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Research Article

Effect of Corn Syrup Impurity on Dielectric Properties and Electrical Conductivity of Honey

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ABSTRACT

The present work investigates the effect of adulteration of corn syrup on dielectric properties and electrical conductivity of pure honey. Honey was adulterated at five different concentrations (10-50%) of corn syrup. The relative permittivity and loss tangent were measured for selected samples at five different frequencies (10, 30, 50, 70 and 100 kHz) and five different temperatures (30º-70ºC). The effect of temperature was also studied on the density and viscosity of the selected samples. The relative permittivity and loss tangent were found to decrease linearly with the increase in temperature and frequency. Electrical conductivity of selected samples was also measured and was found to increase linearly with the increase in temperature, however, the frequency has negligible effect on it. Both loss tangent and electrical conductivity increased with the increase in temperature whereas dielectric constant, density and viscosity decreased. With the increase in concentration of adulterant (corn syrup) in pure honey, the loss tangent and electrical conductivity increased and dielectric constant, density and viscosity decreased. The data obtained were statistically analyzed using one-way analysis of variance at 5% level of significance. These parameters were found to vary significantly with adulteration. The regression models were developed for relationship of dielectric constant, loss tangent, electrical conductivity, density and viscosity with concentration of adulterant in honey and correlation coefficients was found to be greater than > 0.864.

Key words: Honey, Corn syrup, Dielectric constant, Loss tangent, Electrical conductivity, Viscosity

Introduction

Honey is natural sweet and thick golden liquid which is obtained from honey bees. It consists of large amounts of sugars such as glucose, fructose, maltose, sucrose and small amounts of vitamins, lipids, minerals, proteins, enzymes and amino acids. Honey has low moisture content and can be stored for longer times without any change in its properties. Due to increase in pollution, honey bee colonies are decreasing and its demand is increasing. To meet its demand, adulteration of honey is major a concern now a days. Adulterants like corn syrup, starch syrup, maltose syrup, sugar syrup, glucose and fructose are commonly used because properties of all these adulterants are nearly equal to the properties of honey. Hence, it is very difficult to distinguish between pure and adulterated honey.

There has been a lot of work done to identify the level of adulteration in honey and other agricultural products. Various chemical methods are used to detect adulteration in honey but these methods require high technical skills, time and moreover are highly expensive. However, the physical methods deployed earlier to check adulteration have used high frequencies and

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sophisticated skills (Wenchuan *et al*., 2011). There exists another technique known as dielectric measurement which is non-destructive testing technique (NDT), whose utility is increasing day by day (Kono *et al*., 2021). This technique is used to estimate the properties of materials without causing any change in their physical and chemical properties. The dielectric method has been used to investigate the palm oil adulteration in mustard oil by using dielectric properties and electrical conductivity (Singh and Tarsikka, 2021). Several studies also revealed moisture content in honey samples have significant effects on honey dielectric properties (Guo *et al*., 2010; Puranik *et al*., 1991). There was strong positive linear relationship between dielectric constant and moisture content in honey (Guo *et al*., 2010). Dielectric properties could be used to detect honey adulterated with water. Ahmed *et al*. (2007) noticed that dielectric properties of honey were affected by ash content. In present paper, a simple analytic capacitive method (10-100 kHz) has been used to check adulteration of honey using corn syrup in terms of dielectric properties and electrical conductivity.

Materials and Methods

The dielectric properties and electrical conductivity are determined by using HIOKI LCR HiTESTER 3522-50 and test frequency varied in the range of 1mHz to 100kHz. The circuit design used in LCR meter is automatic balance bridge method. This device measures the resistance in the range 10.00 mΩ to 200.00 MΩ, conductance in the range 5.0000 nS to 99.999 S, capacitance in the range of 0.3200 pF to 1.0000 F, loss in the range 0.00001 to 9.99999 and phase angle in the range -180º to +180º. The instrument is designed according to coaxial cable test leads, so the influence of these leads in measuring process was negligible. The well-known capacitive method has been used to determine the dielectric properties and electrical conductivity. A cylindrical shaped sample holder was used for this study. The schematic diagram of this sample holder is given in Fig. 1. It basically consists of two cylinders, where inner cylinder has radius 1.73 cm and outer cylinder of radius 2.38 cm. Both the cylinders have stainless steel as base material. To obtain a capacitive system both the cylinders must be insulated from each other.

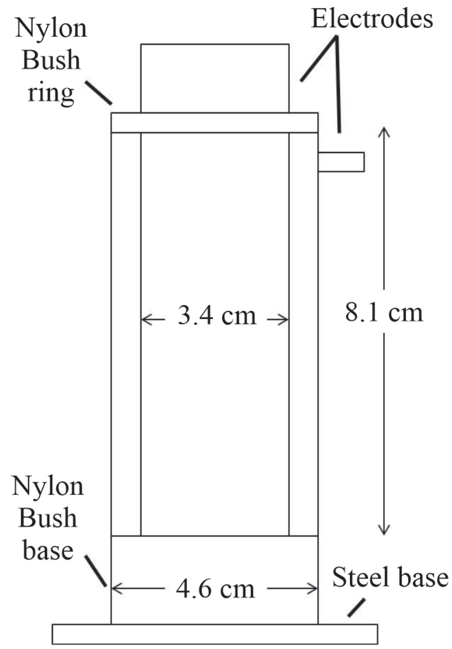

Fig. 1. Schematic diagram of the sample holder

So, the outer cylinder was welded on the steel plate. It acted as the base of the system. The inner cylinder was fixed on the nylon bush, which works as a piston system. The inner cylinder acts as a moveable part and is insulated by nylon bush from outer cylinder. Nylon bush was used because it provides insulation and has low dielectric constant. Further, to keep the cylinders at their position parallel to each other, a ring of nylon bush was fitted on the top of outer cylinder. This provides insulation to sample solution from external factors. Density is determined by using specific gravity bottle and viscosity is determined by Ostwald's viscometer. The experiments were performed using raw honey as raw honey has highest level of purity, and was procured from Department of Entomology, Punjab Agricultural University, Ludhiana. The moisture content of the selected ample was below 19%, which follows the Codex Alimentarius Standard, which stipulates that honey should have a maximum moisture content of 20% (Codex Alimentarius Commission, 2001). The total sugar content was around 78.8%. The honey-corn syrup solutions were prepared on volume-by-volume basis. Five different samples were prepared with 10%, 20%, 30%, 40% and 50% concentrations of corn syrup in honey.

The dielectric constant is determined by the ratio of capacitance of the given material (C) and the capacitance of air (C_o).

$$\varepsilon' = \frac{C}{C_o} \qquad (1)$$

Loss tangent is determined by phase angle as shown in this relation

$$\tan\delta = \left|\frac{1}{\tan\theta}\right| \qquad (2)$$

Electrical conductivity is determined form conductivity by relation

$$G = \sigma \frac{A}{1} \qquad (3)$$

where A is the cross-sectional area perpendicular to the direction of electric current and l is the length of the conductor. The quantity l/A is known as cell constant.

The experimental data was obtained in triplicates and analysed using One-way ANOVA method at 5% level of confidence by using SPSS version 20.0 software. By using Tukey's method, post hoc test for significance was done.

Results and Discussion

Effect of frequency on dielectric constant, loss tangent and electrical conductivity

Fig. 2 depicts the dependence of dielectric constant on the frequency for pure honey, pure corn syrup and different concentration of corn syrup in honey. It was observed that the dielectric constant decreases linearly with increase in frequency at any given temperature. The reason behind this decrease is that dielectric constant is the alignment of molecules with external field. When the oscillating frequency of external field increases, the molecules get lesser time to align and did not aligned completely with the external field. So, electrical energy storage capacity of a material decreases with increase in frequency. This results in decrease in dielectric constant. The dielectric constant also decreases with the increase in adulteration. This was observed by Luczycka *et al.* (2012), Malame *et al.* (2014) and Yang *et al.* (2018) at different frequency ranges.

As shown in Fig. 3, the loss tangent of pure honey is less than that of corn syrup at a given frequency and was found to decrease exponentially with increase in frequency at different temperatures for both pure honey and adulterated honey. With the

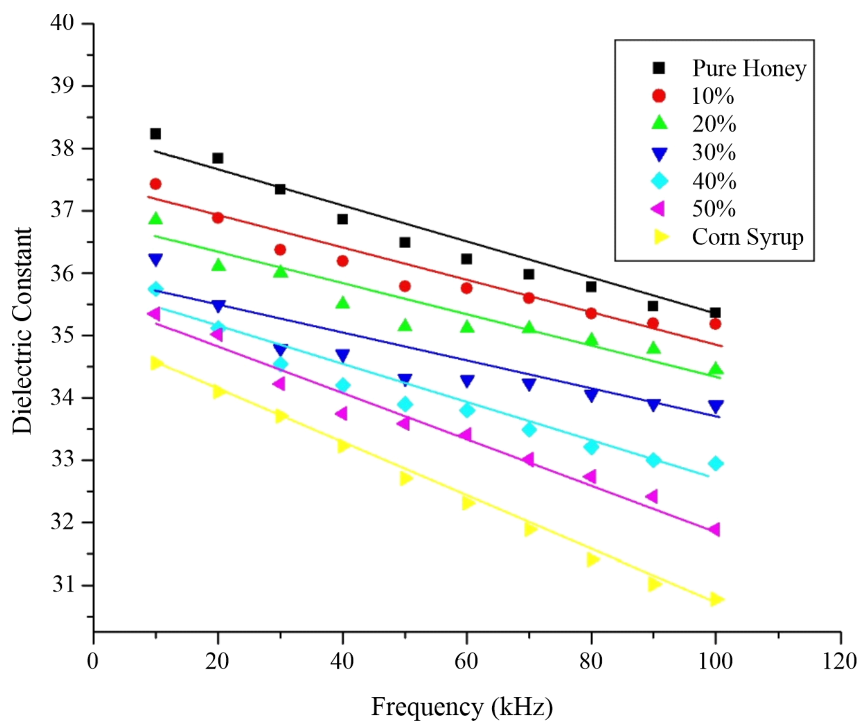

Fig. 2. Effect of frequency on dielectric constant for different concentrations at 30°C temperature

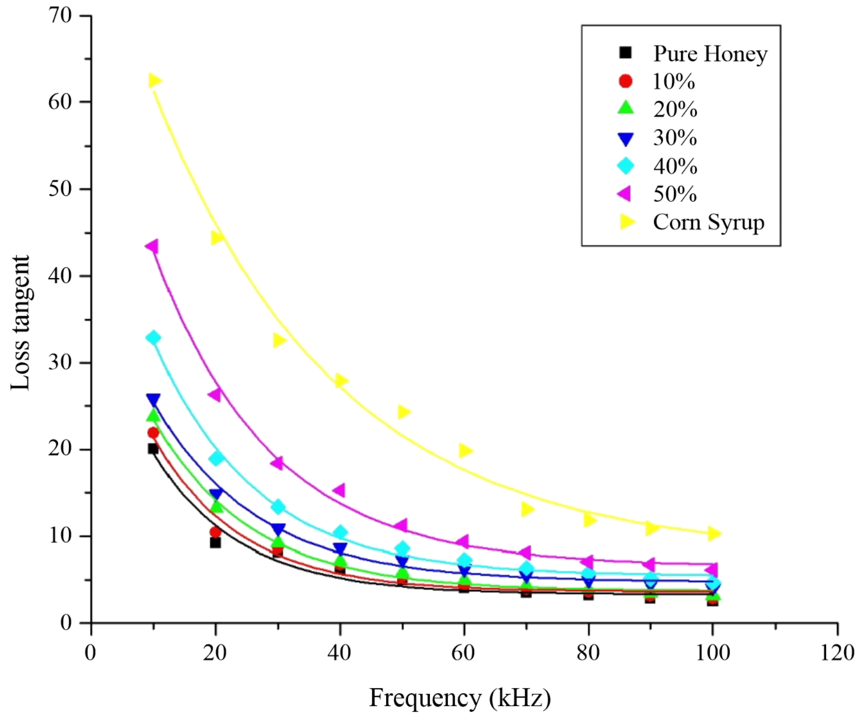

Fig. 3. Effect of frequency on loss tangent for different concentrations at 30ºC temperature

increase in frequency of external field, the molecules of sample didn't get enough time to align along the field. The continuous expanding and shrinking of molecules along the direction of external alternating field decreases and thus the loss also decreases. The pure honey has low value of loss tangent than pure corn syrup as the density of pure honey is more than corn syrup. So, the loss in case of corn syrup is more than pure honey. This results in increase in loss tangent with adulteration. Similar trends were observed by Luczycka (2009), Malame *et al.* (2009), Luczycka *et al.* (2012) and Pentos and Luczycka (2018).

The fitted plot between electrical conductivity and frequency is shown in Fig. 4 for pure honey, corn syrup and different concentrations of corn syrup in honey. The frequency has negligible effect on the electrical conductivity of pure honey, corn syrup and different concentrations of corn syrup in honey. However, the pure honey has very low electrical conductivity compared to that of adulterated honey.

Effect of temperature on dielectric constant, loss tangent, electrical conductivity, density and viscosity

Fig. 5 shows that the dielectric constant decreases linearly with increase in temperature for all frequencies. This decrease in dielectric constant is due to decrease in density of samples. The increase in temperature results in decrease in density of dipoles and the kinetic energy of molecules increases which leads to greater randomness. So, the net polarization decreases, which results in low value of dielectric constant. This was observed by Guo et al (2010) in temperature range 20º-80ºC and frequency 10-4500 MHz. Luczycka *et al.* (2012) and Pentos and Luczycka (2018) also supports this decrease in dielectric constant with temperature.

However, the loss tangent increases linearly with the increase in temperature at any frequency ss shown in Fig. 6. Because of higher densities at low temperature leads to longer relaxation time. So, the dipole moment is low. As the temperature increases, density decreases and which results in higher dipole moment (Lizhi *et al.,* 2008). The density and viscosity of honey is more than that of corn syrup. This shows that honey has lower values of loss tangent than corn syrup and further increases with increase in temperature. Luczycka (2009) reported the similar trends on measuring loss tangent versus temperature for five different varieties of honey.

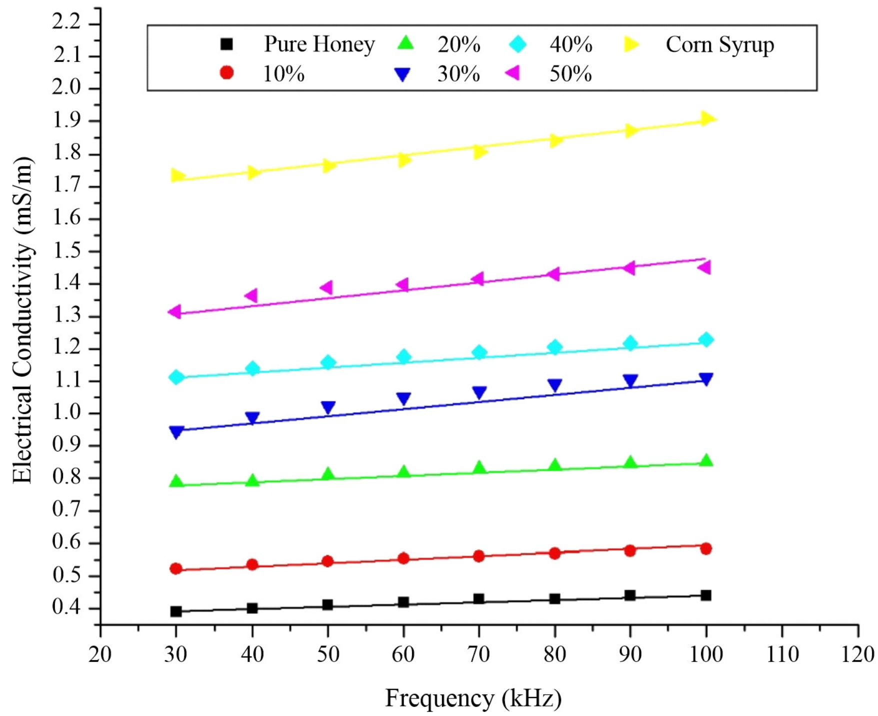

Fig. 4. Effect of frequency on electrical conductivity for different concentrations at 30ºC temperature

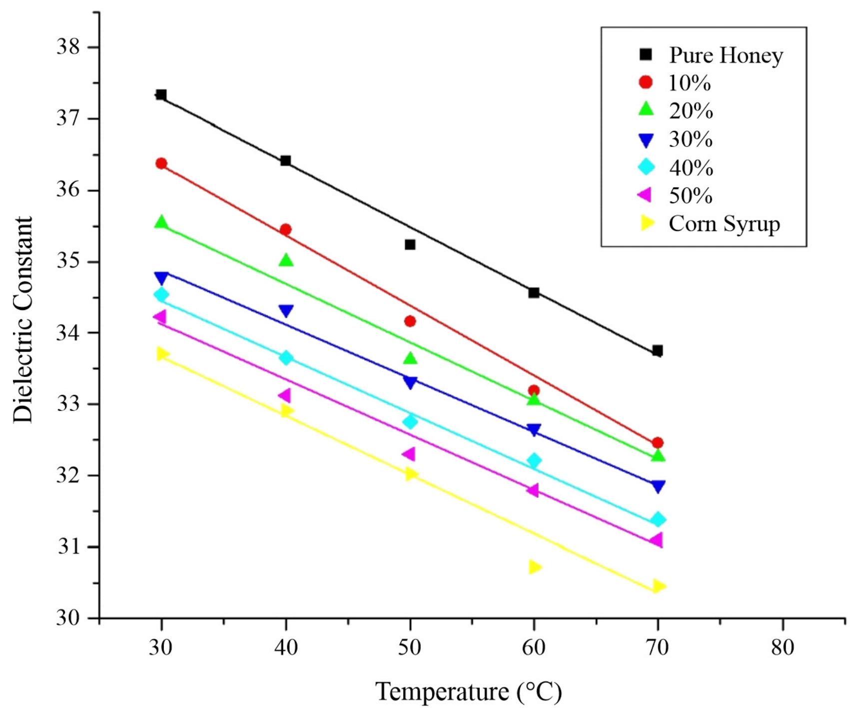

Fig. 5. Effect of temperature on dielectric constant for different concentrations at 30 kHz frequency

The electrical conductivity of the given sample increases linearly with increase in temperature for any frequency has been shown in Fig. 7. The electrical conductivity depends upon the numbers of ions present in the solution. With the increase in temperature mobility of ions increases. This results in increase in electrical conductivity. The density and viscosity of corn syrup is less then honey, so the

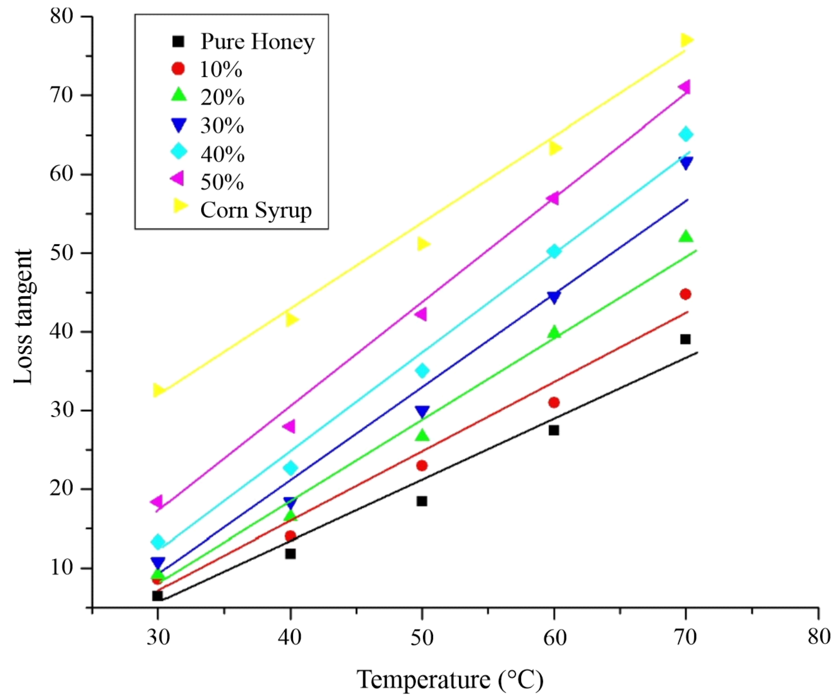

Fig. 6. Effect of temperature on loss tangent for different concentrations at 30 kHz frequency

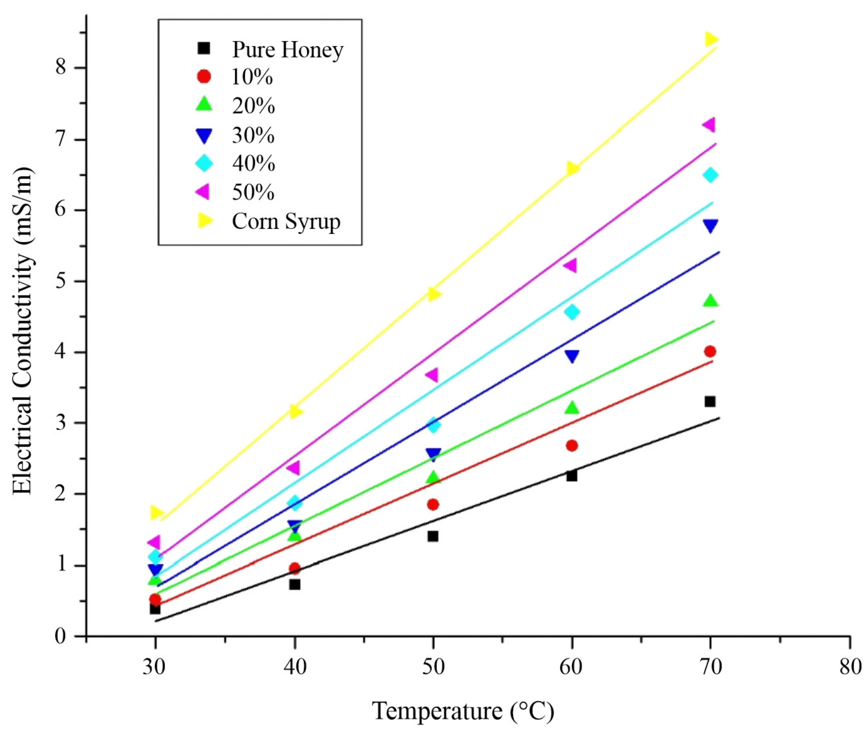

Fig. 7. Effect of temperature on electrical conductivity for different concentrations at 30 kHz frequency

movement of ions increases with increase in concentration of corn syrup. Similar trends were reported by Szczesna and Chmielewska (2004) and Acquarone *et al.* (2007) for pure honey.

Fig. 8 shows the dependence of density on temperature for pure honey, pure corn syrup and different concentration of corn syrup in honey. Density decreases with the increase in temperature.

When the sample was heated its molecules got slightly apart from each other. So, with the increase in temperature the volume of sample increases, hence the density of solution decreases. This was observed by Oroian (2013) that with the increase in temperature the density of pure honey and honey adulterated with corn syrup decreased.

Fig. 9 shows that the viscosity of pure honey, corn syrup and different concentrations of corn syrup

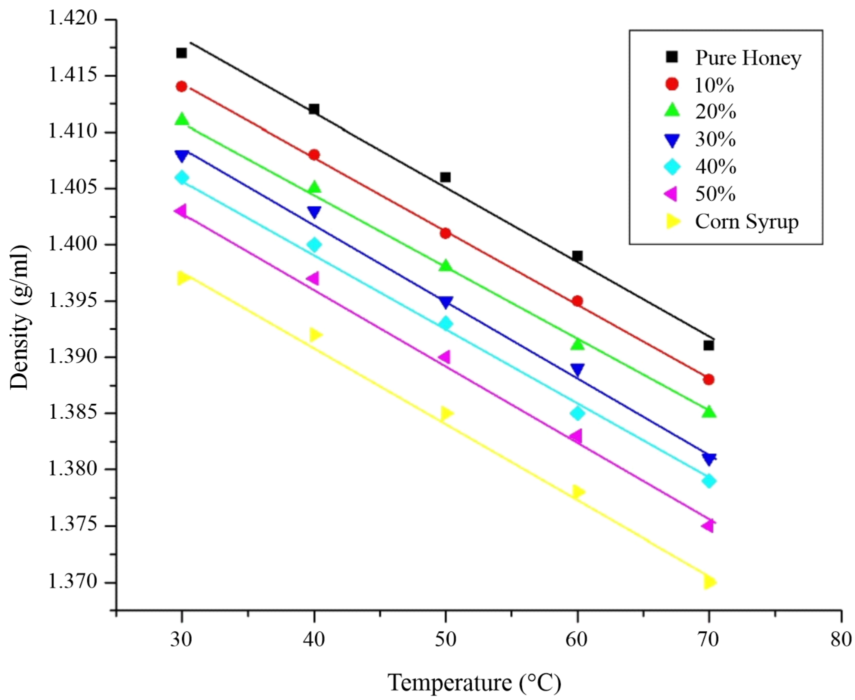

Fig. 8. Effect of temperature on density at different concentrations

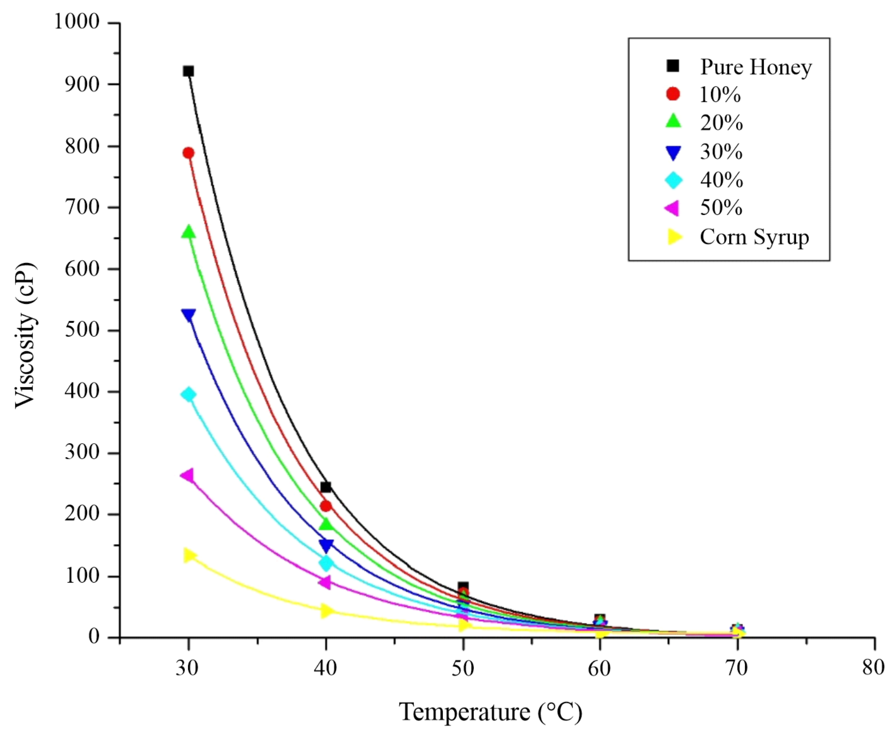

Fig. 9. Effect of temperature on viscosity at different concentrations

in honey and was found to be decreased with the increase in temperature. The viscosity of any fluid is affected by the force fields which determines the interaction among the particles. With the increase in temperature the magnitude of molecular interaction decreases, results in decrease of viscosity. Similar variations were obtained by Bhandari *et al.* (1999), Lazaridou *et al.* (2004) and Gómez-Díaz *et al.* (2006).

Effect of adulteration on dielectric constant, loss tangent, electrical conductivity, density and viscosity

The variation in dielectric constant of honey with adulteration of corn syrup has been expressed in Fig. 10. Dielectric constant of honey decreases linearly with adulteration for different temperatures and frequencies. As honey has very lass moisture content, so the density of dipoles in honey decreases with increase in adulteration. Due to decrease in density of dipoles, the dielectric constant of samples decreases with adulteration. Guo *et al.* (2011) and Singh and Tarsikka (2019) observed similar trends is case of honey adulterated with sugar syrup.

Fig. 11 shows that with the increase in impurity content in honey the loss tangent was found to increase linearly. The corn syrup has large value of loss tangent while pure honey has low value of loss tangent for all temperatures and frequencies. It has been broadly recognized that the loss tangent of honey is significantly affected by moisture content. The density of honey at any temperature is higher than that of corn syrup. So, the dipoles have longer relaxation time and so dipole movement decreases. This results in increase in loss tangent increases with adulteration.

Fig. 12 shows the dependence of electrical conductivity on adulteration. The electrical conductivity increases linearly with the increase in corn syrup concentration in pure honey at any temperature and frequency. The electrical conductivity of pure honey is less than that of corn syrup. The mobility of ions has great effect on electrical conductivity of sample. The addition of corn syrup in honey causes fast movement of ions because of low density and viscosity of corn syrup. So, the electrical conductivity increases with addition of corn syrup in pure honey.

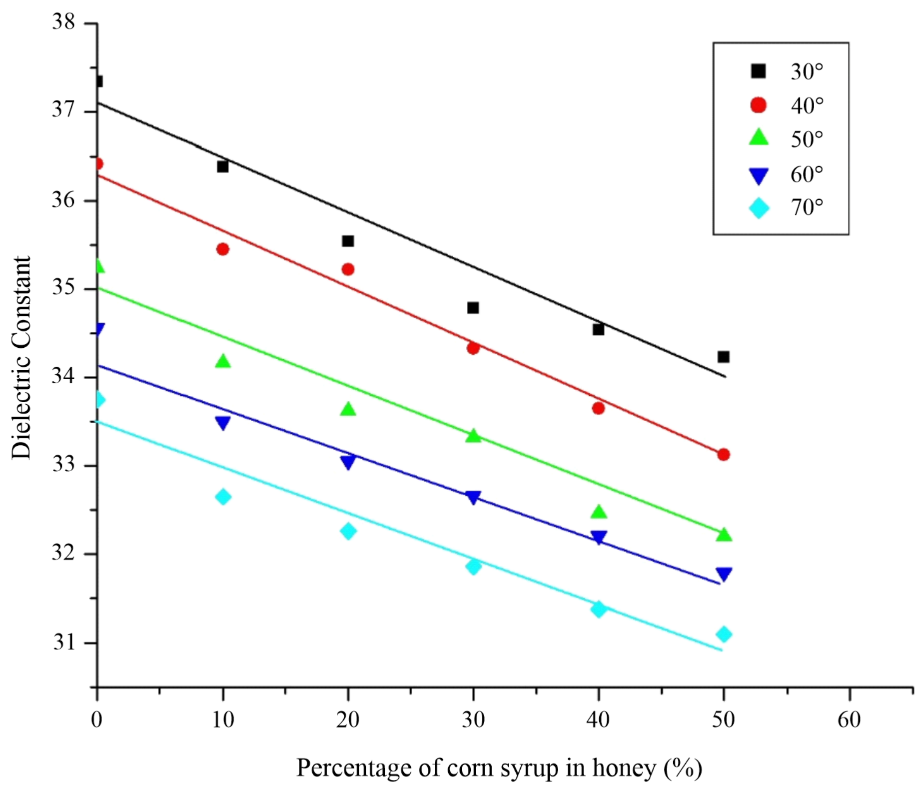

Fig. 10. Effect of corn syrup adulteration on dielectric constant of honey for different temperatures at 30 kHz frequency

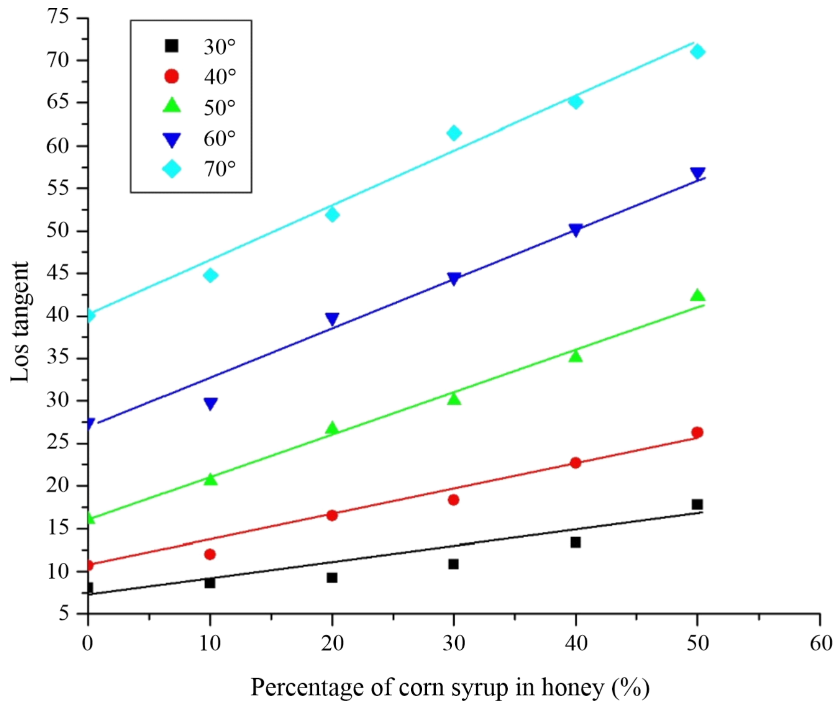

Fig. 11. Effect of corn syrup adulteration on loss tangent of honey for different temperatures at 30 kHz frequency

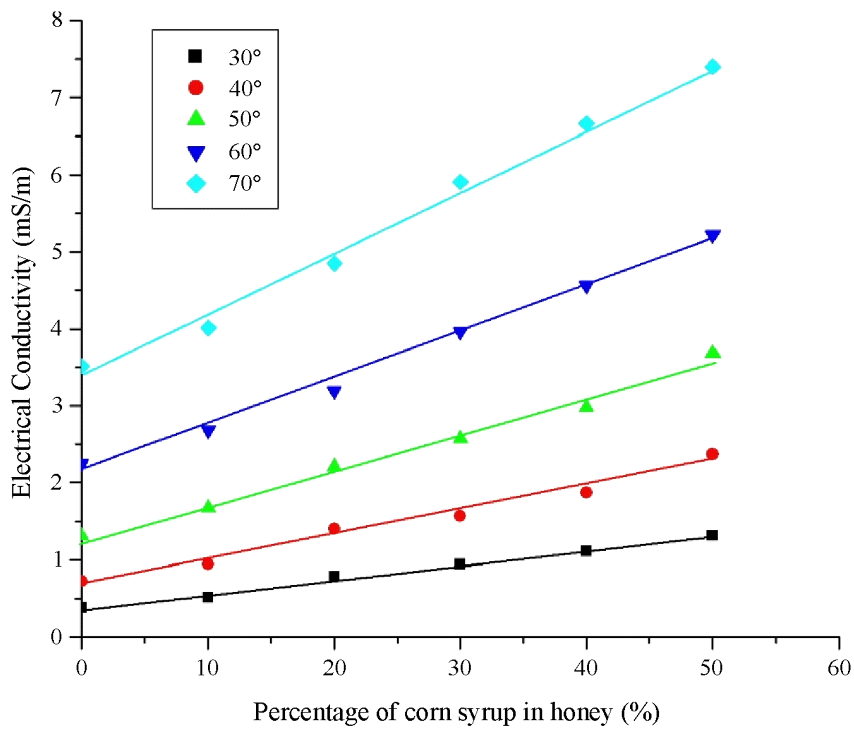

Fig. 12. Effect of corn syrup adulteration on electrical conductivity of honey for different temperatures at 30 kHz frequency

Fig. 13 and 14 show that the density and viscosity decreased linearly with the increase in the level of adulteration in pure honey for any temperature. With increase in the level of adulteration in pure honey, the moisture content got increased in the final solution which results in decreased value of the density and viscosity.

Mathematical modeling of dielectric properties, electrical conductivity, density and viscosity

Using the dielectric properties and electrical conductivity for corn syrup impurity levels in honey at different levels of frequencies and temperatures, a

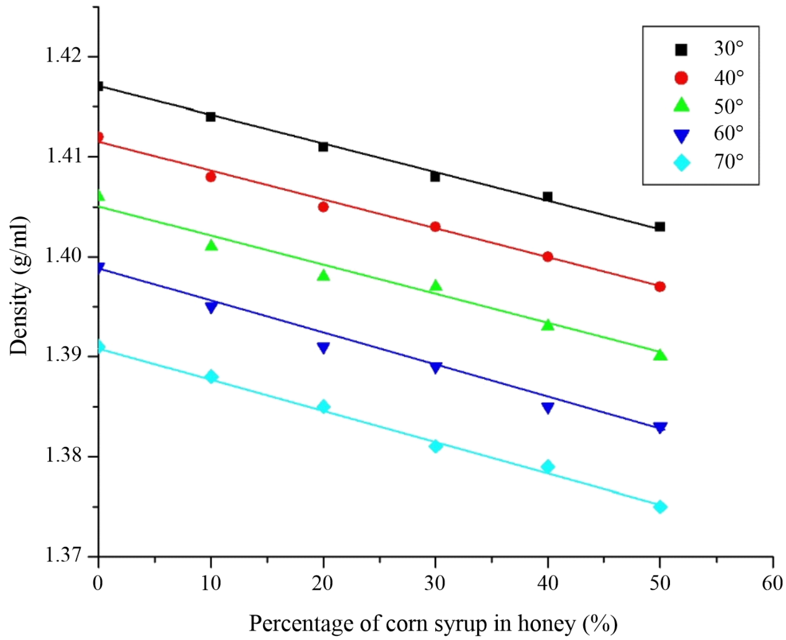

Fig. 13. Effect of corn syrup adulteration on density of honey for different temperatures

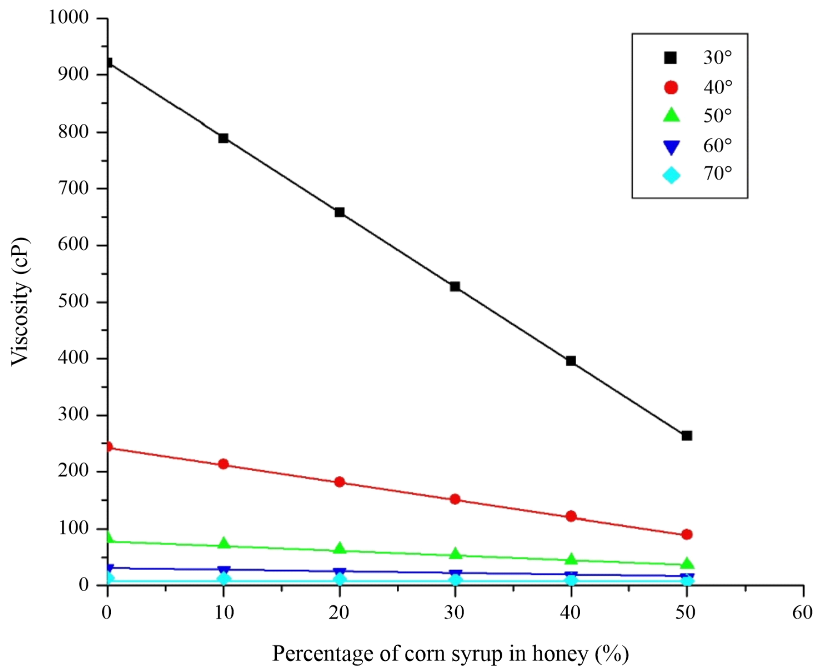

Fig. 14. Effect of corn syrup adulteration on viscosity of honey for different temperatures

mathematical model was analyzed. The mathematical model was also constructed to describe the variation in density and viscosity for different concentrations of corn syrup in honey for different temperatures. A linear model was proposed from obtained of honey samples as:

$$y(f,T,S) = A(f,T) + B(f,T)S \quad (4)$$

where, y(f,T,S) is the given parameter of honey at a given frequency f(kHz) for a specific temperature T(ºC) at impurity by percentage volume S. At particular temperature, A(f,T) and B(f,T) represents the regression constants for frequency. The regression model for dielectric constant and dielectric loss of honey-corn syrup at different temperatures and frequencies are given in Tables 1 and 2. The R^2 values lies in the range of 0.864-0.998 which shows a good fit of the linear model verified by Guo *et al*. (2011). Table 3 gives the regression model of variation of electrical conductivity of honey-corn syrup combination at different temperatures and frequencies. The R^2 values are obtained in range 0.971-0.996 and this model is verified by Sancho *et al.* (1991). The linear model for density and viscosity have been reported in Table 4 for different temperatures and frequencies.

Table 1. The regression model for variation of dielectric constant of honey with different concentrations of corn syrup (S) in honey

Frequency (kHz)	Temperature (ºC)	Dielectric constant-Corn syrup (%)	Regression Coefficient (R^2)
10	30	ε′ = -0.05729S + 38.07	0.988
	40	ε′ = -0.05237S + 37.55	0.998
	50	ε′ = -0.05066S + 37.13	0.974
	60	ε′ = -0.04391S + 36.66	0.985
	70	ε′ = -0.03686S + 35.65	0.930
30	30	ε′ = -0.06234S + 37.02	0.945
	40	ε′ = -0.06511S + 36.32	0.985
	50	ε′ = -0.05886S + 34.97	0.965
	60	ε′ = -0.04909S + 34.13	0.911
	70	ε′ = -0.04817S + 33.33	0.914
50	30	ε′ = -0.06129S + 36.37	0.974
	40	ε′ = -0.06187S + 35.44	0.964
	50	ε′ = -0.05851S + 33.49	0.945
	60	ε′ = -0.06026S + 32.14	0.967
	70	ε′ = -0.05180S + 30.51	0.973
70	30	ε′ = -0.06300S + 36.14	0.985
	40	ε′ = -0.06183S + 34.88	0.970
	50	ε′ = -0.06363S + 32.84	0.966
	60	ε′ = -0.06874S + 31.47	0.973
	70	ε′ = -0.06874S + 29.04	0.956
100	30	ε′ = -0.07097S + 35.76	0.950
	40	ε′ = -0.10047S + 34.90	0.898
	50	ε′ = -0.06511S + 32.32	0.951
	60	ε′ = -0.06377S + 30.66	0.973
	70	ε′ = -0.05489S + 27.37	0.958

Table 2. The regression model for variation of loss tangent of honey with different concentrations of corn syrup (S) in honey

Frequency (kHz)	Temperature (ºC)	Loss tangent- Corn syrup (%)	Regression Coefficient (R^2)
10	30	$\tan\delta = 0.4152S + 18.66$	0.963
	40	$\tan\delta = 0.6237S + 26.18$	0.990
	50	$\tan\delta = 0.6325S + 40.29$	0.980
	60	$\tan\delta = 0.6031S + 48.83$	0.961
	70	$\tan\delta = 0.4245S + 58.94$	0.966
30	30	$\tan\delta = 0.1836S + 6.74$	0.864
	40	$\tan\delta = 0.3196S + 9.76$	0.981
	50	$\tan\delta = 0.5084S + 15.70$	0.991
	60	$\tan\delta = 0.6100S + 26.21$	0.985
	70	$\tan\delta = 0.6445S + 39.60$	0.987
50	30	$\tan\delta = 0.1201S + 4.21$	0.903
	40	$\tan\delta = 0.2263S + 5.90$	0.968
	50	$\tan\delta = 0.3420S + 10.07$	0.990
	60	$\tan\delta = 0.4610S + 16.78$	0.994
	70	$\tan\delta = 0.5466S + 27.22$	0.978
70	30	$\tan\delta = 0.0900S + 3.05$	0.938
	40	$\tan\delta = 0.1619S + 4.41$	0.978
	50	$\tan\delta = 0.2715S + 7.23$	0.980
	60	$\tan\delta = 0.3566S + 12.44$	0.993
	70	$\tan\delta = 0.4202S + 19.72$	0.985
100	30	$\tan\delta = 0.0690S + 2.19$	0.926
	40	$\tan\delta = 0.1096S + 3.27$	0.987
	50	$\tan\delta = 0.1912S + 5.29$	0.987
	60	$\tan\delta = 0.2651S + 9.00$	0.993
	70	$\tan\delta = 0.3405S + 14.32$	0.993

Table 3. The regression model for variation of electrical conductivity of honey with different concentrations of corn syrup (S) in honey

Frequency (kHz)	Temperature (ºC)	Electrical conductivity- Corn syrup (%)	Regression Coefficient (R^2)
10	30	$\sigma = 0.0173S + 0.3556$	0.988
	40	$\sigma = 0.0301S + 0.6727$	0.976
	50	$\sigma = 0.0452S + 1.2003$	0.987
	60	$\sigma = 0.0594S + 2.0299$	0.990
	70	$\sigma = 0.0778S + 3.1941$	0.992
30	30	$\sigma = 0.0187S + 0.3775$	0.994
	40	$\sigma = 0.0317S + 0.6855$	0.981
	50	$\sigma = 0.0460S + 1.2498$	0.989
	60	$\sigma = 0.0608S + 2.1231$	0.993
	70	$\sigma = 0.0812S + 3.3596$	0.992

Contd...

50	30	σ = 0.0198S + 0.3928	0.992
	40	σ = 0.0334S + 0.6869	0.979
	50	σ = 0.0476S + 1.2695	0.986
	60	σ = 0.0620S + 2.1668	0.990
	70	σ = 0.0818S + 3.4765	0.991
70	30	σ = 0.0201S + 0.4115	0.990
	40	σ = 0.0352S + 0.6805	0.971
	50	σ = 0.0488S + 1.2802	0.986
	60	σ = 0.0638S + 2.1810	0.988
	70	σ = 0.0826S + 3.5295	0.990
100	30	σ = 0.0207S + 0.4259	0.989
	40	σ = 0.0387S + 0.6669	0.982
	50	σ = 0.0520S + 1.2721	0.989
	60	σ = 0.0665S + 2.2123	0.989
	70	σ = 0.0818S + 3.5430	0.996

Table 4. The regression model for variation of density (viscosity) with different concentrations of corn syrup in honey (S)

Temperature (ºC)	Density (Viscosity) Corn syrup (%)	Regression Coefficient (R^2)
30	ρ = -0.00028S + 1.416	0.996
	(η = -13.1237S + 920.41)	(0.999)
40	ρ = -0.00029S + 1.411	0.992
	(η = -3.2331S + 246.26)	(0.995)
50	ρ = -0.0003S + 1.405	0.975
	(η = -0.9800S + 82.82)	(0.991)
60	ρ = -0.00031S + 1.398	0.988
	(η = -0.3501S + 30.19)	(0.994)
70	ρ = -0.00032S + 1.391	0.995
	(η = -0.1133S + 13.67)	(0.989)

Conclusions

The findings of this paper have described the effect of corn syrup adulteration on dielectric, electrical and physical properties of honey. It has been observed that the dialectic measurements are useful to detect the adulteration of honey with corn syrup in low frequency range. The measurement of the dielectric properties and electrical conductivity can be considered as good quantifier to check adulteration of pure honey. Also, the effect of other parameters viz. temperature and frequency has been studied on dielectric properties of honey, and this information is useful in processing of honey. It has been observed that dielectric constant decreases with the increase in level of adulteration whereas loss tangent and electrical conductivity increases. The variation in dielectric properties and electrical conductivity of honey with adulteration have been modelled using suitable regression analysis. The anticipated correlation coefficient ($R^2 > 0.86$) for honey is more compatible with the experimental analysis in the temperature range 30°-70°C.

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