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Original Research Article

Measuring Dielectric Properties of MARDI 76 (MRQ76) Rice at the Frequency of 915 MHz and 2.45 GHz

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Abstract: The microwave heating system has been widely used in the food processing and postharvest handling of rice. However, to develop efficient heating energy for the heating and drying process, the knowledge of permittivity or dielectric properties of the MARDI 76 (MRQ76) rice is quite important. The penetration and power dissipation of microwave inside the MARDI 76 (MRQ76) rice is strongly dependent on its dielectric properties or permittivity. Furthermore, characterisation of changes in permittivity or dielectric properties of MARDI 76 rice at elevated temperatures is essential for designing the microwave heating device and system. The permittivity or dielectric properties of MARDI 76 rice (MRQ76) were measured using Agilent open-ended coaxial-line probe and Agilent E5071C Network Analyser. The temperature of the MRQ 76 rice sample was regulated using a WiswCircu Circulator Water bath between temperatures of 27ºC to 70ºC. MARDI MRQ 76 rice sample was placed into the temperature-controlled stainless steel sample holder with water jacket assembly which was designed for permittivity measurement at different temperatures. The effect of temperature on dielectric properties of MARDI 76 rice, power dissipation and penetration depth of microwave radiation at the Industrial, Scientific, and Medical (ISM) heating frequency of 915 MHz and 2.45 GHz was assessed. Results indicated that both dielectric constant and dielectric loss of MARDI 76 rice samples increased with increasing temperature. Power dissipation of microwave radiation inside MARDI 76 rice increases with an increase in temperature. On the other hand, the penetration depth of microwave radiation into the MARDI 76 rice decreased with the increase in temperature. The result of this study shows dielectric properties and heating temperature of MARDI MRQ 76 rice play an important role in designing the microwave heating system for MARDI MRQ 76 rice.

Keywords: dielectric properties; power dissipation; penetration depth; MARDI 76 rice

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1. Introduction

Rice is a main staple food in Asia and about 90% of world rice consumption comes from Asia. Malaysian rice consumption is also high where Malaysia's rice consumption per capita was 74.4 kg/year (2017) and 90.1 kg/year (2012) (Che Omar *et al.*, 2019). Most paddy fields in Asian countries are grown with different rice varieties for the staple food rice while small areas of paddy fields are grown with aromatic rice varieties. The aromatic rice has a unique aroma which is normally served as a special dish in ceremonial dinner or lunch. Its texture is sticky and normally consumed in small portions dishes and also used as an ingredient to make cakes and sweets. As such, fragrant or aromatic rice is becoming more popular in the local and international markets. Due to its fragrant nature and taste which is better than regular rice, the demand for it is high, garnering higher pricing. The Malaysian Research and Agriculture Development Institute (MARDI) has produced a third variety of fragrant paddy strain, code-named MRQ 76, to reduce the country's import of fragrant rice.

The main ingredient that emits a fragrant smell in fragrant rice is 2-Acetyl-1-pyrroline (2-AP) which resembles ‘pandan’ and sometimes 'pop-corn' (Buttery *et al.*, 1982). This scent is directly proportional to the level of 2-AP content in scented rice (Ishitani *et al.*, 1994). Yoshihashi reported that 2-AP does not form during rice cooking or during the process of ripening rice varieties but forms in the aerial part of the rice plant during growth in the field. The compound is very low in concentration and very volatile by absorbing out the rice (Yoshihashi *et al.*, 2002).

The 2-Acetyl-1-pyrroline (2-AP) was found to decrease faster at the high storage temperature (Yoshihashi *et al.*, 2005). This is consistent with several studies that have shown that stored rice losses 2-AP when aromatic rice varieties were stored at high temperatures for extended periods (Yoshihashi *et al.*, 2005; Maneenuam *et al.*, 2014; Wongpornchai *et al.*, 2004). The other drying study conducted on the Khao Dawk Mali 105 Thai aromatic white found that 2-AP content and the milling quality of the aromatic rice were better preserved at relatively low temperatures of 30ºC C and 40ºC compared to hot air drying at 70ºC (Wongpornchai *et al.*, 2004). Meanwhile, microwave drying or heating has considerable advantages over conventional drying or heating methods, especially with regard to energy efficiency and low heating temperature. In the conventional heating mechanism, the heat will flow from the rice surface towards the internal section of the rice layer and causes a temperature difference between the layers inside the rice kernel. As a result, a longer heating time is then required to achieve the targeted heating temperature. Under such conditions, microwave heating has a different heating mechanism where microwave energy penetrates inside the rice kernel and forms a volumetric heating, leading to a reduction of drying or heating time which minimises the temperature gradient between the skin and the internal section of the rice.

The conventional drying method uses hot air to heat the outer layer of rice and the internal layer of rice will be heated gradually through conduction. The reduction of temperature and moisture content from the surface towards the internal core of rice will cause stress on the rice texture that will fracture the rice kernel. This is due to the inability of the rice kernel to withstand the rice breaking and will lead to the loss of the rice milling yield. The head rice volume is an important out factor of the milling process of rice. It is measured as the reducing length of milled rice to 25% or less of their original length. The loss of head rice volume will cause economic loss to the rice miller. Therefore, it is crucial to find a drying technique that will minimise the loss of head rice during the milling process. Microwave has a spectrum within the 300 MHz to 300 GHz frequency range and 1 m to 1 mm wavelength range. Microwave heating has an effect on the water that deters the dipolar alignment of water molecules and ionic mechanism. This will cause the water molecules to vibrate and have friction with each other, then the volumetric heating will form inside the compound. Microwave heating or drying with 915 MHz and 2.45 GHz heating frequency is normally used in the industry. The domestic microwave system uses the 2.45 GHz heating frequency while the industrial microwave system uses the 915 MHz heating frequency. The 915 MHz microwave heating frequency has a longer wavelength and higher penetration depth than the 2.45 GHz microwave heating frequency. The dielectric properties of rice are an important factor in microwave heating or drying. They express the energy coupling of rice with an electromagnetic microwave field and the heating feasibility. In scientific literature, dielectric properties or complex permittivity is reported as a relative complex number as shown in Equation 1:

$$\varepsilon = \varepsilon^{'} - j\varepsilon^{''} \tag{1}$$

where the real part $\varepsilon^{'}$ is the dielectric constant and the imaginary part $\varepsilon^{''}$ is the dielectric loss. The dielectric constant is a measure of how much energy from an external microwave field is stored in the rice grain and the loss factor is related to the loss energy dissipative mechanisms in the rice grain. The other important factors in microwave heating or drying are power dissipation and penetration depth.

Power dissipation inside the rice grain is illustrated as Equation 2:

$$Q = \frac{1}{2}\omega\varepsilon_0\varepsilon''|E|^2 \quad (2)$$

where E is the electric field strength (V/m), ε'' is the dielectric loss of rice grain, ω is the angular frequency (Hz), ε_0 is the permittivity of vacuum.

Bulk heating is achieved when penetration depth (Dp), defined as the distance from the material surface at which the power drops to e-1 of its initial value, is of the same order of magnitude as the material dimension. Assuming an electromagnetic field wave travels along one axis, the penetration depth is calculated following Equation 3:

$$D_p = \frac{c}{2\pi f\sqrt{2\left(1+\tan\delta^2\right)\varepsilon' - 1}} \quad (3)$$

where c is the light velocity in free space (3 x 108 m/s), tan δ is the loss tangent, f is the frequency and ε' is the dielectric constant.

The objective of this research is to study the dielectric properties of MARDI 76 rice, power dissipation and penetration depth at the frequency 915 MHz and 2.45 GHz from temperatures of 27^{o}C to 70^{o}C.

2. Materials and Methods

2.1 MARDI MRQ 76 Rice Sample

The MRQ 76 rice sample was collected from Rice Research Center (RIC) staff at MARDI Pendang and was free from disease and rice weevils. The initial moisture content of MRQ 76 rice sample was 13%. The sample was packed in vacuum plastic PPE packaging materials and brought back to the electronic laboratory at the Engineering Research Centre. The rice sample was prepared in the jacketed sample holder for the measurement of dielectric properties at different temperatures.

2.2 Sample Holder Setup for Dielectric Measurement Using Open-Ended Probe

A specially designed sample holder was constructed using a High-density polyethylene (HDPE) white solid sheet with jacketed features to set the temperature of the MRQ 76 rice sample. The rice sample was placed inside a stainless-steel tube container within the HPDE jacketed sample holder. A Rubber O ring was attached between the stainless tube and HPDE jacketed sample holder to prevent leakage of hot water.

Figure 1. The sample holder and open-ended coaxial-line probe for dielectric properties measurement.

2.3 Dielectric Properties Measurements

The dielectric properties determination of MRQ 76 rice sample was obtained with an Agilent open-ended coaxial-line probe, Agilent E5071C Network Analyser, a sample holder with hot water flow system and Agilent probe. Dielectric properties (dielectric constant and loss factor) were calculated with Agilent Technologies 85070D Dielectric Probe Kit Software which provided dielectric properties values from the reflection coefficient of the material in contact with the active tip of the probe. Settings were made to provide measurements at 51 frequencies on a logarithmic scale from 10 MHz to 8 GHz. The Agilent open-ended coaxial-line probe and Agilent E5071C Network Analyser were calibrated with an open, short, and matched load before the calibration of the open-ended coaxial-line probe with measurements on air, a short-circuit block, and glass-distilled water at 25 °C. The WiseCircu Water Bath Circulator is used to supply the hot water for controlling the temperature of MRQ 76 rice sample inside the jacketed sample holder.

The MRQ 76 rice sample with 0.762 g/cm^3 density was inserted into the sample holder, and the sample holder and the water-jacketed assembly with its supporting platform for the open-ended probe to enter the sample holder and make good contact with the sample. As the sample temperature increased, dielectric measurements were taken at 5°C intervals (3 to 5 min / 5°C interval) until the practical temperature control limit for the equipment was reached at 75°C, where the measurements were terminated.

Figure 2. The permittivity of MRQ 76 rice were measured using Agilent E5071C Network Analyser and an open-ended coaxial-line probe

2.4 Temperature Setting System

The WiseCircu Refrigerator Water Bath was used to regulate the temperature of the MRQ 76 rice sample for measuring the dielectric properties at the different temperatures.

3. Results and Discussion

Results of dielectric properties, penetration depth and power dissipation of MRQ 76 rice at the Industrial, Scientific, and Medical (ISM) heating frequency are presented in Figures 4, 5 and 6. Figure 4 shows a slight increase in dielectric constant and dielectric loss of MARDI 76 rice with the increasing temperature at the heating frequency 915 MHz and 2.45 GHz. The gradual increase in the dielectric constant and dielectric loss with increasing temperature appeared reasonable for MARDI 76 rice containing less water (13% moisture content). A similar trend was also reported by Ling *et al*. (2018) on the effect of temperature on the dielectric constant and dielectric loss of rice bran at heating frequencies of 915 MHz and 2.45 GHz. Both MRQ 76 rice and rice bran have low moisture content of 13% moisture content (MC) and 15% moisture content (MC) respectively. It was also reported that the rate of increase in dielectric constant and dielectric loss with the increased temperature is small for low moisture content samples. Zhao *et al.*, (2019) conducted a study on the trend of dielectric properties of potato starch with low moisture contents (15.1–19.5% w.b.). It was found that its dielectric properties increased with increasing temperature. In another study, Xu *et al.*, (2018) found that for low-moisture food materials, the effect of temperature on the dielectric constant and dielectric loss was mainly because of bound water. Meanwhile, another study conducted by Jones *et al.*, (2022) indicated that a large portion of water inside the grain is in the form of bound water and it has a low value of dielectric properties at the heating frequency of 915 MHz and 2.45 GHz. The dielectric constant and dielectric loss will slightly increase with the increased temperature. The dielectric constant and loss have no significant difference with the influence of temperature changing at the heating frequency of 915 MHz and 2.45 GHz.

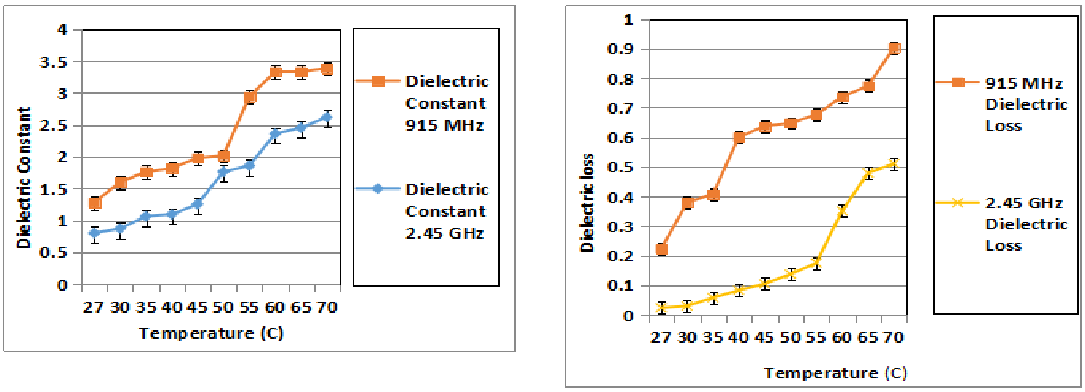

Figure 4. The dielectric constant and dielectric loss of the MRQ 76 rice with measuring temperature 27 C to 70 C at frequency 915 MHz and 2.45 GHz

Figure 5 shows the power dissipation of microwave heating in the MRQ 76 rice increase with the increase in temperature. The power dissipation of microwave heating in the MRQ 76 rice is affected by the dielectric loss of MRQ 76 rice as shown in Equation 2. The higher or lower the dielectric loss factor of MRQ 76 rice will determine the higher or lower microwave power dissipation and the better the MRQ 76 rice can be heated in a microwave field. The result in the figure 5 shows that the power dissipation increases with the increase of temperature for both ISM heating frequencies of 915 MHz and 2.45 GHz. Then, the rate of energy absorption decreases with the increase in temperature. Many studies show that the power dissipation at the ISM heating frequencies is affected by the dielectric properties and temperature (Jain *et al.*, 2018; Ayappa *et al.*, 1991; Budnikov *et al.*, 2023; Wang *et al.*, 2021; Gorakhpurwalla *et al.*, 1975). The change in dielectric properties and temperature will cause the difference of power dissipation and the microwave power distribution pattern inside MARDI 76 rice.

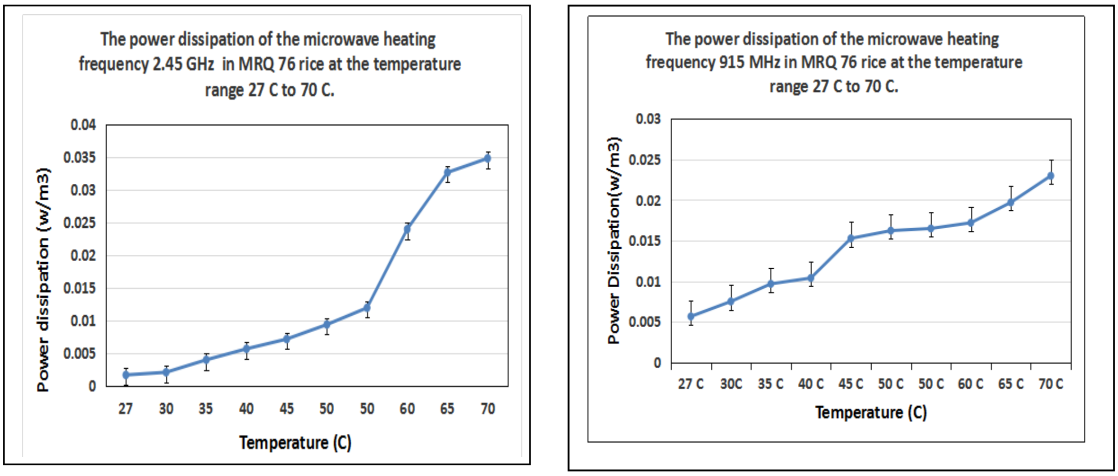

Figure 5. The power dissipation of the MRQ 76 with measuring temperature 27°C to 70°C at frequency 915 MHz and 2.45 GHz

Figure 6 indicates that the penetration depth of microwave heating in the MRQ 76 rice decreases with the increase in temperature. The penetration depth of microwave heating in the MRQ 76 rice is affected by the dielectric loss of MRQ 76 rice as shown in Equation 3. The result in the figure 6 shows that the penetration depth decreases with the increasing temperature for both ISM heating frequencies of 915 MHz and 2.45 GHz. A study conducted by Richard *et al.*, (2016) shows that the penetration of microwave power in beans also decreases with increasing temperature at frequencies of 915 MHz and 2.45 GHz. The penetration depth of MARDI 76 rice is affected by dielectric loss and temperature. Penetration depth is an important parameter to determine the temperature distribution in microwave-heated foods and is generally used to predict the distance that microwave energy can penetrate a food, such as MARDI 76 rice (Auksornsri *et al.*, 2018). Penetration depth is useful to determine the layer for microwave-assisted MARDI 76 rice (Malafronte *et al.*, 2012) or disinfestations procedures using microwave heating technique for the stored MARDI 76 rice at 2450 MHz (Purohit *et al.*, 2013). The penetration depth value is also useful to determine the optimised load dimension of MRQ 76 rice in microwave heating which produces more uniform heating during microwave irradiation (Guo *et al.*, 2010).

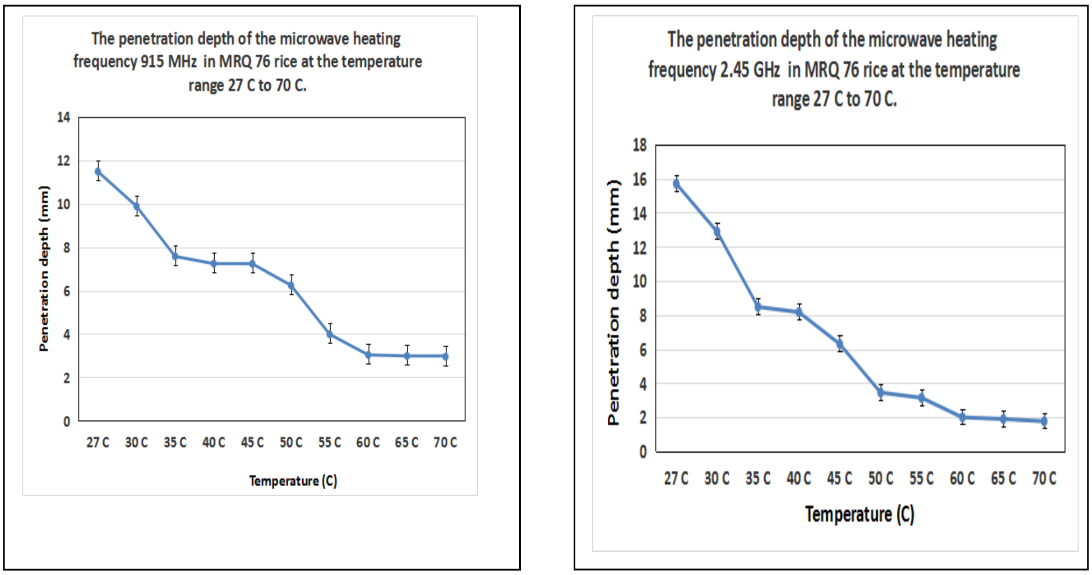

Figure 6. The penetration depth of microwave heating in the MRQ 76 rice with measuring temperature 27 C to 70 C at frequency 915 MHz and 2.45 GHz

4. Conclusions

Dielectric properties, penetration depth and power dissipation of MRQ 76 rice were affected by temperature and moisture content at the ISM heating frequencies of 915 MHz and 2.45 GHz. The dielectric properties and the penetration depth of the rice MRQ 76 decreased with increasing temperature. Low water content in the MRQ 76 rice contributes to the lowest values of dielectric properties and power dissipation of MRQ 76 rice increased with increasing temperature, but is on the order of tens of centimetres, making the development of industrial treatment systems or disinfection possible, particularly at the ISM heating frequency 915 MHz and 2.45 GHz. The result of this study shows that dielectric properties and heating temperature play a vital role in designing the microwave heating system for MARDI MRQ 76 rice.

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References

Auksornsri, T., Tang, J., Tang, Z., *et al*. (2018). Dielectric properties of rice model food systems relevant to microwave sterilization process. *Innovative Food Science and Emerging Technologies*, *45*, 98–105.

Ayappa, G., Davis, H. T., Crapiste, G., *et al*. (1991). Microwave heating: An evaluation of power formulations. *Chemical Engineering Science, 46*, 1005–1016. DOI: 10.1016/0009-2509(91)85093-D.

Budnikov, D., Vasiliev, A., Sharko, A. (2023). Developing of a portable microwave convective drying plant for grain stored in bulk. *Elektrotekhnologii i elektrooborudovanie v APK. 1*. 10.22314/2658-4859-2023-70-1-10-17.

Buttery, R. G., Juliano, B. O., Ling, L. C, (1983). Identification of rice aroma compound 2-acetyl-1-pyrroline in pandan leaves, *Chemistry and Industry*, *23*, 478.

Ling, B., Liu, X., Zhang, L. *et al.* (2018) Effects of temperature, moisture, and metal salt content on dielectric properties of rice bran associated with radio frequency heating. *Sci Rep* **8**, 4427. https://doi.org/10.1038/s41598-018-22567-4

Che Omar, S., Shaharudin, A., Tumin, S. A. (2019). The status of the paddy and rice industry in Malaysia.

Gorakhpurwalla, H. D., McGinty, R. J., Watson, C. A. (1975). Microwave dissipation loss in high-moisture grain. *Journal of Agricultural Engineering Research. 20*. 225–233. DOI: 10.1016/0021-8634(75)90058-X.

Guo, W., Wang, S., Tiwari, G., *et al*. (2010). Temperature and moisture dependent dielectric properties of legumes associated with dielectric heating. *LWT–Food Science and Technology*, 43, 193–201.

Ishitani, K., Fushimi, C. (1994). Influence of pre and postharvest condition on 2-Acetyl-1-pyrroline concentration on aromatic rice. *The Koryo, 183*, 73–80.

Jain, D., Tang, J., Pedrow, P., *et al*. (2018). Effect of changes in salt content and food thickness on electromagnetic heating of rice, mashed potatoes and peas in 915 MHz single mode microwave cavity. *Food Research International. 119*. DOI: 10.1016/j.foodres.2018.10.036.

Jones, S. B., Sheng, W., Or, D. (2022). Dielectric measurement of agricultural grain moisture-theory and applications. *Sensors (Basel)*. *22*(6), 2083. DOI: 10.3390/s22062083. PMID: 35336259; PMCID: PMC8954665.

Malafronte, L., Lamberti, G., Barba, A. A., *et al*. (2012). Combined convective and microwave assisted drying: Experiments and modeling. *Journal of Food Engineering*, *112*, 304–312.

Maneenuam, T., Chanprasert, W., Rittiron, R., *et al*. (2014). Effect of storage temperatures and storage containers on 2-Acetyl-1-pyrroline content in Hom Mali Rice. *The Journal of Agricultural Science*, *45*(2), 377–380

Purohit, P.; Jayas, D. S., Yadav, B. K., *et al*. (2013). Microwaves to control callosobruchus maculates in stored mung bean (Vigna Radiata). *Journal of Stored Products Research, 53*, 19–22.

Richard T-M., María E. S-M., José L. O. C., *et al.* (2016). Dielectric properties of beans at different temperatures and moisture content in the microwave range. *International Journal of Food Properties*, *19*(3), 564–577. DOI: 10.1080/10942912.2015.1038565

Wang, L., Zhao, Y., Ma, W., *et al*. (2021). Utilization efficiency of microwave energy for granular food in continuous drying: From propagation properties to technology parameters. *Drying Technology*, *40*, 1–21. DOI: 10.1080/07373937.2021.1890770.

Wongpornchai, S., Dumri, K., Jongkaewwattana, S., *et al*. (2004). Effects of drying methods and storage time on the aroma and millingquality of rice (Oryzae sativa L.) cv. Khao Dawk Mali 105. *Food Chemistry*, *87*, 407–414.

Xu, B., Wei, B., Ren, X. (2018). Dielectric pretreatment of rape seed 1: Influence on the drying characteristics of the seeds and photochemical properties of cold-pressed oil. *Food and bioprocess technology*, *11*(6), 1236–1247.

Yoshihashi, T. (2002). Quantitative analysis on 2-acetyl-1-pyrroline of an aromatic rice by stable isotope dilution method. *Journal of Food Science*.

Yoshihashi, T., Huong, N. T. T., Surojanametakul, V., *et al*. (2005). Effect of storage conditions on 2-acetyl-1-pyrroline content in aromatic rice variety, khao dawk mali 105. *Journal of Food Science*. https://doi.org/10.1111/j.1365-2621.2005.tb09061.x

Zhao, P., Liu, C., Qu, W., *et al*. (2019). Effect of Temperature and Microwave Power Levels on Microwave Drying Kinetics of Zhaotong Lignite. *Processes*, *7*, 74. https://doi.org/10.3390/pr7020074