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Research Article

Effect of Adulteration of Palm Oil on Dielectric Properties and Electrical Conductivity of Mustard Oil

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ABSTRACT

The current study was planned to investigate the palm oil adulteration in mustard oil by the potential of dielectric properties and electrical conductivity. The analysis was carried out at different frequencies (10, 30, 50, 70 and 100 kHz) and temperatures (30, 40, 50, 60 and 70°C) for mustard oil, palm oil and different concentrations of palm oil in mustard oil (10, 20, 30 and 40%). The frequency had negligible effect on dielectric constant, whereas dielectric loss decreased with increase in frequency. Dielectric constant decreased with increasing temperature, while loss increased with increase in temperature. Both parameters increased with increase of palm oil concentrations in mustard oil. Electrical conductivity increased with increasing temperature, frequency and palm oil concentration in mustard oil. The correlation coefficients (R^2>0.87) were established using regression equations relating dielectric constant, dielectric loss and electrical conductivity.

Key words: Dielectric constant, dielectric loss, electrical conductivity, mustard oil, palm oil

Introduction

Edible oils are fatty liquids that can be extracted from seeds or fruits of several plants like sunflower, rapeseed, soybean, palm etc. These form an important part of a healthy diet and have great nutritional value. These compose natural antioxidant agents to counteract auto-oxidation, which helps preserve oil consistency and are the versatile form of fats. Fatty acids of edible oils are classified into saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA). SFA are considered to be harmful. Edible oils having good amount of unsaturated fatty acids are good for human health. Mustard oil is widely used edible oil as it contains a good ratio of monounsaturated and polyunsaturated fatty acids. Kachchi ghani mustard oil is pure form of mustard oil.

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Mustard oil accounts for 18% of Indian edible oil consumption. The large consumption for edible oils has been increasing ever since and these facts make edible oils vulnerable to adulteration. Therefore, there is need of developing efficient methods to detect edible oil adulteration. The non-destructive techniques (NDT) are used to evaluate the properties of a material without influencing the physical or chemical properties.

The measurement of dielectric and electrical properties has opened up new avenues for understanding and interpreting the material and characterization of physiochemical properties. During this period of development, these two parameters become excellent standards for quality assurance and refining of various agricultural and food products. The dielectric properties are mainly defined in terms of two important terms; relative permittivity or dielectric constant, ε′ and dielectric loss, ε″. The permittivity of a material is associated with its (electrical) energy storage capacity. On the other hand, a parameter that involves in dissipation of energy in the form of heat when the external field is oscillating at some definite frequency is defined by dielectric loss. The electrical conductivity of material is important for evaluation of quality. Electrical conductivity of a substance is the ability to conduct an electrical current.

In the present study, the effect on dielectric properties and electrical conductivities due to palm oil adulteration in mustard oil has been analysed at different temperatures and frequencies.

Materials and Methods

In this study, the experiments were performed on kachchi ghani mustard oil and palm oil procured from the local departmental store. The raw mustard oil was adulterated with four different concentrations (10, 20, 30 and 40%) on volume-by-volume basis. All the measurements were made for pure mustard oil, palm oil and four different concentrations of palm oil in mustard oil in the temperature range 30 to 70°C. The construction of cylindrical-shaped cell was carried out for this study. It consisted of two cylinders of stainless steel. These cylinders acted as electrodes and the sample solution was filled in the space between the two cylinders. The schematic diagram of sample cell has been shown in Fig. 1. The parameters were measured using the HIOKI LCR Hi-TESTER (model 3522-50). The dielectric constant of the given mustard oil sample was calculated by measuring the capacitance of the sample holder with air (C_0) as dielectric medium and then that with the mustard oil sample as the dielectric medium (C). The relative permittivity of mustard oil sample is then simply evaluated by dividing later with former.

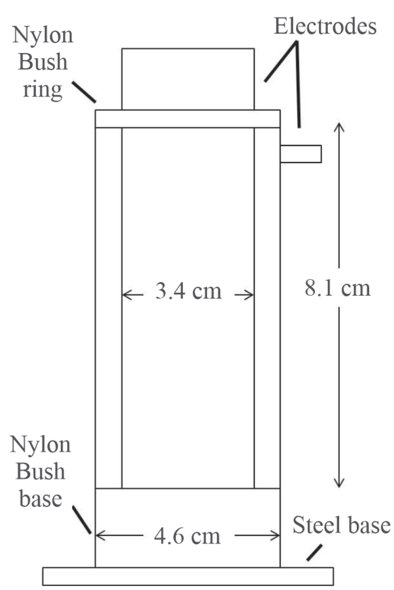

Fig. 1. Simple outline of the sample holder

$$\varepsilon' = \frac{C}{C_0}$$

The permittivity of the material is known as complex relative permittivity when the applied field is alternating and it is given as;

$$\varepsilon = \varepsilon' + i\,\varepsilon''$$

The value of the dielectric loss is directly measured by LCR. The conductivity was evaluated by measuring the conductance of the sample using relationship.

$$\sigma = Gl/A$$

where, G is conductance, l is the distance between electrodes and A is the common surface area of the electrodes.

Results and Discussion

Variation of dielectric properties and electrical conductivity with temperature and palm oil adulteration

The plot of variation of dielectric constant with temperature for all the concentrations of palm oil in mustard oil at 50 kHz frequency have been shown in Fig. 2. Similar plots have been observed at other frequencies. The dielectric constant was observed to decrease with increasing temperature for all concentrations. The dielectric constant of mustard oil was less as compare to palm oil. With the increase of palm oil concentrations in mustard oil, the dielectric constant increases. The values of mustard oil were observed to be in the range of 2.17 to 1.96 at 50kHz and over the temperature range of 30 to 70°C. The similar range of dielectric constant of mustard oil was 2.4-2.1 over the temperature range of 30-80°C as reported by Bhargava *et al.* (2016) at

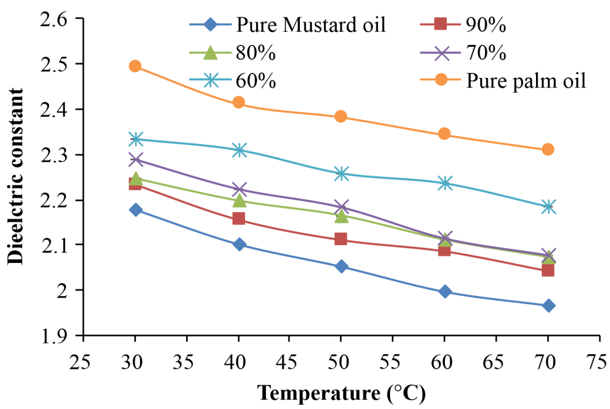

Fig. 2. Variation of dielectric constant with temperature for different concentrations at 50 kHz frequency

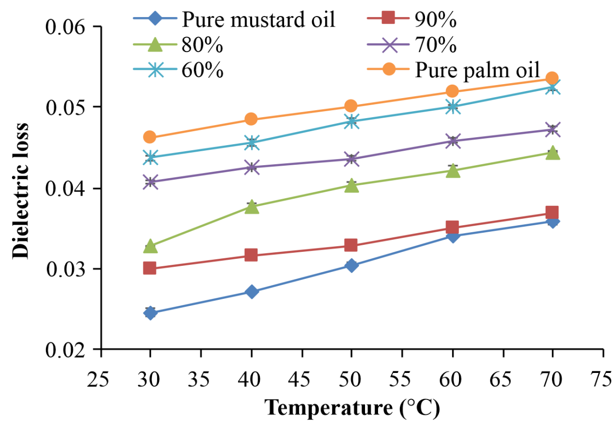

Fig. 3. Variation of dielectric loss with temperature for different concentrations at 50 kHz test frequency

9.32GHz. Chaudhari (2017) observed the similar variation of dielectric constant in the frequency range 5.85-8.2 GHz for safflower oil, mustard oil, coconut oil and sesame seed oil with increasing temperature having range 30 to 70°C. The dielectric constant of palm oil at 50kHz frequency was observed to be in the range of 2.41 to 2.30 in temperature range from 30 to 70°C. Sunuwar *et al.* (2017) reported the value of dielectric constant for palm oil was 2.43 at 25°C, consistent with the present study. The decrease in dielectric constant with increasing temperature is on account of the increase in the kinetic energy of molecules, which leads to greater randomness in motion and it decreases the dipole orientation which results in low dielectric constant. The variation of dielectric constant with palm oil concentration in mustard oil can be observed from Fig. 2. The dielectric constant of mustard oil was observed to increase with increase in concentration of palm oil. At 50 kHz frequency and 30°C temperature, the value dielectric constant was 2.17 for pure mustard oil and 2.49 for pure palm oil. The values of dielectric constant for 10, 20, 30 and 40% impurity of palm oil in mustard were 2.23, 2.27, 2.28 and 2.33 respectively. Bansal *et al*. (2001) also observed the increase in dielectric constant of mustard oil adulterated with rapeseed oil at frequency of 100 KHz and 8.93GHz. The increase in dielectric constant of mustard oil with increasing concentration of palm oil may be due to change in degree of unsaturation. As the concentration of impurity increases in mustard oil, the amount of unsaturation gets lower and hence, density decreases. The change in degree of unsaturation contributes to increase in dielectric constant (Agrawal and Bhatnagar, 2005).

Dielectric loss was observed to increase with increasing temperature as shown in Fig. 3. The dielectric loss of was observed to be in range of 0.024 to 0.035 for mustard oil and 0.046 to 0.053 for palm oil at 50kHz frequency and in the temperature range from 30 to 70°C. The similar trend of increase in dielectric loss with temperature for mustard oil was also reported by Bhargava *et al.* (2016) and for palm oil by Pecovska-Gjorgjevich *et al.* (2011). On increasing the temperature, the decrease in viscosity corresponds to decrease in relaxation time and hence, dipole moment increases (Hsung *et al*., 2019) which results in increase in dielectric loss. Dielectric loss was also observed to increase with increasing palm oil concentration in mustard oil. The increase in value of dielectric loss with increasing concentration of palm oil may be due to the change in degree of unsaturation. At 50 kHz frequency and 30°C temperature, the value of dielectric loss was 0.024 for pure mustard oil and 0.046 for pure palm oil. The values of dielectric loss for 10, 20, 30 and 40% impurity of palm oil in mustard were 0.029, 0.032, 0.040 and 0.043 respectively. The dielectric loss of mustard oil was 0.05 as reported by Chaudhari (2017) at 30°C and at frequency of 7.0 GHz. Lizhi *et al.* (2008) studied the dielectric properties of edible oils and fatty acids over the frequency and temperature range 100-1 MHz and 20-45°C. They observed the similar trend of increase in dielectric loss with

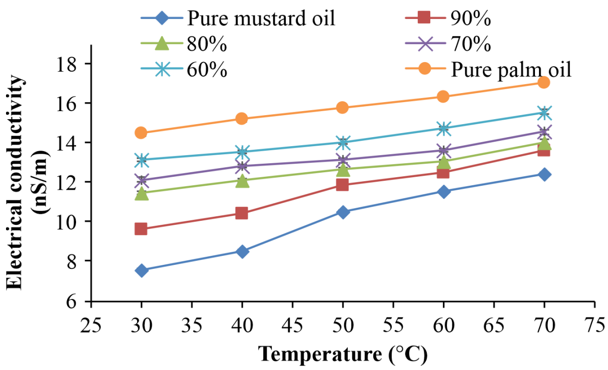

Fig. 4. Variation of the electrical conductivity with the temperature for different concentrations at 50 kHz test frequency

composition of fatty acids. Bansal *et al.* (2001) explained that dielectric properties of edible oils are directly associated with fatty acid composition of sample.

The electrical conductivity also increased with increasing temperature and the plot has been shown in Fig. 4. The electrical conductivity of mustard oil was observed to be in the range of 7.59 to 12.42 nS/m at 50 kHz frequency and in the temperature range from 30 to 70°C. Valantina *et al.* (2016) studied the conductivity of mustard oil over the temperature range of 25 to 85°C and reported it to be 5 nS/m. The trends of this study are also in good agreement with the study of Kumar *et al.* (2011). They reported the value of electrical conductivity of mustard oil was found to increase with increasing temperature in the range of 20 to 100°C and at frequency of 50 KHz. Corach *et al.* (2014) studied the variation of electrical conductivity with temperature in the range of 27 to 70°C. The measurements were done for different edible oils over the frequency range 20 Hz to 2 MHz. They reported the similar trend of increase in conductivity with increasing temperature and the variation was correlated with a good fit to a linear function. The increase in temperature decreases the viscosity of oil and this increases the mobility of polar molecules and hence, electrical conductivity increases (Kumar *et al.,* 2011). The electrical conductivity of mustard oil was observed to increase with concentration of palm oil. At 50 kHz frequency and 30°C temperature, the value of electrical conductivity was 7.59 nS/m for pure mustard oil and 14.47 nS/m for pure palm oil. The values of electrical conductivity for 10, 20, 30 and 40% impurity of palm oil in mustard were 9.63, 11.48, 12.14 and 13.14 nS/m respectively. The similar trend of increase in electrical conductivity with increase in impurity concentration for mustard oil was also reported by Kumar *et al*. (2011). Further, Rashvand *et al*. (2016) studied the adulteration of olive oil with maize, sunflower and soya oil using dielectric technique. Since the electrical conductivity of edible oils is directly associated with its chemical composition, hence the conductivity gets increased in edible oils with increase in impurity. Valantina *et al.* (2016) explained that conductivity is an intrinsic property of the material to allow the flow of electrical charges. This movement of charges in the oil sample depends mainly on unsaturation composition. The decrease in unsaturation leads to easy movement of charges and hence, conductivity increases on decreasing the amount of unsaturation with addition of impurity.

Variation of dielectric properties and electrical conductivity with frequency

The dielectric constant slightly increases with increase in frequency as shown in Fig. 5. The dielectric constant of mustard oil was observed to be in range of 2.11 to 2.20 over the frequency range of 10-100 kHz and at temperature of 30°C. Lizhi *et al.* (2008) also observed the negligible variation of dielectric constant with frequency for edible oils and fatty acids in the range 100 Hz to 500 KHz. The dielectric constant of palm oil was observed to be in range of 2.43 to 2.51 over the frequency range of 10-100 kHz and at temperature of 50°C. Further,

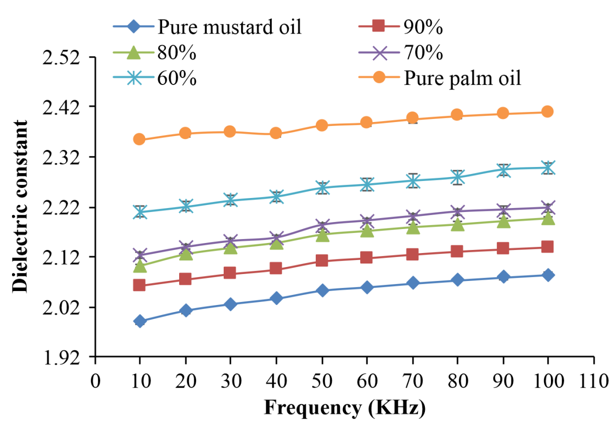

Fig. 5. Variation of dielectric constant with frequency for different concentrations at 50°C temperature

Pecovska-Gjorgjevich *et al.* (2011) studied the variation of dielectric constant with frequency for palm oil and observed the similar variation with frequency. The dependence of frequency on dielectric constant can be understood by the fact of polarisation. Over a small range of frequencies, the polarisation is incomplete and the change in electric field has negligible effect on electric dipoles. This does not correspond to orientation polarisation and hence, dielectric constant does not show considerable variation with increasing frequency.

Dielectric loss decreased with increase in frequency as shown in Fig. 6. The dielectric loss of mustard oil was observed to be in range of 0.029 to 0.020 over the frequency range of 10-100 kHz and at temperature of 30°C. Bhargava *et al.* (2016) observed the slight decrease of dielectric loss for mustard oil as the frequency was increased from 4.65-9.42 GHz. Further, Vrba and Vrba (2013) supported the decreasing trend of dielectric loss with increasing frequency in the range of 1-3000MHz for sunflower oil and olive oil.

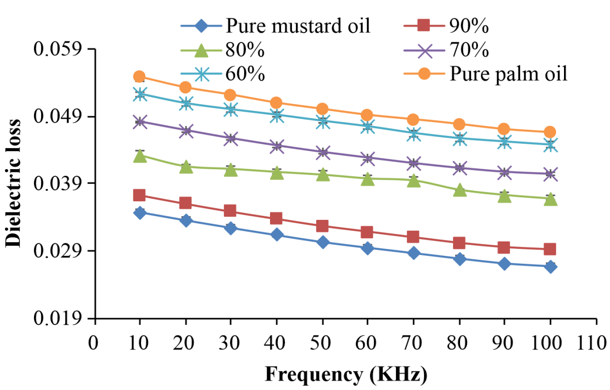

Fig. 6. Variation of dielectric loss with temperature for different frequencies at 50 °C temperature

Kumar *et al.* (2011) interprets that with change in frequency, phase of polarisation changes relative to applied electric field. The relaxation of polarisation attributes to relaxation time and this change in relaxation time accounts to decrease in dielectric loss.

The electrical conductivity was found to increase with an increasing frequency as shown in Fig. 7. The electrical conductivity of mustard oil was observed to be in range of 1.86 to 14.01 nS/m over the frequency range of 10-100 kHz and at temperature of 30°C. Irfan *et al.* (2020) studied the electrical conductivity of different vegetable oils in the frequency range of 20 Hz to 2 MHz and they observed the similar linear trend of increase in conductivity with frequency. Vrba and Vrba (2013) also reported the increase in conductivity with increasing frequency in the range of 1-3000 MHz for sunflower oil and olive oil. The conductance of charge in an a.c. field is made possible due to the frequent motion of charge carriers about their mean positions. It has been clearly established that the a.c. conductivity directly depends upon the frequency of the applied field.

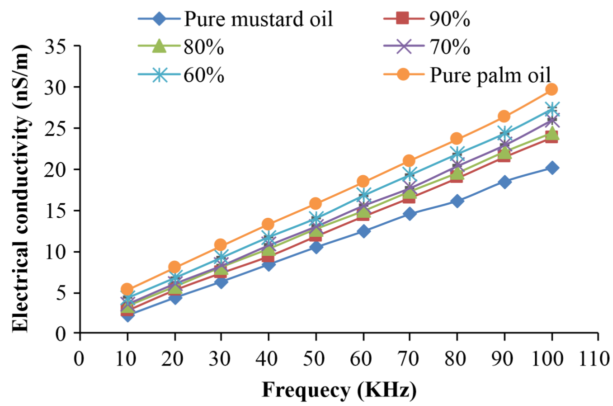

Fig. 7. Variation of electrical conductivity with temperature for different frequencies at 50°C temperature

The Analysis of Variance (ANOVA) method has been applied on the dielectric constant, dielectric loss and electrical conductivity data to determine the significance of effect of palm oil adulteration in mustard oil on the dielectric properties at 5% confidence level for different temperatures. The statistical analysis showed that the adulteration of palm oil has significant effect on dielectric properties and electrical conductivity for impurity levels above 20% at all temperatures respectively.

Mathematical modeling of dielectric properties and electrical conductivity

A mathematical model was constructed using the data of dielectric constant, dielectric loss and conductivity for different palm oil concentrations in mustard oil at different temperatures and frequencies. The regression model is a modelling technique which investigates the goodness of fit and the statistical significance of the estimated parameters. This analysis is important for modelling the relationship between a single variable called dependent variable (y(f,T,S)) and independent variables and sketches out a relationship them. It also quantifies the alterations produced in a dependent variable by the independent variables (S) independently. In this context the most well-known model is coefficient of regression (R^2). Larger coefficient of determination is favourable to obtain the goodness of fit. A mathematical model was analysed using the dielectric constant-palm oil impurity levels in mustard oil at different temperatures and frequencies. A linear model was established for the data of mustard oil samples, given as

$$y(f,T,S) = A(f,T) + B(f,T)S$$

where y(f,T,S) represents the given parameter of mustard oil sample obtained at a specific frequency, f(kHz) for a particular temperature, T(°C) in terms of impurity by percentage volume, S. A(f,T) and B(f,T) are regression coefficients. A(f,T) denotes the constants of dielectric constant-palm oil impurity concentration relationships whereas, B(f,T) measures the extent to which dielectric constant, dielectric loss and electrical conductivity values change on raising the palm oil concentration in pure mustard oil. Physically, regression constants B(f,T) and A(f,T) represent the slopes and the intercepts respectively. The linear models for dielectric properties have been given in Table 1 and 2. The linear dependence is also verified for dielectric constant and dielectric loss by Lizhi *et al.* (2008) and Bhargava *et al.* (2016). The linear model for conductivity has been given in Table 3, and such model was verified by Valantina *et al.* (2016).

Table 1. The constants and coefficients of dielectric constant-palm oil relationships for mustard oil adulterated at different levels for different temperatures

Frequency (kHz)	Temperature (°C)	Dielectric constant-Palm Oil (%)	Regression coefficient (R^2)
10	30	$\varepsilon' = 0.0041S + 2.1158$	0.988
	40	$\varepsilon' = 0.005S + 2.0421$	0.975
	50	$\varepsilon' = 0.005S + 1.9976$	0.959
	60	$\varepsilon' = 0.0049S + 1.9976$	0.924
	70	$\varepsilon' = 0.0047S + 1.9277$	0.881
30	30	$\varepsilon' = 0.0036S + 2.1626$	0.977
	40	$\varepsilon' = 0.0049S + 2.081$	0.969
	50	$\varepsilon' = 0.0048S + 2.0305$	0.964
	60	$\varepsilon' = 0.0048S + 1.9887$	0.887
	70	$\varepsilon' = 0.0046S + 1.9604$	0.881
50	30	$\varepsilon' = 0.0037S + 2.1817$	0.976
	40	$\varepsilon' = 0.0048S + 2.1009$	0.968
	50	$\varepsilon' = 0.0048S + 2.0573$	0.976
	60	$\varepsilon' = 0.005S + 2.0084$	0.878
	70	$\varepsilon' = 0.0047S + 1.9757$	0.900
70	30	$\varepsilon' = 0.0037S + 2.1961$	0.982
	40	$\varepsilon' = 0.0048S + 2.1164$	0.969
	50	$\varepsilon' = 0.0049S + 2.0715$	0.981
	60	$\varepsilon' = 0.0052S + 2.0196$	0.900
	70	$\varepsilon' = 0.0047S + 1.9878$	0.911
100	30	$\varepsilon' = 0.0036S + 2.2051$	0.985
	40	$\varepsilon' = 0.0048S + 2.1299$	0.968
	50	$\varepsilon' = 0.005S + 2.0863$	0.977
	60	$\varepsilon' = 0.0054S + 2.0472$	0.924
	70	$\varepsilon' = 0.0048S + 2.0063$	0.908

Table 2. The constants and coefficients of dielectric loss-palm oil relationships for mustard oil adulterated at different levels for different temperatures

Frequency (kHz)	Temperature (°C)	Dielectric loss-Palm Oil (%)	Regression coefficient (R^2)
10	30	$\varepsilon'' = 0.0005S + 0.0292$	0.974
	40	$\varepsilon'' = 0.0005S + 0.0315$	0.988
	50	$\varepsilon'' = 0.0005S + 0.0341$	0.988
	60	$\varepsilon'' = 0.0004S + 0.037$	0.967
	70	$\varepsilon'' = 0.0004S + 0.039$	0.958
30	30	$\varepsilon'' = 0.0005S + 0.0267$	0.981
	40	$\varepsilon'' = 0.0005S + 0.0293$	0.993
	50	$\varepsilon'' = 0.0005S + 0.0317$	0.986
	60	$\varepsilon'' = 0.0004S + 0.0347$	0.967
	70	$\varepsilon'' = 0.0004S + 0.0364$	0.967
50	30	$\varepsilon'' = 0.0005S + 0.0245$	0.979
	40	$\varepsilon'' = 0.0005S + 0.0274$	0.989
	50	$\varepsilon'' = 0.0005S + 0.0297$	0.977
	60	$\varepsilon'' = 0.0004S + 0.0329$	0.965
	70	$\varepsilon'' = 0.0004S + 0.0346$	0.961
70	30	$\varepsilon'' = 0.0005S + 0.0229$	0.986
	40	$\varepsilon'' = 0.0005S + 0.0259$	0.974
	50	$\varepsilon'' = 0.0005S + 0.0282$	0.965
	60	$\varepsilon'' = 0.0004S + 0.0312$	0.964
	70	$\varepsilon'' = 0.0004S + 0.0327$	0.970
100	30	$\varepsilon'' = 0.0005S + 0.0211$	0.973
	40	$\varepsilon'' = 0.0005S + 0.0239$	0.948
	50	$\varepsilon'' = 0.0005S + 0.0261$	0.978
	60	$\varepsilon'' = 0.0004S + 0.0295$	0.970
	70	$\varepsilon'' = 0.0004S + 0.0312$	0.974

Table 3. The constants and coefficients of electrical conductivity-palm oil relationships for mustard oil adulterated at different levels for different temperatures

Frequency (kHz)	Temperature (°C)	Electrical conductivity-Palm Oil (%)	Regression coefficient (R^2)
10	30	$\sigma = 0.0407S + 1.8787$	0.997
	40	$\sigma = 0.0484S + 2.0232$	0.993
	50	$\sigma = 0.0526S + 2.198$	0.990
	60	$\sigma = 0.0576S + 2.3586$	0.991
	70	$\sigma = 0.0604S + 2.8732$	0.987
30	30	$\sigma = 0.092S + 4.8986$	0.957
	40	$\sigma = 0.092S + 5.3155$	0.961
	50	$\sigma = 0.0691S + 6.4953$	0.966
	60	$\sigma = 0.0642S + 7.0752$	0.950
	70	$\sigma = 0.0683S + 7.824$	0.956
50	30	$\sigma = 0.1361S + 8.0782$	0.953
	40	$\sigma = 0.1244S + 9.0059$	0.949
	50	$\sigma = 0.084S + 10.761$	0.966
	60	$\sigma = 0.0758S + 11.583$	0.981
	70	$s = 0.0722S + 12.608$	0.966

70	30	s = 0.1883S + 11.07	0.932
	40	σ = 0.1702S + 12.383	0.947
	50	σ = 0.1083S + 14.942	0.945
	60	σ = 0.0761S + 16.684	0.974
	70	σ = 0.0688S + 18.063	0.928
100	30	σ = 0.2616S + 15.714	0.903
	40	σ = 0.2217S + 18.122	0.917
	50	σ = 0.1643S + 21.078	0.916
	60	σ = 0.1162S + 23.614	0.966
	70	σ = 0.0852S + 26.141	0.974

Conclusions

The variation in dielectric properties and electrical conductivity with temperature and palm oil concentration can be utilised as a set of complementary techniques for the quality of product. Further, the variation in dielectric properties and electrical conductivity with impurity had been correlated using regression analysis to provide the desired information about the quality of product. The predicted correlation coefficient (R^2>0.87) for edible oil is more consistent with the experimental analysis in the temperature range 30-70°C. These techniques have provided more breaks for non-invasive sensing of food products in the industry.

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