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VARIATION OF DIELECTRIC PROPERTIES OF OIL PALM MESOCARP WITH MOISTURE CONTENT AND FRUIT MATURITY AT MICROWAVE FREQUENCIES

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Dielectric properties at frequencies from 0.2 GHz to 20 GHz of mashed mesocarp of oil palm fruits at various stages of maturity are presented.

Measurement of microwave permittivity was done by using open-ended coaxial line probe and automated network analyzer. The accuracy of measurement is about 5% for dielectric constant, ε' and 3% for dielectric loss factor, ε". Results of measurement show that the ionic conductivity dominated in the region less than 3GHz, while above 3GHz the dipole orientation of water molecules becomes dominant. The effect of ionic conductivity is higher in young fruit and decreasing as degree of maturity increases.

Permittivity of oil palm mesocarp over the frequency range was found to increase with moisture content. A significant variation of ε' and ε" with maturity at 0.2GHz and 10GHz respectively make it suitable to form a maturity index as suggested by Nelson et al.. *With moisture content ranging from 25% to 85%, the ε' at 2GHz varies from 11 to 61 and the ε" varies from 2.1 to 24.6 at 10 GHz. Based on the above values the permittivity-based maturity index for young and fully ripe fruits are 1 and 0.3 respectively.*

The results of the dielectric properties of mashed mesocarp also agree reasonably with predicted values from mixture model especially at frequencies above 3 GHz. At 10 GHz the difference between predicted and measured values are within 5%.

This study gives valuable information for the analysis and design of microwave sensor for quality assessment of the oil palm fruits and could also be used for estimating microwave absorption during fruit sterilization and fruit loosening.

INTRODUCTION

Palm oil has emerged to be one of the major world's imports/exports among edible oils (FAO,1994). Besides its nutritional value it is increasingly popular as raw materials for oleochemical industry and fuel for automobiles.

Oil yield and quantity are determined by the quality of the fruits during harvesting or the amount of oil, water and free fatty acid (FFA) in the fruit. It was reported that the amount of moisture content in fresh mesocarp is about 85% at 14-15 weeks after anthesis and decreasing rapidly to about 30% in ripe fruits at about 20-24 weeks after anthesis (Ariffin, 1984; Khalid *et al.*, 1992). The decrease in moisture content is due to the accumulation of oil in mesocarp. Twenty weeks after anthesis only a small amount of oil is increased and at the same time the percentage of FFA in oil increases which reduce the quality and quantity of oil. The fibre content in mesocarp is almost constant after certain stage of maturity whereas water and oil vary with ripeness.

The interaction of electromagnetic waves with the non-magnetic material are determined by the complex permittivity or dielectric properties of material, $\varepsilon = \varepsilon' - j\varepsilon''$. The real part, ε', which is known as dielectric constant expresses the ability of material to store energy and the imaginary part, ε'', known as dielectric loss factor, is a measure of the energy absorbed from the applied field. Dielectric properties of the material depend on the physical properties of material especially moisture content.

The close relationship between moisture content and dielectric properties of mesocarp gives a possibility of using these parameters to gauge the ripeness of the fruit. Furthermore the knowledge of the microwave dielectric properties of oil palm mesocarp are useful especially to improve the design of microwave moisture sensor (Khalid *et al.*,1996) and to estimate the microwave absorption during fruit sterilization process, fruit loosening and drying of fruits prior to oil extraction (Thomas, *et al.*, 1992).

In this study the dielectric properties of oil palm mesocarp at various moisture contents and over a frequency range of 0.2 to 20 GHz are presented. Variations in the dielectric constant and loss factor will be related to the stages of maturity of the fruits and the usefulness of the finding will be highlighted.

MATERIAL AND METHODS

The normal fruits from 5 to 11 years oil palm of tenera variety at various stages of maturity were selected. From the previous classification (Khalid *et al.*, 1992) the fruit maturity can be categorised as follows:

stage of maturity	% oil/fresh mesocarp	% moisture content/fresh mesocarp
under-ripe	less than 5%	40-85%
nearly-ripe	40-48%	35-40%
ripe	48-50%	33-35%
fully ripe	> 50%	<33%

The rate of ripening of a single fruit is not uniform with ripening usually starts from upper region to lower and outer to inner region. The experimental result for moisture content of mesocarp at 20 positions on a single fruit from various degrees of maturity is shown in *Figure 1.* This is done by taking about 10 mg of mesocarp at those positions and the moisture content is obtained by standard oven dry method. The corresponding moisture content of the mashed mesocarp of the whole fruit is also measured. There is a wide variation of moisture content especially for under-ripe, nearly ripe and ripe. However the young and fully ripe fruit shows a greater uniformity in moisture content. Thus it is better to use moisture content of the mashed mesocarp of the whole fruit in order to give a reliable relationship between moisture content and degree of maturity.

The dielectric properties of mashed mesocarp are measured by using 4mm open-ended coaxial-line probe (HP85070M) couple with network analyzer (HP 8720B) and computer. The reflection from the probe is related to the permittivity of the sample and with proper calibration procedures, the accuracy of the measurement is about ± 5% for ε' and ± 3% for ε". All the measurement are done at room temperature, 26°C ±1°C and the actual moisture content is determined by oven drying method.

RESULTS AND DISCUSSIONS

Figure 2 shows the dielectric spectrum of mashed mesocarp at various stages of maturity and mesocarp constituents *i.e.* water, fibre and oil. The dielectric constant, ε' for almost all samples follows the trend of deionized water and their magnitudes are found to be decreasing as the moisture content in the mesocarp decreases. In the frequency range of 0.2 GHz to 20 GHz, the loss factor can

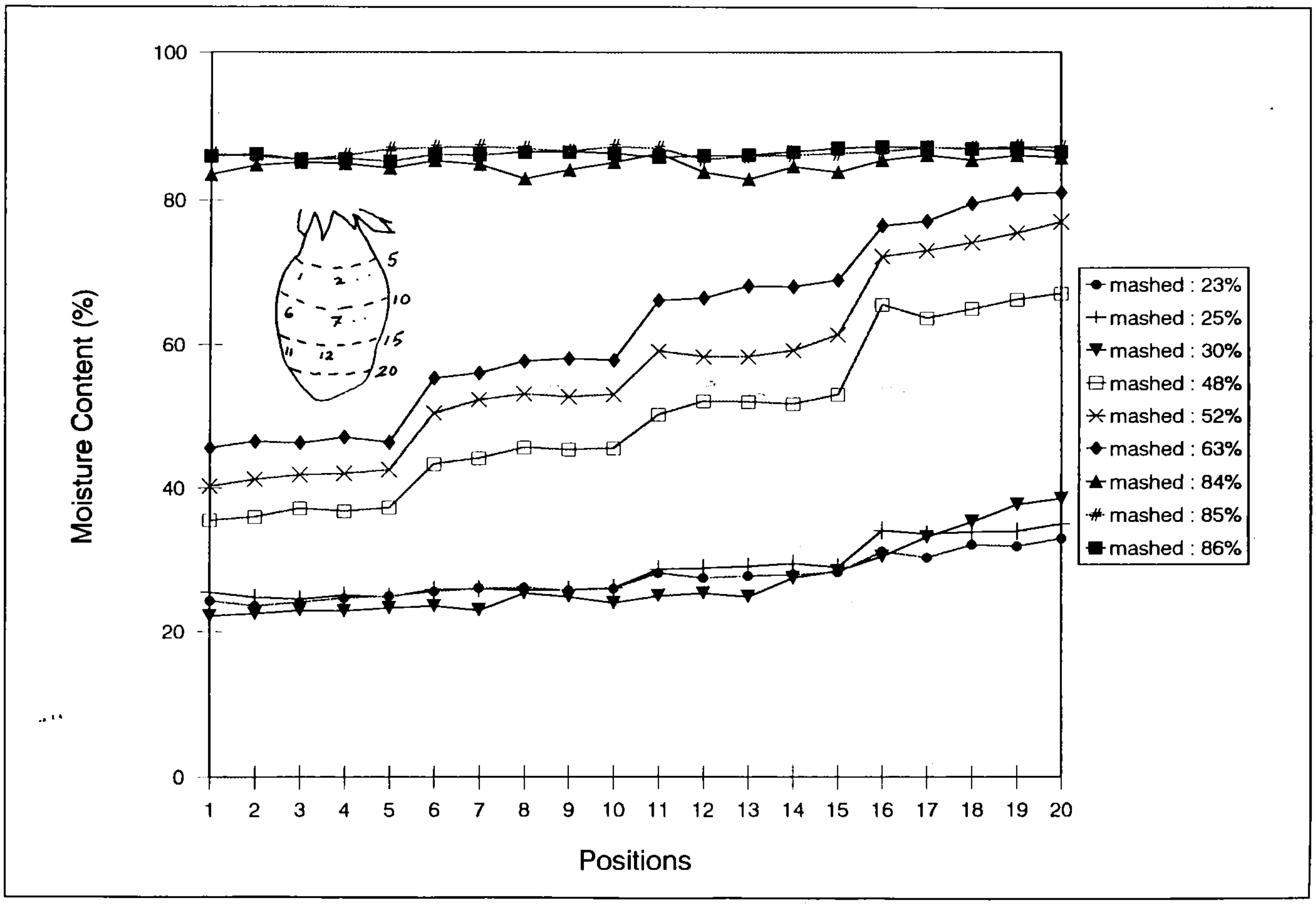

Figure 1. Variation of moisture content at 20 positions of an oil palm fruit and at various stages of maturity. The corresponding moisture content of mashed mesocarp of the fruits is ranging from 23% to 86%.

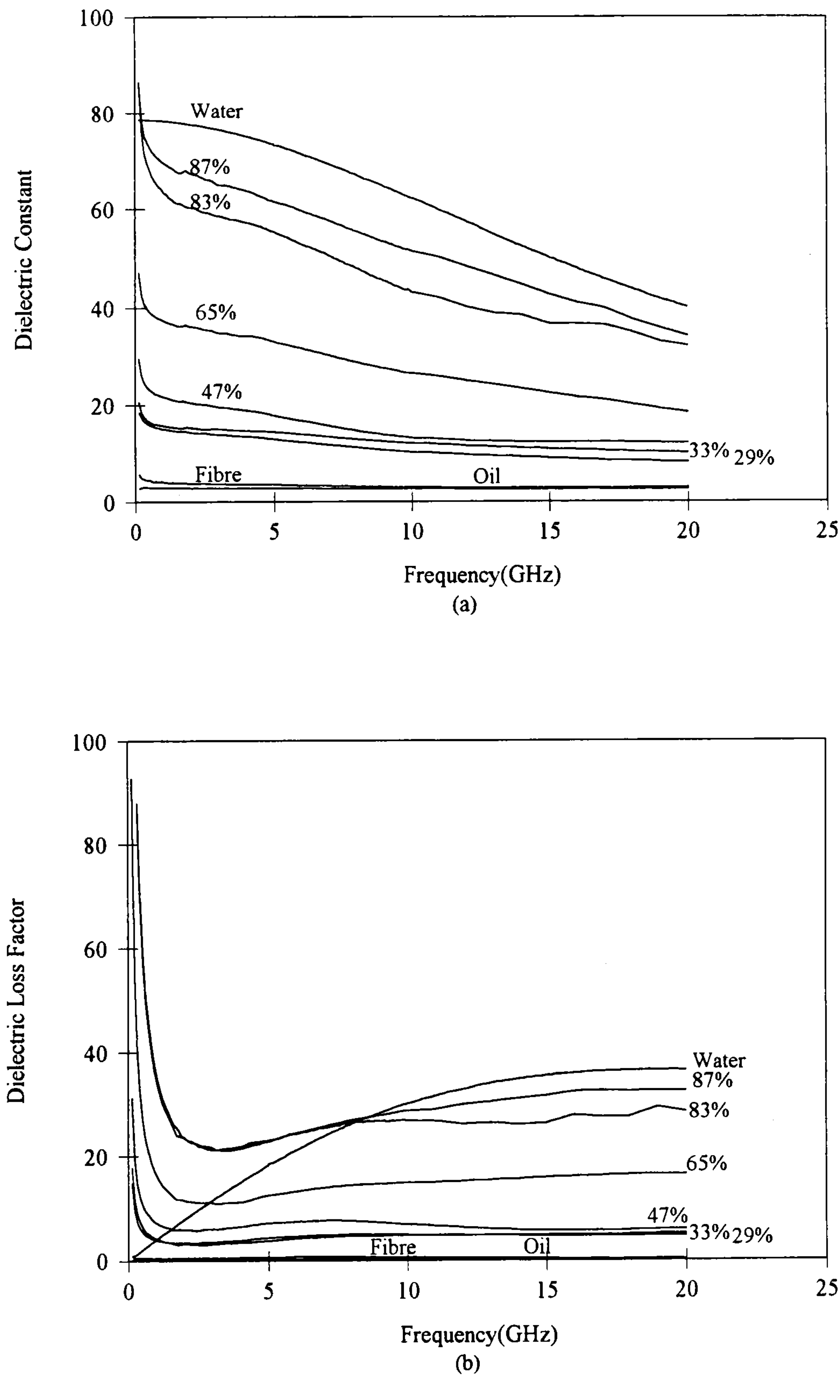

Figure 2. Dielectric spectrum of mashed mesocarp from 0.2 GHz to 20 GHz at various stages of maturity.

be divided into two regions.

For frequencies less than about 3 GHz dielectric loss is dominated by conductive loss while in the upper region (> 3GHz) the loss mechanism is dominated by dipole orientation of water molecules. Thus it is clear that at low frequency the value of ε" depends on the strength of conductive phases in the mesocarp while at higher frequency (> 5 GHz) the ε" increases proportionately with the moisture content.

The dielectric properties of oil and fibre are about the same and their values are about 2.6−j0.02 and dielectric properties are almost constant throughout the frequency of measurement.

Pervious workers (Nelson *et al.,* 1995) who were working on peach maturity introduced a permittivity maturity index based on the real part ε' at 0.2 GHz and the imaginary part, ε" at 10 GHz which was postulated as follows:

$$M_P = \frac{(\varepsilon')_{0.2} + (\varepsilon'')_{10}}{100} \qquad (1)$$

Base on the variation of permittivity or dielectric properties of oil palm mesocarp at 0.2 GHz and 10 GHz with respect to maturity (see *Figure 3*) the index is found to be suitable for oil palm fruit. From *Table 1* the maturity index for oil palm fruit varies from about 1 at young fruit and 0.3 at fully ripe fruit.

A simple model could be developed to predict the dielectric properties of mashed mesocarp at various moisture contents or fruit maturity. By considering the mashed mesocarp as three phase mixtures, the form of effective dielectric permittivity of mashed mesocarp can be written as follows:

$$\sqrt{\varepsilon_m} = v_w\sqrt{\varepsilon_w} + v_l\sqrt{\varepsilon_l} + v_f\sqrt{\varepsilon_f} \qquad (2)$$

where ε_w, ε_l and ε_f are the permittivity of water, oil and fibre respectively and v_w, v_l and v_f are the corresponding volume fractions. The volume fraction for the fibre is about 16% and almost constant throughout the maturity (Hartley, 1977). Thus v_l and v_w can be written as follows:

$$v_l = 1 - v_w - v_f \qquad (3)$$

$$v_w = \frac{M(\rho_f v_f + \rho_l - \rho_l v_f)}{\rho_w - M\rho_w + M\rho_l} \qquad (4)$$

where M is the moisture content (wet basis) and ρ_f, ρ_l and ρ_w are the densities of fibre, oil and water respectively and their values are 0.92, 0.93 and 1.

Figure 3 shows the variation of ε' and ε" with moisture content at 0.2 GHz, 2.45 GHz, 5.8 GHz, 10 GHz , 15 GHz and 20 GHz. The lines are the values predicted from mixture equation (Eqn. 2). Generally the experimental results are closed to the predicted values especially for frequencies greater than 2 GHz. The deviation between predicted values and measured values at 10 GHz are within 5 %. At lower frequencies (less than 2 GHz) the experimental results for dielectric loss are found to be higher than the predicted values and the reason is that the conduction loss is not considered in the calculation. This effect is more pronounced at 0.2 GHz with ε" varies from 160 to 20 over the moisture content from 85% to 30%.

Based on the previous profile of moisture content in mesocarp with day of anthesis (Kaida *et al.,* 1992) the variation of ε' and ε" at 0.2 GHz and 10 GHz can be plotted and as shown in *Figure 4*. As expected the ε' and ε" almost follow the same pattern as moisture content.

CONCLUSIONS

It is found possible to predict the maturity of oil palm fruit through their dielectric properties. It was shown that based on the dielectric constant of mashed mesocarp at 0.2 GHz and dielectric loss factor at 10 GHz the maturity index varies from nearly 1 for unripe fruit and to about 0.3 for fully ripe fruit.

At frequencies above 3 GHz the variation of dielectric properties of mashed mesocarp with moisture content is well predicted by a mixture model since they are not much affected by the ionic conductivity. These frequencies are found to be suitable for the

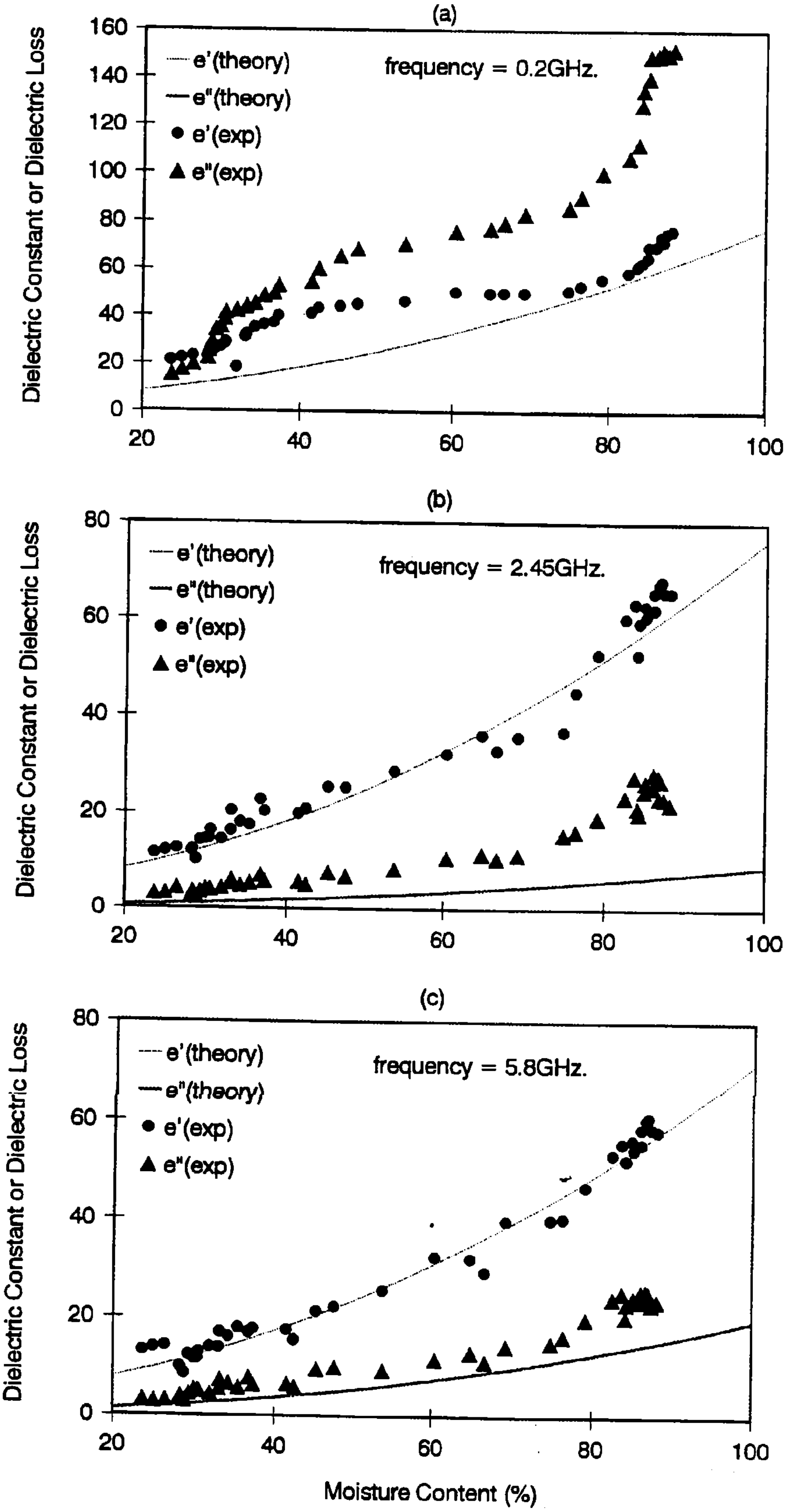

Figure 3. Comparison of the experimental dielectric data for mashed mesocarp with predicted values from mixture equation at 26°C and at specific frequency (a) 0.2 GHz (b) 2.5 GHz (c) 5.8 GHz (d) 10 GHz (e) 15 GHz and (f) 20 GHz.

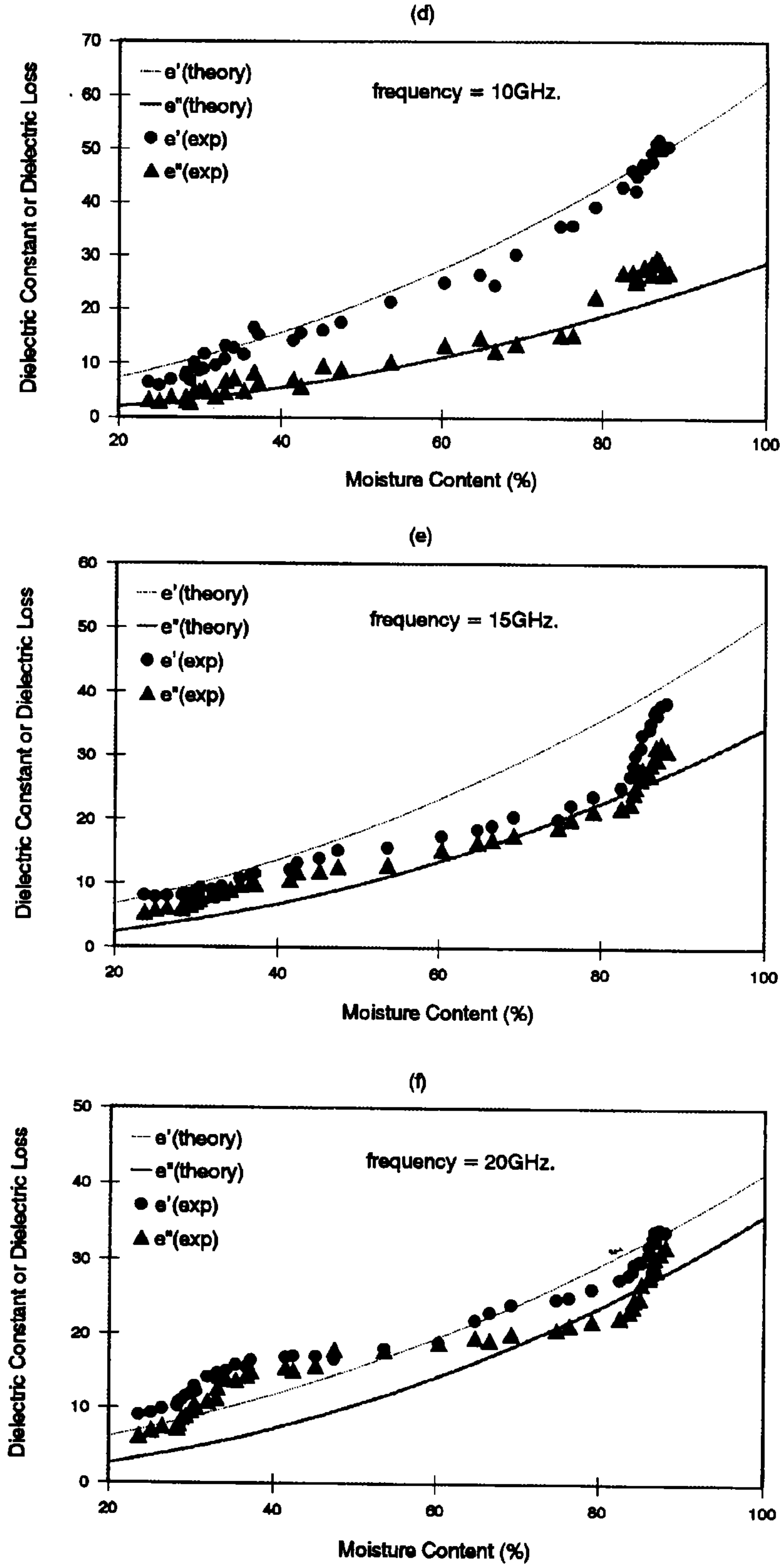

Figure 3 (Cont). Comparison of the experimental dielectric data for mashed mesocarp with predicted values from mixture equation at 26°C and at specific frequency (a) 0.2 GHz (b) 2.5 GHz (c) 5.8 GHz (d) 10 GHz (e) 15 GHz and (f) 20 GHz.

TABLE 1. DIELECTRIC PERMITTIVITY AND MATURITY INDEX AT 26°C OF MASHED MESOCARP AT FOUR STAGES OF MATURITY

Stage of Maturity	Moisture Content (%)	Frequency						Maturity Index
		0.2GHz		2.45GHz		10GHz		$M_P = \frac{(\varepsilon')_{0.2} + (\varepsilon'')_{10}}{100}$
		ε'	ε"	ε'	ε"	ε'	ε"	
Under-ripe	40 - 85	35 - 70	42.5 - 140	19 - 61	5 - 23.5	13.3 - 48.3	6 - 26.7	0.410-0.967
Nearly-ripe	35 - 40	30 - 35	37.5 - 42.5	17 - 19	4 - 5	11.7 - 13.3	5.4 - 6	0.358-0.410
Ripe	33 - 35	29 - 30	36.5 - 37.5	16 - 17	3.5 - 4	10.8 - 11.7	5 - 5.4	0.340-0.358
Fully-ripe	< 33	< 29	< 36.5	< 16	< 3.5	< 10.8	< 5	< 0.340

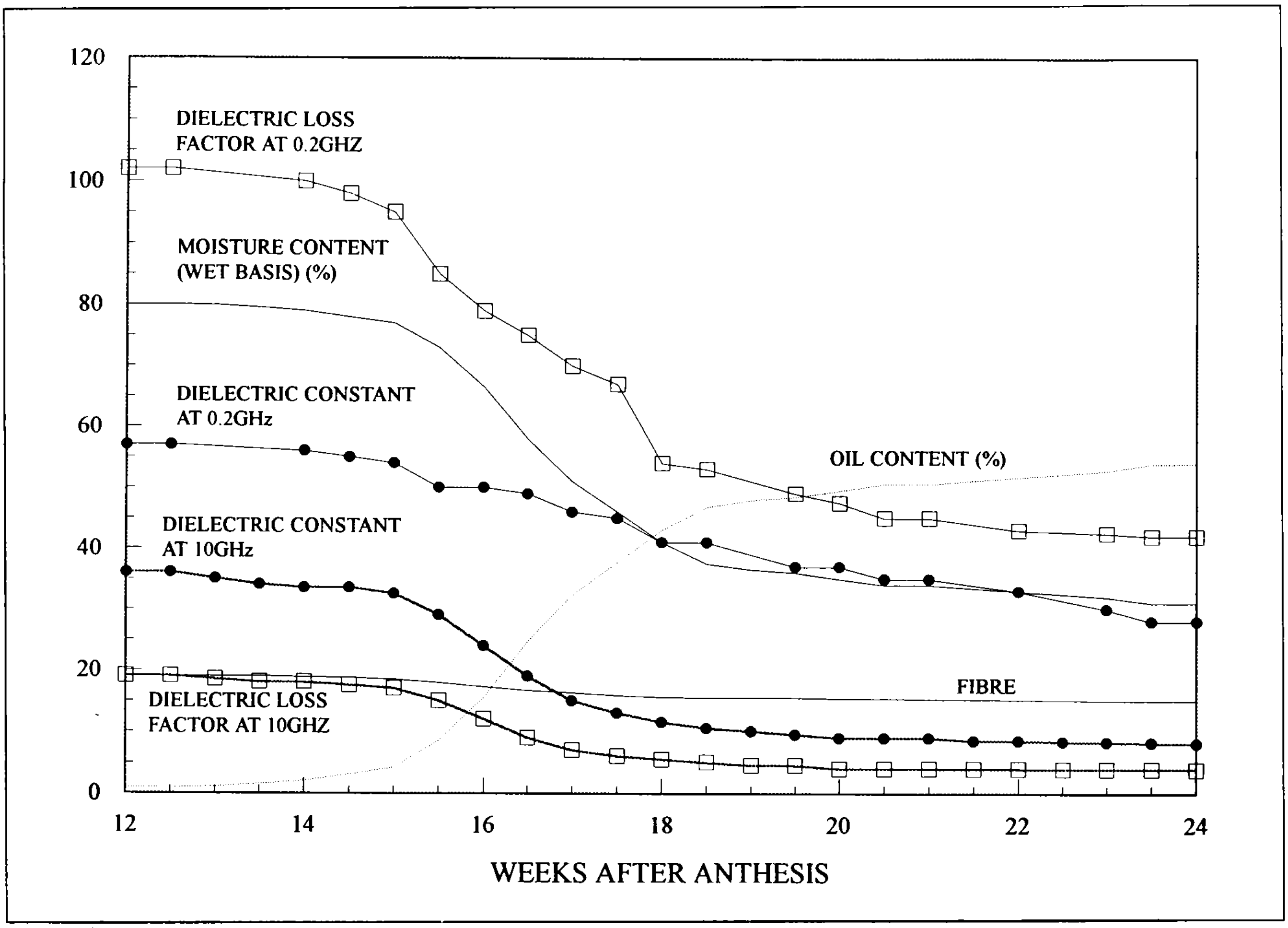

Figure 4. Variation of microwave dielectric properties of mashed mesocarp, oil content, fibre content and moisture content as a function of development time of oil palm fruit.

development of microwave moisture sensor for oil palm fruits.

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