Soluble Solid Content Determination of Limau Madu Using Microwave Sensing Technique at 2.0 -2.6 GHz

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Abstract. Orange is a fruit that essentially made up of a lot of nutrients. It is rich in vitamin C and folate. These are the qualities that must be maintained. Maintaining the qualities of this fruit is necessary. One of the prominent techniques is by measuring the solid soluble content of these local oranges non-destructively. In this study, the monopole sensor has been selected as the medium to find out the sweetness. The relationship of reflection coefficient, S₁₁ and dielectric constant is observed. It is given by coefficient of determination, \( R^2 = 0.9103 \) at 2.4 GHz. The statistics show a promising result of frequency at 2.4GHz.

1. Introduction

The prominent type of orange in Malaysia is citrus suhuiensis. Or well known to the local as limau madu. Sometimes they are being called limau manis due to their sweetness taste. Orange generally is known as important sources of vitamin C and folate [1]. Besides these nutrients, it also has significant amount of antioxidants, such as beta-carotene and flavonoid compounds [2]. These nutrients are simplified in the table below.

| Nutrients          | Content  | Nutrients   | Percentage |
|--------------------|----------|-------------|------------|
| Total fat          | 0.13 g   | Vitamin A   | 1%         |
| Saturated fat      | 0.015 g  | Vitamin C   | 138%       |
| Cholesterol        | 0 mg     | Calcium     | 6%         |
| Sodium             | 1 mg     | Iron        | 2%         |
| Total Carbohydrate | 16.28 g  | Thiamine    | 6%         |
| Dietary Fiber      | 3.4 g    | Folate      | 12%        |
| Sugars             | 11.9 g   |             |            |
| Protein            | 1.4 g    |             |            |
2. Literature review

Dielectric studies gained interest in learning the penetration of electric fields can be utilized in product quality determination non-destructively [3]. Microwave techniques also have been widely used in various studies due to its penetration [4]. The internal quality that is most important for all type of fruits is solid soluble content (mostly sugar), which can be determined only by destructive method. Hence, in order to preserve the condition of the fruit several non-destructive methods are proposed. Microwave measurement is potential in providing information related to permittivity.

Permittivity is the magnitude of dielectric properties which stimulus electromagnetic waves reflection and attenuation within materials[5]. Relative permittivity of a material can be expressed as:

$$\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$$  \hspace{1cm} (1)

An optimal monopole probe is designed to measure the moisture content of mangosteen [4]. This study used the Misra-Blackham model for permittivity calculation. The magnitude of reflection coefficient is highest at 2.45 GHz. As the primary results, this study is able to prove that microwave techniques by open-ended coaxial probe can be effectively used in grading mangosteen non-destructively.

R. Rosman et. al observed the effect on reflect coefficient, $\Gamma$ when an electromagnetic wave is emitted from the coaxial line port through a microwave monopole antenna [6]. On top of it, the idea of antenna monopole is to investigate the sweetness level of Malaysian local oranges non-destructively. The significance of this study is the author designed a unique holder for sample that is made up of nylon.

3. Materials and Methods

This experiment will be conducted into two separate forms. The first experiment is non-destructive, where the reflectance coefficient of each sample is measured at frequencies of 85MHz to 5 GHz. The second experiment is on destructive which will measure pH, brix, acidity and moisture content.

3.1. Sample

There are 40 samples of oranges that are bought at local market. These samples are being kept at temperature of 26°C. They are weighed by an electronic balance. Diameter of the oranges is measured using a digital caliper. These oranges were numbered accordingly and their weight is recorded every day.

3.2. Non-destructive method

3.2.1. Microwave. This method is used to determine the reflection coefficient $S_{11}$ of local oranges fruit. It is done by connecting the cabanR54 reflectometer to a personal computer. The sample is then touched at the end of the pole which connected to the CABAN R54 reflectometer.
3.3. Destructive method. During this method, the brix, acidity, pH and moisture content is identified. Brix and acidity can be obtained by using digital hand-held pocket refractometer (Hybrid PAL-BX|ACID F5 ATAGO). While pH is measured with a Combo pH/EC/TDS/Temperature with Only One Tester (Model HI 98129). The fleshes of oranges were placed back into their skins respectively.

After 24 hours, the dried oranges are weighted. The moisture content (mc%) is then obtained by [7]:

$$mc\% = \frac{m_{initial} - m_{dried}}{m_{initial}} \times 100\%$$

4. Results and Discussion
Initially, it was necessary to investigate the linearity of the relationship between the permittivity of the material and the resulting microwave attenuation. During the process it was essential to ensure the consistency of the results. Figure 3 shows the reflection coefficient of local oranges at different days. As the day increases, the magnitude of $S_{11}$ also increases.
Figure 3. $S_{11}$ is being measured using CABANR54

Figure 4. $\varepsilon_r$ and $S_{11}$ at 2.4 GHz

Figure 5. SSC and $S_{11}$ at 2.4 GHz

Figure 6. Moisture content and $S_{11}$ at 2.4 GHz

Figure 4, 5 and 6 shows the relationship of $\varepsilon_r$, SSC, moisture content (MC) at 2.4 GHz. It is considered a good operating frequency. The linearity and sensitivity of the antenna are determined at 2.4 GHz to test performance of the antenna [8].
Figure 7 and 8 show the percentage of acidity and pH value at different frequency. The frequency is chosen according to the highest value of coefficient determination. Percentage of acidity decreases while pH value is increasing. This can relate to the condition of *limau madu* which in general as it is riper, the fruit is less acidic [2].

| Table 2. Multiple linear regression equations at 2.0 GHz, 2.4 GHz and 2.6 GHz |
|-------------------------------|----------------|-------------|
| Function               | R²       | Frequency |
| εᵣ                      | 5E-13e⁰.3143x | 0.9279     | 2.4 GHz    |
| SSC                    | 3.0288x - 13.18 | 0.6016     | 2.4 GHz    |
| Moisture Content       | -1.6372x + 154.11 | 0.6387     | 2.4 GHz    |
| Acidity                | -6.1766x + 26.065 | 0.5246     | 2.6 GHz    |
| pH                     | 13.007x - 39.803 | 0.6701     | 2.0 GHz    |

Table 2 shows the equation and value of R² at 2.0 GHz, 2.4 GHz and 2.6 GHz. Dielectric constant shows the maximum value of R² at 0.9279.

5. Conclusion

The paper focuses on reflection coefficient, S₁₁. This measurement is obtained open-ended coaxial line probe technology and a network analyzer over the frequency range from 85 MHz to 5 GHz. At increasing S₁₁, permittivity, brix or SSC (mostly contain sugars) and pH also increases. Only percentage of acidity decreases. This proves that as the fruit gain maturity it is less acidic. During the decline in S₁₁, the percentage of moisture content increases. It is observed that at 2.6 GHz, S₁₁ is at the highest magnitude of -42.84 dB. However, it does not comply with other measurements. Averagely, frequency of 2.4 GHz shows an interesting relationship with dielectric constant, solid soluble content and also moisture content. Hence, it can be said that 2.4 GHz is the best operating frequency.

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