1. Wittawat WASUSATHIEN[1], 2. Chanchai THONGSOPA[1], 3. Samran SANTALUNAI[1], 4. Thanaset THOSDEEKORAPHAT[1], 5. Nuchanart SANTALUNAI[2]

Suranaree University of Technology (1), Rajamangala University of Technology Isan (2)
ORCID: ORCID: 1. 0009-0004-3269-7479; 2. 0000-0003-2534-4398; 3. 0000-0001-6777-2230; 4. 0000-0001-5976-2438
5. 0000-0002-5598-1534;

doi:10.15199/48.2024.02.37

Measurement of Dielectric Properties in Mixtures of Various Rice Cultivars for Purpose of Detecting Contamination in Industry

***Abstract**. This study investigates the dielectric properties of diverse mixtures of rice cultivars as a means to detect potential contamination in the rice industry. Experiments were conducted within the frequency range of 0.2-1 GHz, employing a 20% concentration saline solution at a rice-to-saline ratio of 1:1.5. This technique effectively accentuated differences in dielectric properties. Precise measurements were carried out using the open-ended coaxial probe technique. Jasmine 105 rice was selected as the reference rice for adulteration testing, with adulteration levels ranging from 10% to 50% using other rice varieties, including Hompathum, Gorkor 79, Phitsanulok, and Saohai. The experiment consisted of two phases. The first phase involved measuring pure ground rice samples to evaluate the fundamental dielectric properties of the raw material. In the second phase, adulterated rice samples mixed with saline were measured to explore the potential for detecting adulteration based on dielectric property variations compared to the reference rice (Jasmine 105). Results indicated that conducting measurements without the saline solution resulted in minimal differences in dielectric constant and dielectric loss factor properties, posing challenges in distinguishing mixed rice samples. However, the addition of the saline solution revealed more pronounced differences in properties, particularly in terms of dielectric loss and at lower frequencies, as the mixing ratios increased. These findings have significant implications for rice adulteration detection techniques, especially when combined with artificial intelligence methods, and highlight the potential for utilizing dielectric property measurements in the agricultural industry. They also indicate possibilities for future advancements in this technology.*

Streszczenie.** W badaniu tym zbadano właściwości dielektryczne różnych mieszanek odmian ryżu w celu wykrycia potencjalnego zanieczyszczenia w przemyśle ryżowym. Doświadczenia przeprowadzono w zakresie częstotliwości 0,2-1 GHz, stosując 20% roztwór soli fizjologicznej w stosunku ryżu do soli fizjologicznej 1:1,5. Technika ta skutecznie uwypukliła różnice we właściwościach dielektrycznych. Precyzyjne pomiary przeprowadzono przy użyciu techniki sondy współosiowej z otwartym końcem. Ryż Jasmine 105 został wybrany jako ryż referencyjny do testów pod kątem zafałszowań, przy czym poziom zafałszowania wahał się od 10% do 50% w przypadku innych odmian ryżu, w tym Hompathum, Gorkor 79, Phitsanulok i Saohai. Eksperyment składał się z dwóch faz. Pierwsza faza obejmowała pomiar próbek czystego mielonego ryżu w celu oceny podstawowych właściwości dielektrycznych surowca. W drugiej fazie zmierzono próbki zafałszowanego ryżu zmieszanego z solą fizjologiczną, aby zbadać możliwość wykrycia zafałszowań na podstawie zmian właściwości dielektrycznych w porównaniu z ryżem referencyjnym (Jasmine 105). Wyniki wykazały, że prowadzenie pomiarów bez roztworu soli spowodowało minimalne różnice we właściwościach stałej dielektrycznej i współczynniku strat dielektrycznych, co stwarzało wyzwania w rozróżnianiu mieszanych próbek ryżu. Jednakże dodanie roztworu soli ujawniło wyraźniejsze różnice we właściwościach, szczególnie pod względem strat dielektrycznych i przy niższych częstotliwościach, w miarę zwiększania się proporcji mieszania. Odkrycia te mają znaczące implikacje dla technik wykrywania zafałszowań ryżu, zwłaszcza w połączeniu z metodami sztucznej inteligencji, i podkreślają potencjał wykorzystania pomiarów właściwości dielektrycznych w przemyśle rolniczym. Wskazują także możliwości przyszłego rozwoju tej technologii.* (Pomiar właściwości dielektrycznych mieszanin różnych odmian ryżu w celu wykrywania zanieczyszczeń w przemyśle***)

Keywords: Dielectric properties, Rice, Saline
Słowa kluczowe: Właściwości dielektryczne, ryż, sól fizjologiczna

1. Introduction

Rice is one of the most important food crops in the world and is a staple food for more than half of the global population. It is grown in over 100 countries and is the second most produced cereal crop after corn. The rice industry has a significant impact on the global economy, with rice exports and imports amounting to billions of dollars each year. Overall, the rice industry is a complex and dynamic field that plays a crucial role in feeding the world's population and driving economic growth.

Currently, it has been discovered that the rice industry is experiencing financial gain through the adulteration of rice [1, 2]. This practice involves combining pure rice with less expensive grains or other materials to increase volume and enhance financial gain. This can happen at any stage of the supply chain, from the farmer to the retailer. Some common examples of adulterants include broken grains of rice and cereals. Adulteration can occur with any type of rice, including different varieties such as basmati, jasmine, and wild rice. It can be difficult to detect and can have serious health implications for those who consume it.

Adulteration of rice can have a variety of negative effects on both consumers and the industry. From a health perspective, consuming adulterated rice can lead to various health issues. Adulterants can contain harmful chemicals and toxins that can cause serious health problems if consumed in large quantities. Additionally, mixing different varieties of rice can also lead to allergic reactions in some individuals. From an economic perspective, adulteration can have a negative impact on the rice industry. Adulteration can lead to a decrease in consumer trust and confidence in the industry, which can result in decreased sales and revenue. Additionally, adulteration can lead to increased costs for the industry, as companies may need to spend more money on testing and quality control measures to ensure the purity of their products. Additionally, adulteration can lead to a decrease in the demand for high-quality, pure rice, which can further harm the livelihoods of farmers. Overall, adulteration of rice can have serious negative consequences for both consumers and the industry, and it is important for measures to be taken to prevent and detect adulteration to ensure the purity and safety of rice products.

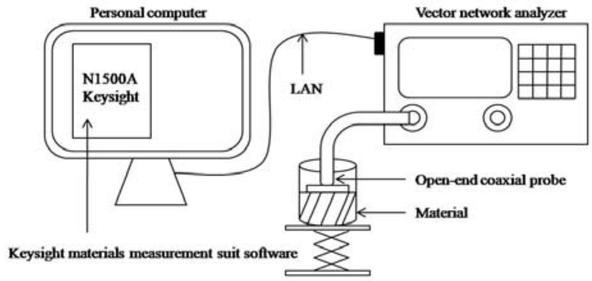
The normally techniques used to inspect adulterated rice are iodine testing and DNA (deoxyribonucleic acid) testing. The disadvantage of iodine testing is unable to inspect the rice that have similar amylose, due to Iodine testing is used to examine an amylose content in rice [3] and shows it in color. The DNA testing (DNA test is used to examine rice species from DNA [4, 5]) is the only technique that has the highest precision and is used to inspect rice before exporting. The disadvantage of DNA testing is taking a long time to inspect and expensive. There are also other techniques used in adulterated rice inspection such as image processing, R-CNN (Mark Regional Convolution Neuron Network) or dielectric measurement technique, but they are in under study which is gaining a lot of attention.

Dielectric measurement techniques, which are utilized to analyze the electrical properties of materials, such as Soil [6], Fungi [7], Rice [8] and Freshwater fishes [9], can be employed to differentiate the characteristics of grains, including rice. A prevalent dielectric measurement technique is dielectric spectroscopy, which entails measuring the dielectric constant and loss tangent of a material at various frequencies. These measurements can furnish insights regarding the structure and composition of the material and can be utilized to distinguish between different varieties of rice and detect impurities or adulterants. The utilization of dielectric measurement techniques can be non-destructive, expeditious, and can detect impurities at a very low level. They are commonly employed in the food industry, agriculture, and various other fields to analyze grains, seeds, and other materials. In conclusion, dielectric measurement techniques are potent tools that can be employed to differentiate the properties of grains and detect impurities or adulterants. These techniques can aid in ensuring the quality and purity of rice products and can also be utilized to enhance crop yields and grain storage.

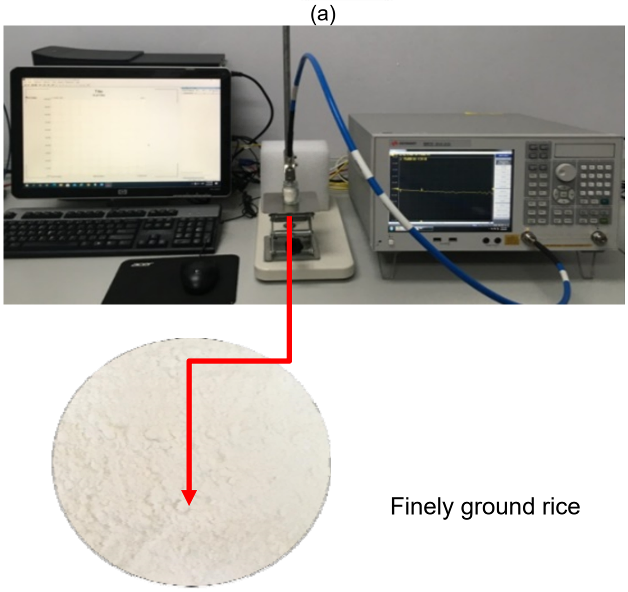
Dielectric is one of the fundamental parameters that define the electrical insulating ability of materials, as well as an indicator that how much energy is stored and dissipated in the materials [10]. Dielectric properties (ε) consist of dielectric constant (ε'') and dielectric loss factor (ε'') [11]. When dielectric materials are in electric field, they will be polarized. Dielectric polarization of material has 3 types as Ionic, Dipolar and Electronic polarization [12]. Ionic polarization occurs in the materials with an ionic bond structure, such as NaCl, an electric field will pull an ion in the structure until the bond length has changed, resulting in dipole moment. Dipolar polarization occurs in the materials with permanent dipole moment, such as H_2O, which dipole will be vibrated when materials are in an electric field, resulting in dipole moment. Electronic polarization occurs in all of materials, electric field is going to pull ions apart until dipole moment is occurred. Dipole moment from polarization can be used to calculate the polarizability and dielectric properties of materials [13].

Dielectric properties play a crucial role in electrical engineering as they are essential for characterizing the insulation properties of devices and capacitors. Moreover, these properties are employed in the characterization of raw materials in various fields such as agriculture, engineering, and medicine. For instance, they are used to analyze plant seeds, insects, and fruit juice, utilizing radio frequency (RF) and microwave frequencies [14-16]. Furthermore, dielectric properties find application in dielectric heating technology [17-20] or treatment technology [21]. Because water is the main component, this makes it well polarized in this frequency range [22, 23]. Therefore, it is important to know dielectric properties of materials before operating in an electric field. There are several techniques for dielectric property measurement, including parallel plate technique, which is suitable for low frequencies and small materials but it requires preparation of a fit on the copper plate [24], free space technique, which is suitable for high frequencies and no need to shape material surface [25], and open-end coaxial probe technique, which is suitable for RF and microwave frequency range but the material surface should be flatness or liquid [26, 27], therefore Open-end coaxial probe technique is suitable and quite popular for food or agricultural materials [28] such as rice. All materials have unique dielectric properties. there must be some characteristics that is difference in some frequencies. Therefore, all the types of rice also have unique dielectric character [29].

In this paper, we introduce to monitor of dielectric properties in the adulterated rice inspection. Specifically, we use the Hompathum, Gorkor 79, Phitsanulok and Saohai rice in a ratio of 10-50% to contaminate a sample



(a)



(b)

Fig.1. Measurement setup (a) The drawing instructions of experiment setup; (b) The real measurement setup with rice sample.

of Jasmine 105 rice which is the main commercial rice in Thailand. All of which are commonly brought to mix with Jasmine 105 rice to increase the price (Jasmine 105 rice in Thailand has a price higher than other rice about 30%). We also study the measurement of dielectric properties with salt (NaCl) and water (H_2O) filling technique to increase Ionic and Dipolar polarized mechanisms [30]. This allows us to observe the behavior of the contaminated. Because increment of polarization is not the same due to differences of rice character (as discussed by E. M. Cheng, water molecules with other existing polar molecules in honey will move differently [28]). The main contribution of this work can be summarized as, based on main of rice, measurement of dielectric properties in contaminated of Jasmine 105 rice is presented to show the difference between contaminated rice with different varieties of rice and uncontaminated rice. The experimental results showed that dielectric properties could significantly provide the difference be-tween contaminated rice with uncontaminated rice, therefore it can detect the adulterated rice from changing of dielectric properties.

The remaining sections of this paper are organized as follows: Section 2 describe the materials and methods including rice sample preparation, measurement of dielectric properties, and statistical analysis. Results is reported and discussed in Section 3. Finally, Section 4 gives the conclusions.

2. Materials and Methods

2.1 Rice sample preparation

In this study, five distinct varieties of rice samples were analyzed. The primary rice sample under investigation was Jasmine 105 rice, and it had been adulterated with varying amounts ranging from 10-50% of Hompathum, Gorkor 79, Phitsanulok, and Saohai rice. All rice samples were cultivated, controlled, harvested, dried, and milled by the research team of crop science laboratory, department of crop production technology, Suranaree University of Technology (Nakhon Ratchasima province, Thailand). All samples are ground into powder before measurement because coaxial probe does not require an air gap when measuring [31]. The finely ground rice is not only suitable for the open-end coaxial probe technique, but it also used to ensure that it mixed well with the solution. Thailand's ministry of commerce specified the humidity of commercial rice does not exceed 15%, which grinding resulting in moisture contained inside the grain to evaporate to very low level until humidity level is very similar [29]. The adulterated rice is mixed with 20% saline solution. This concentration does not incur saturated saline. Rice is mixed with saline in 1:1.5 of ratio to form a gel. The samples have no air gap and still retain the property of rice when uses this ratio. The temperature of all samples must be stabilized by resting in the room at least 30 minutes before measuring. To create the final test samples, the rice samples in the glass dishes were uniformly dispersed and were prepared for measurement in the next phase of the experiment.

2.2 Rice sample preparation

In this study, we used a vector network analyzer (Keysight E5071C), open-end coaxial probe, and computer with Keysight materials measurement suit software. The experiment is conducted in temperature control room. Calibration is performed using air, short block and water at frequencies ranging from 0.2-1 GHz. The Measurement uses high temperature coaxial probe type because it is suitable for using with liquid samples, and then setup the equipment as shown in Fig. 1. [32].

Dielectric property is the important parameter to analyze energy loss or transmission when the material is in electric field. Dielectric properties are used in a variety of applications, including sensors, heating, and sterilization [33-38]. Dielectric properties consist of dielectric constant and dielectric loss factor. Dielectric constant indicates the amount of energy storage when material is in electric field, and dielectric loss factor indicates the energy dissipation and loss in material when it is in electric field [39]. In addition, both dielectric constant and dielectric loss factor also indicate penetration depth of wave propagation through material [40]. There are many important factors affecting dielectric properties, such as frequency, temperature, and moisture, which are dependent on the polarizability of compounds in the material [41, 42].

All dielectric materials have unique characteristic, therefore food materials with various complex element structures must have different dielectric properties. Rice is one kind of food that has several varieties and different nutrition [43]. Rice mainly contains carbohydrate, protein, fat, fiber, vitamins, and minerals [44]. Rice contains about 70-80% of carbohydrate, depending on the types of rice. Carbohydrate is a chemical compound consisted of carbon (C), hydrogen (H) and oxygen (O). Carbohydrates are classified into three types, including single molecule sugar (Monosaccharide) which is the smallest molecule and dissolves easily in the water such as glucose and fructose, double molecule sugar (Disaccharide) which it is combination of 2 Monosaccharides, and large molecule sugar (Polysaccharide) which is the unsweetened carbohydrate group, large molecule, complex structure and difficult to dissolve in the water such as cellulose and amylose. Therefore, glucose and fructose can be extracted by pouring water to the rice [45]. Glucose and fructose have dipolar polarized mechanism with dipole moment 1.8 and 3.65 Debye respectively [46], and each type of rice has different glucose and fructose as well as difference dielectric properties.

This paper uses saline as a solvent because salt has ionic polarization and water has dipolar polarization. When sugar and carbohydrates are extracted by water, the nutrients will combine with saline to form a new bond structure with ionic and dipolar polarization. In addition, carbohydrate in rice is classified to amylose and amylopectin. Amylose and amylopectin in different types of rice are not the same which amylose can polarize well at low frequencies (Ionic polarization) and amylopectin can polarize well at high frequencies (Dipolar polarization) as discussed by C. Y. Beh [47]. Therefore, the dielectric properties of the samples will change according to the rice types.

Saline water is the solution consisting of salt (NaCl) and water (H_2O). It has Ionic and Dipolar polarization. Dielectric property of saline water is shown in complex form according to equation (1) (Debye equation). Respond of polar molecule in electric field is determined by relaxation time (τ), which it is the indicator of time that dipole can switch polar in electric field [38, 39].

The open-end coaxial probe is the commonly technique used to measure agricultural product dielectric [28]. This paper also used this technique for measurement. This technique is used to measure the reflection coefficient from the material. Dielectric property of material is the indicator of the reflection wave that probe can measure. This probe can be used well with liquid sample and high loss materials. Therefore, this paper uses liquid gel and high loss sample (ground rice mixed with saline water) in the experiment.

$$\varepsilon' - j\varepsilon'' = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + j\omega\tau} + \frac{j\sigma}{\varepsilon_0\omega} \quad (1)$$

Where ε_s is the static dielectric constant, ε_∞ is the dielectric constant at high frequency, ε_0 is the free space dielectric (8.854×10^{-12} F/m), ω is the angular frequency, τ is the relaxation time and σ is the conductivity (S/m).

The open-end coaxial probe is the commonly technique used to measure agricultural product dielectric [28]. This paper also used this technique for measurement. This technique is used to measure the reflection coefficient from the material. Dielectric property of material is the indicator of the reflection wave that probe can measure. This probe can be used well with liquid sample and high loss materials. Therefore, this paper uses liquid gel and high loss sample (ground rice mixed with saline water) in the experiment.

2.3 Statistical Analysis

In this study, a total of three replicate experiments were conducted to gather data for analysis. The data obtained was subsequently processed using SPSS Statistics version 20.0. To determine the statistical variations among the sample means, a one-way analysis of variance (ANOVA) was performed with a significance level of 5%. The results of this analysis revealed that the dielectric properties of the test rice sample were found to be statistically significant, as determined by Fisher's least significant difference test.

3. Results and Discussion

In this section, we present and discuss the results of the dielectric properties of pure rice measurement, dielectric properties of contaminated rice measurement and statistical analysis.

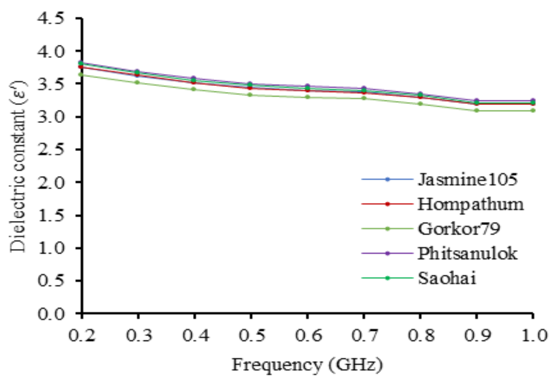
3.1 Dielectric Properties of Pure Rice Measurement

This section presents the dielectric properties of pure rice measurement with 5 different types of rice sample, including Jasmine 105, Hompathum, Gorkor 79, Phitsanulok and Saohai rice. Fig. 2 shows the measurement result, the fundamental dielectric properties of the various rice types in the experiment. We found that, the dielectric constant (Fig. 2 (a)) and dielectric loss factor (b) are very low and similar. The dielectric constant at low frequency (0.2GHz), of Jasmine 105, Hompathum, Gorkor 79, Phitsanulok and Saohai are 4.25, 4.38, 4.41, 4.35 and 4.66 respectively. At the frequency 1 GHz, they have dielectric constant of Jasmine 105, Hompathum, Gorkor 79, Phitsanulok and Saohai as 3.12, 3.21, 3.23, 3.19 and 3.37 respectively. Dielectric constant of rice samples is very similar and very low, likewise dielectric loss factor of rice samples. At the frequency 0.2 GHz, they have dielectric loss factor of Jasmine 105, Hompathum, Gorkor 79, Phitsanulok and Saohai as 0.305, 0.378, 0.385, 0.345 and 0.395 respectively. At the frequency 1 GHz, they have dielectric loss factor of Jasmine 105, Hompathum, Gorkor 79, Phitsanulok and Saohai as 0.712, 0.769, 0.779, 0.759 and 0.848 respectively. We fund that the measured values are very similar, the analysis of the data presented in table 1 reveals a dissimilarity between the Jasmine 105 rice variety and other tested rice varieties.

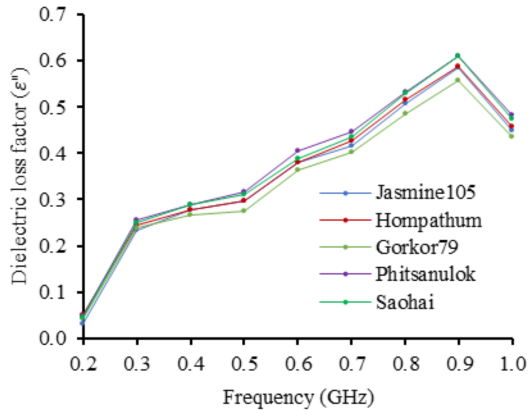
Identifying the specific rice type based on the dielectric properties curve can be challenging. Analyzing the percentage differences in the dielectric loss factor curves at a frequency of 0.2 GHz revealed distinctive patterns for each rice cultivar. The observed differences were 66% in the case of Hompathum, Phitsanulok, and Saohai, and 33% for Gorkor 79. This shows that the incorporating various rice varieties in conjunction with jasmine rice, adulteration can be detected through dielectric properties measurements. Nevertheless, it is worth noting that the differences observed in the obtained values are relatively small, potentially impacting the accuracy of discrimination. Therefore, in this study, a saline filling technique was employed to augment the distinction in dielectric properties among rice samples. The introduction of saline serves to dissolve the chemical constituents within the rice, facilitating the formation of novel bond structures. This will lead to an increased variance, thereby enabling a more precise detection of contamination.

3.2 Dielectric Properties of Contaminated Rice Measurement

Because all rice samples have very similar dielectric properties, they require additional technique which this paper uses saline filling technique. Fig. 3-8 shows dielectric properties measurement results of Jasmine 105 rice and Jasmine 105 adulterated with Hompathum,



(a)



(b)

Fig.2. The measurement dielectric constant and dielectric loss factor of finely ground rice of all rice samples at the frequencies 0.2-1 GHz.

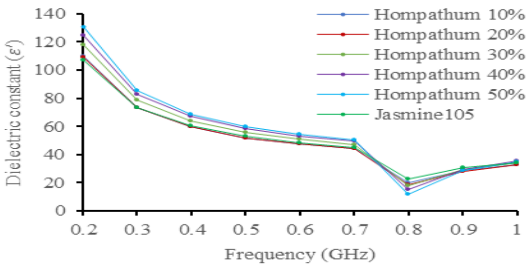
Gorkor 79, Phitsanulok and Saohai. All samples are filled with saline water 20% concentration in 1:1.5 (rice:saline)ratio. The adulteration ratio used in this measurement is 10%, 20%, 30%, 40% and 50% respectively. Where Jasmine 105 rice is used as reference for comparison.

The dielectric properties measurements were conducted on adulterated Jasmine 105 rice mixed with Hompathum rice, the outcomes of these measurements are illustrated in Fig. 3. Fig. 3(a) exhibits the graphs illustrating the variation in dielectric constant as the proportion of Hompathum rice increases in the mixture with Jasmine 105 rice. It can be observed that the dielectric constant shows an upward trend with a higher proportion of Hompathum rice in the mixture. When the dielectric constants were evaluated at a frequency of 1 GHz, the adulterated rice samples exhibited varying dielectric constants depending on the mixing ratio. Specifically, at mixing ratios of 10%, 20%, 30%, 40%, and 50%, the dielectric constants were measured as 32.5, 32.4, 34.2, 35.2, and 35, respectively. Furthermore, when the dielectric constant was assessed at a frequency of 0.2 GHz, the dielectric constants varied among the adulterated rice samples. The dielectric constants were measured as 110, 109, 118, 125, and 131, respectively. Fig. 3(b) illustrates the results of the dielectric loss factor measurements. The graphs depict an increasing trend in the dielectric loss factor as Hompathum rice is mixed with Jasmine 105 rice. At a frequency of 1 GHz, the dielectric loss factors for the adulterated rice samples at mixing ratios of 10%, 20%, 30%, 40%, and 50% were measured as 218, 224, 243, 266, and 281, respectively. At a frequency of 0.2 GHz, the dielectric loss factors for the adulterated rice samples at mixing ratios of 10%, 20%, 30%, 40%, and 50% were measured as 1010, 1040, 1130, 1240, and 1310, respectively.

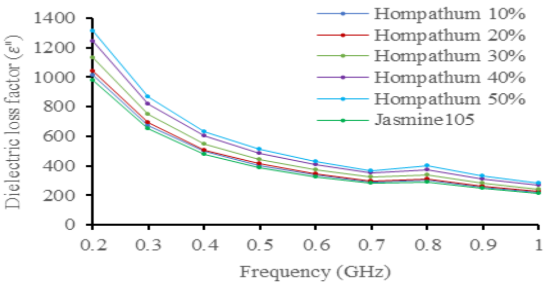
The study encompassed dielectric properties measurements of adulterated Jasmine 105 rice mixed with Gorkor 79 rice. The outcomes of these measurements were presented in Fig. 4. Specifically, Fig. 4(a) depicted the results of dielectric constant measurement for Jasmine 105 rice adulterated with Gorkor 79 rice, along with the dielectric constant of pure Jasmine 105 rice. Evidently, the dielectric constant of the rice increased as the level of adulteration rose. At 1 GHz, the adulterated rice samples at 10%, 20%, 30%, 40%, and 50% proportions exhibited dielectric constants of 34.2, 33.9, 35.2, 35.5, and 35.6, respectively. At a frequency of 0.2 GHz, the adulterated rice samples at 10%, 20%, 30%, 40%, and 50% proportions displayed dielectric constants of 113, 117, 126, 128, and 132, respectively, Furthermore, the dielectric loss factor measurements for Jasmine 105 rice adulterated with Gorkor 79 rice, were depicted in Fig. 4(b). The graph illustrated that the dielectric loss factor of the rice increased proportionally to the level of adulteration, mirroring the behavior observed for the dielectric constant. Notably, this effect was more pronounced at lower frequencies. At 1 GHz, the adulterated rice samples at 10%, 20%, 30%, 40%, and 50% proportions exhibited dielectric loss factors of 228, 243, 261, 270, and 280, respectively, at a frequency of 0.2 GHz, the adulterated rice samples at 10%, 20%, 30%, 40%, and 50% proportions displayed dielectric loss factors of 1060, 1130, 1220, 1260, and 1310, respectively.

Fig. 5 presents the results of dielectric constant measurements for Jasmine 105 rice adulterated with Phitsanulok rice. Phitsanulok rice, a type of hard rice, was chosen as the adulterant. The measurement results are compared to those obtained for pure Jasmine 105 rice. As depicted in Fig. 5(a), the dielectric constants of adulterated rice at 10%, 20%, 30%, 40%, and 50% proportions, measured at 1 GHz, were found to be 33.8, 34.2, 33.9, 33.3, and 13.1, respectively. Conversely, at a frequency of 0.2 GHz, the dielectric constants of adulterated rice at 10%, 20%, 30%, 40%, and 50% proportions were determined to be 109, 106, 103, 89.2, and 60.2, respectively. Fig. 5(b) displays the results of dielectric loss factor measurements for Jasmine 105 rice adulterated with Phitsanulok rice at the same proportions. The graphs demonstrate a significant decrease in the dielectric loss factor with increased adulteration. At 1 GHz, the dielectric loss factors of adulterated rice at 10%, 20%, 30%, 40%, and 50% proportions were 216, 203, 197, 154, and 153, respectively, Similarly, at a frequency of 0.2 GHz, the dielectric loss factors of adulterated rice at 10%, 20%, 30%, 40%, and 50% proportions were found to be 999, 939, 906, 741, and 695, respectively.

The final experiment involved measuring Jasmine 105 rice adulterated with Saohai rice at proportions ranging from 10% to 50%. Saohai rice, another type of hard rice, is commonly used due to its low cost for adulterating Jasmine 105 rice. Fig. 6(a) presents the results of the dielectric constant measurements for Saohai rice.

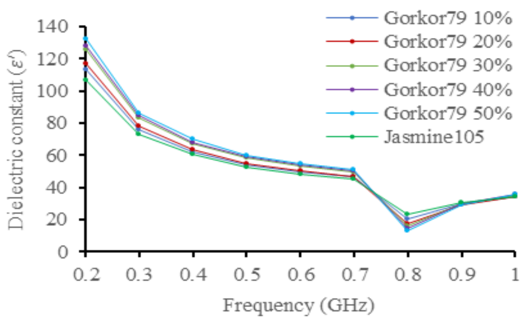


(a) Dielectric constant

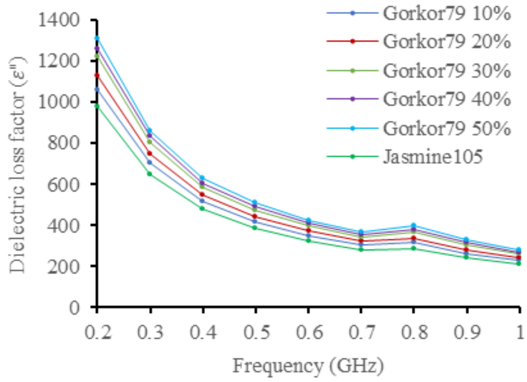


(b) dielectric loss factor

Fig.3. Dielectric properties of Jasmine 105 contaminated with Hompathum rice.

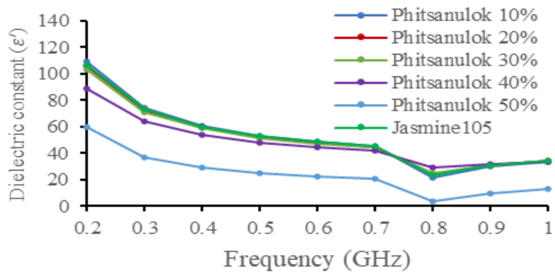


(a) Dielectric constant

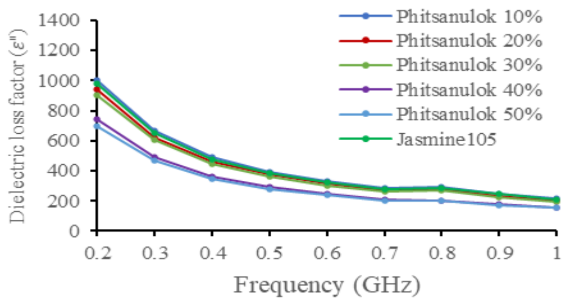


(b) dielectric loss factor

Fig.4. Dielectric properties of Jasmine 105 contaminated with Gorkor79 rice.



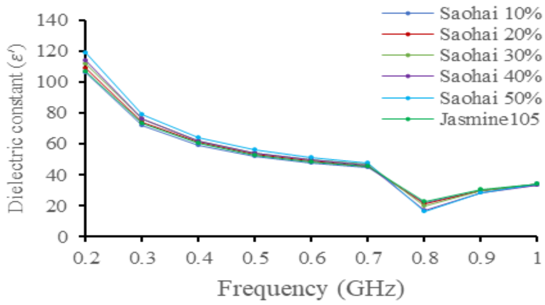
(a) Dielectric constant



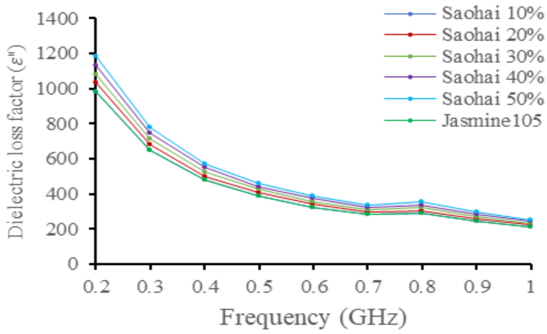
(b) dielectric loss factor

Fig.5. Dielectric properties of Jasmine 105 contaminated with Phitsanulok rice.

At 1 GHz, the dielectric constants of adulterated rice at 10%, 20%, 30%, 40%, and 50% proportions were determined as 33.3, 33.9, 34.2, 33.1, and 34, respectively. Similarly, at a frequency of 0.2 GHz, the dielectric constants of adulterated rice at 10%, 20%, 30%, 40%, and 50% proportions were found to be 106, 109, 112, 114, and 119, respectively, compared to the reference rice value of 107. Fig. 6(b) displays the dielectric loss factor of Jasmine 105 rice adulterated with Saohai rice at the same proportions. At 1 GHz, the dielectric loss factors of adulterated rice at 10%, 20%, 30%, 40%, and 50% proportions were determined as 212, 221, 232, 242, and 253, respectively. Similarly, at a frequency of 0.2 GHz, the dielectric loss factors of adulterated rice at 10%, 20%, 30%, 40%, and 50% proportions were found to be 980, 1030, 1080, 1130, and 1180, respectively.



(a) Dielectric constant



(b) dielectric loss factor

Fig.6. Dielectric properties of Jasmine 105 contaminated with Saohai rice.

Table 1. Dielectric constant and dielectric loss factor of finely ground rice of all rice samples at the frequencies 0.2 GHz and 1 GHz.

Mean ± SD	**Dielectric Constant**		**Dielectric Loss**	
	Frequency (GHz)			
	0.2	**1**	**0.2**	**1**
Jasmine 105 (A)	3.76 ± 0.0376	3.19 ± 0.0319	0.03 ± 0.0003	0.45 ± 0.0045
Hompathum (B)	3.76 ± 0.0376	3.19 ± 0.0319	0.05 ± 0.0005	0.46 ± 0.0046
Gorkor 79 (C)	3.63 ± 0.0363	3.09 ± 0.0309	0.04 ± 0.0004	0.44 ± 0.0044
Phitsanulok (D)	3.83 ± 0.0383	3.24 ± 0.0324	0.05 ± 0.0005	0.48 ± 0.0048
Saohai (E)	3.81 ± 0.0381	3.22 ± 0.0322	0.05 ± 0.0005	0.47 ± 0.0047
Different A:B/(%)	≈ 0.00/0.00	≈ 0.00/0.00	≈ 0.02/66.66	≈ 0.01/2.22
Different A:C/(%	≈ 0.13/3.45	≈ 0.10/3.13	≈ 0.01/33.33	≈ 0.01/2.22
Different A:D/(%	≈ 0.07/1.86	≈ 0.05/1.56	≈ 0.02/66.66	≈ 0.03/6.66
Different A:E/(%	≈ 0.05/1.32	≈ 0.03/0.94	≈ 0.02/66.66	≈ 0.02/4.44

Table 2. Dielectric constant and dielectric loss factor of Jasmine 105 contaminated with all rice samples 10% at the frequencies 0.2 and 1 GHz.

Mean ± SD	**Dielectric Constant**		**Dielectric Loss**	
	Frequency (GHz)			
	0.2	**1**	**0.2**	**1**
Jasmine 105 (A)	107 ± 1.07	34.2 ± 0.342	978 ± 9.78	211 ± 2.11
Hompathum (B)	110 ± 1.10	32.5 ± 0.325	1010 ± 10.10	218 ± 2.18
Gorkor 79 (C)	113 ± 1.13	34.2 ± 0.342	1060 ± 10.60	228 ± 2.28
Phitsanulok (D)	109 ± 1.09	33.8 ± 0.338	999 ± 9.99	216 ± 2.16
Saohai (E)	106 ± 1.06	33.3 ± 0.333	980 ± 9.80	212 ± 2.12
Different A:B/(%)	≈ 3/2.80	≈ 1.7/4.97	**≈32 /3.27**	≈ 7/3.32
Different A:C/(%)	≈ 6/5.61	≈ 0.0/0.00	**≈ 82/8.38**	≈ 17/8.06
Different A:D/(%)	≈ 2/1.87	≈ 0.4/1.17	**≈ 21/2.15**	≈ 5/2.37
Different A:E/(%)	≈ 9/0.93	≈ 0.9/2.63	**≈ 2/0.20**	≈ 1/0.47

Table 3. Dielectric constant and dielectric loss factor of Jasmine 105 contaminated with all rice samples 50% at the frequencies 0.2 and 1 GHz.

Mean ± SD	**Dielectric Constant**		**Dielectric Loss**	
	Frequency (GHz)			
	0.2	**1**	**0.2**	**1**
Jasmine 105 (A)	107 ± 1.07	34.2 ± 0.342	978 ± 9.78	211 ± 2.11
Hompathum (B)	131 ± 1.31	35 ± 0.350	1310 ± 13.10	281 ± 2.81
Gorkor 79 (C)	132 ± 1.32	35.6 ± 0.356	1310 ± 13.10	280 ± 2.80
Phitsanulok (D)	60.2 ± 0.60	13.1 ± 0.131	695 ± 6.95	153 ± 1.53
Saohai (E)	119 ± 1.19	34 ± 0.340	1180 ± 11.80	253 ± 2.53
Different A:B/(%)	≈ 24/22.43	≈0.8 /2.34	**≈ 332/33.95**	≈ 70/33.18
Different A:C/(%)	≈ 25/23.36	≈ 1.4/4.09	**≈ 332/33.95**	≈ 69/32.70
Different A:D/(%)	≈ 46.8/43.74	≈ 21.1/61.7	**≈ 283/28.94**	≈ 58/27.49
Different A:E/(%)	≈ 12/11.21	≈ 0.2/0.58	**≈ 202/20.65**	≈ 42/19.90

The experiments involved mixing Jasmine rice 105 with four different rice varieties at proportions ranging from 10% to 50%. Analysis of the dielectric constant properties revealed an increasing trend in the dielectric constant for all rice types as the mixing ratio increased. Notably, significant differences were observed at lower frequencies, as evidenced by the comparison results at 0.2 GHz versus 1 GHz. Similarly, the analysis of dielectric loss factor properties demonstrated higher dielectric losses for all hybridized rice cultivars. The difference in dielectric loss was found to be substantially greater than the difference in dielectric constant, particularly at lower frequencies. These findings highlight significant differences among the rice varieties. Tables 2 and 3 provide a comparative analysis of the four rice cultivars mixed at 10% and 50%, respectively. When considering a small mixing ratio of 10%, the largest difference was observed between Jasmine rice and Gorkor 79, with a value of 82 and 8.38% difference. In contrast, at the highest mixing ratio of 50%, the largest difference of 332 and 33.95% difference, was observed between Jasmine rice, Gorkor 79, and Hompathum. These results indicate that larger mixing proportions lead to greater differences in the properties, particularly in terms of dielectric loss and at lower frequencies. Hence, the primary focus of this study was to utilize Jasmine 105 rice as the main test subject, aiming to establish a valuable reference for future research concerning other rice varieties. Moreover, the significant disparities observed in the property differential values have implications for the application of rice adulteration detection techniques, such as Artificial Intelligence, in the agricultural industry. These findings underscore the potential impact on the advancement of such technologies in the future.

4. Conclusions

The research examining the measurement results of dielectric properties in mixed rice varieties revealed that each rice cultivar exhibited remarkably similar characteristics, making it challenging to differentiate between them. However, when introducing a 20% saline to enhance the dielectric properties of the rice, significant differences were observed, particularly in terms of the dielectric loss factor and at lower frequencies. Additionally, it was noted that an increased combination of rice varieties resulted in higher property values. These distinctive dielectric properties stem from the variations in nutrient content among the different rice varieties, leading to unequal polarization at different frequencies. This experimental study lays the groundwork for the development of novel sensing innovations utilizing electromagnetic waves, leveraging the substantial impact of the dielectric loss factor on material electromagnetic absorption. These findings hold vital implications for the implementation of rice adulteration detection techniques, especially when combined with artificial intelligence methodologies. Consequently, dielectric properties measurement holds promising applications in the future of the agricultural industry.

Acknowledgment: This research was funded by Suranaree University of Technology (SUT), Thailand Science Research and Innovation (TSRI), and National Science Research and Innovation Fund (NSRF) (NRIIS no. 160360).

***Authors**: Mr. Wittawat Wasusathien, E-mail: Wittawat_wasusathien@hotmail.com, School of Electronic Engineering, Suranaree University of Technology, Nakhon Ratchasima,Assoc. Prof. Dr. Chanchai Thongsopa, E-mail: chan@sut.ac.th, School of Electronic Engineering, Suranaree University of Technology, Nakhon Ratchasima, Assist. Prof. Dr. Samran Santalunai, E-mail: samran.sa@sut.ac.th, School of Electronic Engineering, Suranaree University of Technology, Nakhon Ratchasima, Thailand; Assist. Prof. Dr. Thanaset Thosdeekoraphat, E-mail: thanaset@sut.ac.th, School of Electronic Engineering, Suranaree University of Technology, Nakhon Ratchasima, Thailand; Assist. Prof. Dr. Nuchanart Santalunai, E-mail: nuchanart.fa@rmuti.ac.th, Department of Telecommunication Engineering, Faculty of Engineering and Architecture, Rajamangala University of Technology Isan, Nakhon Ratchasima, Thailand.*

REFERENCES

[1] McGrath, T.F., Haughey, S.A., Patterson, J., Fauhl-Hassek, C., Donarski, J., Alewijn, M., van Ruth, S., Elliott, C.T., What are the scientific challenges in moving from targeted to non-targeted methods for food fraud testing and how can they be addressed? – Spectroscopy case study, *Trends in Food Science and Technology*, 76 (2018), 38-55

[2] Esteki, M., Regueiro, J., Simal-Gándara, J., Tackling Fraudsters with Global Strategies to Expose Fraud in the Food Chain, *Comprehensive Reviews in Food Science and Food Safety*, 18 (2019), no. 2, 425-440

[3] Tuano, A.P., Roferos, L.T., Juliano, B.O., Field test for apparent amylose type for milled rice quality classification, *The Philippine Agricultural Scientist,* 92 (2009), no. 2, 228-232

[4] Verma, R.L., Singh, S., Singh, P., Kumar, V., Singh, S.P., Singh, S., Samantaray, S., Singh, O.N., Genetic purity assessment of indica rice hybrids through DNA fingerprinting and grow out test, *Journal of Environmental Biology*, 38 (2017), no. 6, 1321-1331

[5] Bora, A., Choudhury, P.R., Pande, V., Mandal, A.B., Assessment of genetic purity in rice (Oryza sativa L.) hybrids using microsatellite markers, *3 Biotech*, 6 (2016), no. 1, 1-7

[6] Yodrot, T., Santalunai, S., Thongsopa, C., Thosdeekoraphat, T., Santalunai, N., Measurement of Dielectric Properties in Soil Contaminated by Biodiesel-Diesel Blends Based on Radio Frequency Heating, *Applied Sciences,* 13 (2023), no. 3, 1248

[7] Sutacha, C., Santalunai, S., Thongsopa, C., Thosdeekoraphat, T., Penkhrue, W., Inactivation of Contaminated Fungi in Rice Grains by Dielectric Heating, *Applied Sciences,* 12 (2022), no. 20, 10478

[8] Ahmed, J., Ramaswamy, H.S., Raghavan, V.G.S., Dielectric properties of Indian Basmati rice flour slurry, *Journal of Food Engineering*, 80 (2007), no. 4, 1125-1133

[9] Kornsing, S., Santalunai, S., Thosdeekoraphat, T., Thongsopa, C., Dielectric Property Measurement of Freshwater Fishes and Parasite Affecting Infection Opisthorchis Viverrini for Dielectric Heating Application, *9th International Symposium on Electrical Insulating Materials*, (2020), 439-442

[10] Nelson, S.O., Dielectric Properties of Agricultural Materials and Their Applications, First edition, Elsevier, (2015)

[11] Nelson, S.O., Dielectric properties of agricultural products: measurements and applications, *IEEE Transactions on Electrical Insulation*, 26 (1991), 845-869

[12] Khaled, D.E., Castellano, N.N., Gazquez, J.A., Moreno, A.P., Agugliaro, F.M., Dielectric Spectroscopy in biomaterials: agrophysics, *Materials*, 9 (2016), no. 5, 2-26

[13] Kasap, S.O., Principles of Electronic Materials and Devices, Third edition, McGraw-Hill, (2006)

[14] Saeung, P., Santalunai, S., Thosdeekoraphat, T., Thongsopa, C., Improved Efficiency of Insect Pest Control System by SSPA, *The 5th International Conference on Industrial Engineering and Applications*, (2018), 179-183

[15] Srisuma, C., Santalunai, S., Thosdeekoraphat, T., Thongsopa, C., The Analysis and Design of Milk Pasteurization System by Using Radio Frequency Electric Fields, *The 2017 Asia-Pacific International EMC Symposium,* (2017), 158-160

[16] Santalunai, S., Thongsopa, C., Thosdeekoraphat, T., The efficiency of dielectric heating by using symmetrically electric power ports on electrode plate for pest control, *2015 12th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology*, (2015), 1-4

[17] Ratniyomchai, K., Santalunai, S., Thosdeekoraphat, T., Thongsopa, C., Optimization of capacitor copper plate for dielectric heating to eliminate insect, *Applied Mechanics and Materials*, 343 (2013), 101-105

[18] Santalunai, N., Santalunai, S., Meesawad, P., Tongsopa, C., Santalunai, S., Plus-Shape of Mushroom-Like EBG with Square Microstrip Emitter to Expand the Working Space in Dielectric Heating Applications, *International Journal of Intelligent Engineering and Systems*, 14 (2021), no. 3, 189-200

[19] Seehanan, T., Fhafhiem, N., Santalunai, S., Krachodnok, P., Analysis of electric fields distribution by using EBG structure for dielectric heating applications, *4th International Conference on Engineering, Applied Sciences and Technology: Exploring Innovative Solutions for Smart Society*, (2018), 1-4

[20] Kotchapradit, S., Thosdeekoraphat, T., Santalunai, S., Thongsopa, C., Improvement of Electric Field Focusing for Deep Hyperthermia in Breast Cancer Treatment by Using Microwave Dielectric Heating with Curved Plate Applicator, *Asia-Pacific Microwave Conference*, (2018), 1474-1476

[21] Ebihara, K., Stryczewska, H., Ikegami, T., Mitsugi, F., Pawlat, J., On-site ozone treatment for agricultural soil and related

applications, Corn, and Rice Starch. *Przegląd Elektrotechniczny*, 87 (2011), no. 7, 148-152
[22] Ramaswamy, H., Tang, J., Microwave and radio frequency heating, *Food Sci*, 14 (2008), 423-427
[23] Guoa, W., Tiwarib, G., Tangb, J., Wang, S., Frequency, moisture, and temperature-dependent dielectric properties of chickpea flour, *Bio systems engineering IOI*, 101 (2008), no. 2, 217-224
[24] Kandala, C.V., and Puppala, N., Parallel-plate capacitance sensor for nondestructive measurement of moisture content of different types of wheat, *IEEE Sensors Applications Symposium*, (2012), 1-5
[25] Wee, F.H., Soh, P.J., Suhaizal, A.H.M., Nornikman, H., Ezanuddin, A.A.M., Free space measurement technique on dielectric properties of agricultural residues at microwave frequencies. *2009 SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference (IMOC).* (2009), 183-187
[26] Gregory, A.P., Clarke R.N., A review of RF and microwave techniques for dielectric measurement on polar liquids. *IEEE Transactions on Dielectrics and Electrical Insulation.* 13 (2006), 727-743
[27] Jha, S.N., Narsaiah, K., Basediya, A.L., Sharma, R., Jaiswal, P., Kumar, R., Bhardwaj, R., Measurement techniques and application of electrical properties for nondestructive quality evaluation of foods—a review. *Journal of Food Science and Technology*, 48 (2011), 387-411
[28] Cheng, E.M., Lee, K.Y., Khor, S.F., Nasir, N.F.M., Mohamad, C.W.S.R., Aziz, N.A.A., Tarmizi, E.Z.M., Baharuddin, S.A., Microwave Dielectric and Reflection Analysis on Pure and Adulterated Trigona Honey and Honey Gold. *Radioengineering.* 31 (2022), no. 3, 281-294
[29] Wasusathien, W., Santalunai, S., Thosdeekoraphat, T., Thongsopa, C., Rice Types Classification by Using Dielectric Properties Measurement with Saline Water Increasing Technique. *9th International Symposium on Electrical Insulating Materials.* (2020), 433-438
[30] Gadani, D.H., Rana, V.A., Bhatnagar, S.P., Prajapati, A.N., Vyas, A.D., Effect of salinity on the dielectric properties of water, *Indian Journal of Pure & Applied Physics*, 50 (2012), 405-410
[31] Zulaika, S., Rahim, R.A., Dielectric properties of rice paddy and sitophilusoryzae for microwave heating treatment, *2018 IEEE International RF and Microwave Conference (RFM)*, (2018), 317-320
[32] Srichamnong, W., Thiyajai, P., Charoenkiatkul, S., Conventional steaming retains tocols and γ-oryzanol better than boiling and frying in the jasmine rice variety Khao dokmali 105, *Food Chemistry*, 191 (2016), 113-119
[33] Trabelsi, S., Krazsewski, A.W., Nelson, S.O., New density-independent calibration function for microwave sensing of moisture content in particulate materials, *IEEE Transections on Instrumentation and Measurement*, 47 (1998), no. 2, 613-622
[34] Wang, J., Fan, L., Zhou, O., Li, J., Zhao, P., Wang, Z., Zhang, H., Yan, S., Huang. L., Rapid determination of meat moisture content using radio-frequency dielectric measurement, *IEEE Access*, 6 (2018), 51384-51391
[35] Jafari, F., Khalid, K., Daud, W.M., Yusoff, M., Hassan, J., Development and design of microstrip moisture sensor for rice grain. *International RF and Microwave Conference Proceedings.* (2006), 258-261
[36] Xu, X., Sun, Y., Yin, Y., Xue, Y., Ma, F., Song, C., Yin, H., Zhao, L., A Free-Space-Based Model for Predicting Peanut Moisture Content during Natural Drying. *Journal of Food Quality.* 2022 (2022), 1-12
[37] Das, I., Kumar, G., Shah, N.G., Microwave Heating as an Alternative Quarantine Method for Disinfestation of Stored Food Grains. *International Journal of Food Science*, 2013 (2013), 1-13
[38] Kim, D.Y., Park, C.S., Leem, J.Y., Kim, S.O., Raw food sterilization of flexible dielectric barrier discharge device using biocompatible tubing. *IEEE Transections on Plasma Science.* 42 (2014), no. 10, 2758-2759
[39] Trabelsi, S., Frequency and temperature dependence of dielectric properties of chicken meat. *IEEE International Instrumentation and Measurement Technology Conference Proceedings.* (2012), 1-4
[40] Sosa-Morales, M.E., Valerio-Junco, L., Lopez-Malo, A., Garcia, H.S., Dielectric properties of foods: reported data in the 21st century and their potential applications, *LWT - Food Science and Technology*, 43 (2010), no. 8, 1169-1179
[41] Nelson, S.O., Bartley Jr., P.G., Measuring frequency- and temperature-dependent permittivities of food materials, *IEEE Transections on Instrumentation and Measurement*, 51 (2002), no. 4, 589-592
[42] Chen, J., Pitchai, K., Birla, S., Jones, D.D., Subbiah, J., Development of a multi-temperature calibration method for measuring dielectric properties of food, *IEEE Transactions on Dielectrics and Electrical Insulation*, 22 (2015), no. 1, 626-634
[43] MohdFairulnizal, M.N., Norhayati, M.K., Zaiton, A., Norliza, A.H., Rusidah, S., Aswir, A.R., Suraiami, M., Mohd Naeem, M.N., Jo-Lyn, A., MohdAzerulazree, J., Vimala, B., MohdZainuldin, T., Nutrient content in selected commercial rice in malaysia: an update of malaysian food composition database, *International Food Research Journal*, 22 (2015), no. 2, 768-776
[44] Cheng, E.M., You, K.Y., Lee, K.Y., Abbas, Z., Rahim, H.A., Khor, S.F., Zakaria, Z., Lee, Y.S., Dielectric spectroscopy technique for carbohydrate characterization of fragrant rice, brown rice and white rice, *Progress in Electromagnetics Research Symposium*, (2017), 205-209
[45] Navarro, D.M.D.L., Abelilla, J.J., Stein, H.H., Structures and characteristics of carbohydrates in diets fed to pigs: a review. *Journal of Animal Science and Biotechnology.* 10 (2019), no. 39, 1-17
[46] Mazurkiewicz, J., Tomasik, P., Effect of external electric field upon charge distribution, energy and dipole moment of selected monosaccharide molecules. *Natural Science.* 4 (2012), no. 5, 276-285
[47] Beh, C.Y., Cheng, E.M., Nasir, N.F.M., Majid, M.S.A., Khor, S.F., Jamir, M.R.M., Tarmizi, E.Z.M., Lee, K.Y., Dielectric Properties of Hydrothermally Modified Potato, Corn, and Rice Starch. *Agriculture*, 12 (2022), no. 6, 1-14