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Characterization of Engineering Properties (Electrical Properties) of *Rubus fruticosus*

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Some engineering properties of *Rubus fruticosus* fruits were characterized in order to provide fundamental information about their properties that will aid in designing modern technology for their handling, processing, storage, preservation, quality evaluation, distribution and marketing. The engineering properties studied are electrical properties. The fruits samples of moisture content (5, 15, 30, 45, 60% (wb)) were conditioned to four different temperature levels, respectively before testing. American Standards for Testing and Materials (ASTM) and American Society of Agricultural and Biological Engineering (ASABE) standard procedures were used to test all the properties considered. Genstat, Mathlab, JMP in SAS, Duncan in SPSS and Microsoft excel statistical packages were used to analyze the generated data and the means were compared using the analysis of variance (ANOVA) at 5% level of probability. Dielectric constant and loss factor of the fruits decreased with increase in frequency (200 MHz – 20 GHz) and increased with temperature. The study was carried out in Anambra State Nigeria and took duration of 9 months. This information is recommended for design and development of efficient and effective technology for mechanizing *Rubus fruticosus* products.

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Keywords: Conductivity of dielectric; dielectric constant; loss factor; depth of microwave penetration.

1. INTRODUCTION

Since man started discovering and cultivating various types of food, there has never been food without work or work for abundant food without machines. The effectiveness of these machines for mechanizing agricultural production depends on adequate knowledge of engineering properties of the products to be mass produced. Mechanization involves replacing human and animal labour with mechanical devices in crop production, processing, storage and distribution. It reduces production cost, ensures timeliness, and optimizes and protects product quality [1].

In handling and processing of agricultural products, some fundamental information about their characteristics is essentially needed. This information can be obtained through the knowledge of engineering properties of the products which constitutes essential data in designing and developing modern technologies for their production, handling, processing, storage, preservation, quality evaluation, distribution and marketing.

Engineering properties of agricultural product are profitably used for mechanizing their planting, harvesting, drying, processing and storage. It improves working efficiency of processing equipment, reduces losses and waste of constructional materials and, saves time and money. It also helps to maintain quality even in adverse storage and handling conditions and offer ways in which products can be utilized effectively. In recent time, strong growing interest on tree crop for food, money and medicine has been ongoing. This is because there is high demand of food due to effects of development and increasing population, besides, many economic tree crops are fading away without being harnessed and replaced.

Tree crops are those perennial woody plants with a single elongated stem of about 3 m high and above (Orwa et al. [2]) and, have head of branches and foliage on which fruits grow. The fruits of tree crops are of great interest to food scientists, food producers and other scientists who work towards achieving food security. Modern agriculture has led to handling and processing of agricultural products into more useful product through various unit operations like cleaning, grading, sorting, drying, dehydration, storage, milling and transportation. *Rubus fruticosus* fruit is an edible fruit from *Rubus fruticosus* tree. It is eaten boiled or fresh for its nutritional and medicinal values.

Nigeria is blessed with a lot of economic tree crops that are rich in food and medicinal values. Development and high quest for foreign food have led to the abandonment of these crops as a result, they are gradually fading away, attracting effect of desertification to our environment.

The agro-industries are dying down due to over dependent on root, tubers, vegetables and grains for raw materials. These products have a lot of competition which increases their price; hence the industries find it difficult to cope due to little or no profit margin. *Rubus fruticosus* fruits are protenious and contain edible oil which waste away in the farm annually and when harvested, a lot of losses are encountered due to low patronage. Processing of this important fruit is still by conventional method which encourages losses of both oil and kernel, is unhygienic and subjects the fruits to vagaries of heat treatment which results in poor quality oil. Olawale [3] reported that the extraction of oils from elemi pulp and kernel are not being carried out at commercial level at present, despite ready availability of the fruit in large quantity in Nigeria and elsewhere in Sub-Sahara Africa. This situation would improve if data needed for the design and operation of the oils' extraction plants are available. *Rubus fruticosus* nuts which house the kernel are usually thrown away after eaten the mesocarp, causing environmental pollution and loss of biomass resources for alternative energy generation. These are as a result of limited knowledge of engineering characteristics of this important fruit and nuts that will promote mechanization of its processing into other useful products.

Oni [4] reported in his inaugural lecture that good number of machines and equipment targeted at agro-industries are substandard and break down frequently. This problem could be because of wrong choice of construction materials, which could be attributed to poor knowledge of engineering characteristics of the targeted agricultural product. Besides, the efficiency of most of the imported processing machines are too poor because they were produced and calibrated based on the engineering data of agricultural products obtained from the manufacturing countries causing maintenance challenges and abandonment of these machines.

Literature has revealed that several studies have been carried out on engineering properties of different agricultural products; chick pea seeds [5] millet (*Pennisetum glaucum* L.) [6] *Lablab purpureus* (L) [7] *Jatropha curcas* L. fruit, nut and kernel [8] *Jathropha curcas* L. seed [9] African yam bean (*Sphenostylis stenocarpa*) [10] water melon [11] orange [12] rice [13] Despite all these studies, there has not been any published work on engineering properties of *Rubus fruticosus* fruits. The objective of this study is to investigate the electrical properties of *Rubus fruticosus* fruits.

Electrical property involves heating the product due to its own electron losses when placed in an electrostatic field. Electrical properties are normally described in terms of dielectric property of the product which include dielectric constant (ε') and loss factor (ε'').

The dielectric constant of a material is associated with the energy storage capability in the electric field in the material and the loss factor (dissipation factor) has to do with the energy dissipation or absorption due to conversion of electric energy to heat energy in the material. The dielectric constant and loss factor are usually influenced by the volume of air void in sample, moisture content and temperature, frequency as well as chemical composition of the product. In complex permittivity of most materials, dielectric constant ε' and loss factor ε'' are expressed as real and imaginary part of the permittivity (ε) as shown in Eq. 1

$$\varepsilon = \varepsilon' - j\varepsilon'' \quad (1)$$

The loss tangent is given as, Eq. 2:

$$tg\delta = \frac{\varepsilon''}{\varepsilon'} \quad (2)$$

2. MATERIALS AND METHODS

2.1 Electrical Properties of the Fruits

Dielectric properties of *Rubus fruticosus* fruits were experimented at frequency range of 50 MHz – 40 GHz using dielectric analyzer (S – Parameter 8722ES). The fruits were sourced from Ebonyi state, the principal dimensions of the fruits were also measured using digital venier calliper. Transmission line techniques were used to determine the electrical properties of the product. Samples of moisture content (5, 15, 30, 45, 60% (wb)) were conditioned to temperatures of 50ºC, 65ºC and 80ºC using water bath, the moisture content of the fruits were determined by oven drying method. Initial moisture content of the fruits was allowed to be uniform by placing in a refrigerator at 5ºC for about 18 hours. The moisture content of the fruits was determined at average environmental temperature and relative humidity of 38ºC and 77% respectively. The fruits samples were weighed using digital balance of 0.01g accuracy before putting them in the oven. The oven was set at 105ºC for 8 hours. The difference between the initial and final mass of each sample was used to calculate the moisture content of the sample as Eq. 3.

$$\%\, M_{wb} = \frac{W_1 - W_2}{W_1} \times \frac{100}{1} \quad (3)$$

Where: M_{wb} = moisture content wet basis (%), W_1 = initial mass (g). W_2 = final mass. These moisture and temperature levels were chosen considering samples under dried and softening conditions. The hot samples were quickly transferred to the probe of the calibrated system which measures and displays the fruits dielectric constant and loss factor automatically. Loss tangent and depth of penetration were calculated as shown in Eqs. 4 and 5, respectively.

$$tg\delta = \frac{\varepsilon''}{\varepsilon'} \quad (4)$$

$$D_p = \frac{c}{2\pi f\sqrt{2\varepsilon'\left[\sqrt{1+(\frac{\varepsilon''}{\varepsilon'})^2}-1\right]}} \quad (5)$$

Where:

c = speed of light ($3\mathrm{x}10^8$ m/s), D_p = depth of penetration (mm)

The experiment was replicated three times for each temperature and moisture content studied.

3. RESULTS AND DISCUSSION

3.1 Electrical Properties of *Rubus fruticosus* Fruits

3.1.1 Effect of moisture content and frequency on ε' and ε'' of the fruits

Figs. 1 and 2 showed the dielectric properties of *Rubus fruticosus* fruits as a function of frequency at five different moisture contents. The dielectric constant (ε') and loss factor (ε'') for both long and short fruits decreased with

Table 1. Principal dimensions of *Rubus fruticosus.* long and short fruits at different moisture content

M. C.	Fruits					
	Long			Short		
	A	b	c	A	b	c
40.91%	42.86 ± 0.91 (2.13)	20.05 ± 0.66 (3.27)	19.56 ± 0.65 (3.33)	26.06 ± 1.09 (4.18)	16.69 ± 0.59 (3.52)	16.17 ± 0.27 (1.98)
34.92%	42.59 ± 0.88 (2.09)	18.54 ± 0.63 (3.41)	18.06 ± 0.64 (3.56)	25.08 ± 1.37 (5.47)	15.89 ± 0.56 (3.56)	15.36 ± 1.54 (1.05)
23.44%	42.36 ± 0.93 (2.09)	18.44 ± 0.51 (2.77)	17.89 ± 0.53 (2.97)	24.20 ± 2.08 (8.62)	15.05 ± 0.78 (5.24)	14.57 ± 1.54 (1.05)
18.5%	42.02 ± 0.97 2.30	17.39 ± 2.38 (1.36)	17.18 ± 0.98 (3.74)	23.87 ± 2.24 (9.39)	14.45 ± 0.84 (5.80)	13.94 ± 1.59 (1.14)
11.03%	41.71 ± 1.36 (3.27)	16.90 ± 2.43 (1.44)	16.58 ± 1.13 (3.82)	23.05 ± 2.73 (1.18)	13.99 ± 0.96 (1.20)	13.48 ± 1.62 (1.20)

The values in bracket are the coefficient of variation (%CV); a = major diameter (mm); b = intermediate diameter (mm); c = minor diameter (mm); M .C. = moisture content wet basis.

increase in frequency and increased as moisture content rises from 5.00% – 60.00% wet basis. The dielectric constant ($\mathcal{E}'$) for short and long fruits increased from 2.06 – 6.79 and 1.12 – 33.68 respectively as moisture content increased from 5.00% – 60.00% wet basis. Loss factor ($\mathcal{E}''$) for short and long fruits also increased from 0.6594 – 5.99 and 1.22 – 14.99, respectively.

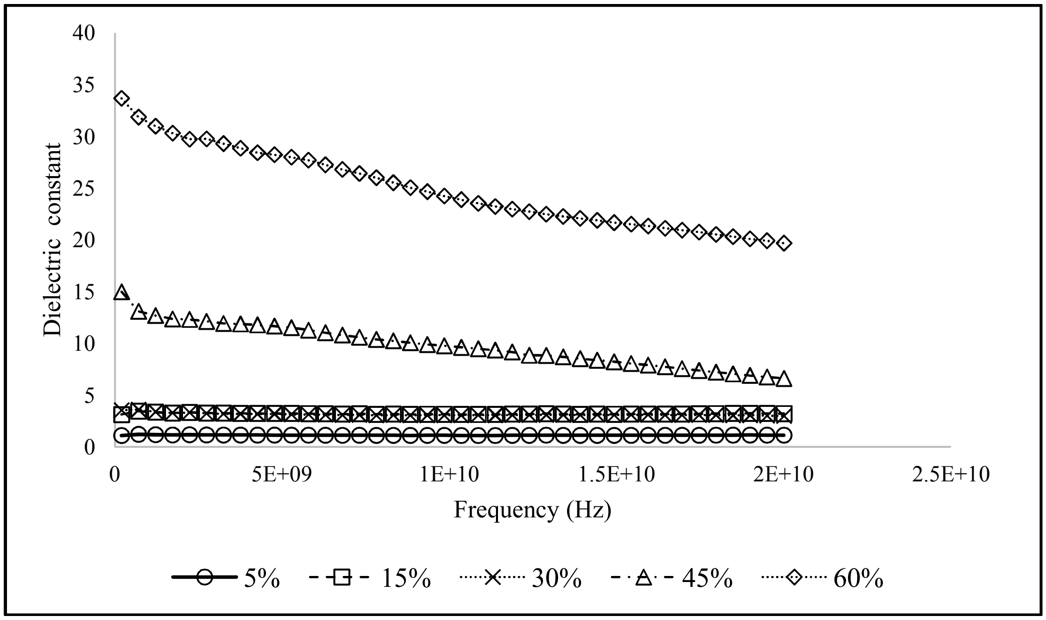

Fig. 1a.

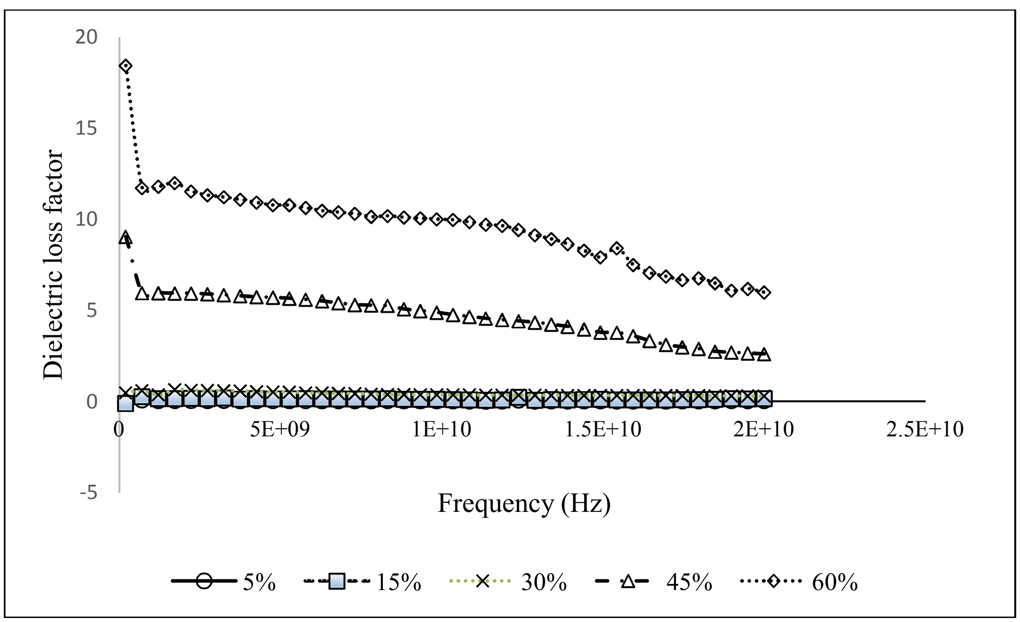

Fig. 1b.

Fig. 1. The dependence of Rubus fruticosus long fruits (a) dielectric constant and (b) dielectric loss factor) on frequency at five various moisture content wet basis

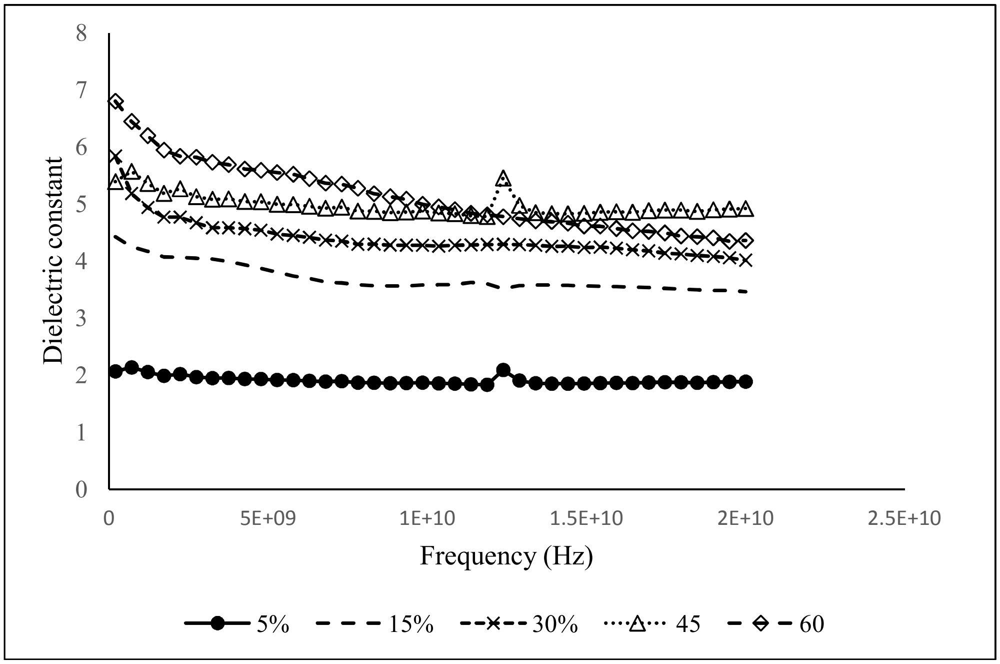

Fig. 2a.

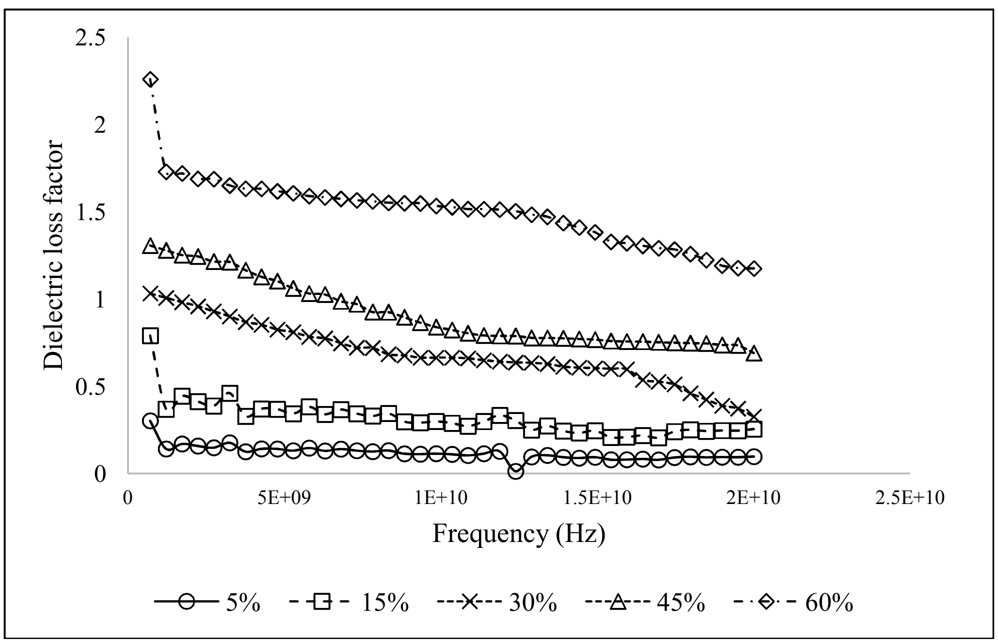

Fig. 2b.

Fig. 2. The dependence of Rubus fruticosus short fruits (a) dielectric constant and (b) dielectric loss factor) on frequency at five various moisture content wet basis

At lower moisture content (5% wet basis), $\mathcal{E}^{'}$ and $\mathcal{E}^{''}$ of both fruits are very low throughout the frequency range studied except $\mathcal{E}^{'}$ of short fruit. The reduction in $\mathcal{E}^{'}$ with moisture content and frequency was reported to be due to low dispersion of water molecules caused by the effects of relaxation process and ionic conduction [14] Long and short fruits had the lowest value of ε' at 10 GHz and 11 GHz under dry condition (5.00% wet basis). Respectively while under wet condition (60.00% wet basis) both fruits attend the lowest values at 20 GHz. [15] observed similar trend with apple fruits at lower moisture content.

ANOVA at 5% level of significance summarized in Table 2 also revealed that moisture content and frequency had high significant effect on ε' and ε''.

Variation of ε' with frequency and moisture content was not linear as shown in Table 3. High values of R^2 obtained justifies the good fit of non-linear relationship while the equations can be used to estimate ε' of the fruits at any given moisture content.

3.1.2 Effect of temperature and frequency on ε' and ε'' of the fruits

The variation of dielectric constant (ε') and dielectric loss factor (ε') with temperature plotted at frequency range of 200 MHz to 20 GHz is presented in Figs. 3 and 4.

It was observed that the values of ε' and ε'' are significantly (5%) low for all temperatures studied. Dielectric constant (ε') of long fruit decreased with increase in frequency (9.16 – 5.29, 14.18 – 6.41 and 16.53 – 8.02 at 50ºC, 65ºC and 80ºC, respectively for 200 MHz – 20 GHz). Short fruit (ε') also decreased with increase in frequency (13.79 – 6.88, 10.88 – 5.36 and 9.23 – 5.35 at 50ºC, 65ºC and 80ºC respectively for 200 MHz – 20 GHz).

Both fruits at all temperatures experienced a sharp decrease in dielectric constant (ε') up to 2.23 GHz afterwards, reduction becomes gradual. At lower temperature (50 ^{o}C), changes in ε' of both fruits over frequency range considered are insignificant while significant (5%) changes were observed above 50 ^{o}C. Besides, dielectric loss factor *(ε'')* also had a very sharp decrease up to 1.21 GHz and then increased as frequency increased in all the temperatures of both fruit sizes.

Loss factor (ε'') decreased from 5.05 – 4.61, 10.75 – 3.07 and 15.17 – 2.89 at 50ºC, 65ºC and 80ºC, respectively and increased with increase in temperature for long fruit and also decreased from 12.14 – 3.04, 8.55 – 2.64 and 6.37 – 1.87 at 50ºC, 65ºC and 80ºC respectively for short fruits. Low changes in ε' and ε'' at low temperature could be because the dipole molecules are weak at low temperature causing slow movement of the molecules and ionic conductivity of the product. Similar observation was reported of apple, wheat, fresh fruits and vegetables (Feng et al. [14]). The temperature dependence of ε' and ε'' are highly significant (5%) for both fruits (Table 4).

The relationship between ε' and ε'' with temperature could be established using regression functions and equations as shown in Table 5.

Table 2. ANOVA of dielectric properties of *Rubus fruticosus* fruits as a function of moisture content (5, 15, 30, 45, 60% (wb))

Size	**Dielectric property**	***F- value***	***P- value***	***F - critical***
Long	ε'	1315.51**	5.1E-119	2.43
	ε''	654.89**	2.27E-96	2.43
Short	ε'	1297.13**	1.5E-118	2.43
	ε''	1577.42**	1.3E-122	2.43

*NB; ** means highly significant at 5% level*

Table 3. Regression equations of relationship between dielectric properties of *Rubus fruticosus* fruits and moisture content

Size	**Dielectric properties**	**Regression equation**	**R^2**
Long	ε'	$2.34\ h^2 - 8.61\ h + 8.58$	0.96
	ε''	$0.97\ h^2 - 3.45\ h + 2.68$	0.99
Short	ε'	$1.31\ \ln(h) + 5.95$	0.99
	ε''	$2.37\ h^{1.0549}$	0.99

h = moisture content.

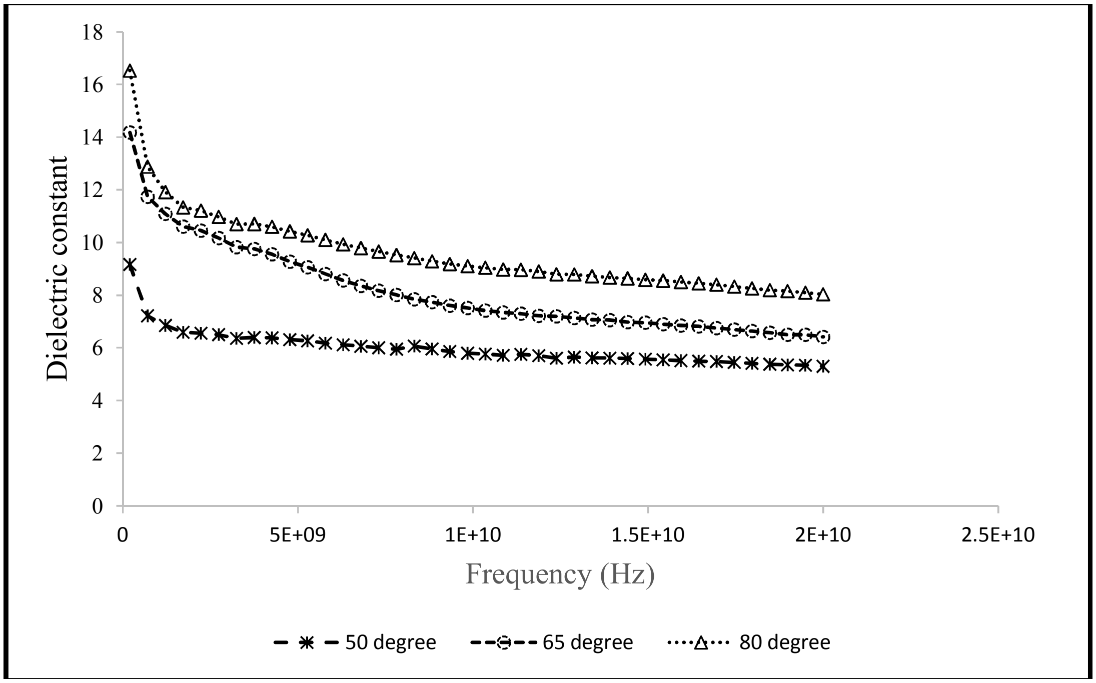

Fig. 3a.

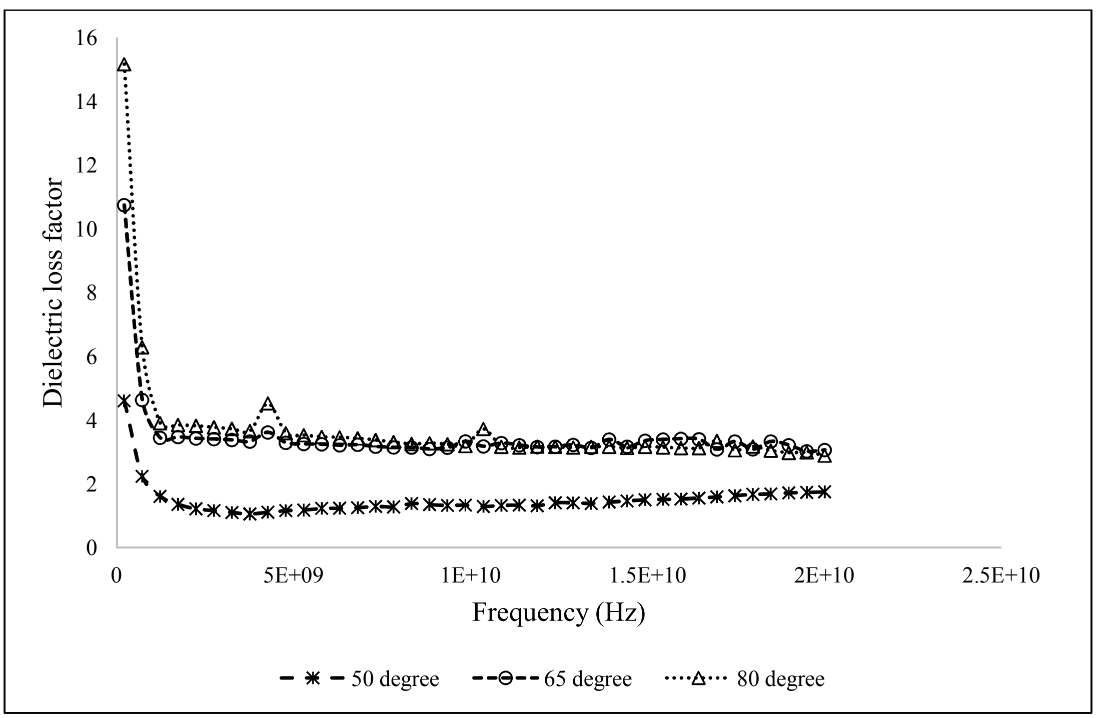

Fig. 3b.

Fig. 3. The dependence of *Rubus fruticosus Long* fruits (a) dielectric constant and (b) dielectric loss factor) on temperature

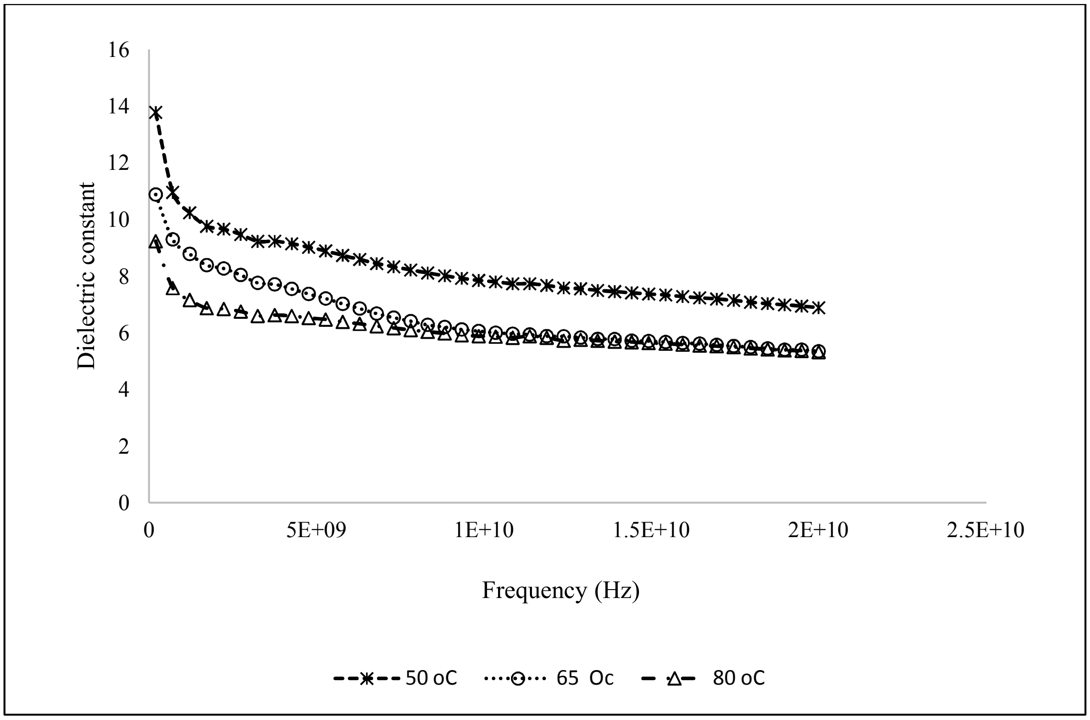

Fig. 4a.

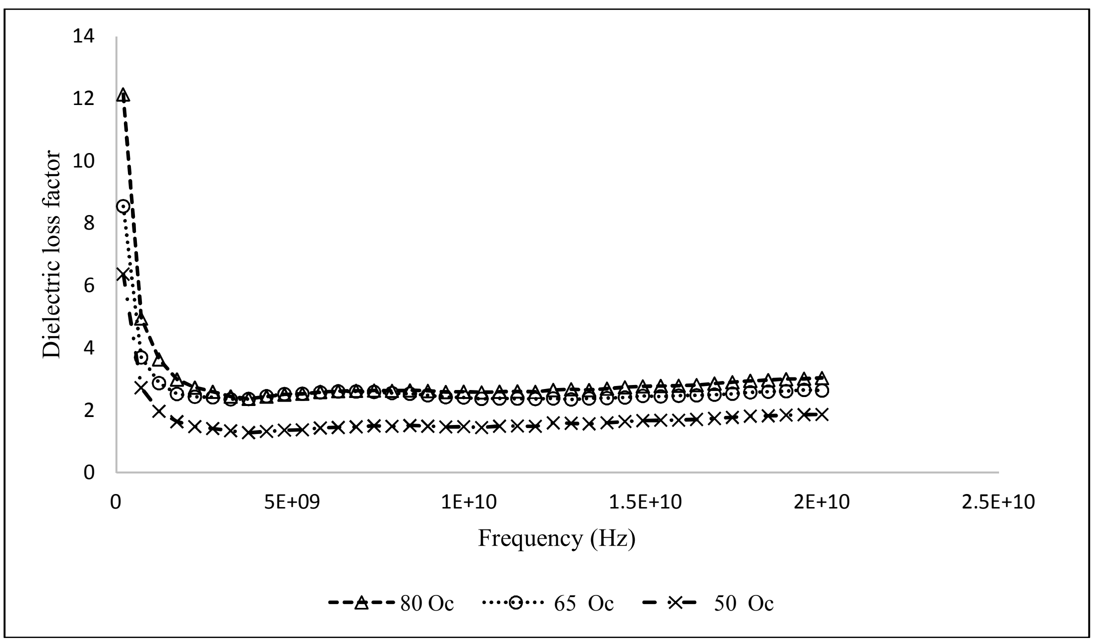

Fig. 4b.

Fig. 4. The dependence of *Rubus fruticosus* short fruits (a) dielectric constant and (b) dielectric loss factor) on temperature

Table 4. ANOVA of dielectric properties of *Rubus fruticosus* fruits as a function of temperature

Size	Dielectric property	*F- value*	*P- value*	*F - critical*
Long	ε'	372.78**	1.2E-40	3.11
	ε''	109.85**	2.06E-23	3.11
Short	ε'	424.69**	1.17E-42	3.11
	ε''	112.29**	1.09E-23	3.11

Level of probability = 5%

Table 5. Regression equations of relationship between dielectric properties of *Rubus fruticosus* fruits and temperature

Size	Dielectric properties	Regression equation	R^2
Long	ε'	$3.29ln(T) + 5.96$	0.99
	ε''	$2.24 + 0.8205T - 0.3473T^2$	1
Short	ε'	$45.12e^{0.1506T}$	0.92
	ε''	$2.76 + 0.5673T – 0.303T^2$	1

T = temperature

3.1.2.1 Loss tangent of Rubus fruticosus fruits

Loss tangent changed significantly (5%) as moisture level of the samples increased (Fig. 5).

Long and short fruit loss tangent increased from 3.52 – 26.55 and 3.52 – 16.27 respectively as moisture content increased from 5.00% – 60.00% wet basis and, 13.96 – 23.19 and 15.53 – 22.06 respectively as temperature increases from 50ºC – 80ºC.

The relationship of loss tangent with temperature as shown in Fig. 6 was positive. At lower moisture content (5.00%), the loss tangent of both fruits are relatively the same but from 30% wet basis and above, clear differences were observed. The behaviour of loss tangent for both fruits was the same at all temperatures studied. The increase in loss tangent with increase in temperature and moisture content confirms dielectric constant (ε') and dielectric loss (ε'') dependence on the mobility of water molecules and ionic conductivity of the given sample.

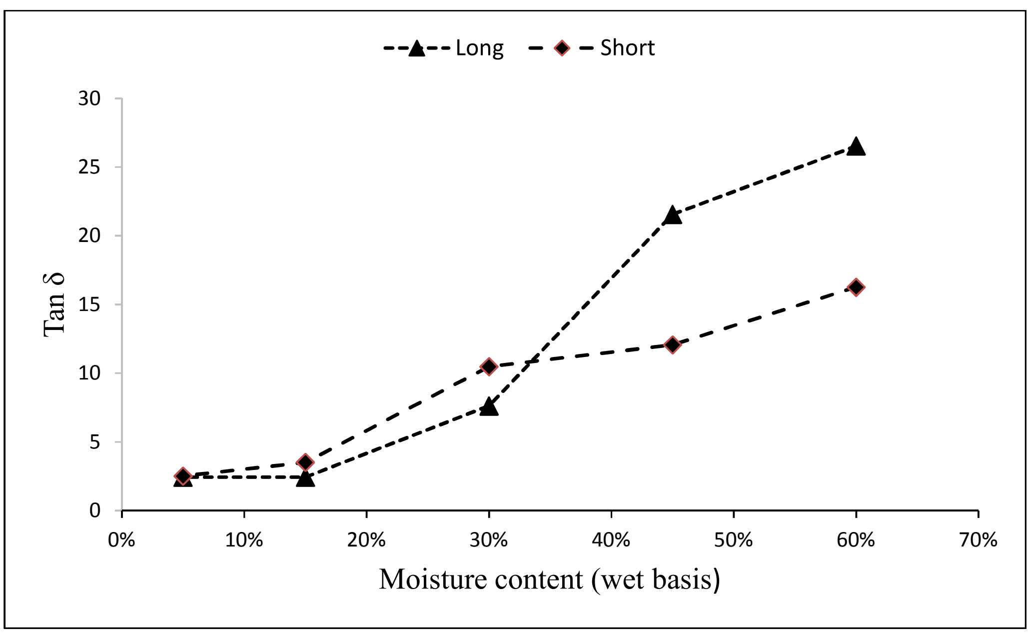

Fig. 5. The plot of loss tangent of *Rubus fruticosus* fruits against moisture content

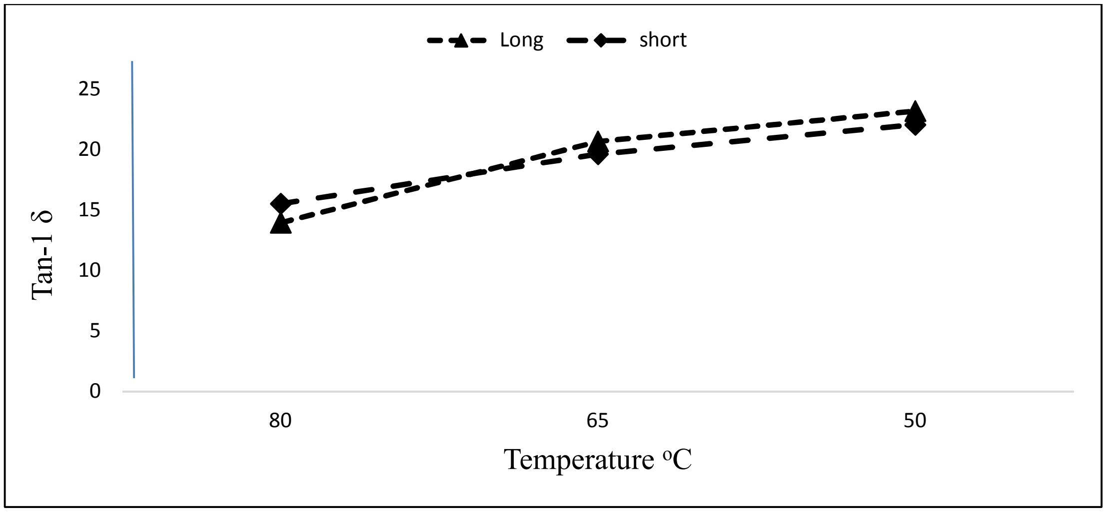

Fig. 6. The plot of loss tangent of *Rubus fruticosus* fruits against temperature

This result also showed that the ability of *Rubus fruticosus* fruits to convert electromagnetic energy to heat energy is enhanced at higher temperature and moisture content. Regression equation showing the relationship between, loss tangent, temperature and moisture content is presented in Table 6, with high values of coefficient of determination *(R^2)* which indicates good fit.

3.1.3 Depth of penetration of electromagnetic wave

The depth of penetration of electromagnetic waves in *Rubus fruticosus* fruits decreased with increase in moisture content and frequency (Table 7, Fig. 7 a and b) for both fruits. Penetration depth had no regular behaviour with moisture content until the fruits attained 30% moisture level, further reduction in moisture content resulted in sharp increase in depth of penetration. This is as a result of sharp increase in dielectric constant at lower moisture content. At all level of moisture content studied, depth of penetration of both fruits were higher than microwave penetration in free space and deionized water at 915 MHz and 2450 MHz except that of 30% moisture content. This means that higher moisture content would not negatively affect electromagnetic wave penetration in *Rubus fruticosus* fruits. Similar trend was reported of legume flour by Guo et al. [16] while Feng et al. [14] reported negative influence of higher moisture content on electromagnetic wave penetration depth of fresh Red Delicious apples.

Increase in temperature from 50ºC - 80ºC resulted in corresponding increase in depth of penetration as shown in Fig. 8 a and b. This is because the ionic conductivity and mobility process is enhanced by higher temperature. This finding negates the report of Tripathi et al. [17] for palm shell. These results, suggests that penetration depth of microwave will not impose any challenge during microwave heating and drying of *Rubus fruticosus* fruits especially at higher temperature.

Table 6. Regression equations of relationship between loss tangent *Rubus fruticosus*, moisture content and temperature

Size	Dielectric properties	Moisture content		Temperature	
		Regression equation	R^2	Regression equation	R^2
Long	Tan δ	$3.49\,h^2 - 11.17\,h + 10.32$	0.97	$3.02 + 13.05T - 2.11T^2$	1
Short	Tan δ	$0.2157\,h^2 + 2.11\,h + 0.469$	0.94	$15.58T^{0.3216}$	0.99

T = temperature; h = moisture content.

Table 7. Depth of electromagnetic wave penetration at constant moisture content and temperature

Size	5%		30%		60%		λ_o		λ_{water}	
	915 MHz	2450 MHz	915 MHz	2450 MHz	915 MHz	2450 MHz	915 MHz	2450 MHz	915 MHz	2450 MHz
Long	0.7481	0.3146	0.2028	0.0972	0.0405	0.0179	0.3277	0.1224	0.1225	0.0168
Short	1.27	1.67	0.9924	0.9162	0.1531	0.1605				

NB. All the values are in m; (λ_o = penetration depth of microwaves in free space; λ_{water} = penetration depth of microwaves in deionized water Feng et al. [14]

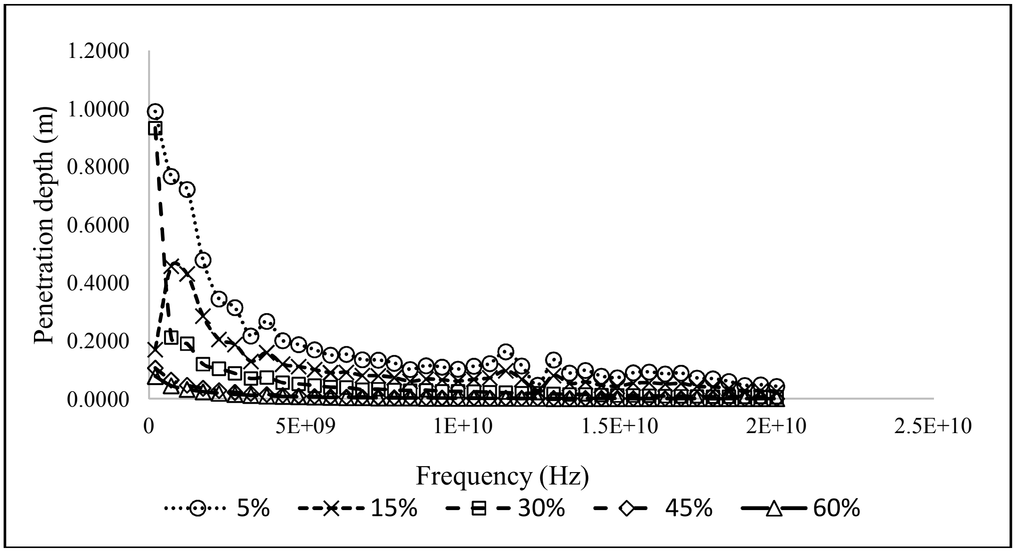

Fig. 7a.

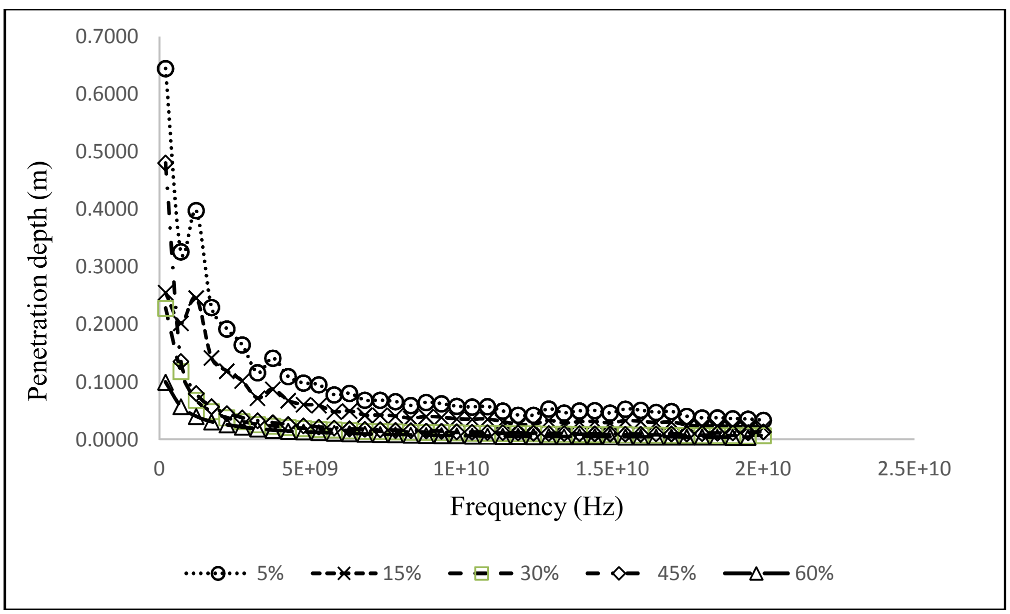

Fig. 7b.

Fig. 7. The plot of penetration depth of electromagnetic wave of *Rubus fruticosus* (a) long and (b) short fruits against frequency as affected by moisture content

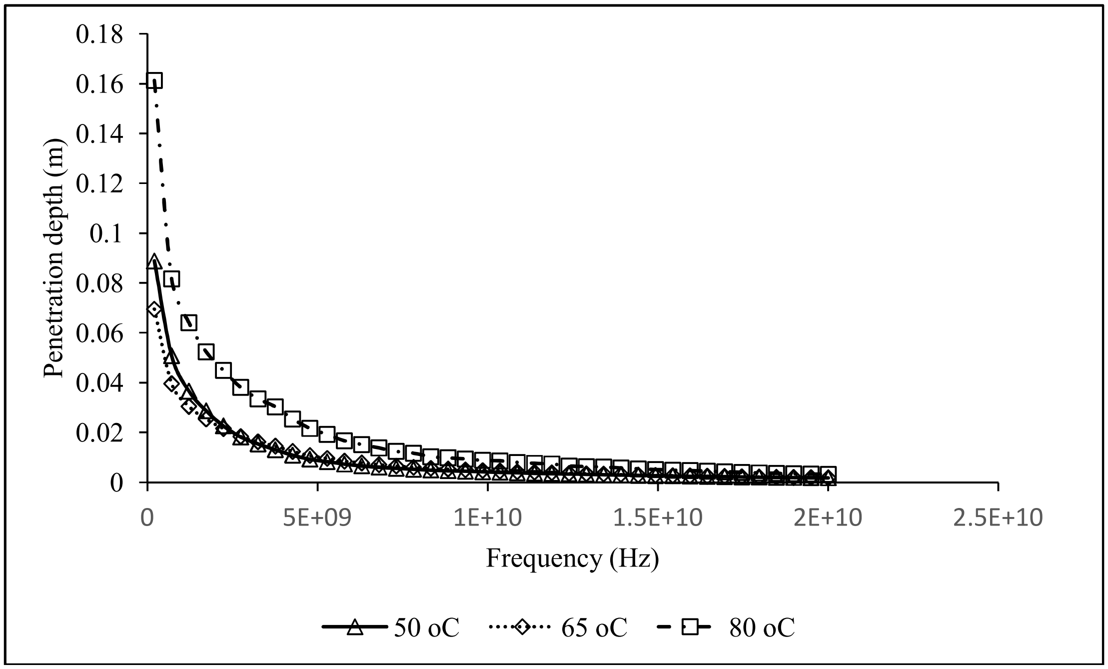

Fig. 8a.

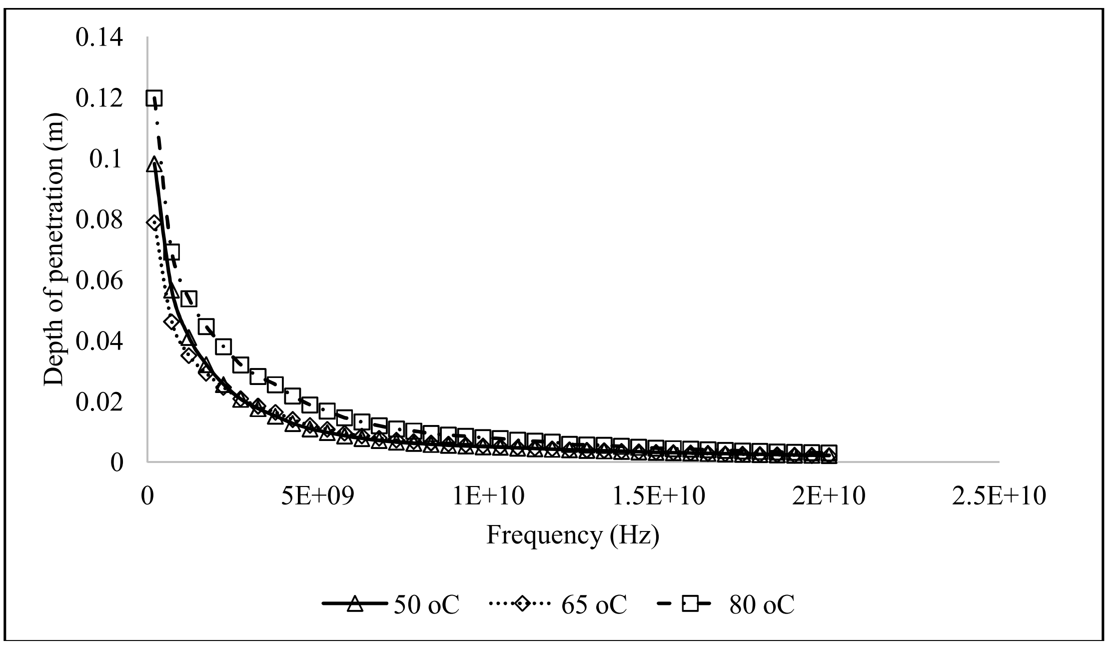

Fig. 8b.

Fig. 8. The plot of penetration depth of electromagnetic wave of *Rubus fruticosus* (a) long and (b) short fruits against frequency as affected by temperature.

The relationship between the depth of electromagnetic wave penetration depth, frequency, moisture content and temperature is given as regression equation in Table 8.

Table 8. Relationship between depth of penetration, moisture content and temperature

Variety	Regression equations	R^2
Long	*DP = 0.0170 + 0.0009 T – 1.47e-11 f – 3.05e-15 Tf*	0.86
Short	*DP = 0.0036 + 0.0002 T – 7.46e-15 f – 1.33e-16 Tf*	0.87
Long	*DP = 0.5851 – 0.0070 h – 7.43e-11 f + 2.44e-12 hf*	0.91
Short	*DP = 0.1132 + 0.0264 h – 3.66e-11 f + 1.02e-12 hf*	0.83

DP = depth of penetration; f = frequency, h = moisture content; T = temperature

This means that higher moisture content does not reduce electromagnetic wave penetration in *Rubus Fruticosus* fruits. Feng et al. [14] reported negative influence of higher moisture content on electromagnetic wave penetration depth of fresh Red Delicious apples. Similar trend was also reported of legume flour by Guo et al. [18].

4. CONCLUSIONS

Some engineering properties of *Rubus fruticosus* fruits were studied and the following conclusions were made: Temperature and moisture content highly affect both dielectric constant and loss factor significantly (5%). Dielectric constant and loss factor of the fruits both long and short fruits decrease with increase in frequency but increase with increase in moisture content. In all, loss tangent and depth of penetration all decreases with increase in frequency.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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