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Dielectric properties of edible oils and fatty acids as a function of frequency, temperature, moisture and composition

Hu Lizhi [a], K. Toyoda [b,*], I. Ihara [b]

[a] *Graduate School of Science and Technology, Kobe University, 1-1 Rokkodai-cho, Nadaku, Kobe 657-8501, Japan*
[b] *Faculty of Agriculture, Kobe University, 1-1 Rokkodai-cho, Nadaku, Kobe 657-8501, Japan*

Abstract

Dielectric properties of 10 edible oils and 6 fatty acids were measured over the frequency range 100 Hz–1 MHz. The effects of temperature (20–45 °C), moisture content (0.02–0.31%), and fatty acid component on dielectric properties of oils were investigated. Results indicated that dielectric constant ε' of the oils and fatty acids exhibited same frequency dependence, i.e., a general plateau from 100 Hz to 500 kHz and a decrease from 500 kHz to 1 MHz significantly ($p < 0.05$). The dielectric loss ε'' of the oils decreased with increasing frequency from 100 Hz to 13.2 kHz and then increased with increasing frequency. The ε' of fatty acids increased with an increase in the number of double bonds or molecular chain length. The ε' of oils were mainly affected by the C_{18} unsaturated fatty acids. Partial Least Squares (PLS) analysis provided reliable prediction of the main fatty acid components of oils. Both ε' and ε'' of oils decreased with increasing temperature. The ε' of oil increased with increasing moisture content. The results obtained in this work could be useful for evaluating edible oil quality.

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1. Introduction

As a simple, rapid and non-destructive measuring technique, dielectric spectroscopy provides information about the dielectric response of materials to electromagnetic fields. It is a convenient method for evaluating food quality, especially for detecting moisture content in foods (Toyoda, 2003). This technology has been studied and used extensively in analysis and monitoring quality of various agricultural products and food materials (Nelson, 1991, 2005). The dielectric properties of most materials depend on the frequency of the applied alternating electric field, the temperature, moisture content, density, composition, and structure of the material (Venkatesh and Raghavan,

2004). The studies and applications of these properties were performed in eggs, grains, seeds, fruits, vegetables, juice and wine, baked foods and flours, dairy products, fish, meat products, etc. Much data and information on the dielectric properties of various foods have become available (Christopher, 1997). There have been several attempts to develop relationships between the dielectric properties and composition, based on averages of the dielectric properties of individual components (Sun et al., 1995; Ryynänen, 1995; Kudra et al., 1992). Bengtsson and Risman (1971) reported that both the dielectric constant and loss factor of various foods increased with increasing moisture content. The representative dielectric properties of milk and its constituents at 2.45 GHz were given by Kudra et al. (1992). The equations predicting dielectric properties of fruits and vegetables as a function of moisture and temperature were developed (Calay et al., 1995). Microwave permittivities of bread dough were measured by Zuercher et al. (1990) as a function of water-flour composition,

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* Corresponding author. Tel./fax: +81 78 803 5909.
E-mail address: toyoda@kobe-u.ac.jp (K. Toyoda).

proofing time, and baking time. Nunes et al. (2006) studied the complex permittivity of milk at room temperature (17–20 °C) over the frequency range of 1–20 GHz, they found that the variations of dielectric parameters with fat content and dilution suggested that they may be useful to roughly determine the milk's content in terms of ionic compounds, fats, and carbohydrates and proteins. As a low cost condition-monitoring sensor, the dielectric constant has also been used for monitoring lubricating oil quality on-site, the sensor was designed as a direct measurement of the overall quality of the used oil (contaminants and oxidation) as compare to that of the un-used oil (Carey and Hayzen, 2007).[1]

To guarantee an effective quality control for frying oils and fats, simple and rapid methods for the detection of thermal abuse are needed. Therefore, dielectric method has been studied and applied to determine frying oil deterioration. A patented instrument called Food Oil Sensor (FOS) was developed to measure a change in the ε' of deep-frying oils, the measured value was defined as the FOS readings (Hein et al., 1998). It was reported to be a useful tool in determining heat abuse for frying fats and oils in comparison with conventional analytical techniques (Fritsch et al., 1979). Since the technique was patented in the USA and Germany, the details of the data and information are difficult to access in reported literature. Other similar dielectric measurement instruments have been also developed for evaluating the quality of deep-frying fats and oils (Stier, 2004). Many research works were carried out in dielectric properties of frying fats and oils (EI-Shaml et al., 1992; Paul and Mittal, 1996; Inoue et al., 2002). They reported that the dielectric constant is the most significant indicator for quality control in commercial deep fat frying operations, it was concluded that polymer content and changes of dielectric constant are useful for monitoring frying oil quality. Venkatesh and Raghavan (2000) reported the summaries of various recent studies related to heated edible oils and their characteristics in an effort to establish comparative standards used in deep frying operations in routine food services and processing scenarios. Pace et al. (1968) conducted the dielectric property measurement of commercial cooking oils at microwave frequencies (100, 300, and 1000 MHz) and at varying frying temperatures. It was reported that the differences in dielectric properties among tested fats and oils appear to be attributable to the phase of the material and generally correspond to the degree of unsaturation as evidenced by iodine values. Rudan-Tasič and Klofutar (1999) investigated the dielectric properties and physical and chemical constants of 11 edible oils. They reported that the values of ε' lie in the range of about 3.0–3.2 (at 298.15 K) for the most

oils, the ε' of oils increased somewhat with increasing in the unsaturation (IV) of the oil and decreased with increasing temperature. On-line monitoring of moisture and salt contents of butter was researched over the MW frequency range. It was found that the moisture and salt contents could be independently predicted by measuring the two microwave propagation properties of phase shift and attenuation. It is useful for monitoring the moisture and salt contents of salted butter in its manufacturing process (Shiinoki et al., 1998). Recently, Ahmed et al. (2007) studied dielectric properties of butter with and without salt over the MW frequency range covering 500–3000 MHz. They found that dielectric spectra of unsalted butter differed significantly from the salted one as a function of temperature and moisture content.

In past researches on dielectric properties of edible oils, deterioration evaluation of frying oil has been focused chiefly; the study and application of dielectric properties to oil processing, storage, and food making were limited. Therefore, the fundamentals of dielectric properties relevant to the quality of edible oils, the interaction mechanisms of oil/fat molecules subjected to MW radiation at a broad range of approved frequencies and temperature ranges, and dielectric measurement and its simplicity in analysis needs more research (Venkatesh and Raghavan, 2004).

The objectives of this study were to investigate the effects of frequency, temperature, moisture content, and fatty acid composition on the dielectric properties of oils and fatty acids, and discuss the relationship between dielectric properties and fatty acid composition of the oils.

2. Materials and methods

2.1. Samples

The samples were obtained from 10 different oils, whose fatty acid compositions are presented in Table 1. The oil samples were selected from ordinary edible oils according to the oil types, i.e., the oleic acid type: safflower, sunflower, and olive oils; linoleic acid type: sesame and corn oils; linolenic acid type: soybean and canola oils; and modified oil type: the interesterified oil containing middle chain fatty acids.

The samples were purchased from Japanese and overseas market. The fatty acid component was determined by gas chromatography (GC), in accordance with American Oil Chemist's Society Official Method Ce 1-62 (Reapproved 1997), i.e., the Official and Tentative Methods of AOCS. Preparation of the methyl ester derivatives of fatty acids followed the AOCS Official Method Ce 2-66 (Reapproved 1997).

The 6 fatty acids tested were caprylic, palmitic, stearic, oleic, linoleic, and linolenic acids. Beside caprylic acid, these were the major saturated and unsaturated fatty acids in ordinary oil composition. They are all reagent

Table 1
Measured oil samples and fatty acid composition % (w/w)

Sample	Caprylic	Capric	Palmitic	Stearic	Oleic	Linoleic	Linolenic	Remarks
Sesame			11.12 (9)	3.86 (6)	41.18 (41)	40.67 (43)	0.37 (0–1)	*Reagent, code 25620-65
Soybean			10.64 (11)	4.38 (4)	26.08 (23)	49.99 (53)	5.36 (8)	*Reagent, code 25621-55
Olive			11.78 (10)	3.27 (2)	76.57 (78)	5.71 (7)	0.52 (1)	*Regent, code 25632-44
Olive[2]			10.88 (10)	3.04 (2)	75.97 (78)	7.06 (7)	0.57 (1)	Salad oil
Modified	4.91	2.11	3.35	1.53	61.62	17.11	5.56	Salad oil
Safflower			4.17 (6)	1.56 (2)	79.67 (74)	12.92 (16)	0.31 (0–1)	Salad oil
Corn			11.19 (13)	2.01 (3)	30.68 (31)	53.05 (52)	0.68 (31)	Salad oil
Sunflower			3.28 (4)	3.13 (5)	87.09 (81)	4.36 (8)	0.35 (0–1)	Salad oil
Canola[1]			3.73 (4)	1.78 (2)	64.85 (62)	18.80(22)	6.93 (10)	Salad oil
Canola[2]			3.98 (4)	1.99 (2)	58.59 (62)	20.53 (22)	7.51 (10)	Salad oil

Olive[2], salad oil from Japanese market. Canola[1], salad oil from Japanese market. Canola[2], salad oil from Canada market.
The data in () as average values from "The Chemistry of Oils and Fats" (Gunstone, 2004).
*Regent from Nacalai Tesque. Co., Japan.

grades and were purchased from Nacalai Tesque Co., Japan.

2.2. Dielectric property measurement

Dielectric parameters of oils and fatty acids were measured with a precision liquid test fixture (Agilent, 16452A, Agilent Technologies, Hyogo, Japan) and a precision LCR meter (Agilent, 4284A, Agilent Technologies, Hyogo, Japan) that was connected to a personal computer for control and data logging. The dielectric parameters were measured at 21 logarithmically distributed frequencies between 100 Hz and 1 MHz. The procedure of dielectric measurements is as follows: after measurement system was calibrated, air capacitance C_0 of the test fixture was tested in an incubator controlled at $23 \pm 0.5\,°C$. Around 3.4 ml sample was poured into the test fixture, the dielectric data of the samples were measured automatically at an interval of 11 min at a designated temperature. The measured data were recorded and plotted as a Bode diagram with a Matlab program.

After finishing the measurements for each replicate, the oil sample was drained out from the test fixture, and then the fixture was disassembled, cleaned, and dried in room temperature.

The ε' and ε'' of the oil samples were calculated using the following equations by the software:

$$\varepsilon' = \alpha \left(\frac{C_p}{C_o} \right) \tag{1}$$

where ε' is the dielectric constant (–); α is the correction coefficient (–) (Agilent Technologies, 2000); C_p is the oil capacitance (pF) and C_0 is air capacitance (pF).

$$\varepsilon'' = \frac{1}{C_0 R_P \omega} \tag{2}$$

where ε'' is the dielectric loss; C_0 is the air capacitance (pF), R_p is the equivalent parallel resistance (Ω); ω is angular frequency ($2\pi f$).

Dielectric measurements of oils and fatty acids were taken at $25 \pm 0.5\,°C$. The effect of temperature on the ε'

was evaluated at temperature intervals of $5\,°C$ between 20 and $45 \pm 0.5\,°C$.

The effect of moisture content on the ε' of oils was investigated at different moisture content ranges from 0.02% to 0.31% (w/w).

As the saturated fatty acids have higher melting point, for comparing the dielectric properties of saturated and unsaturated fatty acids in liquid state, the measurement of the fatty acids was carried out at $75 \pm 0.5\,°C$.

Moisture content of oil was determined in accordance with Air Oven Method 2.1.3.2$_{-1996}$ (Standard Method for the Analysis of Fats, Oils and Related Materials by Japan Oil Chemists' Society, 1996), i.e., the samples were weighed and dried in oven for 30 min at $105 \pm 1\,°C$. This procedure was repeated until constant weights were obtained.

2.3. Statistical analysis

All the measurements were carried out in triplicate and mean values and standard deviations were calculated.

The R Project for Statistical Computing (R version 5.2.0) and Matlab (version 7.0) were used to carry out statistical and linear regression analysis of experimental data. The effects of frequency, temperature, moisture, and fatty acid composition on dielectric parameters were determined by paired samples t-test and significance of differences was defined at $p < 0.05$.

3. Results and discussion

3.1. Effect of frequency on dielectric properties

Figs. 1 and 2 present the dielectric spectra of 8 oils and 6 fatty acids as a function of frequency between 100 Hz and 1 MHz. The ε' of various edible oils and fatty acids showed same frequency dependence. In the frequency range of 100 Hz–500 kHz, the dielectric spectra of the tested oils and fatty acids indicated a general plateau and the maximum value, which is much like the values measured at static electric field. It could be assumed that at low frequencies
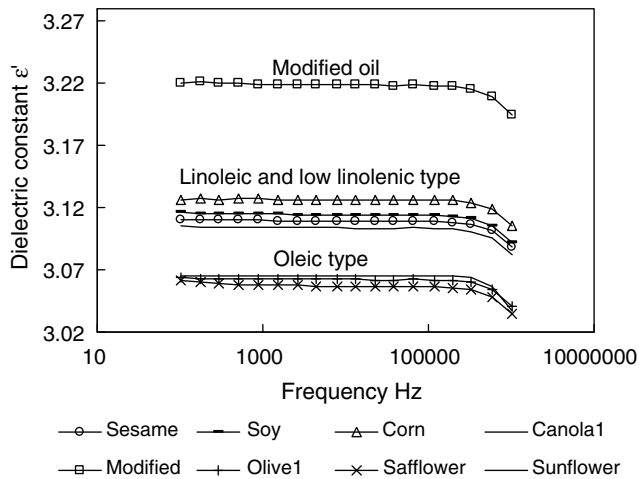
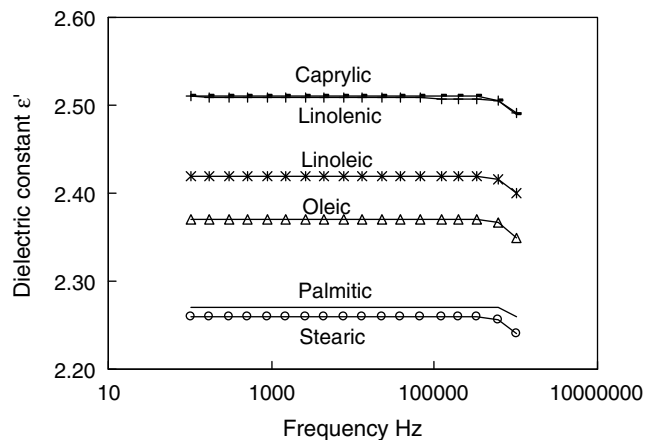Fig. 1. Spectra of dielectric constant of various oils at 25 °C.

Fig. 2. Spectra of dielectric constant of saturated and unsaturated fatty acids at 75 °C.

Fig. 3. Spectra of loss factor of soybean oil at different temperatures.

there is equilibrium between the orientation of the oil molecule and the electric field, therefore, the ε' values showed virtually no frequency dependence in this frequency region, the ε' indicated a constant and the maximum value. As dielectric dispersion occurred, the dielectric spectra diminished from 500 kHz to 1 MHz, significantly ($p < 0.05$).

The ε'' of the oils decreased with increasing frequency from 100 Hz to 13.2 kHz, reached a minimum, and then increased as frequencies were further increased to 1 MHz. As a typical result, the spectra for ε'' of soybean oil are shown in Fig. 3. On the other hand, the stable results for the ε'' of the fatty acids were not observed in this work, the reason was not clear. In this experiment, the dielectric spectra of soybean oil are in close agreement with earlier results of Inoue et al. (2002) in which authors reported the frequency dependence of the ε' and ε'' of fresh soybean oil at 16.5 °C.

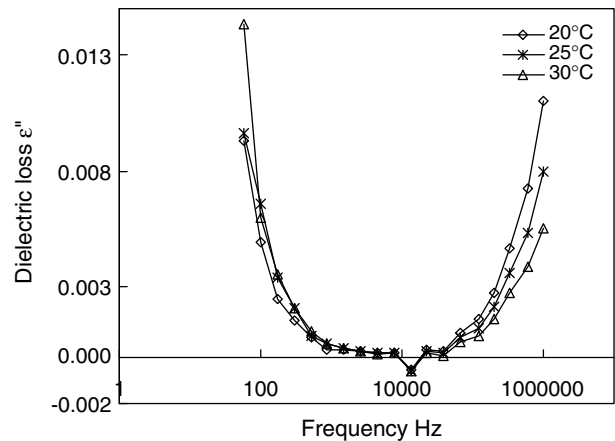It is satisfactory for investigating the variation of dielectric constant of oils and fatty acids in the frequency range of 100 Hz to 1 MHz. The dielectric spectra of oils and fatty acids exhibited a general plateau and the maximum value at lower frequencies, and a decrease significantly at dielectric dispersion area ($p < 0.05$). This change is in accord with the Debye equations for dependence of the ε' on frequency which show that ε' decrease from ε_0 to ε_∞ as frequency is increased. This decreasing tendency is also in close agreement with earlier results of Pace et al. (1968) in which authors reported that in the frequency range of 100 Hz to 8 GHz, the ε' of selectively hydrogenated vegetable shortening showed a general plateau in low frequency range and then a sharp decrease as the frequency was further increased. Otherwise, the study of dielectric properties of oils in low frequency region will benefit the development of a simple and cheap method for evaluating oil quality. Because the investigation was carried out in low frequency region, the ε'' values of the oils were too small to differentiate them clearly from each other. Such that ε'' could be only used as a reference value for each oil.

3.2. Effect of oil composition on dielectric properties

Edible oil can be regarded as a mixture of triacylglycerides (TAGs) which are fatty acid esters of the trihydric alcohol glycerol and contain three alkyl chains in each molecule. It is well-known that ordinary vegetable oils have around 80–90% (w/w) C_{18} unsaturated fatty acids in its composition, so that, the oil physical and chemical properties should be mainly affected by the C_{18} unsaturated fatty acids.

According to the results obtained in this experiment, it was found that the ε' of oils were determined by their fatty acid composition significantly ($p < 0.05$). For instance, as shown in Tables 1, 2 and Fig. 1, the oils of oleic acid type, such as sunflower oil, safflower oil, and olive oil that containing oleic acid of 75.97–87.09% (w/w), indicated the values of the ε' from 3.076 to 3.057 at the frequency range of 100 Hz–500 kHz, and 3.049–3.035 at 1 MHz. The oils that belong to linoleic and low linolenic acid types, like sesame oil, canola oil, soybean oil, and corn oil that containing

Table 2
Dielectric parameters of various oils and fatty acids

Sample	100 Hz–500 kHz		1 MHz	
	25 °C ε'	75 °C ε'	25 °C ε'	75 °C ε'
Oils				
Sesame	3.110 ± 4.2e−04	–	3.088 ± 6.1e−04	–
Soybean	3.115 ± 1.2e−03	–	3.092 ± 1.0e−03	2.911 ± 1.6e−03
Olive[1]	3.062 ± 1.1e−04	–	3.041 ± 1.6e−04	–
Olive[2]	3.076 ± 1.2e−03	–	3.049 ± 3.1e−04	–
Corn	3.127 ± 4.4e−04	–	3.105 ± 5.4e−04	–
Safflower	3.057 ± 1.3e−03	–	3.035 ± 1.7e−03	–
Sunflower	3.065 ± 2.3e−04	–	3.037 ± 2.0e−04	–
Canola[1]	3.104 ± 1.3e−04	–	3.082 ± 1.4e−03	–
Canola[2]	3.110 ± 7.1e−04	–	3.087 ± 5.5e−04	–
Modified	3.220 ± 1.5e−03	–	3.195 ± 5.4e−04	–
Fatty acids				
Caprylic	2.540 ± 5.5e−04	2.508 ± 2.5e−03	2.521 ± 6.6e−04	2.491 ± 8.3e−04
Palmitic	–	2.272 ± 1.6e−03	–	2.258 ± 9.2e−04
Stearic	–	2.253 ± 3.1e−04	–	2.239 ± 1.3e−03
Oleic	2.377 ± 1.4e−03	2.370 ± 1.3e−03	2.361 ± 1.3e−03	2.353 ± 1.2e−03
Linoleic	2.438 ± 4.2e−04	2.418 ± 9.6e−04	2.411 ± 3.2e−04	2.402 ± 7.2e−04
Linolenic	2.543 ± 7.2e−04	2.509 ± 4.2e−04	2.526 ± 1.3e−03	2.493 ± 5.8e−04

Olive[1], regent from Nacalai Co. Olive[2], salad oil from Japanese market. Canola[1], salad oil from Japanese market. Canola[2], salad oil from Canada market.

linoleic acid of 18.80–53.05% (w/w), exhibited the values of 3.104–3.127 between 100 Hz and 500 kHz, and 3.082 to 3.105 at 1 MHz. Although the soybean oil and canola oil belong to linolenic acid type according to the traditional classification, these oils have low linolenic acid content (<10% w/w) and close oleic and linoleic acid composition to that of linoleic acid type, so that they showed the ε' very closely to the oils of linoleic acid type. Modified oil, containing medium chain saturated fatty acid ($C_{8:0}$ of 3.35% w/w and $C_{10:0}$ of 2.11% w/w) and linolenic acid (5.56% w/w), showed the value of 3.220 between 100 Hz and 500 kHz, and 3.195 at 1 MHz. Therefore, according to the spectra of oils as shown in Fig. 1, tested oils could be classified into three groups, i.e., sunflower, safflower, and olive oils had lower ε' values, whereas the sesame, canola, soybean, and corn oils had higher values. The modified oil indicated the highest value ($p < 0.05$).

From these observations, the ε' values of oils were mainly affected by C_{18} unsaturated fatty acids. Furthermore, the ε' of oils increased with increasing the degree of unsaturation of oils (Table 1 and Fig. 1). Therefore, it could be expected that the oils containing high linolenic acid content (50–60%), such as perilla oil and others, will have higher value of dielectric constant than oleic and linoleic type oils. Therefore, it is clear that the ε' of the oils increase with the degree of unsaturation or the number increasing of double bonds of unsaturated fatty acids in oils. This observation is in close agreement with earlier results, i.e., Pace et al. (1968) reported the differences in dielectric properties among tested oils generally correspond to the degree of unsaturation as evidenced by iodine values (*IV*). Rudan-Tasič and Klofutar (1999) also observed that the ε' of oils increased somewhat with increasing in the unsaturation (IV) of the oil.

Relationship between fatty acid composition and dielectric constants were further assessed using Partial Least Squares (PLS) analysis. In this analysis, independent variables, X, were dielectric constants of oils measured over the measured frequencies (15 frequencies), while the dependent variables, Y, were fatty acid components (saturated, oleic, linoleic, and linolenic acids) of oils. The prediction capability of the regression model was assessed by cross-validation, i.e., the root mean square (RMS), standard error of root mean square sd(RMS) and Q^2 value. Q^2 value is determined by the following equations:

$$PRESS = \sum_{i-1}^{n}(y_i - \hat{y}_i)^2 \tag{3}$$

$$Q^2 = 1 - \frac{PRESS}{\sum_{i-1}^{n}(y_i - \bar{y})^2} \tag{4}$$

where *PRESS* was the Predicted Residual Sum of Squares, $\hat{y}$ was the fitting values, y was the response values, $\bar{y}$ was the mean values.

Fig. 4 shows that the regression model provided reliable prediction of the percentage of oleic acid and linoleic acid of oils. The RMS was 11.49, sd(RMS), 4.06, and Q^2, 0.71 for oleic acid; The RMS was 11.55, sd(RMS), 4.08, and Q^2 value, 0.60 for linoleic acid. From this result, dielectric spectroscopy could be applied in predicting the main fatty acid components of oils.

Fig. 5 shows the regression coefficients of fatty acids at 15 measured frequencies. The different measured frequencies indicated different coefficients. From this figure, the relationship between the ε' of oils and fatty acid composition was further clarified. For example, at 1 MHz, saturated fatty acids and linolenic acid showed weak positive correlation on ε' of oils, 2.9 and 4.2 respectively, oleic acid
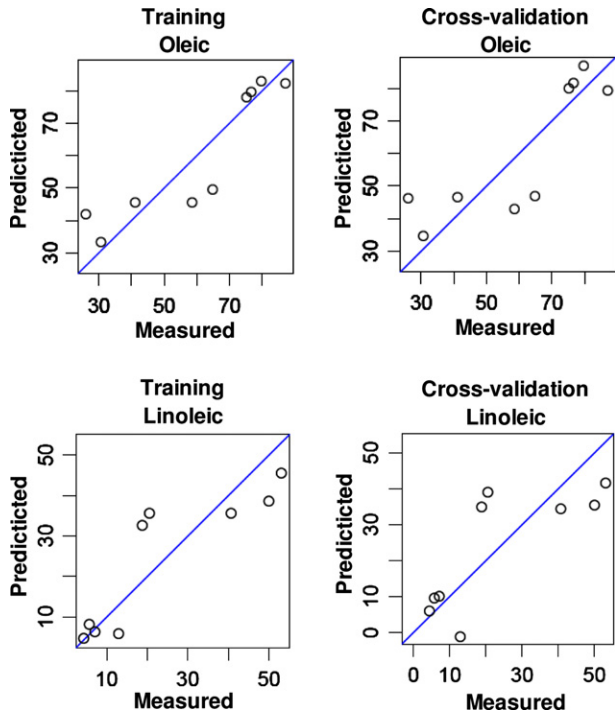
Fig. 4. Prediction capability of regression model.

indicated large minus correlation on ε' of oils, −53.8, whereas linoleic acid showed large positive correlation on ε' of oils, 44.2.

The results indicated that ε' of the oils could be useful to classify the oils into several groups depending on their fatty acid compositions. These findings suggested that dielectric spectroscopy could be useful for differentiating the oils and estimating fatty acid composition of oils.

3.3. Effect of temperature on dielectric properties

Tested edible oils showed small values of dielectric constant. It indicates that the dielectric measurement with high precision is necessary for the identification of edible oil products and the monitoring of oil quality. Therefore, the effect of temperature on the ε' should be quantitatively evaluated as a factor of the measurement disturbance. Besides, the temperature dependence of dielectric constant can provide useful information for temperature compensation of the measured values.

As a representative result among the tested oils, Figs. 3 and 6 show the dielectric spectra of soybean oil at different temperatures. Both ε' and ε'' of edible oils demonstrated a remarkable decrease with increasing temperature ($p < 0.05$). A similar tendency also existed in the tested unsaturated fatty acids as shown in Fig. 7, the ε' of oleic, linoleic, and linolenic acids diminished linearly with increasing temperature, the decreased gradient was lower than that of the oils. The linear regression analysis by Matlab showed that the effect of temperature on the ε' and ε'' of
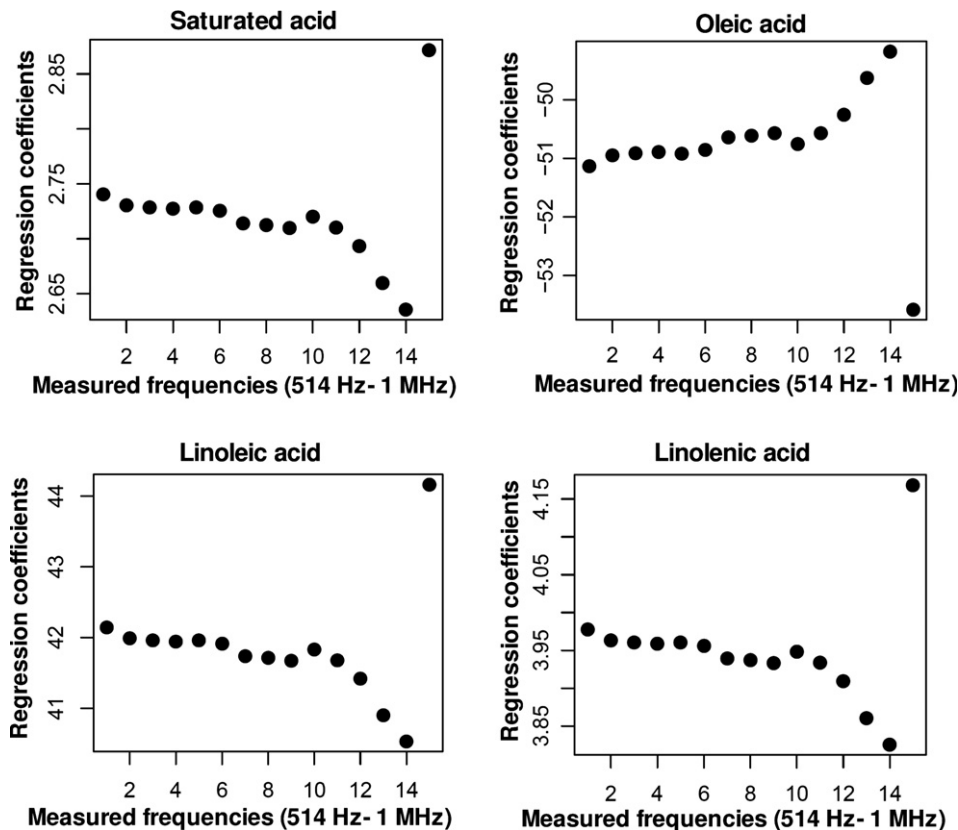

Fig. 5. Regression coefficients of fatty acids at different frequencies.
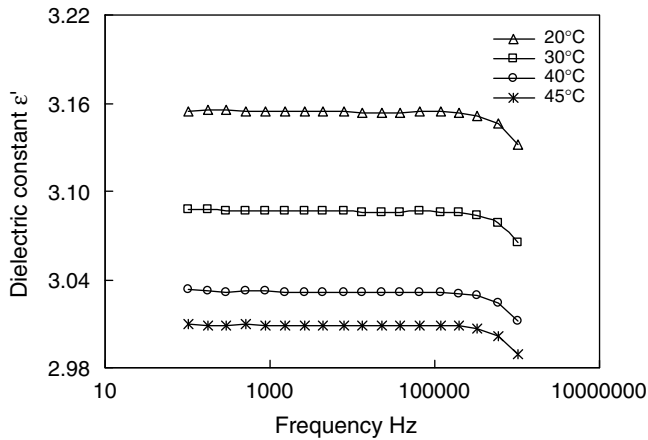
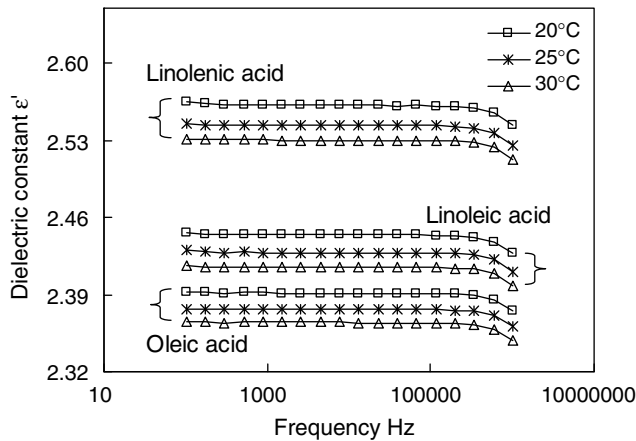Fig. 6. Temperature dependence of dielectric constant of soybean oil.

Fig. 7. Temperature dependence of dielectric constant of C_{18} unsaturated fatty acids.

oils and the ε' of unsaturated fatty acids were adequately fitted to the following first-order polynomial equations:

Soy $\varepsilon' = -0.006t + 3.25$,   (Linear: norm   of residuals = 0.00057).

Soy $\varepsilon'' = -0.00048t + 0.019$,   (Linear: norm   of residuals = 0.00028).

Linolenic $\varepsilon' = -0.003t + 2.6$,   (Linear: norm   of residuals = 0.00163).

Linoleic $\varepsilon'' = -0.003t + 2.49$,   (Linear: norm   of residuals = 0.0016).

Oleic $\varepsilon' = -0.002t + 2.41$,   (Linear: norm   of residuals = 0.00083).

The temperature dependence of the ε' of oils and C_{18} unsaturated fatty acids could be assumed that at low temperature high internal viscosity leads to longer relaxation time, and little dipole orientation and low values for the ε' and ε''. As the temperature increased, oil and fatty acid viscosity decrease, relaxation times decrease leading to an increase in dipole moment and a decrease in the ε' and ε''. It is well-known that the viscosity of oils and fatty acids decrease with the degree of unsaturation increasing. Therefore, it could be assumed that the different viscosity of oils

and fatty acids resulted in the differences of decreased gradient of ε' of different oils and fatty acids with increasing temperature.

3.4. Effect of moisture content on dielectric properties

From the results obtained in this experiment, the oil and water showed different values of dielectric constant. For example, water showed ε' value of 77.02, whereas the ordinary oils investigated showed 3.04–3.20 at 1 MHz and 25 °C, the wide differences between the ε' of oils and water resulted in the remarkable effect on the ε' of oils. The differences are due to water is a polar molecule, it experiences an orientation or polarization with the applied field, orientation of the molecule in response to the electric field stores energy, the magnitude of the energy storage of water molecules is much greater than that of oil molecules.

As shown in Fig. 8, the results indicated clearly that the ε' of corn oil increased with increasing moisture content and decreased with increasing frequency, significantly ($p < 0.05$). The change in the ε' of corn oil was found to follow second-order polynomial equations with moisture content (Fig. 9). The determined regression curve can be
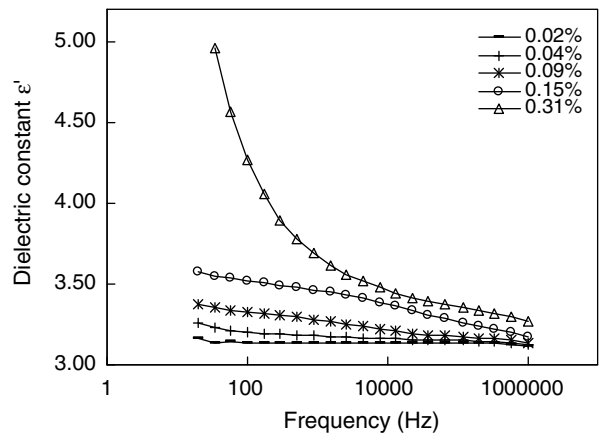

Fig. 8. The effect of moisture content on dielectric constant of corn oil at different frequencies.
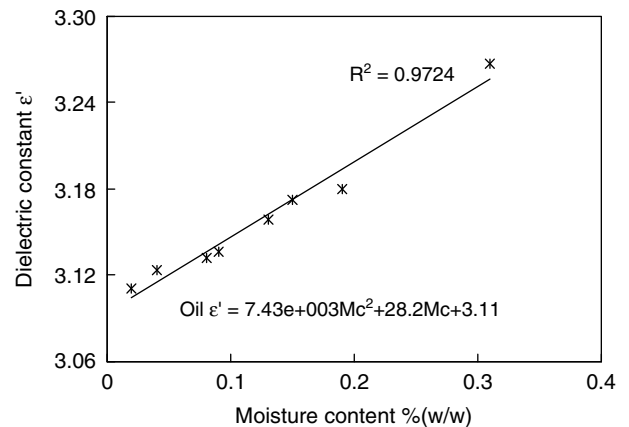

Fig. 9. The effect of moisture content on dielectric constant of corn oil at 25 °C and 1 MHz, where, Mc: moisture content % (w/w).

applicable to predict the effect of moisture content on ε' of the oil from 0.02% to 0.31% (w/w).

Accordingly, the effect of moisture content on ε' of the oils could be evaluated by the dielectric spectra measured. The moisture content in oils, on the other hand, could be estimated by monitoring the variation of the dielectric spectra of oil in oil processing and storage.

4. Conclusions

The ε' of various edible oils and fatty acids showed same frequency dependence and specific values for each oil and fatty acid. The dielectric spectra exhibited a general plateau and the maximum value at lower frequencies, and a decrease significantly at dielectric dispersion area.

The ε' values of oils were affected by their fatty acid composition significantly. The ε' of oils is in good agreement with the degree of unsaturation or the type of oils. PLS analysis indicated that dielectric spectroscopy could be used for predicting the main fatty acid components of oils.

Both ε' and ε'' of oils demonstrated a gradual decrease with increasing temperature, the ε' of fatty acids also showed similar temperature dependence. The effect of temperature on the ε' of oils and unsaturated fatty acids can be adequately evaluated by a first-order polynomial equation.

The ε' of the oils increased with increasing moisture content, this effect diminished as frequency was increased, significantly ($p < 0.05$).

The results obtained in this study could be useful in oil identification, quality evaluation, and quality monitoring during oil processing and storage.

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