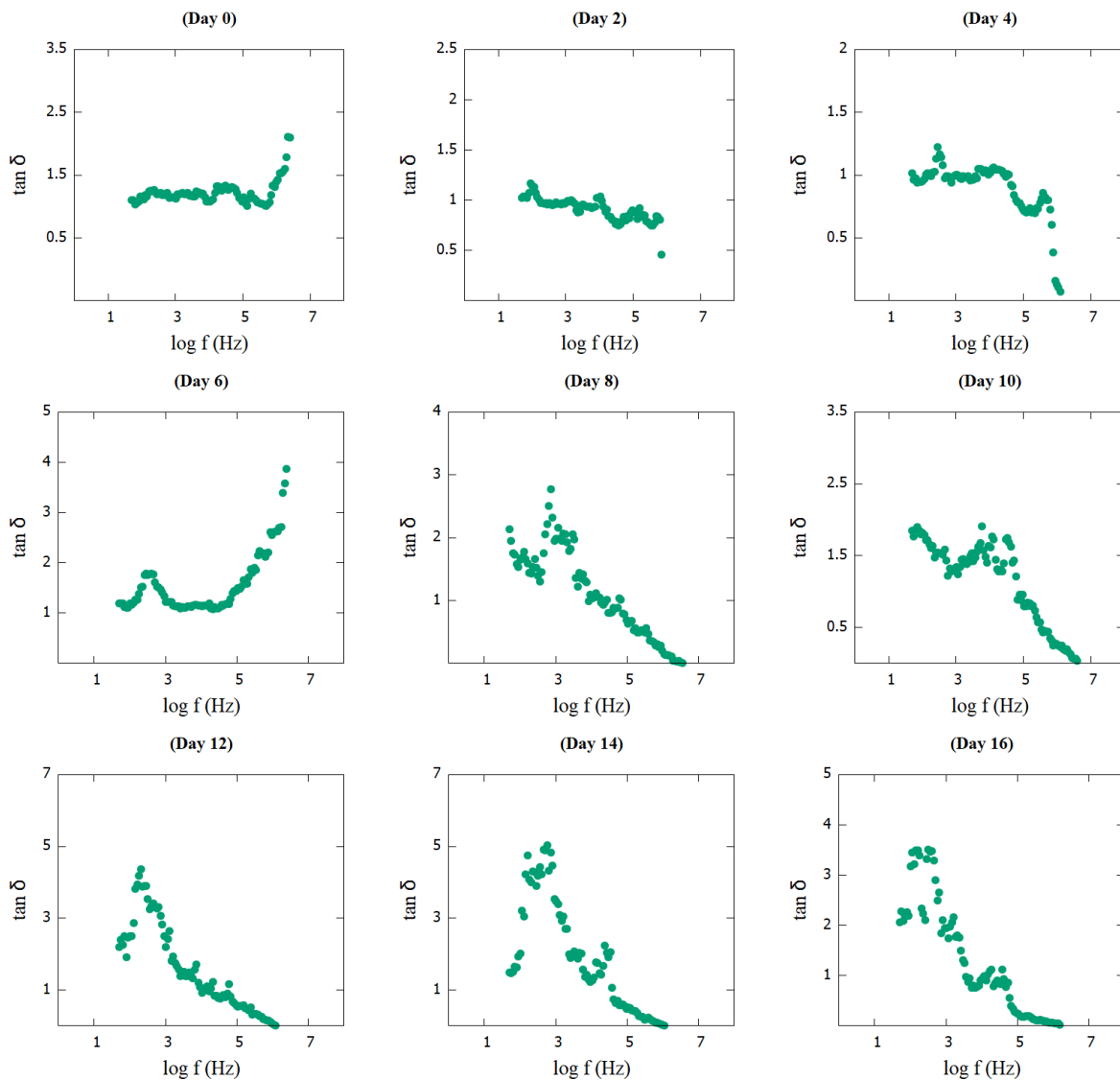


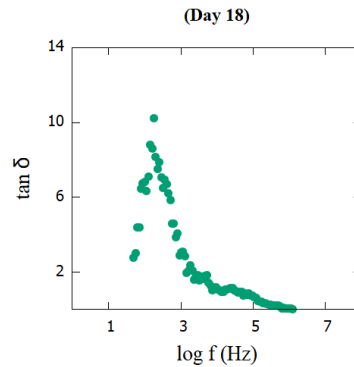
Figure 3. Imaginary Dielectric of Quail Eggs from Day-0 to Day 24

### Dielectric Loss Tangent

This analysis is used to describe the dielectric relaxation process in SPEs. Dielectric loss tangent ( $\tan \delta$ ) analysis as a function of frequency is defined as the ratio of dielectric constant values in a periodical field or called as dissipation factor. This is an opportunity to obtain more information about the alteration of resistive ( $\epsilon''$ ) and capacitive ( $\epsilon'$ ) respond depended to frequency. We obtained the plot shape of  $\tan \delta$  in the Fig 4. with calculated by following the equation (3).<sup>9</sup> We found unclear peaks on day 0 until day 4 that caused by low current of charge carriers in QE, where electrode doesn't penetrate the charge across the QE. Maddu et al. explained that the presence of single peak indicates a ion migration phenomena,<sup>6</sup> therefore we assumed the ohmic component only interacts with QE shell without transmission to inside. Nevertheless, on days 6 to 18 peaks began to appear some single peaks. This phenomenon represents a long-range dielectric relaxation because it happened at low frequency.<sup>10</sup> in this case, the electrode cannot be easily transmit the QE interface due to the high thickness of QE.



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**Figure 4.** Loss Tangent Spectra of Quail Eggs in Day-0 to Day-24.

In addition, The peaks which obtained correspond to the electrode polarization frequency. Principally, an increasing  $\tan \delta$  curves at the lower frequency indicated that ohmic components as current is higher than capacitive components.<sup>11</sup> We believe that the QE storage time has an effect on the QE interface because in the dielectric constant analysis the value decreases and in the impedance analysis the resistance increases. Therefore, the peak loss tangent obtained increases with the length of storage time.

## Conclusion

QE storage time has affected electrical test results. There is a fluctuation phenomenon in impedance, dielectric and loss tangent values. Microscopically, QE will decrease or increase its bulk resistance due to water evaporation in white egg following with ion activity. The increase of real dielectric values of each samples possible due to re-orientation of dipole in QE, whereas the decrease of dielectric values are possible to polarization effect. Furthermore, the imaginary dielectric value represents the ability of the material, namely QE to store charge. Then, the QE storage time has an effect on the QE interface because in the dielectric constant analysis the value decreases and in the impedance analysis the resistance increases. Therefore, the peak loss tangent obtained increases with the length of storage time.

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## Conflicts of Interest

The authors declare no conflict of interest.

## Author Contribution

**Bagus Irawan:** Validation, Formal analysis, Investigation, Data curation, Writing – review & editing. **Akhiruddin Maddu:** Validation, Formal analysis, Investigation, Data curation, Supervision, Project administration, Funding acquisition. **Erus Rustami:** Validation, Formal



analysis, Investigation. **Ahmad Sofyan Sulaeman**: Investigation, Writing – review & editing. **Permono Adi Putro**: Writing – original draft, Writing – review & editing.

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