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DIELECTRIC PROPERTIES OF FRESH CASSAVA TUBER AT 2-2.90 GHZ MICROWAVE FREQUENCY

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Abstract–Rapid quantification of starch present in fresh cassava tuber by electronic means requires a conductivity work at various points of the tuber. The dielectric parameters of different samples of cassava tuber (*Manihot esculenta* L.) at the S-band of the microwave frequencies were determined. Tubers of cassava varieties of CTCRI, H-226, H-97, Sree Harsha, Sree Prabha, Sree Rekha, Sree Jaya, Sree Sahya, Sree Vijaya, Sree Prakash, Sree Visakham and H-165 were subjected to the cavity perturbation technique. The range of S-band microwave frequency tested were 2247, 2440, 2684 and 2970 MHz. Tubers of the variety H-226 had significantly lower conductivity value was 0.02s/m and the variety H-165, 1.49s/m and are significantly different. The dielectric constant (real part) of tubers of the varieties, H-165 and H-226 were 34.82 and 14.97 respectively and were significantly different. The proximal part of the tuber had the lowest level of conductivity followed by the middle portion and then the distal portion being 0.60s/m, 0.65s/m and 0.69s/m respectively. The dielectric constant decreases steadily with increase in frequency between 2.00-2.90GHz range for fresh cassava tubers and the dielectric loss factor follows the same pattern. The moisture content of different varieties of fresh cassava tuber, H-226, H-97, Sree Harsha, Sree Prabha, Sree Rekha, Sree Jaya, Sree Sahya, Sree Vijaya, Sree Prakash, Sree Visakham and H-165 ranged between 44.52% and 58.66% as analysed using the moisture analyser at 80 °C. The starch content values estimated by the chemical method for all the varieties of fresh tuber ranged between 20.78% and 35.94%. The difference in starch content of tuber between the proximal and the middle region was found to be 3% and that of the middle and distal region was found to be 2%. The conductivity values of fresh cassava tuber can be used for the development of a starch indicator based on moisture content.

INTRODUCTION

Cassava occupies a major role in satisfying the global demand of food and feed. It is a perennial crop, has no physiological maturity and the plants do not exhibit signs as they are ready for harvest. Cassava can be harvested at anytime from few months after being planted, but generally harvested at 9-10 months after planting (Gonzalez *et al.*, 2001). Fresh Cassava tubers consists of carbohydrates, especially starch, protein, fat, calcium and phosphorous. The starch content present in fresh cassava tubers is mostly in the range of 20-30% (Balagopalan *et al.*, 1988). Tubers of various varieties of cassava differ in the amount of starch present and this varietal difference necessitates an elaborative view of the dielectric properties. The amount of extractable starch is often less as compared to the amount of chemical starch available in the tuber. (Sheriff and Balagopalan, 1999; Rickard and Behn, 1987). The dielectric constant of free water is about 80 (Jackson, 1990) and the bound water has a lower dielectric constant. The dielec- tric properties are highly correlated with moisture content because the dielectric properties of water are much greater than those of the dry matter and thus these properties of fruits and vegetables, (Nelson, 1992) dielectric properties of fruits and vegetables are useful for non

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destructively measuring other quality factors such as maturity (Nelson, 1983). The variation in the dielectric properties at various portions of fresh cassava tuber has to be viewed to know the moisture distribution along the whole length of the cassava tuber. Out of the several methods to view the conductivity of the fresh cassava tuber, the frequency method seems to be the most simple and non destructive method. Therefore the more rapid method of estimating the dielectric properties and the conductivity of the fresh tuber by frequency method was attempted using the microwave principle. Though various methods are available for permittivity measurement, the cavity perturbation technique has unique advantages and is the most accurate method (Biju Kumar *et al.*, 2001). The moisture that is present in fresh cassava tubers can be estimated as a measure of conductivity. The dielectric parameters, loss or imaginary part of the complex permittivity at 4 different frequency levels of s-band, 2247, 2440, 2684 and 2970MHz at a temperature of 23 °C was measured. Differs at different parts of a fresh tubers, proximal, middle and distal regions. Water content in cassava tuber is highly attributed to the level of maturity. This work aims at the distribution of water content in terms of conductivity of the tubers of optimum maturity. The conductivity of the cassava tuber samples were done at a lower frequency level since the ionic conductivity is more pronounced at a lesser frequency level as compared to higher level of frequency. At present chemical methods are used for the estimation of starch that are laboursome and time consuming. Moreover it requires trained personnel and facilitates that are out of the reach of most cassava starch factories (Douglas and Robert, 1979). The specific gravity method based on Archimide's principal of displacement of water and estimation of dry matter followed at present is only near to the accuracy. Small electronic devices can be designed and developed for use in various levels of cassava processing for rapid quantification of starch content of fresh tubers. This study was undertaken to develop a hand operated mobile/transportable instrument based on the principle of electrical conductivity for use by the farmers as well as the processors for the insitu estimation of starch in the raw material.

MATERIALS AND METHODS

The varieties taken here were harvested during Feb-Mar'2002 for all the cassava tubers. The varieties of fresh cassava tuber samples were collected from the field at optimum maturity. The size of the Cassava tuber were approximately similar to that of that noted by Ohwovoriole *et al.* (1988). The length of the whole cassava tuber was 31.66 cm, the diameter at the proximal portion of the tuber being 6.04 cm, at middle portion of the tuber being 4.66 cm, at the distal end being 3.55 cm. The thickness of the peel at proximal portion being 0.19 cm, at middle end being 0.16cm, at the distal end being 0.14 cm. The tubers were washed under tap water for the removal of mud surrounding it and then peeled using a knife. The whole tubers were cut into three different portions of the same length and each piece was labeled separately and then cut into small cylindrical pieces by a punching tool. Representative sample from three different portions viz. proximal, middle and distal regions were taken for the cavity perturbation study.

Experimental Setup and Methods of Measurement Moisture Content Measurement

The moisture content of 1.0g samples from proximal, middle and distal portions of the fresh cassava tuber were measured in a Sartorius Moisture Analyser Series (Model MA100/ MA 150) at 80°C. Each sample approximately took 10-15 minutes for moisture content determination.

Estimation of Starch

Different cassava varieties of fresh cassava tuber of 10 months were taken. Each tuber was cut into three different portions, proximal, middle and distal. A representative sample (at the middle) rectangular in shape weighing 2g dry weight (fresh cassava tuber dried in oven at 60 °C for 2 days) approximately was kept overnight under 20 mL of 80% alcohol in a conical flask. After filtration the residue was taken for starch analysis. To the residue, 20 ml of 2N Hcl was added and hydrolysed by keeping it on a hot plate for about 15-20 minutes. This hydrolysate was made upto 100 ml and used for the titrimetric determination of starch. 10 ml of 1% potassium ferri- cyanide and 5 ml of 10% sodium hydroxide were taken in a 100 ml of conical flask. The contents were allowed to boil by keeping it on a heater. To this 2 drops of methylene blue were added as the above reagents started boiling. The hydrolysate was then pipette out drop by drop into the above conical flask till the contents became colourless. The end point reading was noted down (Moorthy and Padmaja, 2000). The dry weight of the tuber was converted into fresh weight for starch content calculation. For fresh weight, % starch (g/100 g of fresh weight)=(90/5.12) X titre value

Cavity Perturbation Technique

The dielectric theory had been proposed by many research workers for fruits and vegetables as well as for liquids (Nelson, 1980; Raveendranath and Mathew, 1995; Kuang and Nelson, 1998). The real and imaginary parts of the relative complex permittivity of the biological samples by the above technique are given by the formula (Raveendranath and Mathew, 1995); Mathew and Raveendranath, 1996) €r′=(ft-fs/2fs)(Vc/Vs)+1,€r″=(Vc/4Vs)/(Qt-Qs)/QtQs). The AC conductivity values were worked out using the following formula, σ=ω€o€r″, ω=2Πf is the angular frequency. The loss tangent is the ratio of the imaginary part to that of the real part of the cassava sample and is given by the formula, LT=(€r″/€r′) Here ft is the frequency of the empty cavity, fs is the frequency of the sample, €r′ is the real part of the relative complex permittivity and is usually known as the dielectric constant, €r″ the imaginary part of the relative complex permittivity and is associated with the dielectric loss of the material,€0 is the permittivity of the free space and is equal to $8.85X10^{-12}$f/m. Vs and Vc are the volumes of the sample and the cavity resonator in m^3, respectively. From equations 1 and 2 it is observed that the real part of the complex permittivity depends on the resonant frequency shift and the imaginary part depends on the quality factor. The present measurement technique is simple and easy to operate compared to the conventional cavity resonator techniques. (Raveendranath and Mathew, 1996).

RESULTS AND DISCUSSION

The conductivity values have to be found out to design and develop an electronic gadget for starch estimation since the conductivity values the measure of moisture content values can be correlated to the starch content to display the starch content in the device to be developed. Hence a study with the Cassava tuber pieces were made for conductivity. The Cassava tuber piece was connected to the two terminals of the eliminator. The input voltage being kept constant the output voltage from a known thickness of the cassava tuber piece was found out to fix the upper limit of the voltage that is conducted by a known thickness of the Cassava tuber piece. The voltage conducted at 59% moisture content, the upper limit of moisture found out by oven method of moisture content determination was found to be the highest value of voltage that is conducted, the value being 90 mV and the lowest voltage was found to be 15mV at a moisture content of 48%. The highest moisture content was found in the variety Sree Visakham and the lowest moisture bearing variety was H-226. This voltage conducted increases with increase in thickness of the cassava tuber piece. This difference in conductivity value in the same tuber variety may be due to the varied conductance at different regions of the same fresh Cassava tuber. The moisture content at different regions of the same tuber varies and hence conductivity. A study of the conductivity of the tuber at different regions is a must to develop an electronic gadget for the in-situ estimation of starch in fresh Cassava tubers. Experiments show that Varietal differences also exist and hence this conductivity study should be extended to different varieties also for accurate measurement of Starch content in fresh Cassava tubers. Starch, a major ingredient of Cassava tubers has to be estimated to fix the price of the harvested matured crop. The specific gravity balance now used for the estimation of starch content made in Thailand is sturdy in appearance and hence a handy electronic gadget was fabricated for the insitu estimation of starch in fresh tubers. Primarily conductivity trials were conducted in fresh Cassava tubers, cut into proximal, middle and distal, both longitudinally and laterally. The programming was done in 'C' language. Digital display of the starch content was made. Nearly 1000 starch factories based on tuber crops are situated in TamilNadu alone and hence the handy small equipment weighing 2 kg will surely benefit the farmers growing tuber crops for the estimation of starch content. This can also be calibrated to other tuber crops viz. Sweet potato, Colocasia and Xanthosoma for estimation of starch content.

Fabrication of An Electronic Gadget

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Table 1. Moisture, Starch and Conductivity values of fresh Cassava tuber

Sl. No.	Varieties	Moisture Content (%)	Starch (%)	Conductivity (s/m)
1	H-226-p	44.67	35.54	0.03
	H-226-m	45.78	33.49	0.04
	H-226-d	46.79	32.21	0.05
2	H-97-p	44.92	35.55	0.05
	H-97-m	45.93	32.35	0.06
	H-97-d	49.38	31.36	0.08
3	Sree Harsha-p	45.00	34.7	0.10
	Sree Harsha-m	48.56	31.35	0.13
	Sree Harsha-d	49.95	28.96	0.17
4	Sree Prabha-p	48.15	31.56	0.24
	Sree Prabha-m	49.66	29.35	0.29
	Sree Prabha-d	50.63	26.92	0.37
5	Sree Rekha-p	48.83	30.64	0.43
	Sree Rekha-m	50.73	28.83	0.51
	Sree Rekha-d	52.74	26.76	0.56
6	Sree Jaya-p	48.93	30.35	0.64
	Sree Jaya-m	50.93	28.24	0.70
	Sree Jaya-d	54.07	25.42	0.76
7	Sree Sahya-p	49.77	29.2	0.84
	Sree Sahya-m	52.77	27.46	0.89
	Sree Sahya-d	55.33	25.11	0.96
8	Sree Vijaya-p	50.8	28.77	1.03
	Sree Vijaya-m	53.03	26.33	1.10
	Sree Vijaya-d	55.48	24.59	1.16
9	Sree Prakash-p	51.42	28.76	1.23
	Sree Prakash-m	54.68	25.04	1.30
	Sree Prakash-d	55.71	23.68	1.36
10	Sree Visakham-p	53.36	26.01	1.42
	Sree Visakham-m	55.24	23.60	1.49
	Sree Visakham-d	57.77	22.05	1.55
11	H-165-p	54.51	25.60	1.62
	H-165-m	55.50	21.74	1.69
	H-165-d	59.41	21.43	1.76
	p-Proximal, m-Middle, d-Distal			
	SD	3.87	3.89	0.57
	SEM	0.67	0.68	0.10
	Cv	0.08	0.14	0.77

the value of the capacitors being 0.01μF. The Intel chips made of ceramic, a semi-conducting material of different pin sizes are fitted to the Printed Circuit Board. The voltage to every chip is examined by a capacitor and only it allows dc voltage to pass through and blocks ac through the intel chips, otherwise the chips may get damaged. Holes for connecting point wire are also made and silver coated copper wires are laid for better conductance. 20 Transistors (switching type) are fitted and safe guarded by resistors. The memory chips, Erasable programmable Read Only Memory (N.2732) has a memory capacity of 4KB and Random Access Memory (N.6116) has a memory capacity of 2K. The chips that are assembled in the Printed Circuit Board has different number of pins each differing in the number and functions. viz. 40 Pin IC – 88320, 24 Pin IC-8824SUM6116, (S-Ram of 2 × 8 bit size) 24Pin IC-U64300-36S (Analogtodigital convertor), 20Pin IC-HD74LS273P, 20PinIC–SN74LS244N, (Bidirectional buffer) 16 PinIC-HD74 LS138P,(D-coder) 14 Pin IC-DM74 LS90N, 14 PinIC–HD74LS04. A bidirectional buffer is also attached for two way signal. 3 S-G Connectors are also fitted and a rechargeable battery of 7V is fitted for power supply. This set up of Printed Circuit Board with all the components fixed is mounted on to a metal cabinet of size 23 × 21 × 7 cm. The light emitting diode (Light Emitting Diode) display board is attached to the front of the cabinet. There are provisions in front of the cabinet for digital display. Fig.10 shows the schematic diagram of the starch indicator developed using the above technique to measure the starch content of the fresh cassava tubers in the field. The values of moisture content and starch content were loaded in the memory chips to set the range of display for all the varieties of cassava tuber. The sensor probe is affixed to the above circuit to sense the moisture and the corresponding value of starch gets displayed in the Light Emitting Diode display unit. The selector switches are for the following functions, ON/OFF, display of moisture content and dis - play of starch content. The sensor accuracy is adjusted to ±0.5%. The values of 11 varieties of starch were stored in Random Access Memory and the values of moisture which is sensed by the sensor were stored in Programmable Read Only Memory. The higher limit of millivolts sensed by the sensor for starch content estimation is within 100 mV. Appropriate electrical connections were made for the digital display of starch content of the fresh cassava tuber. Detachable probe of length 80cm is attached in front of the cabinet of size 22.5 × 20.5 × 7 cm. The Light Emitting Diode display is for 2 decimal places along with a whole number. The starch value is to be displayed, the alphabet 'S' is also displayed along with the value. The maximum value loaded for moisture is 74% for a starch content of 20% and the minimum value of moisture being 44% for a starch content of 50%. This calibration is made based on the values obtained by chemical method of estimation of starch. In addition to the alternating current supply, the battery connection to work with direct current supply is also made. Field trial with the developed gadget with direct current power supply is made and found reliable. A glass panel is fitted in front of the metal cabinet with an ON/OFF switch at the right side and a power indicator bulb at the top of the ON/OFF switch. The wire probe at the other end is provided with a plastic teflon rod of length 8 cm to provide the inserting (testing) needle of size, length 4cm and 2mm thickness to project into the fresh tuber to measure its starch content. Assembly program had been loaded in the memory chip (Microprocessor INTEL780CPV) occupying a space of 1000KB. Battery operation was also made. A regulator circuit is provided to make it to work on 6V rechargeable battery, a cut off relay cuts and provides 5V supply to the circuit and this battery can be charged for 3 h simultaneously while operating on alternating current supply. This direct current supply makes the developed gadget to be portable in the true sense. The current carrying capacity of the battery is 300 mA. A control switch is provided at the back of the developed gadget to have ON/OFF functions. The switch of direct current has to be kept in OFF position while operating using alternating current supply. This is more helpful in field evaluation where alternating current supply is not possible. In the alternate method using frequency principle, the conductivity of the fresh cassava tuber is estimated to be 1.76S/m at the distal portion of the tuber and the value being 1.63S/m at the proximal end and the value being 1.70S/m at the middle portion of the fresh cassava tuber by cavity perturbation technique studies at a highest frequency of 2970MHz. It was found that the values tend to decrease at a still higher frequency level. The dielectric properties dielectric constant, dielectric loss factor and the loss tangent for the fresh cassava tuber were also worked out. The moisture content of all the 11 varieties of cassava were compared with the chemical method of estimation of starch.

Feasibility of the fabrication of the STARCH INDICATOR was studied with the voltage principle. The circuit diagram with Random Access Memory and PROM facility were made so as to have a digital display of starch content of the tuber in the electronic gadget that is to be made. An alternate method was also tried using the microwave principle. Conductivity studies at S-band frequency level were conducted for all the varieties of cassava tubers. Different varieties of fresh cassava tubers viz. H-226, H-97, Sree Harsha, Sree Prabha, Sree Rekha, Sree Jaya, Sree Sahya, Sree Vijaya, Sree Prakash, Sree Visakham and H-165 at tenth month maturity stage were analysed for its moisture content. Fig. 4 shows that variation of moisture content and starch content of three different parts of fresh cassava tuber. Three different regions proximal, middle and distal in each fresh cassava tuber were taken and analysed for its moisture content in the moisture analyser and starch content by chemical method. Fresh cassava tubers at tenth month maturity were analysed for its electrical conductivity by cavity perturbation technique in the S-band frequency level. The experimental set up consisted of a HP 8510 vector network analyser, a sweep oscillator, a S- parameter test set and a rectangular cavity resonator. The resonant frequency and quality (Q) factor of the resonant cavity with and without the samples in the cavity were measured and the dielectric parameters were evaluated. All the measurements were done in S-band (2-4GHz) at 23 °C. Cylindrical shaped fresh cassava samples from proximal, middle and distal portions of all the varieties were analysed using the above technique for its microwave conductivity. In the microwave studies the conductivity (s) is expressed in terms of the loss or imaginary part of the complex permittivity. The conductivity is found to increase with the increase in the frequency level. Fig.3. shows the variation in conductivity to starch content in different varieties of fresh cassava tuber. Assembly program had been loaded in the memory chip (Microprocessor INTEL 780CPV) occupying a space of 1000KB. 'C' language is used in the chip programming. The moisture content and starch content values are coded in terms of binary coding of 0's and 1's. First initialization of the display takes place, then the values is sensed in terms of millivolt and then converted into percentage reading, for moisture value the value is as such read and for starch content value the value in percentage is subtracted from 94%, the starch value is displayed along with the 'S' symbol. The device A to D convertor converts the reading in analog to digital value. Detachable probe of length 80 cm is attached in front of the cabinet of size 22.5 × 20.5 × 7.0 cm. The Light Emitting Diode display is for 2 decimal places along with a whole number. Starch value is to be displayed, the alphabet 'S' is also displayed along with the value. The maximum value loaded for moisture is 60% for a starch content of 20% and the minimum value of moisture being 45% for a starch content of 35%. This calibration is made based on the values obtained by chemical method of estimation of starch. In addition to the alternating current supply, the battery connection to work with direct current supply is also made. Field trial with the developed gadget with direct current power supply is made and found reliable. A glass panel is fitted in front of the metal cabinet with an ON/OFF switch at the right side and a power indicator bulb at the top of the ON/OFF switch. The wire probe at the other end is provided with a plastic teflon rod of length 8cm to provide the inserting (testing) needle of size, length 4 cm and 2 mm thickness to project into the fresh tuber to measure its starch content. The values of moisture content, dielectric constant, dielectric loss factor, conductivity and loss tangent of fresh cassava tuber is represented in Table 1 for all the varieties of fresh cassava tuber in three different regions at 2247, 2440, 2684 and 2970 MHz at 23°C. The dielectric properties, or permittivity, describe the interaction of the material with an electric field. (Tanaka *et al.,* 2002). The dielectric properties of the materials include dielectric constant, dielectric loss factor, conductivity and loss tangent. The varieties H-226 showed significantly lower value of conductivity and the value recorded was 0.02S/m and the variety H-165 recorded 1.49S/m value and are significantly different when statistically analysed. The proximal portion showed a lower level of conductivity followed by the middle portion and then the distal portion, the values of conductivity being 0.60S/m, 0.65S/m and 0.69s/m. The frequency 2970MHz had a pronounced effect as compared to the other frequencies since it recorded the highest values of conductivity of 0.73S/m and the lowest was 0.58S/m at 2247MHz. It was found that the amount of moisture was high at the proximal region followed by the middle and then the distal region. Any change in the moisture content of the fresh cassava tuber, produces a relative change in dielectric properties. In the case of dielectric loss factor (imaginary part) the variety H-165 recorded 10.38 value and was found to be the highest and in the variety H-226 the value was found to be the lowest, the value being 0.16. The imaginary part is the loss factor describing the rate of energy dissipation in the material (Garcia *et al.,* 2001). Dielectric properties are highly correlated with frequency, temperature and moisture content of the material (Table 2). The conductivity values increase with increase in frequency level. The dielectric constant decreases steadily with increase in frequency between 2.00-2.90GHz and the dielectric loss factor also follows the same pattern. The dielectric constant (real part) of the varieties H-165 and H-226 recorded the highest and the lowest values respectively and the values were 34.82s/m and 14.98s/m respectively. This trend agrees with the previously published data for fresh fruits and vegetables from 0.20 to 20GHz (Nelson *et al.,* 1994). The frequency 2970MHz had a pronounced effect and the least effective frequency was found to be 2247MHz. At low frequency the dielectric constant is very much dependant on the specific material properties especially conductivity. High frequency measurements are therefore essential to minimize the sensitivity of the material type (Wobschal, 1978) All the dielectric parameters are plotted against the frequency will determine the contribution of water to dielectric polarization (Fig. 1). (Hoekstra and Delaney, 1974) As loss tangent was considered, the

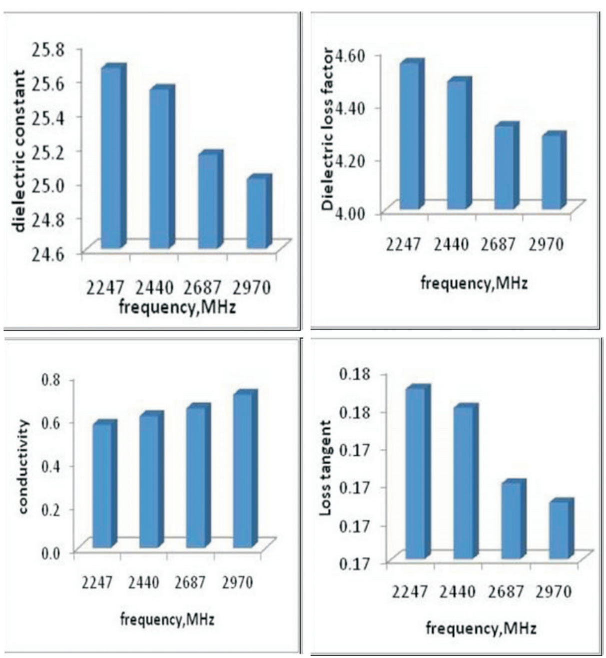

Fig. 3. Variation of Mean values of Dielectric Constant, Dielectric loss Factor, Conductivity and Loss Tangent values of fresh Cassava Tuber with respect to 4 different frequency levels (MHz)

variety H-226, 0.01 showed the lowest value and the highest was recorded by the H-165, 0.29 variety. The loss tangent was lowest, 0.15 at 2970MHz frequency and the highest, 0.15 was at 2247MHz frequency. The loss tangent values for all the varieties were less than one in the 2-3GHz region of microwave frequency. Fig. 7 shows the relaionship between moisture content and dielectric loss tangent at different parts of cassava. Fig. 4 shows that relationship between moisture content and dielectric constant at different parts of cassava. As the frequency increases the inertia of the molecule and the binding forces become dominant and it is the basis of the dielectric heating or dielectric loss (John *et al.,* 2001). The proximal part showed the lowest loss tangent whereas the distal part showed the highest value of loss tangent and the values recorded were 0.15 and 0.16 respectively. Very little difference is only noted between the three different regions of the same tuber for all dielectric properties. Even the small difference would be helpful in accurate determinations. The conductivity being higher at the distal end may be due to the presence of moisture to a large extent in the fresh cassava tuber than starch. The lower value of conductivity at the proximal end may be due to the presence of higher amount of starch. This result is confirmed with all the varieties of cassava tuber being tested. Fig. 3 shows that the variation of dielectric constant, dielectric loss factor, conductivity and loss tangent values of fresh cassava tuber with respect to 4 different frequency levels (MHz). The variation with the frequency is also found to be small. This may be due to the fact that the very narrow range of frequency is used for experimental purposes. In Table 1 the varieties of cassava tuber are listed in order of increasing

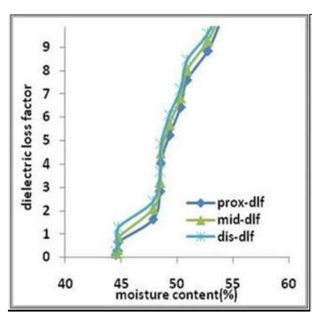

Fig. 4. Relationship between moisture content dielectric loss factor at three different of parts of cassava tuber

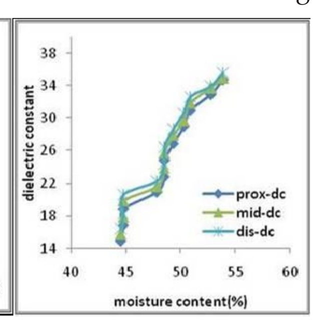

Fig. 5. Relationship between moisture and and dielectric constant at three different parts of cassava tuber

Table 2. Moisture Content, Dielectric Constant, Dielectric Loss Tangent, Conduc tivity and Loss Tangent values of fresh cassava tuber.

S. No.	Frequency (MHz)	Variety	M.C (%)	DC	DLF	C (S/m)	LT
1a	2247	H-165-p	53.86	34.66	10.17	1.27	0.29
	2440			34.45	10.01	1.35	0.29
	2687			34.40	9.93	1.48	0.28
	2970			34.35	9.86	1.62	0.28
1b	2247	H-165-m	54.8	34.87	10.56	1.32	0.30
	2440			34.83	10.48	1.42	0.30
	2687			34.80	10.37	1.54	0.29
	2970			34.71	10.25	1.69	0.29
1c	2247	H-165-d	58.66	35.56	10.97	1.37	0.30
	2440			35.36	10.82	1.46	0.30
	2687			35.25	10.76	1.60	0.30
	2970			35.21	10.66	1.76	0.30
2a	2247	Sree Visakham-p	52.76	32.87	8.95	1.11	0.27
	2440			32.84	8.80	1.19	0.26
	2687			32.72	8.75	1.30	0.26
	2970			32.71	8.60	1.42	0.26
2b	2247	Sree Visakham-m	54.59	33.65	9.38	1.17	0.27
	2440			33.60	9.20	1.24	0.27
	2687			33.17	9.08	1.35	0.27
	2970			33.10	9.03	1.49	0.27
2c	2247	Sree Visakham-d	57.07	33.90	9.68	1.21	0.28
	2440			33.86	9.64	1.30	0.28
	2687			33.81	9.51	1.42	0.28
	2970			33.69	9.41	1.55	0.27
3a	2247	Sree Prakash-p	50.87	30.89	7.70	0.96	0.24
	2440			30.81	7.65	1.03	0.24
	2687			30.65	7.50	1.12	0.24
	2970			30.57	7.47	1.23	0.24
3b	2247	Sree Prakash-m	54.08	31.87	8.10	1.01	0.25
	2440			31.56	8.02	1.08	0.25
	2687			31.31	7.96	1.19	0.25
	2970			31.19	7.89	1.30	0.25
3c	2247	Sree Prakash-d	55.06	32.57	8.56	1.07	0.26
	2440			32.48	8.40	1.14	0.25
	2687			32.35	8.30	1.24	0.25
	2970			32.22	8.24	1.36	0.25
4a	2247	Sree Vijaya-p	50.3	28.89	6.53	0.81	0.22
	2440			28.86	6.44	0.87	0.22
	2687			28.82	6.38	0.95	0.22
	2970			28.72	6.27	1.03	0.21
4b	2247	Sree Vijaya-m	52.48	29.63	6.92	0.86	0.23
	2440			29.50	6.88	0.93	0.23
	2687			29.25	6.78	1.01	0.23
	2970			29.03	6.69	1.10	0.23
4c	2247	Sree Vijaya-d	54.88	30.56	7.30	0.91	0.23
	2440			30.45	7.20	0.97	0.23
	2687			30.37	7.10	1.06	0.23
	2970			30.12	7.04	1.16	0.23
5a	2247	Sree Sahya-p	49.32	26.88	5.31	0.66	0.19
	2440			26.88	5.24	0.71	0.19
	2687			26.46	5.17	0.77	0.19
	2970			26.45	5.08	0.84	0.19

Table 2. *Continued ...*

S. No.	Frequency (MHz)	Variety	M.C (%)	DC	DLF	C (S/m)	LT
5b	2247	Sree Sahya-m	52.27	27.87	5.76	0.72	0.20
	2440			27.87	5.67	0.77	0.20
	2687			27.42	5.57	0.83	0.20
	2970			27.09	5.42	0.89	0.20
5c	2247	Sree Sahya-d	54.78	28.61	6.19	0.77	0.21
	2440			28.59	6.01	0.81	0.21
	2687			28.15	5.92	0.88	0.21
	2970			28.10	5.84	0.96	0.20
6a	2247	Sree Jaya-p	48.53	24.77	4.16	0.52	0.16
	2440			24.64	4.09	0.55	0.16
	2687			24.61	3.93	0.58	0.16
	2970			24.61	3.88	0.64	0.15
6b	2247	Sree Jaya-m	50.48	25.66	4.55	0.56	0.17
	2440			25.53	4.48	0.60	0.17
	2687			25.15	4.31	0.64	0.17
	2970			25.01	4.27	0.70	0.17
6c	2247	Sree Jaya-d	53.57	26.40	4.94	0.61	0.18
	2440			26.31	4.82	0.65	0.18
	2687			26.06	4.75	0.71	0.18
	2970			25.98	4.62	0.76	0.17
7a	2247	Sree Rekha-p	48.48	22.86	2.92	0.36	0.12
	2440			22.86	2.80	0.38	0.12
	2687			22.52	2.72	0.40	0.12
	2970			22.47	2.63	0.43	0.11
7b	2247	Sree Rekha-m	50.33	23.90	3.32	0.41	0.13
	2440			23.73	3.27	0.44	0.13
	2687			23.56	3.17	0.47	0.13
	2970			23.36	3.08	0.51	0.13
7c	2247	Sree Rekha-d	52.29	24.39	3.79	0.47	0.15
	2440			24.25	3.63	0.49	0.15
	2687			24.24	3.54	0.52	0.14
	2970			24.14	3.40	0.56	0.14
8a	2247	Sree Prabha-p	47.85	20.92	1.75	0.21	0.08
	2440			20.89	1.61	0.21	0.07
	2687			20.79	1.56	0.23	0.07
	2970			20.70	1.49	0.24	0.07
8b	2247	Sree Prabha-m	49.31	21.64	2.19	0.27	0.10
	2440			21.52	2.06	0.28	0.09
	2687			21.36	1.93	0.28	0.09
	2970			21.28	1.80	0.29	0.08
8c	2247	Sree Prabha-d	50.23	22.35	2.51	0.31	0.11
	2440			22.33	2.48	0.33	0.11
	2687			22.08	2.34	0.35	0.10
	2970			22.07	2.28	0.37	0.10
9a	2247	Sree Harsha-p	44.75	18.91	0.78	0.09	0.04
	2440			18.80	0.73	0.10	0.03
	2687			18.65	0.69	0.10	0.03
	2970			18.43	0.66	0.10	0.03
9b	2247	Sree Harsha-m	48.26	19.90	0.95	0.12	0.04
	2440			19.77	0.93	0.12	0.04
	2687			19.47	0.86	0.13	0.04
	2970			18.96	0.82	0.13	0.04

Table 2. *Continued ...*

S. No.	Frequency (MHz)	Variety	M.C (%)	DC	DLF	C (S/m)	LT
9c	2247	Sree Harsha-d	49.6	20.66	1.37	0.17	0.06
	2440			20.52	1.27	0.17	0.06
	2687			20.38	1.17	0.17	0.05
	2970			20.16	1.07	0.17	0.05
10a	2247	H-97-p	44.72	16.89	0.37	0.04	0.02
	2440			16.76	0.36	0.04	0.02
	2687			16.67	0.35	0.05	0.02
	2970			16.51	0.34	0.05	0.02
10b	2247	H-97-m	45.68	17.89	0.45	0.05	0.02
	2440			17.65	0.46	0.06	0.02
	2687			17.58	0.42	0.06	0.02
	2970			17.16	0.38	0.06	0.02
10c	2247	H-97-d	49.08	18.26	0.61	0.07	0.03
	2440			18.25	0.58	0.08	0.03
	2687			18.24	0.55	0.08	0.03
	2970			18.12	0.52	0.08	0.02
11a	2247	H-226-p	44.52	14.85	0.23	0.03	0.01
	2440			14.85	0.22	0.03	0.01
	2687			14.55	0.22	0.03	0.01
	2970			14.31	0.20	0.03	0.01
11b	2247	H-226-m	45.58	15.77	0.28	0.03	0.01
	2440			15.74	0.27	0.03	0.01
	2687			15.617	0.26	0.03	0.01
	2970			15.384	0.24	0.04	0.01
11c	2247	H-226-d	46.54	16.452	0.33	0.04	0.02
	2440			16.426	0.32	0.04	0.02
	2687			16.299	0.31	0.04	0.01
	2970			16.177	0.30	0.05	0.01
		Average	50.78	25.44	4.66	0.67	0.16
		SD	3.67	6.27	3.46	0.50	0.10
		SEM	0.32	0.55	0.30	0.04	0.01
		CV	0.07	0.25	0.74	0.75	0.61

p-Proximal, m-Middle, d-Distal

moisture content. From the experiments it is found that the moisture content and the starch content are inversely proportional thus showing that as the moisture content increases conductivity increases and starch content values decreases. Since moisture content is a dominant variable affecting the permittivity values, a correlation between the dielectric constant and water content is to be expected. As far as accuracy is concerned by this measurement technique it would require many more measurements on numerous samples of a given variety both longitudinalwise and lateralwise of the different varieties of the fresh cassava tuber. The frequency dependant behaviour of the dielectric constant and loss factor in 2-3GHz range exhibits evidence of ionic conductivity. The results clearly shows that the imaginary part influences the conductivity factor of the fresh tuber. The coefficient of variation for conductivity among varieties ranged in between 10.08 to 72.33 for dielectric loss factor it was between 3.45 to 71.87, for loss tangent it varied between 2.20 to 75.13, for dielectric constant it varied in between 1.12 to 6.14. As part difference was considered, for conductivity, the coefficient of variation ranged between 74.99 to 81.98, for dielectric loss factor, it varied between 74.06 to 81.08, for loss tangent it varied between 61.87 to 69.01, for dielectric constant it varied between 24.56 to 26.70. As frequency difference was considered, for conductivity the coefficient of variation values ranged between 76.55 to 79.08, for dielectric loss factor it ranged between 76.55 to 79.08, for loss tangent it ranged between 64.37 to 67.02, for dielectric constant it ranged between 25.49

to 26.05. The moisture content of different varieties of fresh cassava tubers H-226, H-97, Sree Harsha, Sree Prabha, Sree Rekha, Sree Jaya, Sree Sahya, Sree Vijaya, Sree Prakash, Sree Visakham and H-165 ranged in between 44.50 to 58.66% as analysed by the moisture analyzer at 80 °C. Fig. 6 shows that relationship between moisture content and conductivity at different parts of cassava tuber. Fig.5 shows that relationship between moisture content and dielectric constant at three different parts of cassava tuber. The starch content values estimated by the chemical method for all the varieties of fresh tuber ranged in between 20.78 to 35.94%. The starch content values decreased from the proximal to the distal end of the tuber. Similar to the correlation between conductivity and moisture content, the above can be extended to starch content also. The variety H-226 had a higher starch content, 34.58 and the variety H-165 22.92 had a lower starch content. All the other varieties were in between. The proximal part had a higher amount of starch, 30.63 followed by the middle portion, 27.98 and then the distal portion 26.22. The coefficient of variation for varieties varied in between 5.95 to 9.53, for the parts the coefficient of variation varied between 12.40 to 13.12. The coefficient of variation increased from proximal to distal end. The overall coefficient of variation was found to be 14.27. The coefficient of variation for moisture content values ranged between 2.13 to 4.84 for all the varieties for part it ranged between 7.13 to 6.66. The variety H-165 had the higher moisture 45.74 while the variety H-226 had the lower, moisture, 56.47. The proximal part had the lower moisture 49.12 while the distal part had a higher moisture,53.38. The overall coefficient of variation was found to be 7.56 for moisture content analysis.

The distal part conductivity on fresh weight basis is more compared to proximal and middle portions of the tuber, moisture content is most in distal portion followed by middle and then proximal end. This may be due to the formulation of starch more in the middle portion and then little less in the proximal end. Starch and moisture content are the two entities found in cassava starch tubers. Among the parts tested the conductivity at 4 different

Table 3. Study for the Conductivity of voltage through the cassava tuber piece of different thickness (*Sree Visakham var.)* using an eliminator :

S. No.	Range in the eliminator for testing in volts	Thickness the cassava of tuber piece	Resistance in ohms	Dc Voltage
1.	1.5	3.5	0.11	1.6
		4.5	0.126	1.89
		5.5	0.128	1.92
		6.5	0.130	1.95
		7.5	0.135	2.02
2.	3.0	3.5	0.026	0.4
		4.5	0.227	3.41
		5.5	0.243	3.64
		6.5	0.251	3.77
		7.5	0.258	3.87
3.	4.5	3.5	0.366	5.5
		4.5	0.376	5.65
		5.5	0.382	5.74
		6.5	0.388	5.82
		7.5	0.388	5.82
4.	6.0	3.5	0.497	7.45
		4.5	0.513	7.69
		5.5	0.513	7.69
		6.5	0.519	7.78
		7.5	0.528	7.92
5.	7.5	3.5	0.344	5.16
		4.5	0.491	7.37
		5.5	0.553	8.3
		6.5	0.590	8.85
		7.5	0.625	9.38
6.	9.0	3.5	0.003	0.04
		4.5	0.004	0.06
		5.5	0.006	0.09
		6.5	0.008	0.12
		7.5	0.017	0.25
7.	12.0	3.5	0.953	14.3
		4.5	1.030	15.5
		5.5	1.040	15.6
		6.5	1.082	16.23
		7.5	1.093	16.39

Table 4. Voltage conducted and the moisture content in different varieties of fresh Cassava tuber

Sl. No.	Cassava tuber – Variety	Voltage Conducted (mV)	Moisture content by Oven method (%wb)
1.	H-226	15	48
		74	51
		90	53
2.	H-97	17	51
		25	52
		38	54
3.	Sree Sahya	18	52
		24‘	54
		70	57
4.	Sree Visakham	22	55
		48	57
		60	58
		90	59

frequency levels of 2247, 2440, 2687 and 2970MHz. Among the parts tested on fresh weight basis in conductivity, 1.76s/m is the highest conductivity in the distal end, moisture content being 59.41%, starch content being 21.43%. The least moisture content selected variety is H-226 in proximal end and the value is 44.67% and starch content is 35.54%

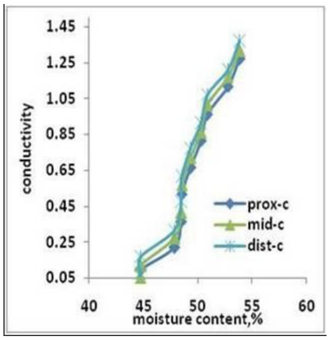

Fig. 6. Relationship between moisture content and conductivity at three different parts of different cassava tuber

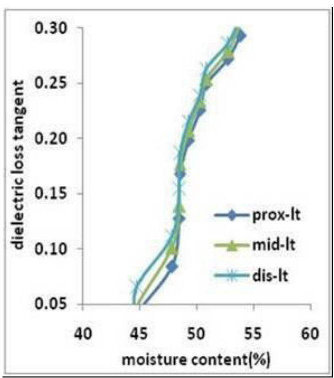

Fig. 7. Relationship between moisture content and dielectric loss tangent at three parts of cassava tuber

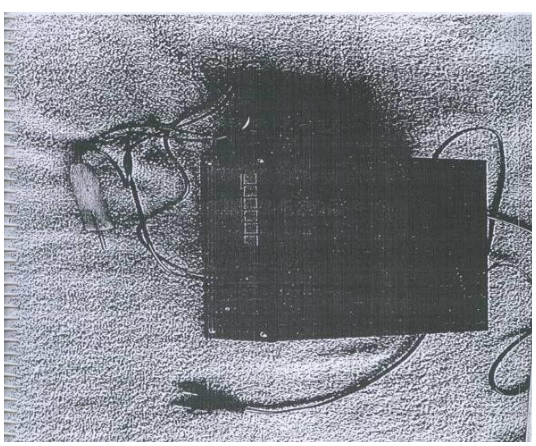

Fig. 10. Schematic diagram of the starch gadget for *in situ* estimation of starch in fresh cassava tubers.

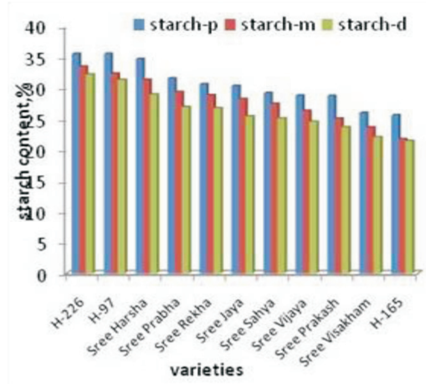

Fig. 8. Starch content at different parts of the fresh cassava tuber

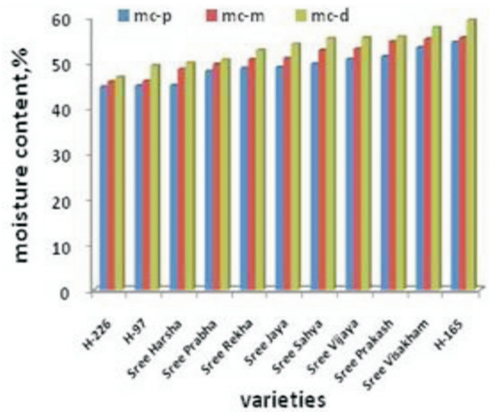

Fig. 9. Moisture content at different parts of fresh cassava tuber the

and the least conductivity is 0.03. The least moisture content variety is H-226 followed by H-97, Sree-Harsha, Sree Prabha, Sree Rekha, Sree Jaya, Sree Sahya, Sree Vijaya, Sree Prakash, Sree Visakham and H-165 in all the three parts of proximal, middle and distal end. The co-efficient of variation in moisture content is 0.08, in starch content is 0.14 and in conductivity it is 0.77. From the anova table, it is found that critical difference at 5% and 1% level of significance is very low for moisture content, starch content and conductivity. The anova for moisture indicator the critical difference at 5% level of significance is 1.04 and at 1% level of significance it is 1.49,cv is 0.96, from the anova for starch indicator, the critical difference of 0.84.

CONCLUSION

In general dielectric properties depend on frequency, moisture content and temperature. The dielectric properties of materials are determined since these properties of materials determine the nature of the interaction of electro-magnetic energy with the materials at microwave frequencies. The deviation of dielectric constant (real part) of different varieties of the cassava tuber samples with respect to the frequency are presented. Since representative sample was taken for all the varieties of the cassava, cavity perturbation study was adopted. Cavity perturbation method is the rapid and non-destructive method of measurement of moisture. This study helps in establishing the distribution of moisture content in terms of electrical conductivity throughout the sample which will be very helpful in the development of an electronic starch indicator. In most of the varieties tested, the conductivity was found to increase with the increase in the frequency level in fresh sample. All the measurements were the average of two observations, the number of replications may be increased along with the analysis both longitudinal wise and lateralwise of the fresh tuber. The study shows the possibility of using this technique for the development of starch indicator for the determination of starch in fresh cassava tubers.

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