Microwave Dielectric and Reflection Analysis on Pure and Adulterated Trigona Honey and Honey Gold

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Abstract. *Honey adulteration is common in the food industry as it provides a cheaper alternative for the user to consume honey. However, it has been abused by industry runners with unsavory practices. As a result, it leads to business fraudulency. Pure honey is very precious due to its powerful health-giving properties. It raises the attention of beekeepers, wholesalers, food manufacturers, retailers, and consumers because this issue has been sensationally reported in mass media. Enforcement of the law is initiated to mitigate the abuse and fraudulency. It also motivates scientists, technologists, and engineers to strive for an effective solution. The microwave sensing method is well known in agricultural products and food. Hence, dielectric and reflection responses are explored to study the potential of the development of an instrumentation system for gauging edible honey. In this work, the dielectric and reflection measurement was conducted using Agilent E8362B PNA Network Analyzer in conjunction with Agilent 85070E Performance Probe from 0.5 GHz to 4.5 GHz. Dielectric and reflection measurements were conducted to investigate dielectric behavior and mismatch impedance due to water and sucrose content in honey. It can be noticed that the dielectric constant, ε', decreases as frequency increases. In the meantime, ε' decreases with the decrement of water and the increment of sucrose content for Honey Gold and Trigona Honey. Meanwhile, for water adulterated Honey Gold and Trigona Honey, the loss factor, ε'' decreases when frequencies increase. In addition, ε'' decreases when the water content is < 36% and < 43% for Honey Gold and Trigona Honey, respectively. It can be found that at 1 GHz to 4 GHz, ε'' increases when sucrose content increases which is applicable for Honey Gold and Trigona Honey. In reflection measurement, the magnitude of reflection coefficient, $|\Gamma|$ decreases when frequency increases for all percentage of water and sucrose content for both kinds of honey. Withal, phase, $-\varphi$ increases as frequency increases for water adulterated honey. $-\varphi$ varies insignificantly when sucrose content increases for sucrose adulterated honey.*

Keywords

Honey, sucrose, water, dielectric, reflection

1. Introduction

Honey is collected from nectar honey by bees. Bees store honey in hives to ensure that food supplies are not interrupted and starved in winter. Bees make honey for bees. However, it is beneficial to humans too. The main compositions of honey are fructose, glucose, water, sucrose, minerals, vitamins, proteins, amino acids, and others [1]. Hence, it is popular among health keepers. Subsequently, pure honey leads to a great and lucrative income for honey industry runners due to its high price in the market. Hence, adulteration of honeys is often used in the food industries to give low honey pricing to people from all walks of life. The adulteration process degrades the precious nutrient and health-giving properties, e.g., anti-inflammatory, and antifungal properties [2]. Some unethical businessmen take this opportunity to manipulate and cheat buyers or consumers by selling adulterated honey to consumers at a high price of authentic honey. The enforcement of an export inspection law and regulation by authorities is insufficient. Therefore, the prevention measure needs to be implemented too. The conventional method of using human sensory reception (five human senses) is subjective and unreliable because the amount of each ingredient in honey varies with bee species, floral sources, geographical origins, and climatic conditions [3]. Also, chemical analyses that need to be conducted in the laboratory are tedious and

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time-consuming. As a result, it drives the advent of a rapid and reliable measurement system to characterize both pure and adulterated honeys.

Microwave dielectric and reflection measurement using an open-ended coaxial dielectric probe is extensively conducted on agricultural products and food [4], [5]. It has been proven to be a reliable method. Several parameters, e.g. pH, soluble content, moisture/water content, viscosity, sweetness, and others, are a function of dielectric properties. Dielectric behavior is due to the reaction of polarization, storage, and dissipation of electromagnetic energy [6]. It can be further elaborated by dielectric constant (ε') and loss factor (ε"). The ε' and ε" vary with the operating frequency. Therefore, the influence of dipolar relaxation and ionic conduction is crucial in determining the dielectric properties of agricultural products and food. In the meantime, dielectric properties also lead to the variation of media impedance. Discontinuity of impedance on the interface between two different media causes the division of electromagnetic energy through reflection and transmission. Hence, reflection analysis is vital to investigate the direct response to the impedance variation (mismatch impedance). Therefore, it justifies the potential of dielectric and reflection analysis in characterizing pure and adulterated honey.

2. Materials and Methods

2.1 Sample Preparation

Pure Honey Gold ('Lebah Asli') honey and Pure Trigona ('Kelulut') honey were provided by Harmony Bee Farm at Sungai Batu Pahat, Kangar, Perlis, Malaysia. Pure Honey Gold ('Lebah Asli') honey and Pure Trigona ('Kelulut') honey has a water content of 18% and 35%, respectively. The standard oven method was applied to determine the water content in honey [7]. The initial water content (W_i) of honey is then calculated using the wet basic formula as follows:

$$W_i(\%) = \frac{W_b - W_a}{W_b} \times 100 \quad (1)$$

where W_b is the weight before dry and W_a is the weight after dry.

In this work, water and sucrose were used to adulterate two types of honey: Honey Gold and Trigona Honey. The selection was because of their high market demand and common in the food industries.

The constant volume of Honey Gold or Trigona Honey in the centrifugal tube is 5 ml. The amount of water added in adulteration varies. The water content (W_c) can be expressed as [8]:

$$W_c(\%) = \frac{M_a \times W_i + M_b}{M_a + M_b} \times 100 \quad (2)$$

where M_a is the mass of 5 ml of honey, M_b is the mass of the added distilled water.

The distilled water with varying amounts is applied to Honey Gold and Trigona Honey to form the required samples. Before dielectric and reflection measurement, the samples were prepared at 23°C–26°C, and the weight of the samples was measured.

Apart from water, sucrose is also applied to the Honey Gold and Trigona Honey for sucrose adulteration. Sucrose is one of the common additives used in the food industry to adulterate honey.

5 ml of honey samples were filled in a centrifugal tube by using the syringe. 10%, 30%, 50%, 70%, 90% and 100% of weight ratio percentage of sucrose syrup were prepared [9]. The sample with 100% is pure sucrose syrup. The expression of weight ratio (W_r) can be written as:

$$W_r(\%) = \frac{M_{sl}}{M_{sv}} \times 100 \quad (3)$$

where the mass of solute (M_{sl}) is sucrose powder and the mass of solvent (M_{sv}) is the distilled water. The sucrose syrups with different weights were applied to pure Honey Gold and Trigona Honey for adulteration. The honey-sucrose mixture samples were placed in a water bath at 35°C for about 20 minutes for dilution. It is necessary to ensure that sucrose is distributed evenly in honey.

2.2 Dielectric Measurement

The complex permittivity ($\varepsilon^* = \varepsilon' - j\varepsilon''$) of samples is measured at room temperature from 1 GHz to 5 GHz using a slim form sensor, as shown in Fig. 1. This slim dielectric sensor is known as Agilent 85070E Performance Probe. Calibration was conducted prior to dielectric measurement. The dielectric calibration media consists of air, short-circuit and 25°C distilled water as shown in Fig. 2. Distilled water is used to verify the performance after calibration. As a precautious measure, the sample and aperture sensor must be in close contact during the dielectric measurement.

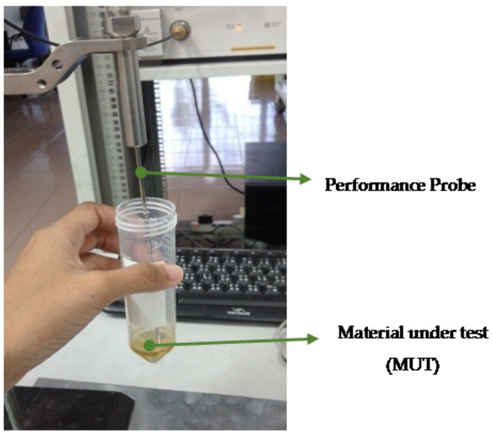

Fig. 1. Sample measurement using PNA.

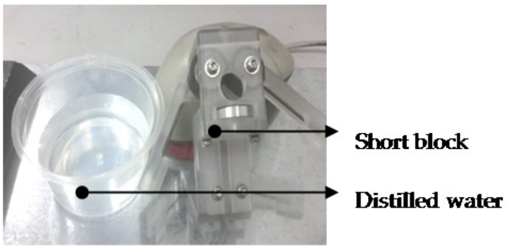

Fig. 2. Calibration kits for dielectric measurement.

2.3 Reflection Measurement

The reflection measurement is conducted using Agilent E8362B PNA Network Analyzer in conjunction with an open-ended coaxial Performance Probe ranging from 0.5 GHz to 4.5 GHz at room temperature. The PNA calibration needs to be conducted before the measurement to remove the systematic error. It could ensure the accuracy of reflection measurement. The constant standard loads method uses Agilent Open, Agilent Short and Agilent 902D Broadband load for PNA calibration. The sample is made to be in contact with the aperture of the open-ended coaxial sensor. The spectrum of the reflection coefficient in terms of magnitude, $|\Gamma|$ and phase, φ can be measured through S-parameter using PNA.

3. Results and Discussion

3.1 Dielectric Measurement of Honeys

The dielectric measurements on Pure Honey Gold, Pure Trigona Honey (Madu Kelulut), and respective water adulterated honey were measured from 1 GHz to 5 GHz. The initial water content for Pure Honey Gold and Pure Trigona Honey was determined, i.e., 18% and 35%, respectively, through the standard oven drying method. The sample measurements were taken three times. This work found that the dielectric behavior for the pure honeys and water adulterated honeys was similar to [8], in which the ε′ of yellow locust flower honey, jujube flower honey, and rape flower honey and their respective water adulterated honeys descended with increasing frequency. The variation of dielectric properties with the water content is due to the behavior of free and bound water contents in honey and food materials [10]. Pure honey has 18% water content, but they are primarily present in the bound water molecules. It can be observed that the ε′ increases with increasing water content. The addition of water to honey results in a decrease in the binding forces relative to ionic movement, thereby increasing the dipole rotation of the free water [11]. Therefore, dielectric polarization is attributed to more bound water molecules than free water molecules. Meanwhile, the free water molecule turns up as the majority in the solution of water adulterated honey when the water content is more than 18%. As a result, Pure Honey Gold (Madu Lebah Asli) has the lowest ε′ due to its lowest water content among the samples under test. It can be observed in Fig. 3 and Fig. 4.

Puranik et al. [12] revealed that the relaxation time is shortened as the water content increases. When water content increases, free water molecules increase too. These water molecules can move freely, and they have high mobility. It leads to a short relaxation time as the inertia of the free water molecule is low. They can easily be polarized by the frequency-dependent applied field. As a result, ε′ of water is the highest as shown in Fig. 3 and Fig. 4. Nevertheless, it does not apply to bound water molecules because their movement is inhibited due to the bonding of these water molecules with other existing polar molecules in honey, e.g., sucrose ($C_{12}H_{22}O_{11}$), fructose ($C_6H_{12}O_6$) and glucose ($C_6H_{12}O_6$). The ε′ of pure and adulterated honey decreased with increasing frequency at different water contents. Theoretically, ε′ increases if full polarization can be conducted by free water molecules. Generally, the free water molecule has high mobility to synchronize with the oscillation of the applied field at high frequencies. At high water content, honey has sufficient free water molecules. When frequency increases, free water molecules do not oscillate synchronously with the applied field, and the orientation polarization of a bipolar water molecule lags at high frequencies. In other words, incomplete polarization takes place. Hence, ε′ decreases when frequency increases. Therefore, it causes a reduction of stored electrical energy due to incomplete polarization. At low water content, there are insufficient free water molecules and bound water molecules bind with other polar molecules. In addition, bound water molecules have high inertia than free water molecules. These factors prevent water molecules from responding to the variation of frequency of the applied field at high frequencies.

Relaxation frequencies between bound and free water molecules are dissimilar in inertia. Hence, relaxation frequencies among bound molecules and free water molecules are dispersed. The difference in terms of inertia increases the asynchronous rotation. Therefore, the losses due to friction among molecules increase significantly. At low water content where the free water molecules are insufficient, dispersion is low because all water molecules are bound and have similar relaxation frequency and inertia. When the operating frequency of the applied field increases, these bound water molecules meet difficulties to polarize synchronously with the operating frequency, especially at high frequencies. As a result, ε″ decreases when frequency increases. It is applicable for water content less than 36% and less than 43% for water adulterated Pure Honey Gold and water adulterated Pure Trigona Honey, respectively. It can be seen in Fig. 5 and Fig. 6. However, ε″ increases with frequency when the water content is more than 36% and more than 43% for water adulterated Pure Honey Gold and water adulterated Pure Trigona Honey, respectively, as shown in Fig. 5 and Fig. 6. For instance, at high water content ($W_c = 80\%$) honey has sufficient free water molecules and a similar ε″ to water. It is because excess free water molecules dominate the solution. Excessive water molecules enhance the asynchrony between bound and free water molecules during polarization. High dispersion of relaxation frequencies and operating frequencies of the

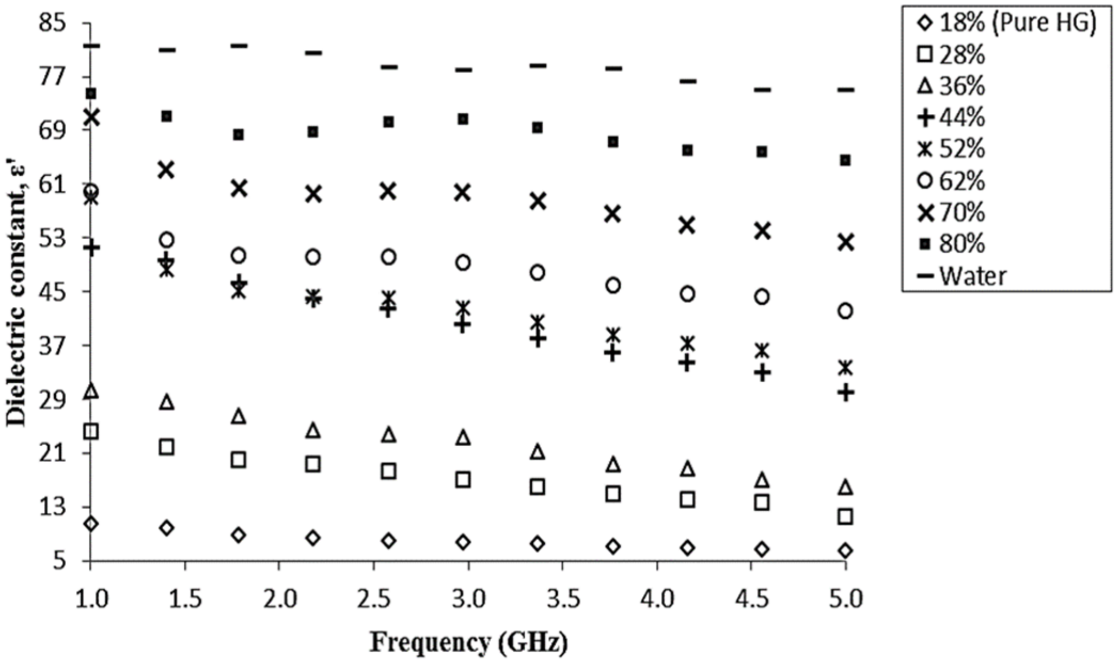

Fig. 3. Dielectric constant, ε′ of pure and water adulterated Honey Gold (HG).

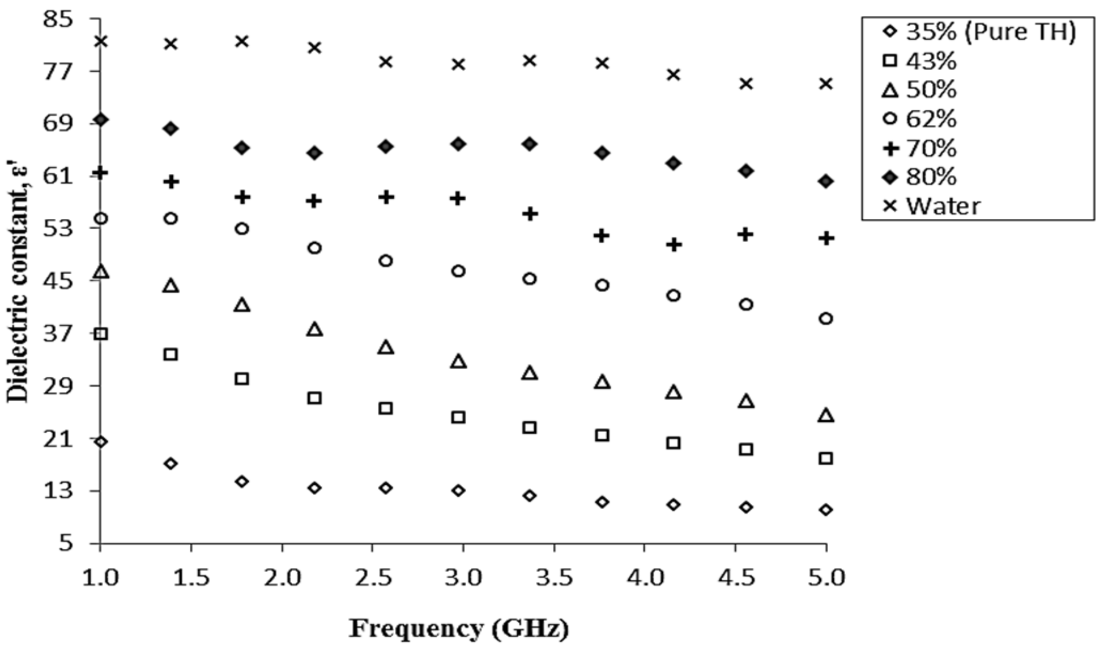

Fig. 4. Dielectric constant, ε′ of pure and water adulterated Trigona Honey (TH).

applied field leads to significant friction loss, especially at the high operating frequency. Dielectric measurements were conducted on honey adulterated with sucrose content for Pure Honey Gold and Pure Trigona Honey from 1 GHz to 5 GHz at room temperature. It can be studied from Fig. 7 to Fig. 10 for ε′ and ε″. Sucrose solution was prepared in a ratio of 20 g of sucrose powder to 20 g of water in a ratio of 1:1 [9]. This prepared sucrose syrup was used for the adulteration of honey.

Sucrose syrup which acts as a control exhibits the lowest measured ε′ for both types of honey, as shown in Fig. 7 and Fig. 8. The dissolved sucrose is bound to water and present as bound molecules because both sucrose molecules ($C_{12}H_{22}O_{11}$) and water molecules (H_2O) are polar. It immobilizes the movement of both molecules during polarization. In addition, the high inertia of the bound molecules increases the difficulty of these bound molecules to orient with time-varying applied field during the orientation polarization, especially at high frequencies. As a result, it shows the lowest ε′ compared with sucrose adulterated honey in different percentages where free sucrose molecules are presented. In the meantime, ε′ decreases when frequency increases. The high inertia causes it to be delayed severely at a higher frequencies where it cannot orient synchronously with the applied field, i.e., the

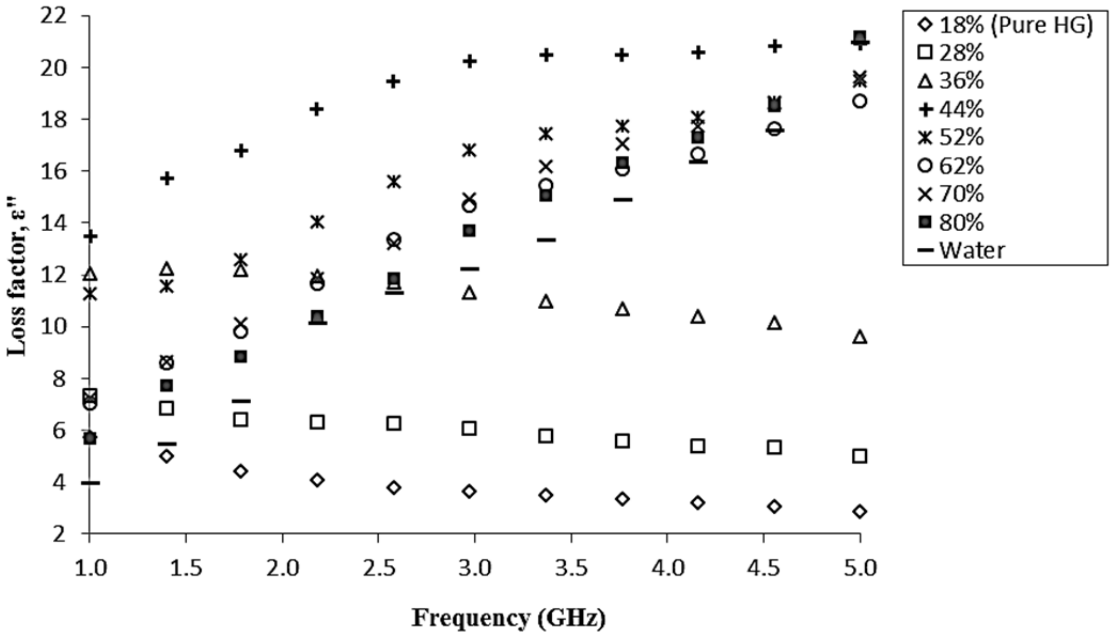

Fig. 5. Loss factor, ε″ of pure and water adulterated Honey Gold (HG).

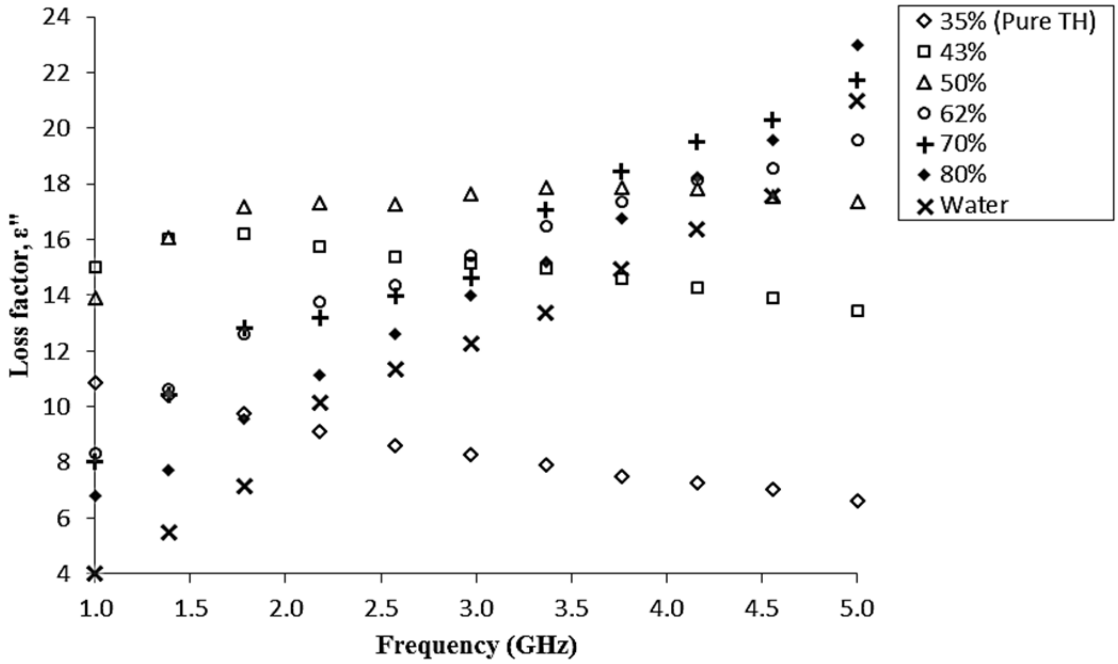

Fig. 6. Loss factor, ε″ of pure and water adulterated Trigona Honey (TH).

incomplete polarization occurs. This dielectric response is in agreement with the findings reported in [8], [9], and [13] for Pure Chinese Honey and Indian Honey, respectively. In [9], it was reported that the ε′ of sucrose syrup is at the lowest level compared to Pure Chinese Honey. Adulterating honey with sucrose syrup affects the dielectric behavior of honey. The dielectric behavior for Pure Honey Gold and Pure Trigona Honey are identical, where the variation of the ε′ range is approximately the same. It implies that Pure Honey Gold and Pure Trigona Honey have significant similarities in terms of their ingredients. In addition, the frequency response of ε′ due to water and sucrose adulterated honey seems similar, where ε′ is linearly decreased over frequency. When sucrose is saturated in solution (90% sucrose adulterated honey), ε′ is similar to the solution of sucrose. Sucrose molecules become dominant in both 90% sucrose adulterated honey.

Likewise, it can be noticed that the frequency response of ε″ for both types of honey is within a similar range too. It is consistent with the frequency response of ε′ as shown in Fig. 7 and Fig. 8. Both types of honey decrease when frequency increases for all ratios of adulterated honey. It is dissimilar to ε″ presented by water adulterated honey as shown in Fig. 9 and Fig. 10. The high dipole moment of water molecules in water adulterated honey

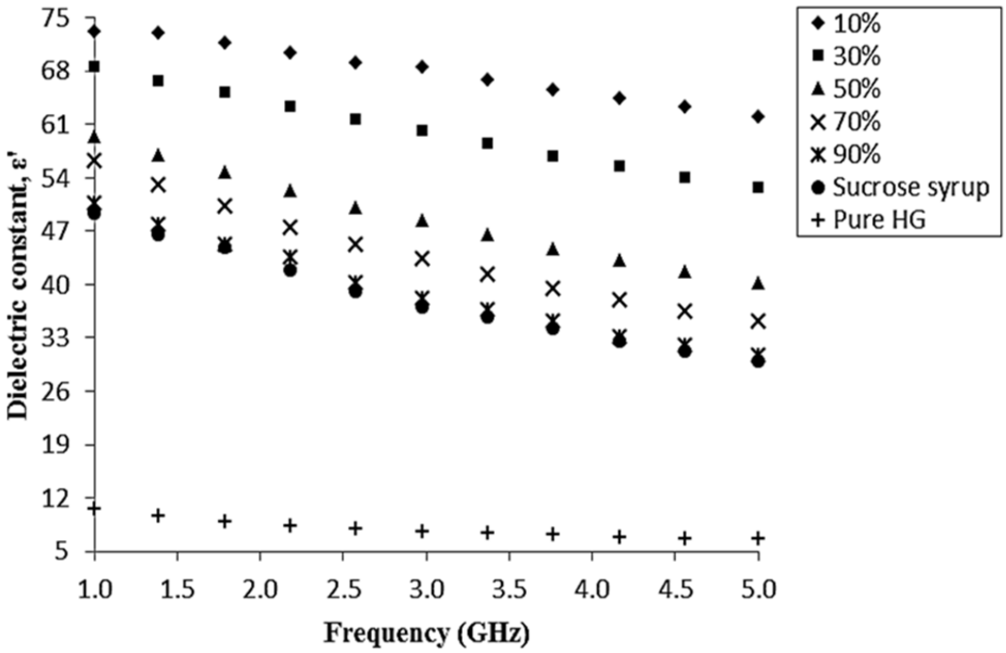

Fig. 7. Dielectric constant, ε′ of pure and sucrose adulterated Honey Gold (HG).

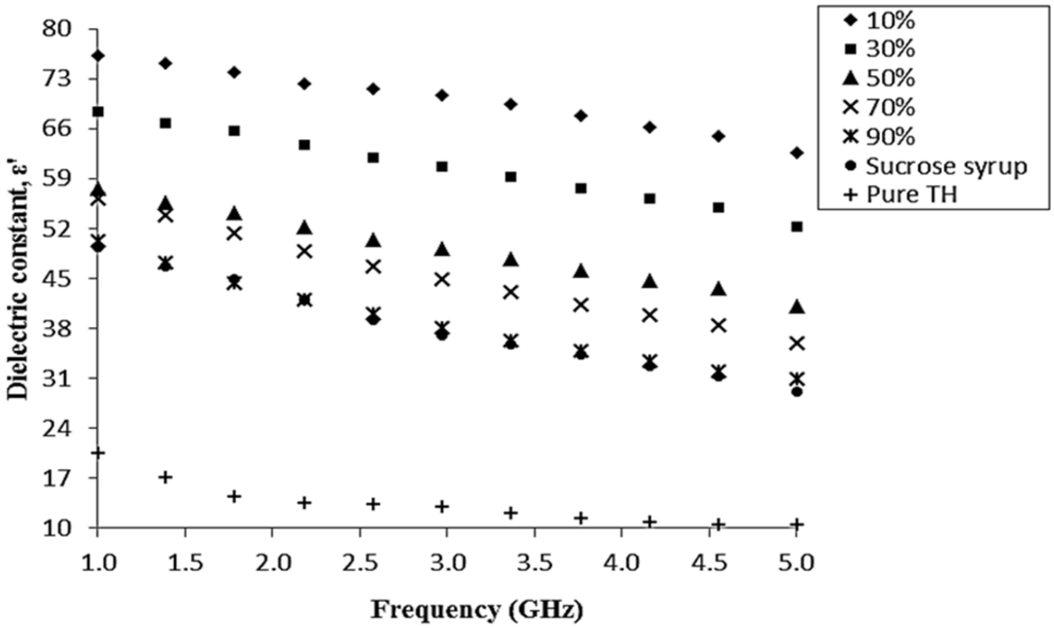

Fig. 8. Dielectric constant, ε′ of pure and sucrose adulterated Trigona Honey (TH).

with low water content is strongly bound with the existing fructose, sucrose and glucose. It causes severe dispersion of relaxation frequencies among molecules. Subsequently, the frictions among the bound and free molecules are heightened. As a result, ε″ increases at low water content when frequency increases as discussed previously. However, sucrose is a polar molecule with a lower dipole moment than water. The weak bind of sucrose with polar molecules in honey leads to insignificant dispersion of relaxation frequencies in honey. It provides a small dipole moment due to the short separation between the molecule chain's electropositive end and electronegative end. Weak binding between sucrose and other polar molecules is due to a small dipole moment that attributes to a smaller distance between the electropositive end and electronegative end in the molecule chain compared with the water molecule (H_2O) or a smaller change of dipole moment. This phenomenon causes weak inertia that insignificantly changes the relaxation frequency of bound molecules. Thus, the addition of low sucrose content, e.g., 10% sucrose syrup (2 g sucrose dissolves in 20 g distilled water), still exhibits ascending variation with increasing frequency. On the other hand, ε″ for all percentages of sucrose adulteration increased as sucrose content increased from 1 GHz to 4 GHz. Nevertheless, ε″ for all percentages of adulteration decreased as sucrose content increased beyond 4 GHz.

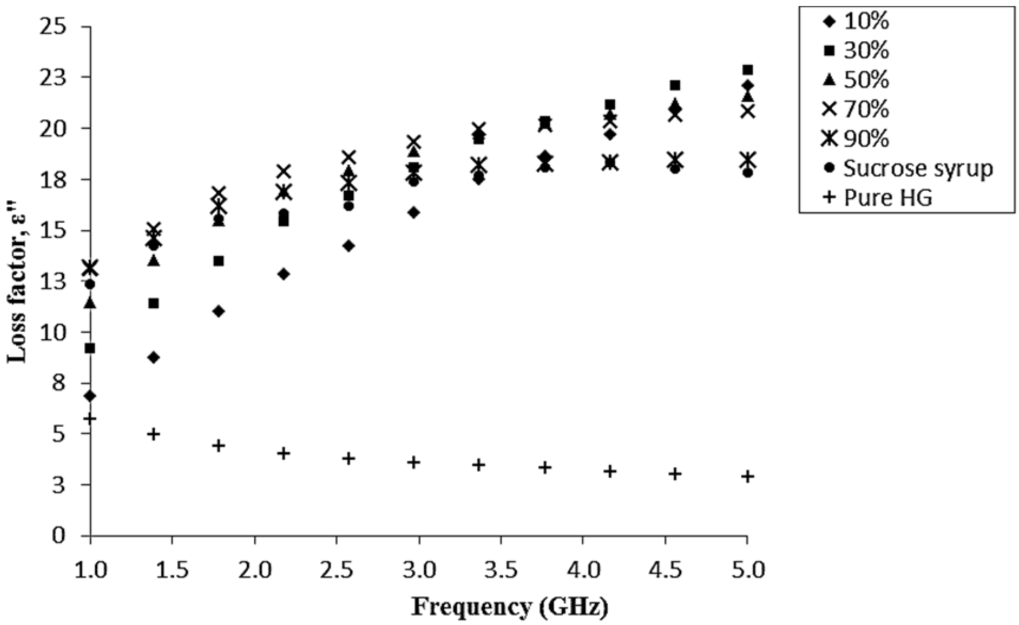

Fig. 9. Loss factor, ε″ of pure and sucrose adulterated Honey Gold (HG).

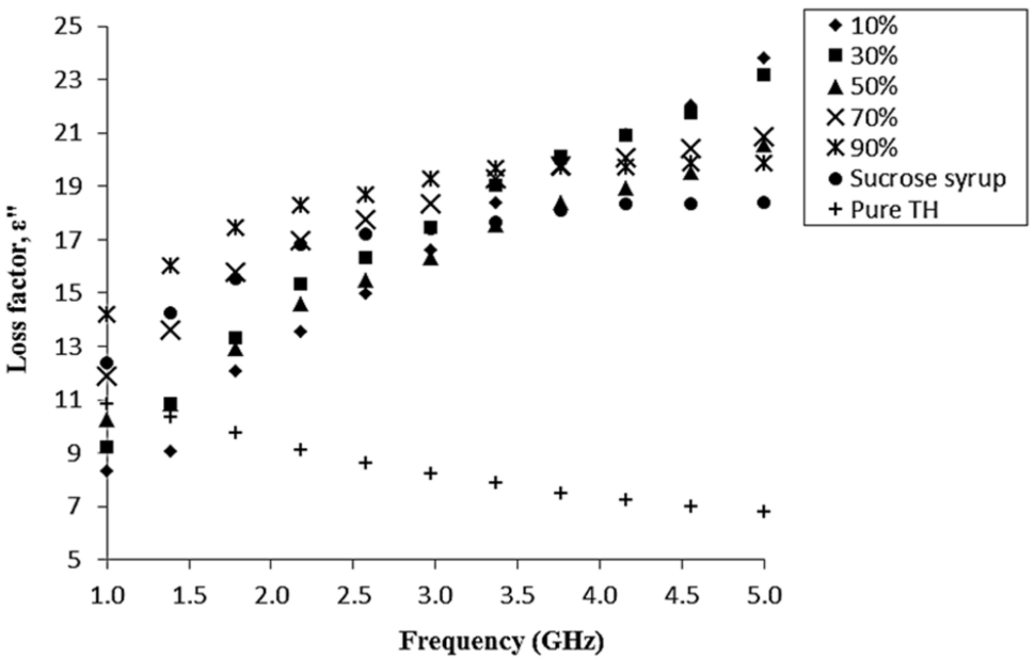

Fig. 10. Loss factor, ε″ of pure and sucrose adulterated Trigona Honey (TH).

At low sugar content and frequency (1 GHz to 4 GHz), sucrose molecules are bound with other polar molecules (e.g., fructose and glucose), leading to dispersion of frequency among molecules in the adulterated honey. These dispersive frequencies cause polarization occurs asynchronously. This asynchrony of polarization results in friction among molecules that becomes vigorous when the frequency of the applied field increases. It is because the increment of the applied field frequency increases the friction rate. Subsequently, the energy loss due to friction is heightened, leading to an increment in ε″. At low frequency, all polar molecules in honey can still be polarized consistently with the applied field, even though sucrose content increases. However, a sufficient number of sucrose molecules will further enhance friction loss with other molecules due to more participation of sucrose molecules in dissipating energy through friction and collision. As a result, the increment of sucrose content leads to an increment of ε″ for frequencies ranging from 1 GHz to 4 GHz. When the frequency is beyond 4 GHz, the friction rate among polar molecules becomes vigorous. However, inertia also increases among polar molecules to conduct high-frequency polarization. As a result, ε′ decreases when sucrose content increases. Subsequently, the reluctance of these polar molecules to conduct polarization also leads to a low friction rate. Likewise, ε″ decreases when sucrose content increases for a frequency range of more than 4 GHz. Expectedly, 90% of sucrose adulterated Honey

Gold and Trigona Honey exhibit similar ε″ with sucrose syrup. This is because the sucrose molecules in 90% of sucrose adulterated honey are saturated.

In Pure Honey Gold, the majority component is fructose. The molar mass of fructose is high compared with the water molecule, i.e. 180 g/mol. Hence, the inertia of the fructose molecule is high, resulting in higher polarization reluctance. Subsequently, ε′ is lowest due to its molar mass and the highest percentage of fructose composition (30.91%–44.26%). Meanwhile, Pure Trigona Honey presents lower ε′ and ε″ than its sucrose adulterated Trigona Honey. It might be due to the presence of majority phenolic acid in Pure Trigona Honey [14]. Phenolic acid has the smallest dipole moment (1.56 Debye) [15] among fructose, sucrose and water. Hence, it provides the lowest level of ε′ as shown in Fig. 8.

3.2 Reflection Measurement of Honeys

In Fig. 11, the |Γ| of Pure Honey Gold declines when frequency increases for all percentage of water content in honey. It can be justified by the frequency response of ε′ as shown in Fig. 3. The impedance of the load, i.e. honey can be defined by Z_L as in (4).

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}. \tag{4}$$

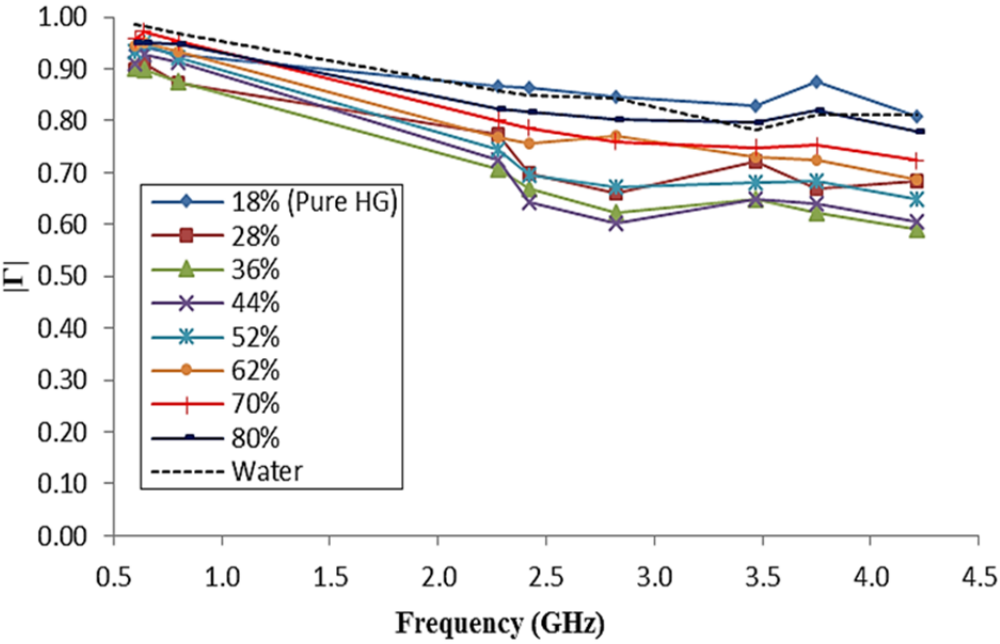

Fig. 11. The variation of measured |Γ| for pure and water adulterated Honey Gold (HG).

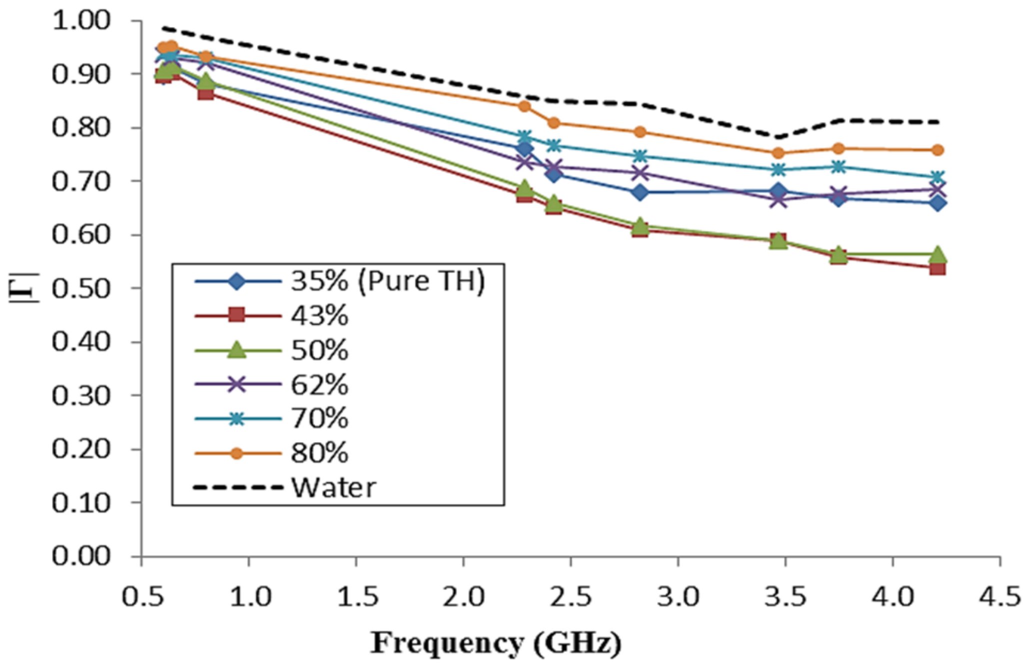

Fig. 12. The variation of measured |Γ| for pure and water adulterated Trigona Honey (TH).

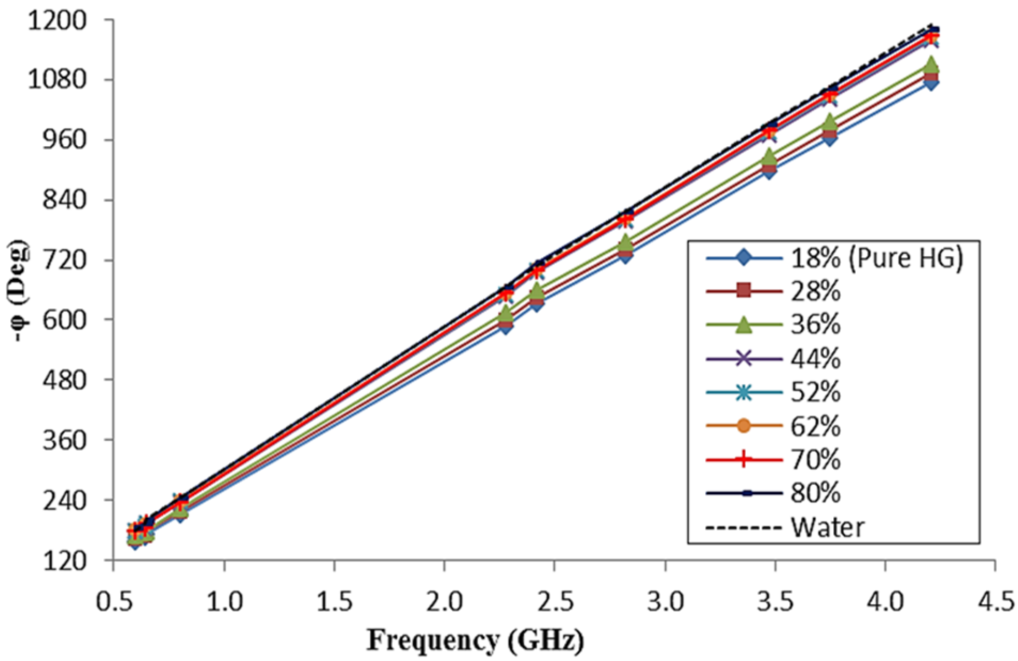

Fig. 13. Negative phase, $-\varphi$ of pure and water adulterated Honey Gold (HG) over frequency.

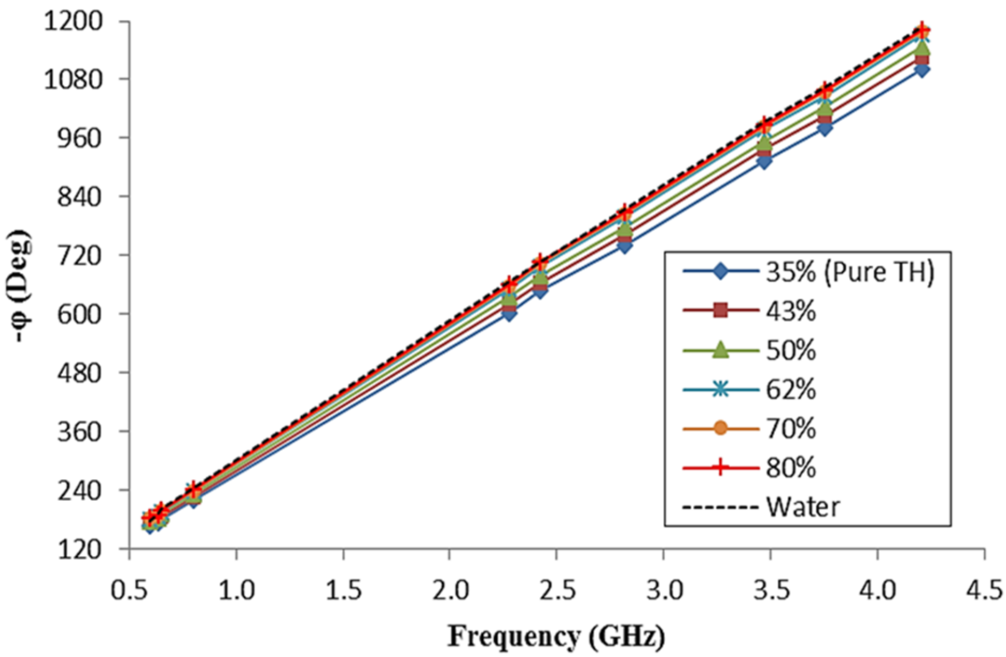

Fig. 14. Negative phase, $-\varphi$ of pure and water adulterated Trigona Honey (TH) over frequency.

If mismatch impedance ($Z_L - Z_0$) decreases, Γ decreases. When an electromagnetic wave propagates encountering media with different dielectric properties, the energy of the electromagnetic wave is divided through reflection and transmission at the interface between two media (coaxial line and honey). The reflection can be depicted by the reflection coefficient. The coefficient is high when the mismatch impedance between media becomes significant. The mismatch impedance is defined by ($Z_L - Z_0$) in (4). In other words, the ε′ with frequency as shown in Fig. 3 is proportional to impedance mismatch. The impedance mismatch decreases because the capacitive impedance of water adulterated honey declines. As a result, it can be noticed that |Γ| decreases when frequency increases as shown in Fig. 11.

The |Γ| of Pure Honey Gold (18%) is the highest compared with water adulterated samples (Fig. 11). Meanwhile, 80% of water adulterated Trigona Honey exhibit the highest |Γ|, as shown in Fig. 12. Pure Honey Gold exhibits high ε′ and low ε″ compared with all percentage of water adulterated Honey Gold. It implies a low loss tangent. This phenomenon results in significant reflection due to the conservation of energy. The energy loss due to transmission is not taken into account because a metal plate back is put under the sample in the test tube during measurement. In addition, a lower loss tangent of Pure Honey Gold than water adulterated honey also suggests that Pure Honey Gold is lossless. The absorption in the medium can be omitted since more electromagnetic energy is reflected. It leads to the highest |Γ| as shown in Fig. 11.

Pure Honey Gold has a contrary response where the least water content of Pure Honey Gold exhibits a similar response of |Γ| as water (Fig. 11). Pure water and 80% water adulterated Honey Gold agree with each other attributed to a similar mismatch impedance between pure water and 80% water adulterated Honey Gold. It is different from the finding in Fig. 12, where 80% of water adulterated Trigona Honey is consistent with water in terms of |Γ|. It seems that Pure Honey Gold has better agreement with water in terms of impedance. Nevertheless, multiple reflections lead to a significant difference of ε′ between Pure Honey Gold and water, as shown in Fig. 3. It might be due to the presence of inhomogeneity in Pure Honey Gold that led to multiple reflections. Pure Honey Gold has the least water content (18% W_c) compared with Pure Trigona Honey (35% W_c). Less water molecule causes high viscosity. It might result in the non-uniform dispersion of fructose, sucrose and glucose molecules in the sample. Low homogeneity is hard to be achieved.

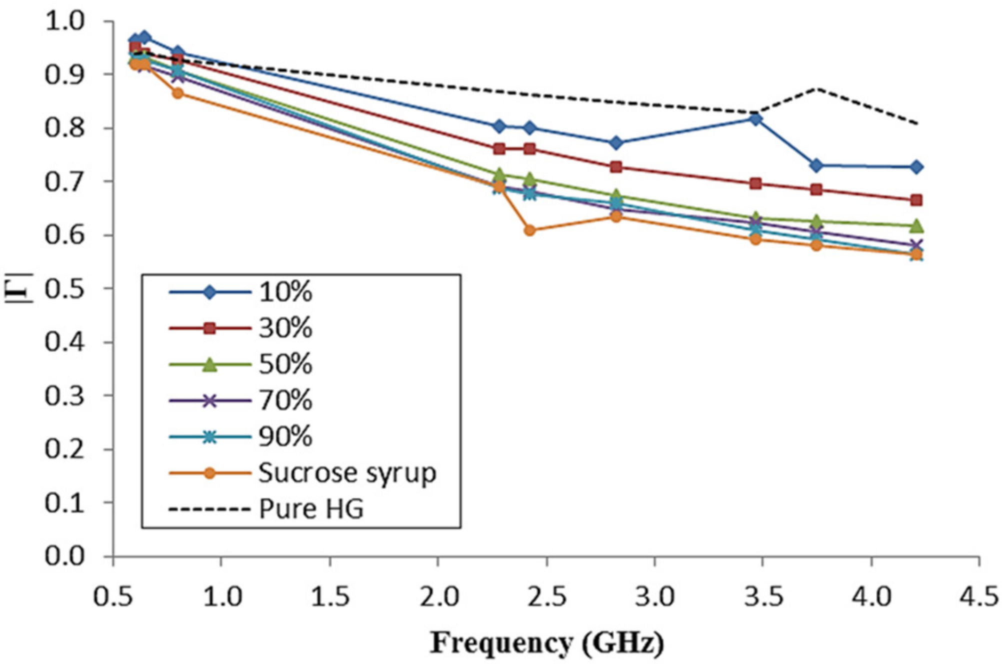

Fig. 15. Measured |Γ| of pure and sucrose adulterated Honey Gold (HG) over frequency.

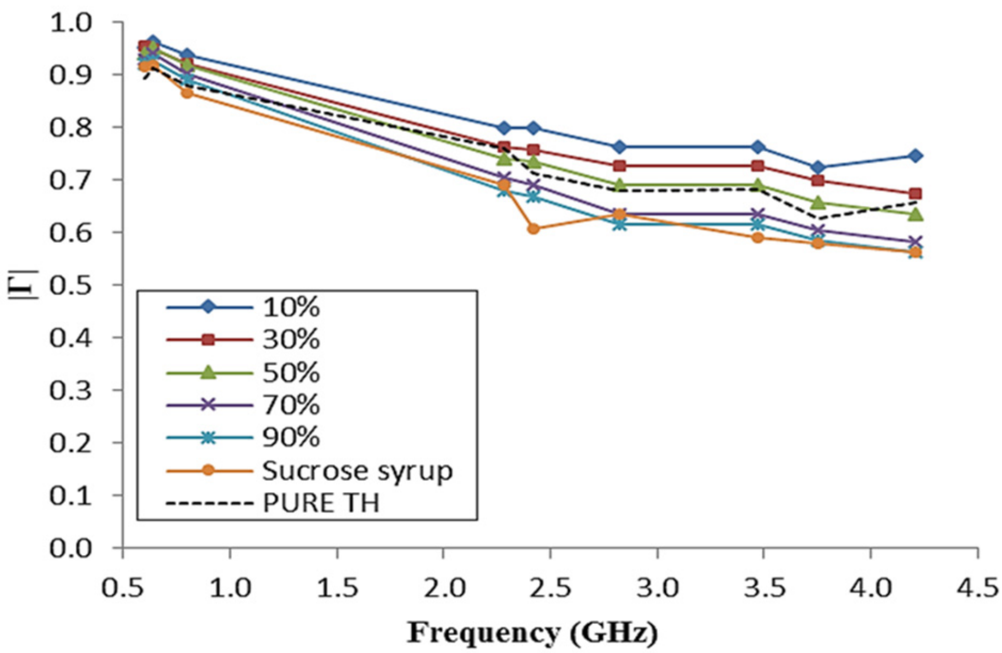

Fig. 16. Measured |Γ| of pure and sucrose adulterated Trigona Honey (TH) over frequency.

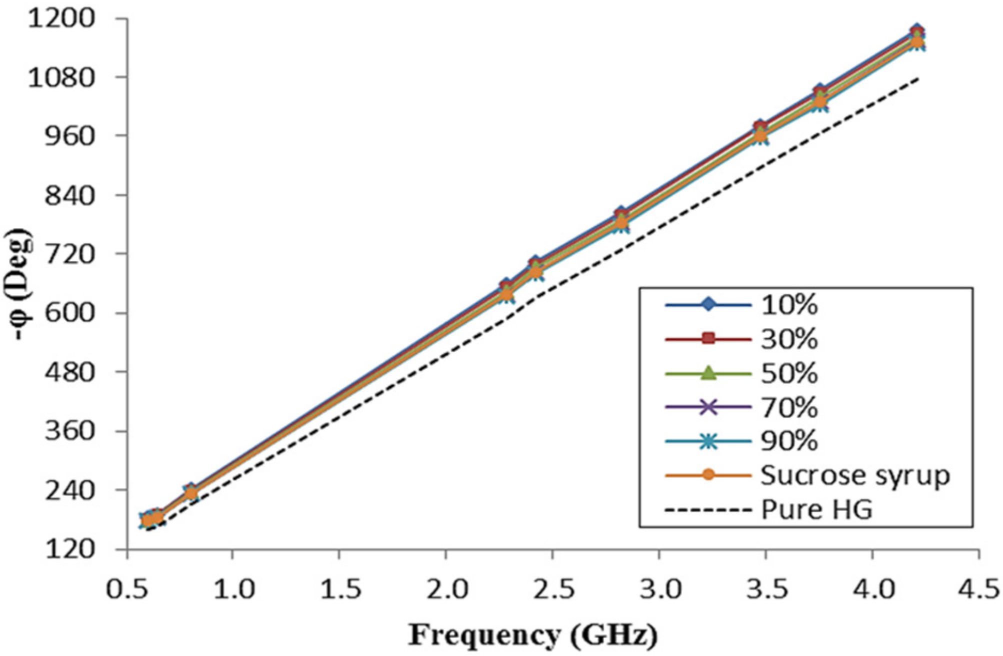

Fig. 17. Measured negative phase, $-\varphi$ of pure and sucrose adulterated Honey Gold (HG) over frequency.

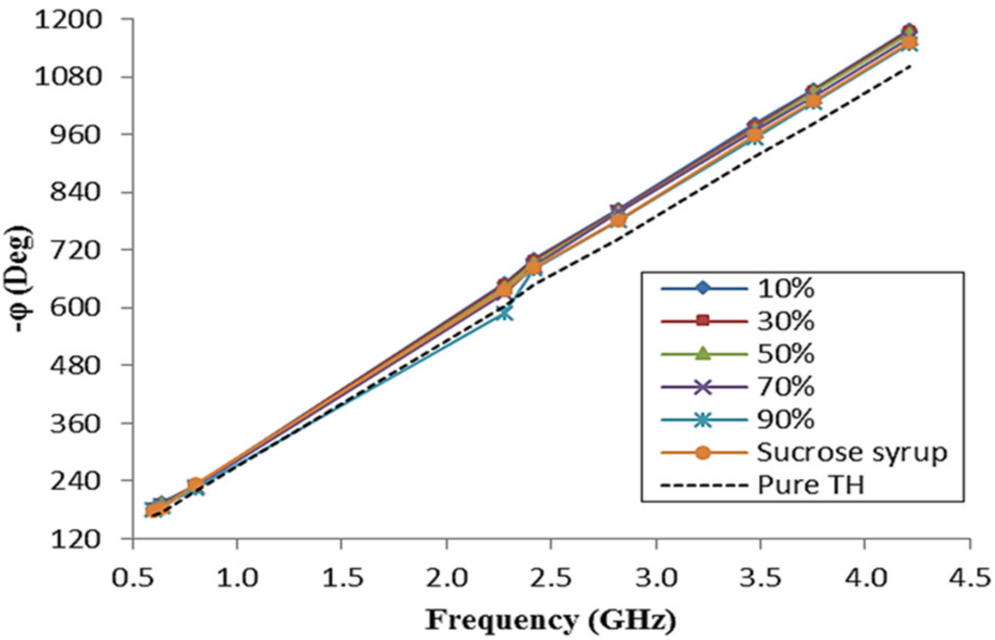

Fig. 18. Measured negative phase, $-\varphi$ of pure and sucrose adulterated Trigona Honey (TH) over frequency.

Previously, it was mentioned that Pure Trigona Honey (35% W_c) has a dissimilar frequency response of $|\Gamma|$ compared with Pure Honey Gold, even though Pure Trigona Honey has lower ε' than its water adulterated samples, as shown in Fig. 4. It is because the minerals present in Pure Trigona Honey, i.e. Calcium, Potassium, Sodium, Magnesium, Zinc, and others [16] are significant magnetic. These minerals are substantially available in Pure Trigona Honey. The presence of water molecules (diamagnetic substance) in water adulterated Pure Trigona Honey could result in the mitigation of the magnetic effect [17]. Pure Trigona Honey with the lowest ε' does not show the highest $|\Gamma|$. Pure Trigona Honey with 35% of W_c has similar $|\Gamma|$ with 50% and 70% water adulterated Trigona Honey, respectively. $|\Gamma|$ of water adulterated Pure Trigona Honey with W_c 43% decreases over frequency. The frequency response of $|\Gamma|$ for water adulterated Pure Trigona Honey which is > 43% is in line with the dielectric response.

Figure 13 and Figure 14 show the frequency response of negative phase, $-\varphi$ for Honey Gold and Trigona Honey, respectively. As seen from the figures, the negative phase, $-\varphi$ rises with increasing frequency. It can be found that $-\varphi$ of water is the highest over frequency among water adulterated Honey Gold and Trigona Honey. ε' and ε'' in Fig. 3 to Fig. 6 are high for water attributed to the time delay between the incident field and reflected field. It suggests that polarization and energy loss occur. Thus, time delay increases and leads to an increment of $-\varphi$. In the meantime, tan δ increases with increasing frequency. In other words, the energy loss increases with frequency, which indicates that the time delay between the incident and reflected waves increases. The energy loss is most probably due to collision and friction. Time delay is directly proportional to lagging phase shift which is represented by $-\varphi$ in Fig. 13 and Fig. 14. Trigona Honey exhibits similar dielectric behavior and tan δ to Honey Gold.

Honey Gold and Trigona Honey contain sucrose, fructose and glucose. Sucrose has a lower nutrition value than fructose and glucose. Therefore, many food industry runners tend to use sucrose in honey adulteration because it is productive and cheap. Nevertheless, sucrose is one of the components that could lead to diabetes. Glycaemic Index (GI) of sucrose exceeds the approved range [18].

The measured $|\Gamma|$ for 35%–85% of sucrose adulterated Honey Gold and Trigona Honey as well as water over frequency can be seen in Fig. 15 and Fig. 16. The dielectric and reflection measurement were carried out at room temperature. Both Honey Gold and Trigona Honey indicate that an increase in frequency leads to a decrease in $|\Gamma|$. Meanwhile, an increase in sucrose content causes a decrease in $|\Gamma|$. $|\Gamma|$ of Pure Honey Gold is higher than sucrose adulterated Honey Gold. Nevertheless, Pure Honey Gold exhibits the smallest ε' and ε'' due to the high inertia of bound fructose (180 grams/mol), water (18 grams/mol), and sucrose (342 grams/mol) molecules. It can be surmised that mismatch impedance is very severe at the interface between Pure Honey Gold and the coaxial line. The difference between capacitive impedance of Pure Honey Gold (Z_L) and characteristic impedance of coaxial line (Z_0) result in the lowest ε' and ε''. Bound molecules are hardly polarized, thereby reducing the rate of energy dissipation. The 10% sucrose content used in adulterated Honey Gold leads to the presence of free molecules that are susceptible to polarization. Hence, $|\Gamma|$ of sucrose adulterated Honey Gold is lesser than Pure Honey Gold because impedance mismatch between Pure Honey Gold and sucrose adulterated Honey Gold is decreased. A similar finding can be found for sucrose content > 10% that was used for adulteration. In Fig. 4, 10% of sucrose adulterated Trigona Honey can raise $|\Gamma|$ with a high gradient due to the presence of minerals in Trigona Honey. Sucrose has the same magnetic properties as water. Water and sucrose can be considered diamagnetic substances [19]. These diamagnetic properties of sucrose tend to decline the magnetic effect in Trigona Honey.

Overall, unnoticeable variation of negative phase, $-\varphi$ of sucrose adulterated Honey Gold (Fig. 17) and Trigona Honey (Fig. 18) are observed. It is due to the increment of applied sucrose content in the adulteration of both Honey Gold and Trigona Honey. Sucrose has high inertia because the mass of glucose, water and fructose is high. Hence, the mechanism of polarization, friction and collision for sucrose is mitigated. On the other hand, $-\varphi$ exhibits lesser sensitivity towards the presence of sucrose content than water content because sucrose is heavier in mass. The influence of sucrose content on phase is minor. Likewise, tan δ increases with frequency, which leads to an increase in time delay. In other words, an increment of tan δ leads to an increment of $-\varphi$.

4. Conclusion

Pure Honey Gold and Pure Trigona Honey were adulterated using water and sucrose. Dielectric and reflection measurements on water and sucrose adulterated Honey Gold and Trigona Honey were conducted. Reflection coefficient in magnitude ($|\Gamma|$) and phase (φ), dielectric constant (ε'), and loss factor (ε'') of pure and adulterated honeys were measured using Agilent 85070E Performance Probe in conjunction with Agilent E8362B PNA Network Analyzer. The frequency responses of dielectric properties and reflection coefficients were investigated for different percentages of water and sucrose contents. The ε' increased for both honeys when water for adulteration was increased. On the contrary, ε' decreases for both honeys when the sucrose content in the adulteration increases. Loss factor, ε'' varies cubically for both honeys when water content used in adulteration increases. Meanwhile, ε'' increased with sucrose content used in adulteration when the frequencies were less than 4 GHz for both honeys. $|\Gamma|$ and $-\varphi$ of both honeys increase as the water content increases. On the contrary, $|\Gamma|$ and $-\varphi$ decreased for both honeys when the sucrose content increased.

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