CHAPTER 5

Maturity dependent dielectric properties of mango fruit associated dielectric heating

Abstract

Dielectric properties data are essential for developing radio frequency application as thermal treatments and are important in heat uniformity approximation in electromagnetic fields. Mango at different ripening stages was dipped in water at temperature of 35, 40 and 50ºC for 30, 60 and 90 minutes. After dipping, treated mango was measured for moisture content of each peel and flesh inside the fruit and time. Dielectric properties of mango at different ripening stage soaked in various temperature and time were measured with an open-ended coaxial probe and impedance analyzer at frequencies of 1-50 MHz. The result found that treated mango showed no significant differences of firmness, however their moisture contents of peel and flesh of mango were varies. The dielectric constant and loss factor of the mango peel samples decreased with increasing frequency but increased with increasing temperature. Moreover, the mangos were dipped in water at temperature of 30 and 45ºC, higher loss factors were observed on ripening stage of mango peel of all three cultivars (Nam Dok Mai, Chok Anan and Fa Lun) in comparison with the peels at physiological maturation.

5.1 Introduction

In general, domestic and international export regulations created the official data for ensuring fruit quality standard requirement after post-harvest. Currently, fumigation with methyl bromide has been appeared to be unfriendly to the environment and harmful to consumer health. Therefore, the use of such methods has been canceled. Under the terms of the international partners, many researchers have sought method regarding to heat treatment control i.e. hot water and hot air, radiation, cold storage, and controlled atmosphere storage to replace the use of chemicals. However, those methods often showed their limitations such as hot water or hot air usually took a long time of the processes because it depends on the thermal conductivity of fruit. Therefore, radio frequency heat treatment is an alternative method and shows a high advantage and available in large quantities with rapid operation. Then, it was focused on controlling insect pest infestation instead of fumigated control.

Nelson (1996) reported about radio frequency heat treatment on controlling insect pests infested in fruit. The report found that heat distribution and un-uniformity in the material plays a major role in heat transfer from radio frequency energy. Recently, many researches showed the effectiveness of microwave in controlling insect pest infesting in cherry fruit (Ikediala *et al.*, 2002) and walnut fruit (Wang *et al.*, 2002), and apple fruit (Wang *et al.*, 2006). In addition, Birla (2004) expressed the method that has been improved uniformity of heat distribution in orange and apple by developing fruit mover as container combined with radio frequency application. The result found that heating rate different between water and fruit caused from dielectric property diverse between water and the fruit.

The product which response for dielectric heating is a material responding for electromagnetic wave where composed with water molecule as dipolar. Without dipolar matter such as air, Teflon and glass could not absorbed energy from the wave which the permittivity of the material equal to zero and the matter is without heat and unchanged. On the other hand, material made from metal reflected all wave then the matter showed non-heating which the material is properly used for oven skeleton and wave reflectors. The dielectric property of material is measured by formula as followed (Ryynänen, 1995):

$$\varepsilon^* = \varepsilon' - j\varepsilon''$$

The principle of dielectric is according to electromagnetic field inside the material, including their shape and electrode. Therefore, wavelength, depth, fruit size, heating method, and electromagnetic field are needed for dielectric heating application as formula followed (Ryynänen, 1995):

$$d_p = \frac{c\,[\{1+(\varepsilon''/\varepsilon')^2\}^{0.5}-1]^{-0.5}}{2\pi f(2\varepsilon')^{0.5}}$$

$$\lambda_m = \frac{c}{f}\,[\tfrac{1}{2}(\{1+(\varepsilon''/\varepsilon')^2\}^{0.5}-1)]^{-0.5}$$

Where c is the speed of light in vacuum (3×10^{8} m s^{-1})

f is frequency of electromagnetic wave (Hz)

5.1.1 Principle of dielectric property measurement

The principle of dielectric property measurement is based on the dielectric material shows the property of energy containing after the electromagnetic field outside is used. When DC electricity was applied to parallel plate electrode (Fig 5.1), dielectric property of air is higher than exposing some material in between the plates in which called the capacitance and it related with dielectric constant of material.

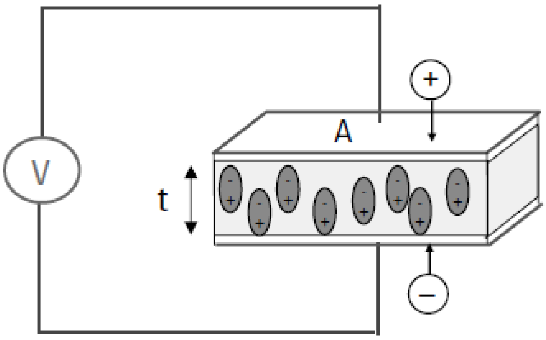

Figure 5.1 Capacitor in form of parallel plate with DC type

$$C_0 = \frac{A}{t}$$
$$C = C_0\kappa'$$
$$\kappa' = \varepsilon_r' = \frac{C}{C_0}$$

Where C and $C_0$are capacitance with or without dielectric

$\kappa' = \varepsilon_r'$ is dielectric constant or permittivity

A and t is plate area of capacitor and distance of the plates

When applied the alternative current to the parallel plates (Fig 5.2), the outputs are I_c and loss current I_l which involved with dielectric constant while shows their loss in the material as conductance (G) inside parallel capacitor (C).

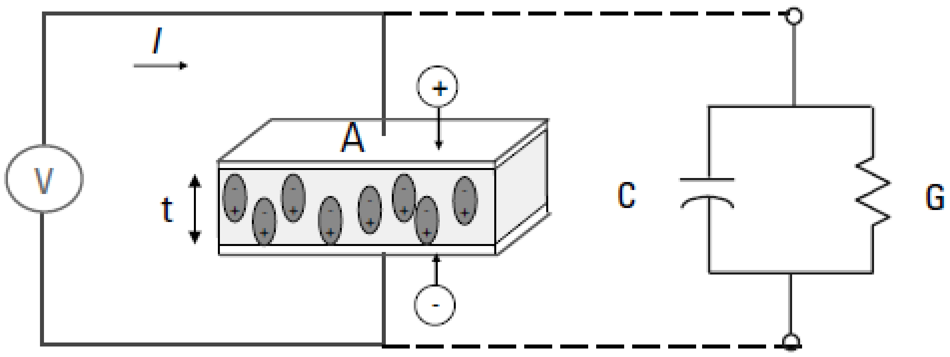

Figure 5.2 Capacitor in form of parallel plate with AC type

$$I = I_c + I_l = V(j\omega C_0\kappa' + G)$$

if $\quad G = \omega C_0\kappa''$

then $\quad I = V(j\omega C_0)(\kappa' - j\kappa'') = V(j\omega C_0)\kappa \quad ; \omega = 2\pi f$

Dielectric complicity constant composed with truth factor(κ') showed capacity and ideal factor (κ'') shoed losing. The following symbols used for exchanging of dielectric complicity.

$$\kappa = \kappa^* = \varepsilon_r = \varepsilon_r^*$$

According to electromagnetic theory, the electric flux density (D_f) relationship was provided by following:

Where $\varepsilon = \varepsilon^* = \varepsilon_0\varepsilon_r$

ε^* is absolute permittivity

ε_r is relative permittivity

$\varepsilon_0 = \frac{1}{36\pi} \times 10^{-9}\, F/m$ is free space permittivity

E is electromagnetic field

Permittivity is described as reaction of material to electromagnetic field (E) and complicated size

$$\kappa = \frac{\varepsilon}{\varepsilon_0} = \varepsilon_r = \varepsilon_r - j\varepsilon_r''$$

Truth factor of permittivity (ε_r') is a measurement of energy from the field outside, but stored inside the material while the ideal factor of permittivity (ε_r'') called "loss factor" which used for measuring the loss energy of material to electromagnetic field outside usually shows the value more than zero and less than the value of true permittivity (ε_r') (Figure 5.3).

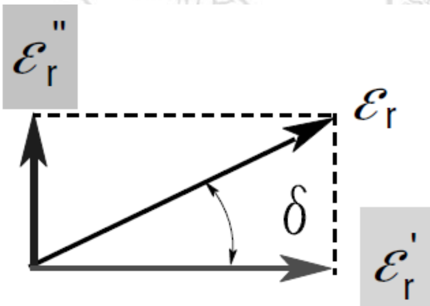

Figure 5.3 Vector of loss factor

Vector of loss factor was shown in figure 5.3 where the angle between truth and ideal permittivity is 90 degree. The summation of vector is in the form of ε_r angle equal to δ with truth permittivity (ε_r') where the relationship as followed:

$$\tan\delta = \frac{\varepsilon_r''}{\varepsilon_r'} = D = \frac{1}{Q} = \frac{Energy\ Lost\ per\ Cycle}{Energy\ Stored\ per\ Cycle}$$

$\tan\delta$ is depended on ratio of ideal fraction and truth fraction of dielectric constant

D is Dissipation factor

Q is Quality factor

Product's dielectric properties provide general guidance for selecting the optimal frequency range and bed thickness for uniform RF treatments (Wang, *et al*., 2003). Dielectric property of fruit has been measured continuously by many researches (Foster and Schwan, 1989; Nelson, 1996; Rynänen, 1995; Venkatesh and Raghavan, 2004). Seaman and Seals (1991) was reported peel and flesh of apple and orange at room temperature. The result found that dielectric property of peel and flesh inside the fruit was significantly difference. However, the report about dielectric of mango fruit has been lack especially the response of dielectric property at difference temperature which is a factor of effectiveness result from radio frequency heat treatment.

This experiment was to measure the dielectric property of each part of fresh mango fruit and fruit fly for more understanding the heat behavior from radio frequency technique when applied with fresh fruit which the results would be benefit for improving combined heat application with radio frequency apparatus.

5.2. Materials and methods

5.2.1 Material and sample preparation

Mango fruit 3 cultivars (Nam Dok Mai, Chok Anan and Fa Lun) ripped at two different stages of maturity which were physiological maturation and ripening. Before measuring, the mango samples were dipped in hot water at 3 different temperatures (30, 45 and 50 °C) for 30, 60 and 90 minutes. The treated mangos were peel and separated in 2 parts of sample as peel and flesh of mango. Each part was chopped in small pieces and divided into 3 portions. Two parts of them were measured for moisture by using 3.5 g puree samples dried in a vacuum oven at 60C for 6 h (AOAC, 1994) and firmness in Newton unit and another part used for dielectric property measurement. The dielectric properties were measured by the precision impedance analyzer in the frequency range 1-50 MHz at the distance of 1.50 cm.

5.2.2 Dielectric properties measurement apparatus

Dielectric properties measurement apparatus composed with temperature controlled chamber where the matter inside was parallel plates (Figure 5.4). When the sample material was placed in between the plates, the temperature probe was used for monitoring temperature during operation. Whole apparatus was operated by computer controller.

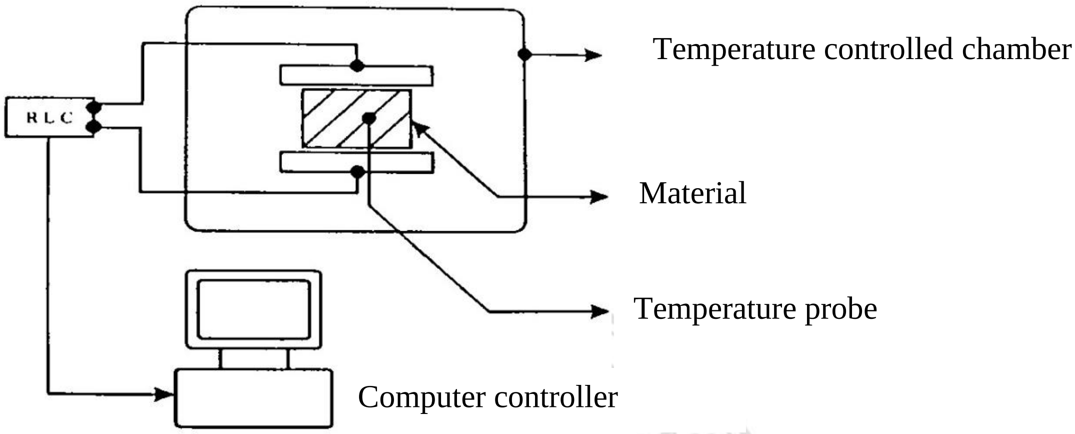

Figure 5.4 Schematic of impedance analyzer as dielectric properties measurement apparatus

F

(a) **(b)** **(c)** **(d)**

Figure 5.5 Dielectric properties measurement apparatuswith high frequency electromagnetic field (a)**,** impedance analyzer (b), power supply (c) and parallel plates capacitor (d)mango flesh sample contained inparallel plates capacitor

5.3 Results and Discussion

5.3.2 Effect of temperature and soaking period on moisture content of mango

Table 5.1 showed the moisture content of non-treated mango cv. Nam Dok Mai, Chok Anan and Fa Lun at ripening stage equaled to 81.01, 80.26 and 75.03% resp. while the over ripening stage were 80.64, 79.35 and 75.42% resp. After soaking in different temperature and time, the moisture of mango flesh cv. Nam Dok Mai was unchanged at both ripens. While the soaking period significantly affected on mc of mango cv. Chok Anan at both ripening and only ripe mango cv. Fa Lun.

The mc of non-treated mango after peeling and measured the moisture of the peel in mango cv. Nam Dok Mai, Chok Anan and Fa Lun at ripening stage were 69.48, 76.26 and 68.87% resp. while the over ripening stage were 68.25, 71.76 and 70.63% resp. After soaking in different temperature and time, the moisture of mango peel cv. Chok Anan was unchanged at both ripens. While the soaking period significantly affected on mc of mango cv. Nam Dok Mai at both ripening and only ripe mango cv. Fa Lun.

Table 5.1 Effect of temperature and soaking period on moisture content of fresh mango

Mango cultivar		Nam Dok Mai		Chok Anan		Fa Lun	
Treatment		ripe	over ripe	ripe	over ripe	ripe	over ripe
		Moisture (%)					
control		81.01	80.64	80.26ab	79.35a	75.03bcd	75.42
Soaking 30°C	30 min	80.95	81.63	80.63ab	79.82a	71.39e	76.22
	60 min	81.44	81.07	81.06a	77.44bc	77.15ab	77.16
	90 min	80.72	82.77	81.10a	78.62ab	76.16abc	76.13
Soaking 45°C	30 min	79.83	81.02	77.82cd	80.14a	75.25bcd	79.38
	60 min	80.59	81.53	81.03a	78.72ab	74.83bcd	78.03
	90 min	81.41	79.90	78.45bcd	78.76ab	73.17de	75.82
Soaking 50 °C	30 min	80.73	80.93	80.17ab	77.06bc	78.34a	74.73
	60 min	80.57	80.13	77.35d	76.53c	74.53cd	77.48
	90 min	80.12	79.68	79.59abc	76.08c	74.75bcd	77.65
F-test		ns	ns	*	*	*	ns
CV (%)		1.01	1.58	1.95	1.67	2.54	4.02

Table 5.2 Effect of temperature and soaking period on moisture content of mango peel

Mango cultivar		Nam Dok Mai		Chok Anan		Fa Lun	
Treatment		ripe	over ripe	ripe	over ripe	ripe	over ripe
		Moisture (%)					
control		69.48d	68.25b	76.26	71.76	68.87c	70.63
Soaking 30°C	30 min	72.16ab	73.31a	74.17	71.74	66.37d	69.44
	60 min	70.40bcd	70.24ab	75.42	82.19	71.25ab	72.22
	90 min	73.11a	72.83a	75.26	72.10	71.47ab	71.22
Soaking 45°C	30 min	72.45ab	73.28a	69.81	73.59	69.77bc	73.54
	60 min	71.58abc	70.62ab	74.93	73.22	69.87bc	72.17
	90 min	69.60cd	71.20ab	79.67	72.49	68.15cd	71.69
Soaking 50 °C	30 min	71.99ab	68.28b	73.77	73.74	72.53a	68.54
	60 min	70.74bcd	68.60b	73.99	71.54	70.26abc	71.62
	90 min	70.86bcd	70.23ab	75.41	71.18	69.66bc	73.47
F-test		*	*	ns	ns	*	ns
CV (%)		2.12	3.89	8.90	10.10	2.38	2.46

5.3.2 Effect of temperature and soaking period on mango density

Temperature and soaking period showed no effect on density of mango all cultivars (Table 5.3). However, the density of ripening mango was significantly different from over ripe mango in all cultivars which density of untreated ripe mango cv Nam Dok Mai was 60.31 compared with overripe (2.87 Newton), Chok Anan was 92.08 compared with overripe 7.6 Newton and Fa Lun was 92.63 compared with over ripening stage (51.44 Newton). The result was parallel with Witthawat (2002) who found that density of mango dip in hot water soaked 52°C and 55°C for 5 and 10 minutes was not different from untreated mango. However, density of mango fruit decreased with storage time due to changing of pectin which was the major composition of cell wall. Pectin in raw fruit presented as pro-pectin with water non-soluble property, after ripen pro-pectin was degraded to pectin and acid with water soluble property by activity of polygalacturonase and pectinesterase enzyme as catalyst, then the fruit firmness was decreased (Danai, 1997).

Table 5.3 Effect of temperature and soaking period on moisture content of mango density

Mango cultivar		Nam Dok Mai		Chok Anan		Fa Lun	
Treatment		ripe	over ripe	ripe	over ripe	ripe	over ripe
		Density (Newton)					
control		60.31	2.87	92.08	7.60	92.63	51.44
Soaking 30°C	30 min	60.25	3.73	89.31	6.96	64.47	18.97
	60 min	67.35	3.23	89.56	7.37	96.00	22.69
	90 min	78.60	5.20	86.78	7.61	86.21	35.99
Soaking 45°C	30 min	67.72	3.33	101.25	9.55	110.05	40.56
	60 min	73.43	3.47	87.97	7.96	79.56	38.46
	90 min	57.28	4.12	87.97	8.80	92.19	44.15
Soaking 50 °C	30 min	71.96	2.38	74.68	7.19	102.85	33.37
	60 min	56.99	3.87	90.05	8.52	109.14	44.50
	90 min	51.97	10.23	88.22	6.53	99.90	39.77
F-test		ns	ns	ns	ns	ns	ns
CV (%)		15.94	58.25	22.97	17.93	31.89	69.19

5.3.3 Dielectric property as influence by frequency and heating period

The plot of the dielectric constant and loss factor at different frequencies is presented for ripe mango peel cv. Nam Dok Mai after dipping in water at temperature range form 30 to 50°C for 30, 60and 90 minutes (Figure 5.6); Chok Anan (Figure 5.7) and Fa Lun (Figure 5.8). Generally both the dielectric constant and loss factor decreased with increasing frequency, especially at high temperature of cv. Nam Dok Mai and Fa Lun. The result parallel with the interpretation measured with chickpea samples (Guo *et al*., 2008) and legume flour (Guo *et al*., 2010). The dielectric constant and loss factor increased with increasing temperature, especially at RF frequencies. The higher frequency, the lower loss factor was also observed. Due to the ionic conductance play an important role under the conditions while the effect of dipole rotation showed slightly effect. This incident has been found in high moisture foods, fresh fruits, vegetable and insects (Guo *et al*, 2008; Wang *et al*., 2005; Wang *et al*., 2008).

When the mangos were dipped in water at temperature of 30 and 45ºC, higher loss factors were observed on ripening stage of mango peel of all three cultivars (Nam Dok Mai, Chok Anan and Fa Lun) in comparison with the peels at physiological maturation (Figure 5.9, 5.10 and 5.11, resp.). Thus, if dielectric heating would be applied for mangoes, the best ripening stage is the closest to the harvest time, when the loss factor is larger and the heat generation is higher. Furthermore, this period would be also easy to handle the fruits and conduct RF treatments without damaging fruit quality.

The flesh of ripe mango responded for the frequency with differently as shown in Figure 5.12-5.17. Dielectric constant of flesh of physiological maturity mango 3 cultivars at temperature between 40 - 50.ºC responded at frequency rage 2-20 MHz while the loss factor increased between 1-10 MHz radio frequencies (Figure 5.12-5.14). Dielectric constant of flesh of ripe mango 3 cultivars responded at frequency range 2-20 MHz. The loss factor of ripe mango 4 cultivars at temperature between 40-50ºC increased between 1-1.5 MHz radio frequencies but remained nearly constant at range 6-50 MHz (Figure 5.15-5.17)

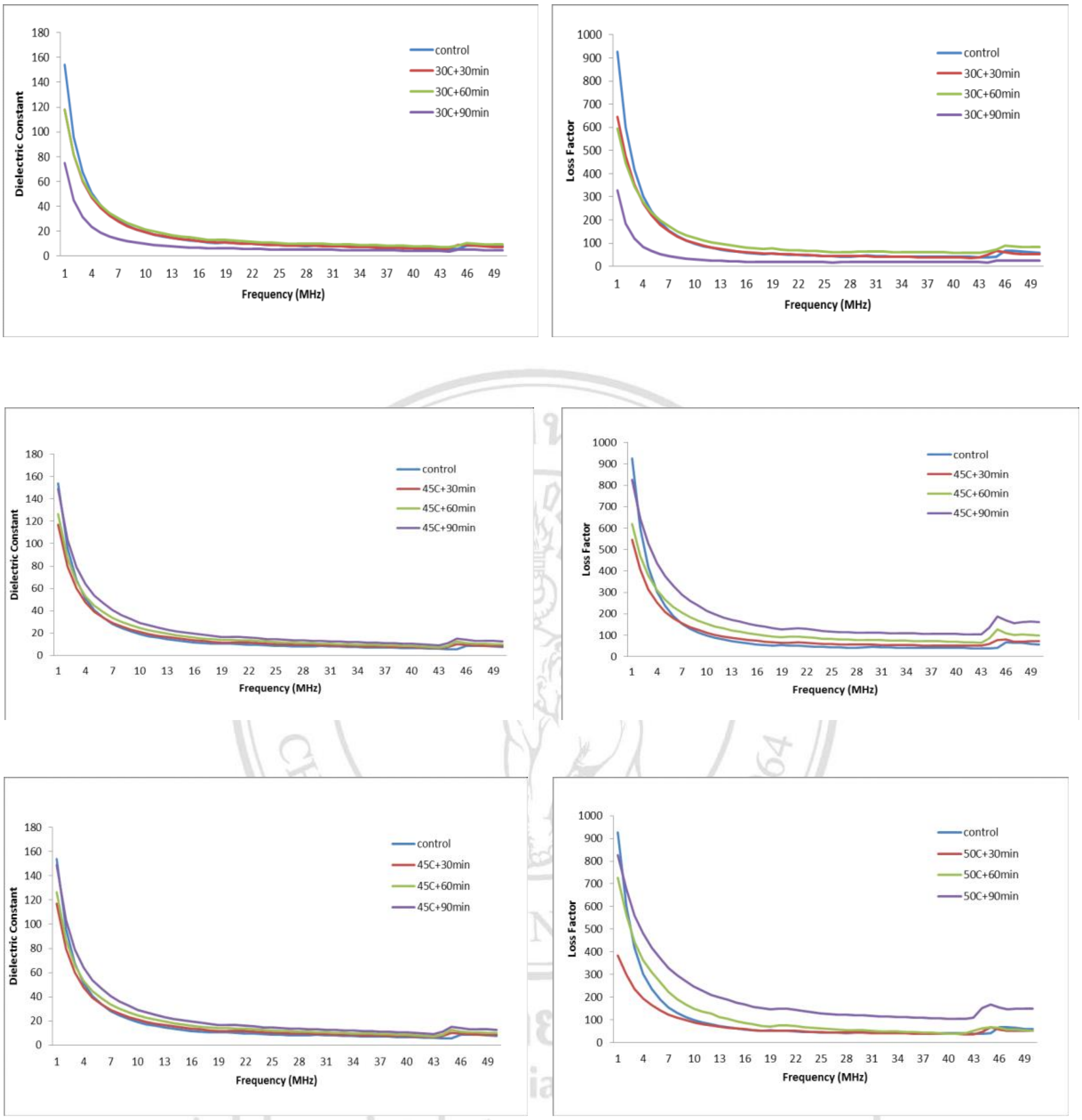

Figure 5.6 Frequency dependence of the dielectric properties of mango peel cv. Nam Dok Mai at physiological maturation after dipping in water at temperature of 30, 45 and 50°C for 30, 60 and 90 minutes

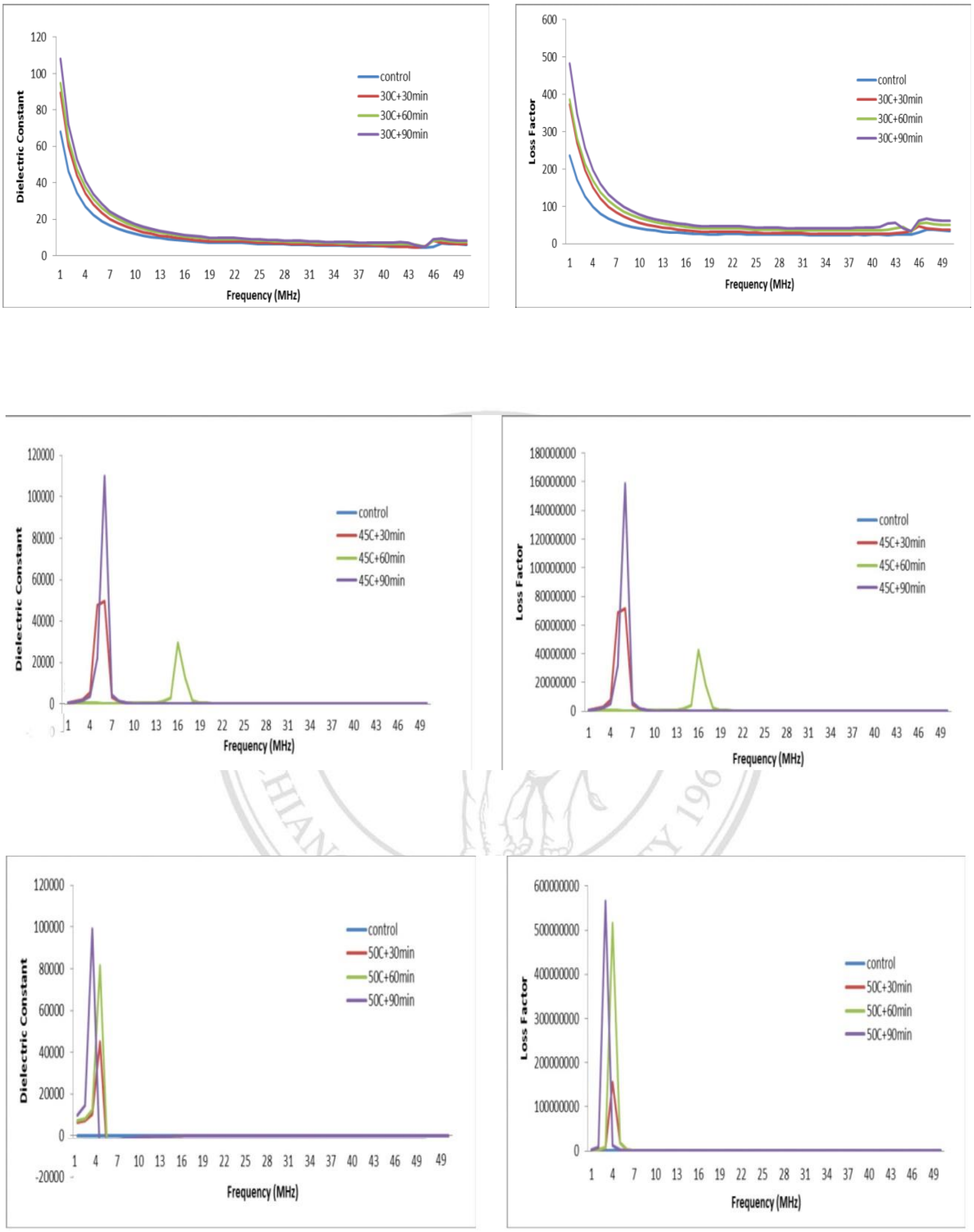

Figure 5.7 Frequency dependence of the dielectric properties of mango peel cv. Chok Anan at physiological maturation after dipping in water at temperature of 30, 45 and 50°C for 30, 60 and 90 minutes

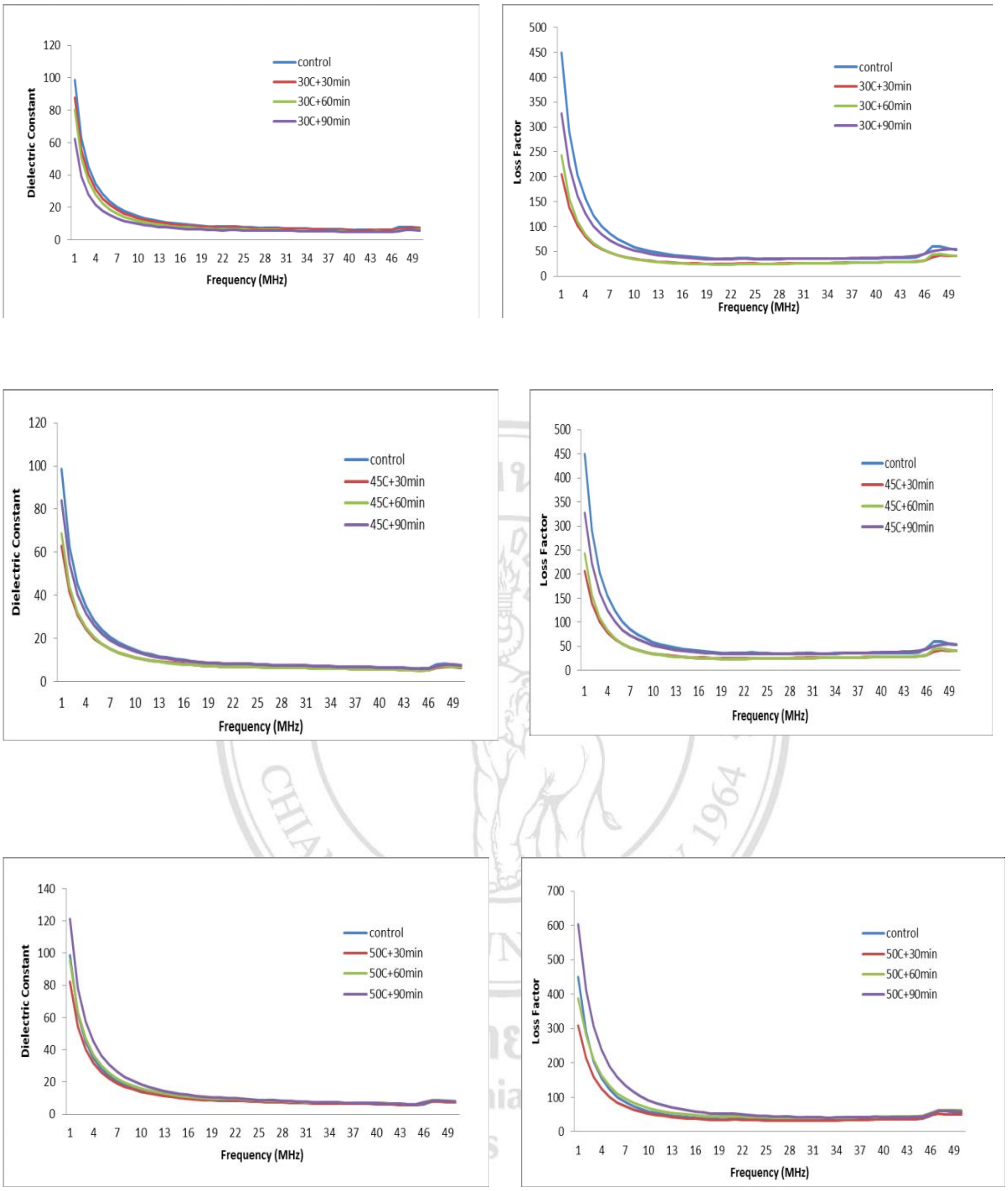

Figure 5.8 Frequency dependence of the dielectric properties of mango peel cv. Fa Lun at physiological maturation after dipping in water at temperature of 30, 45 and 50°C for 30, 60 and 90 minutes

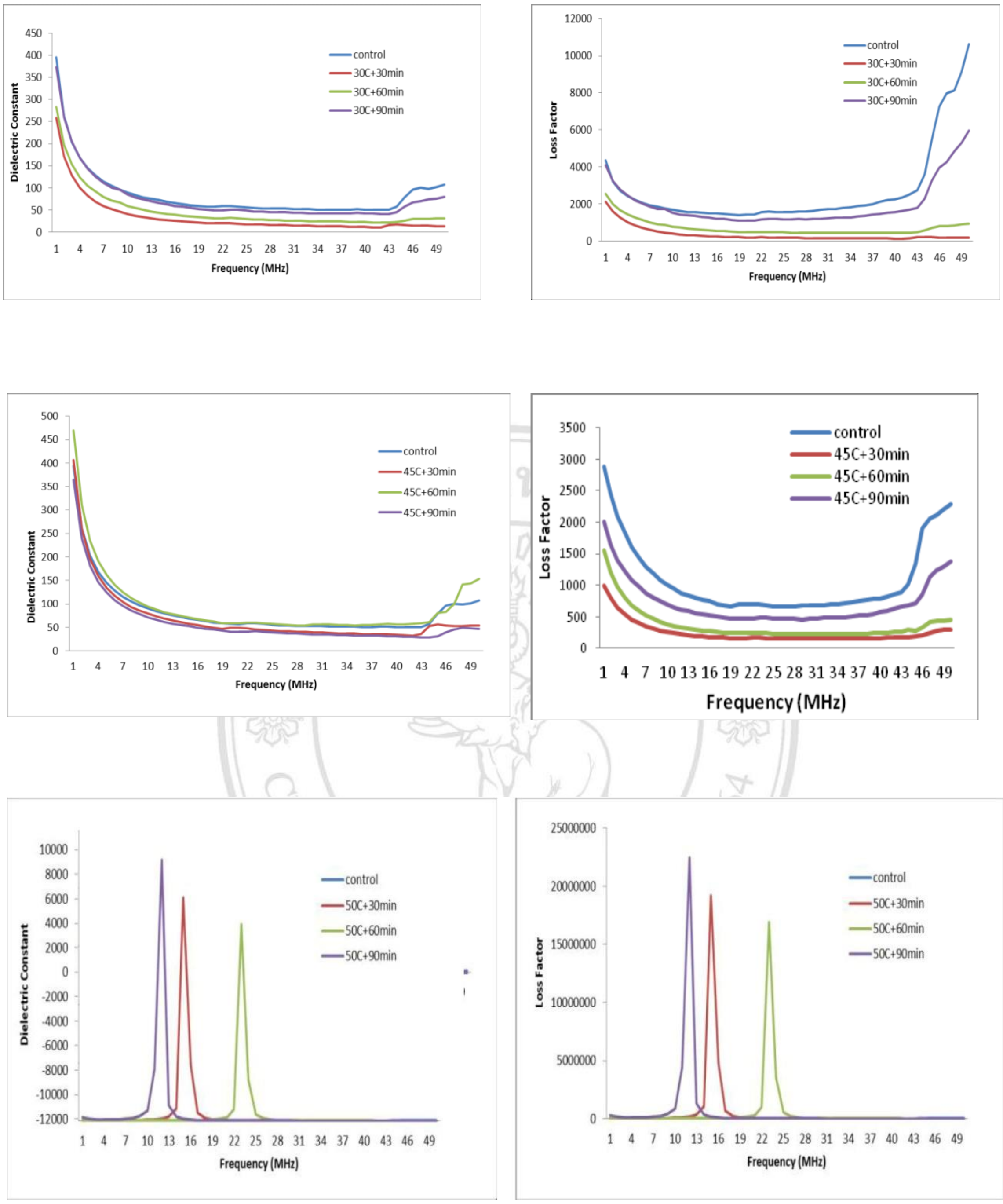

Figure 5.9 Frequency dependence of the dielectric properties of mango peel cv. Nam Dok Mai at ripening after dipping in water at temperature of 30, 45 and 50°C for 30, 60 and 90 minutes

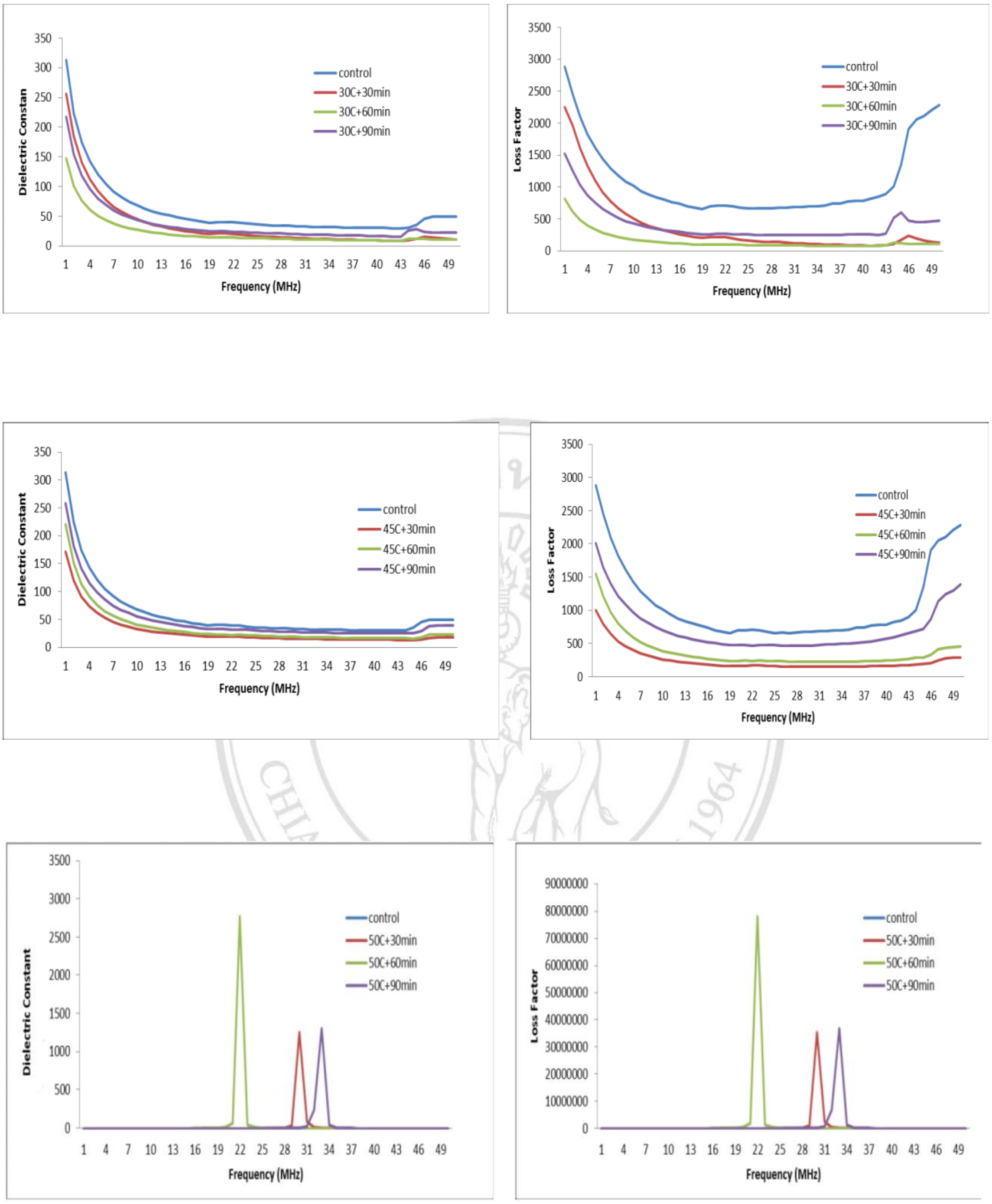

Figure 5.10 Frequency dependence of the dielectric properties of mango peel cv. Chok Anan at ripening after dipping in water at temperature of 30, 45 and 50°C for 30, 60 and 90 minutes

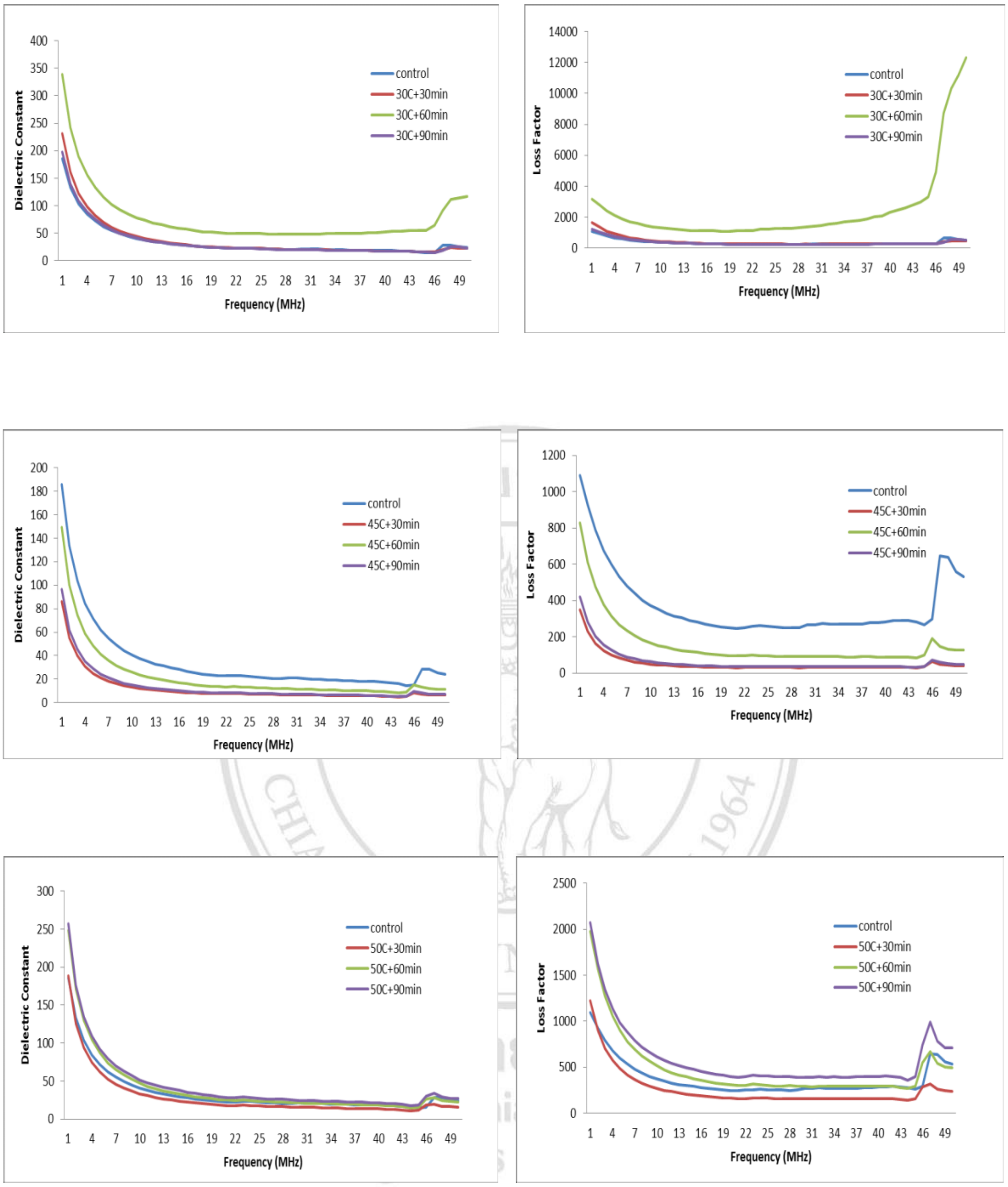

Figure 5.11 Frequency dependence of the dielectric properties of mango peel cv. Fa Lun at ripening after dipping in water at temperature of 30, 45 and 50°C for 30, 60 and 90 minutes

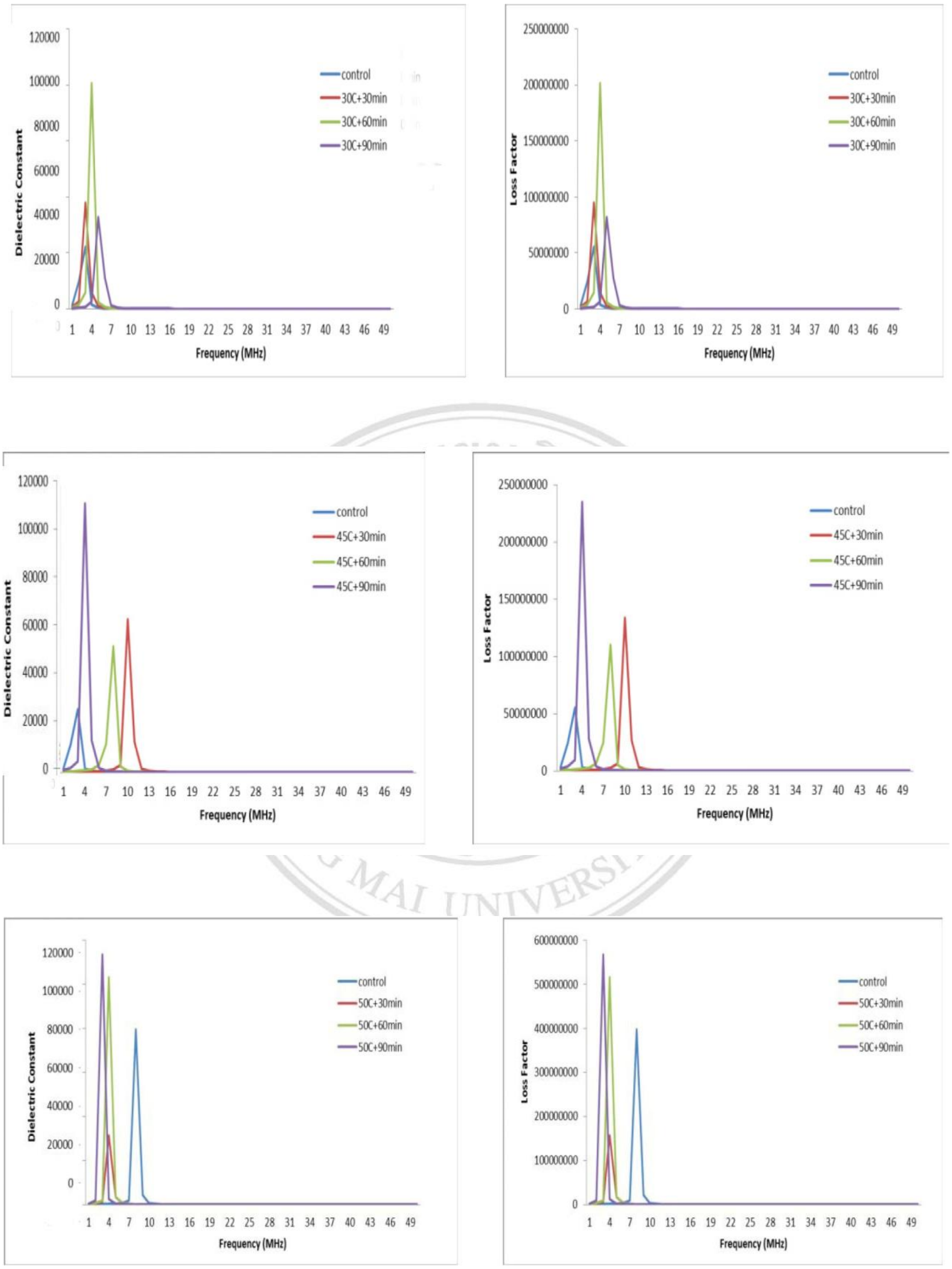

Figure 5.12 Frequency dependence of the dielectric properties of mango flesh cv. Nam Dok Mai at physiological maturation after dipping in water at temperature of 30, 45 and 50°C for 30, 60 and 90 minutes

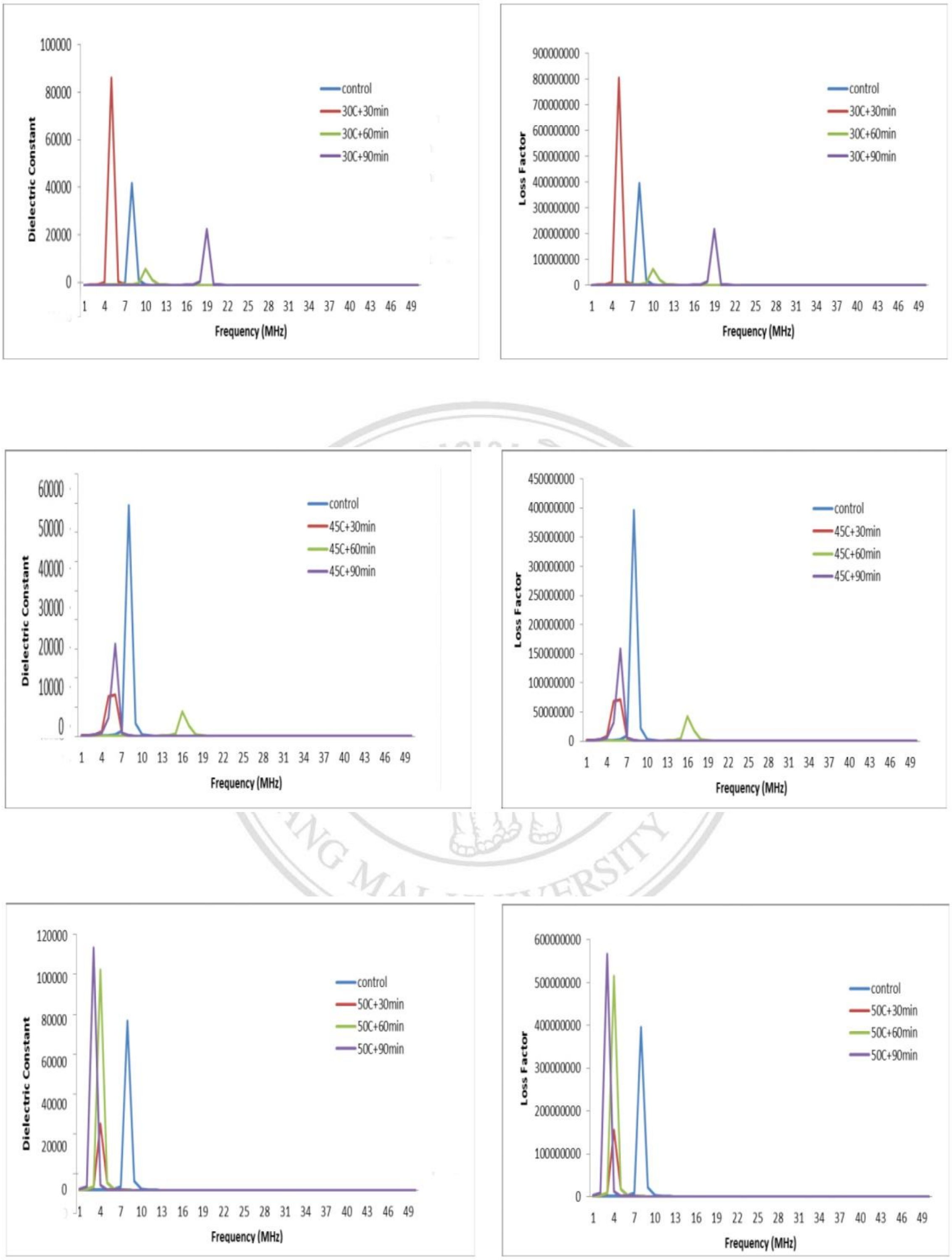

Figure 5.13 Frequency dependence of the dielectric properties of mango flesh cv. Chok Anan at physiological maturation after dipping in water at temperature of 30, 45 and 50°C for 30, 60 and 90 minutes

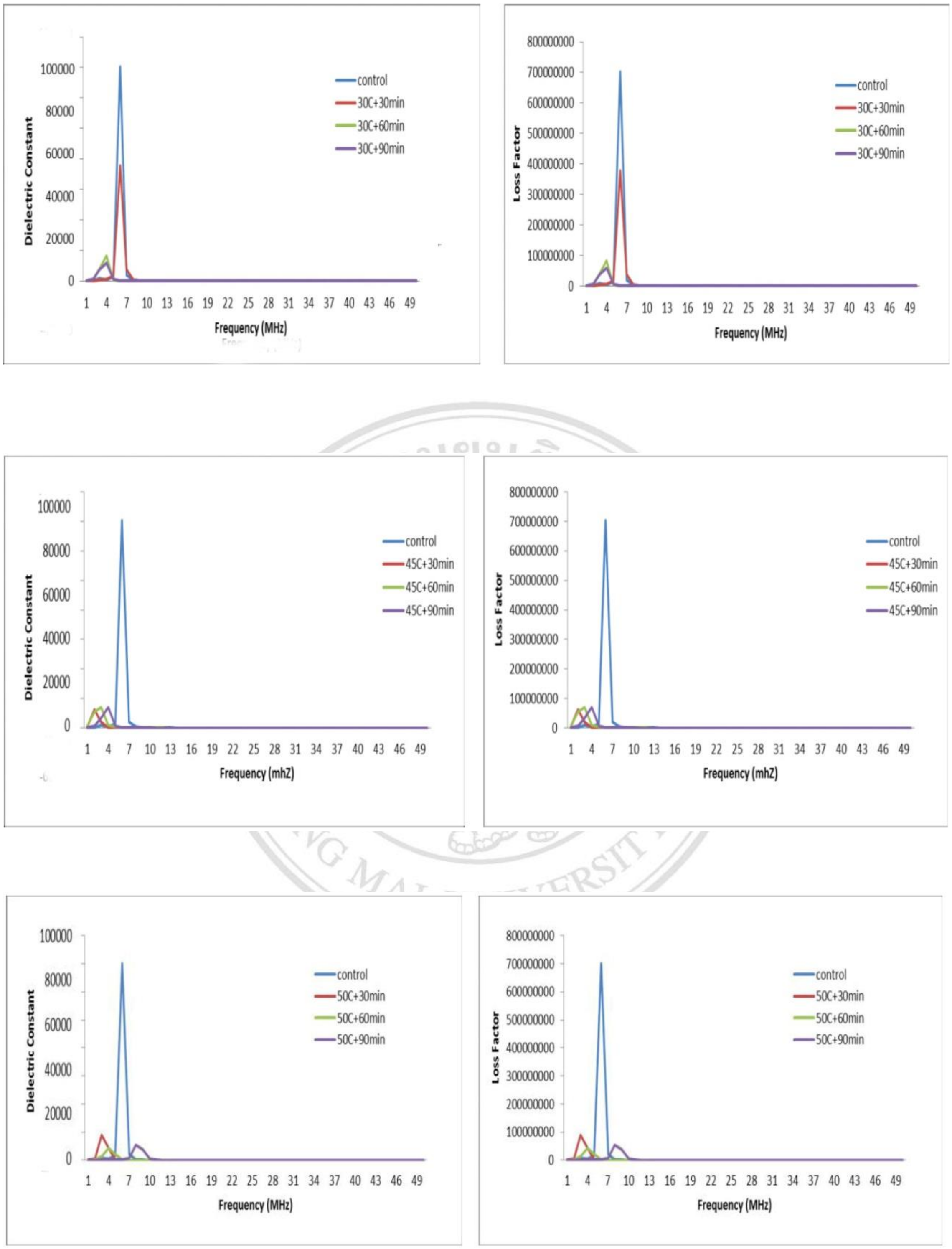

Figure 5.14 Frequency dependence of the dielectric properties of mango flesh cv. Fa Lun at physiological maturation after dipping in water at temperature of 30, 45 and 50°C for 30, 60 and 90 minutes

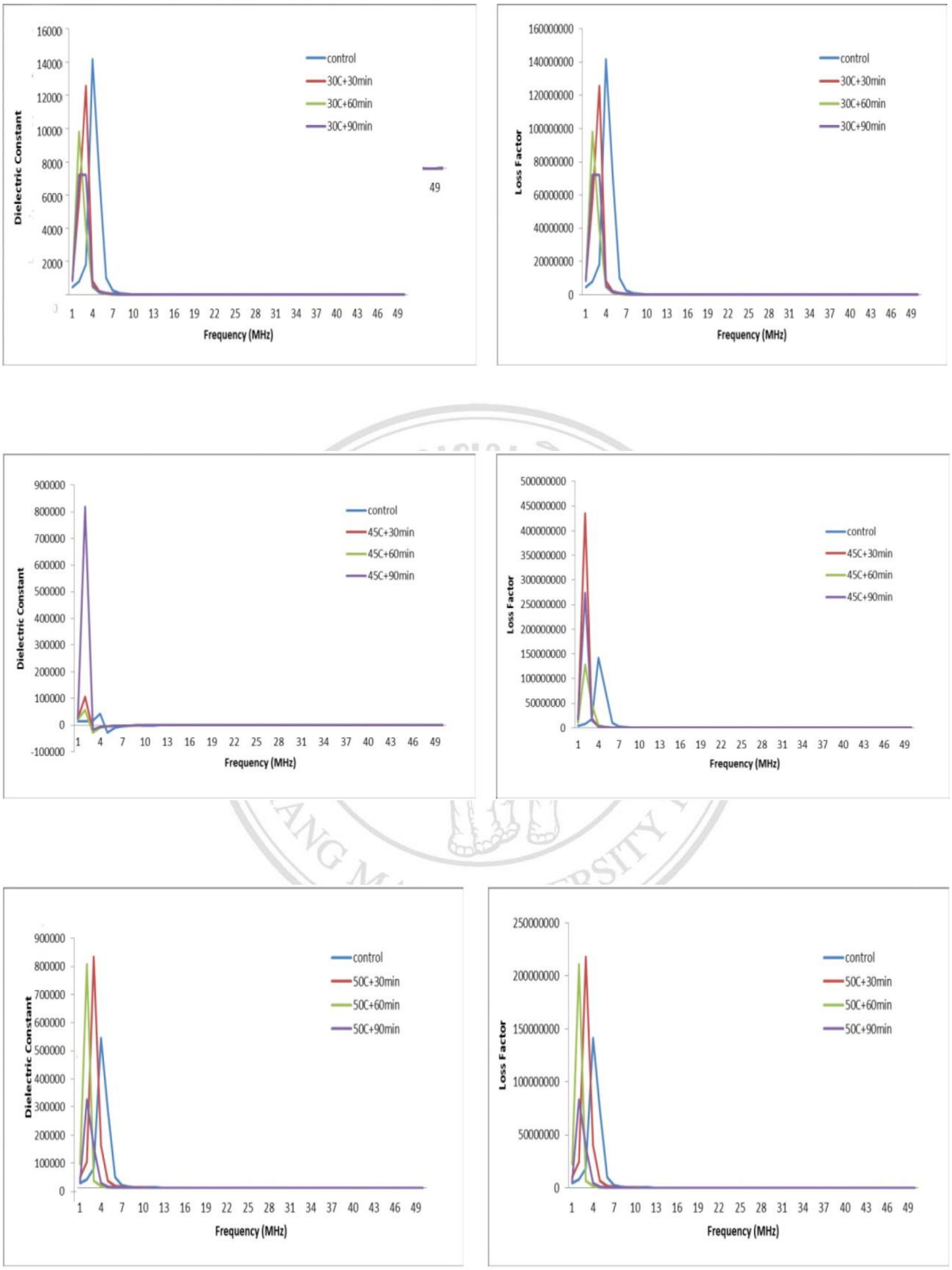

Figure 5.15 Frequency dependence of the dielectric properties of mango flesh cv. Nam Dok Mai at ripening after dipping in water at temperature of 30, 45 and 50°C for 30, 60 and 90 minutes

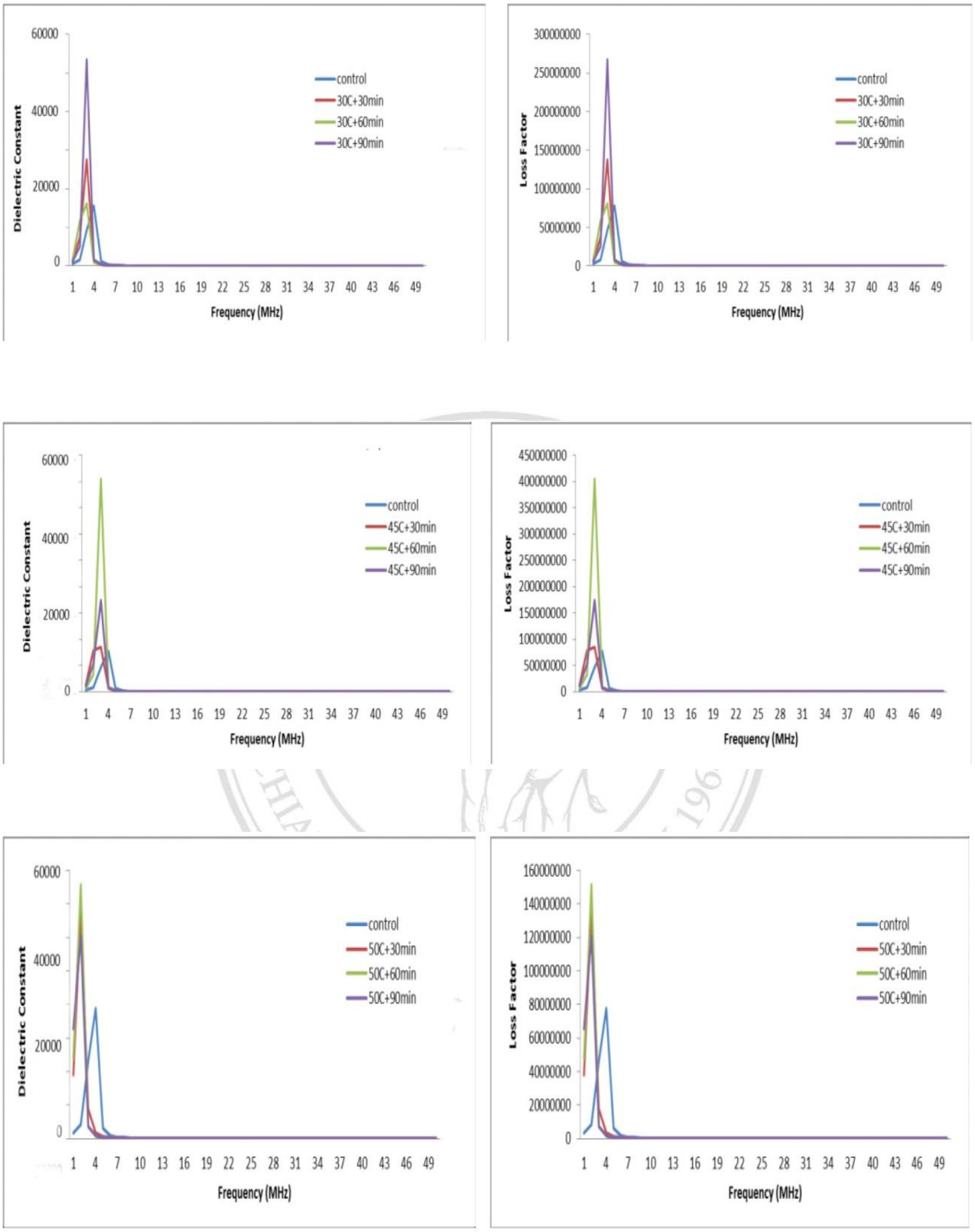

Figure 5.16 Frequency dependence of the dielectric properties of mango flesh cv. Chok Anan at ripening after dipping in water at temperature of 30, 45 and 50°C for 30, 60 and 90 minutes

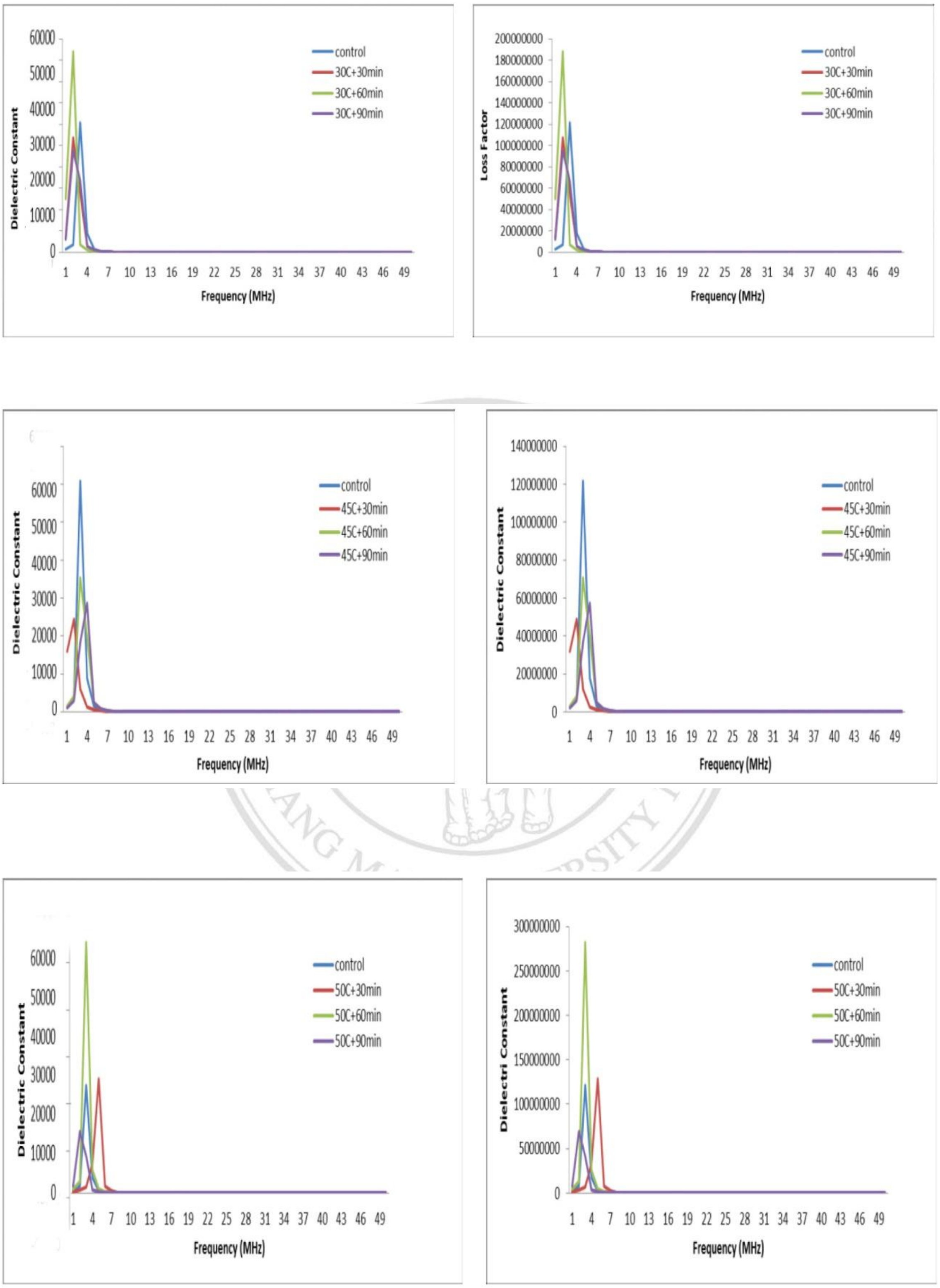

Figure 5.17 Frequency dependence of the dielectric properties of mango flesh cv. Fa Lun at ripening after dipping in water at temperature of 50°C for 30, 60 and 90 minutes

5.4 Conclusion

Dielectric properties of mango as a function of ripening moisture and temperature were measured with an open-ended coaxial line probe, impedance analyzer. Both dielectric constant and loss factor of physiological mango peel decreased with increases in frequency over the detected frequency range from 1to 50 MHz. The dielectric constant and loss factor increased with increasing temperature in the range from 30, 45 and 50ºC. At ripening stage, the obvious evaluation of the dielectric loss factor at different temperature suggested that ionic conduction conquered the dielectric performance in the range of radio frequency 1-50 MHz.

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