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Development of Moisture Prediction Model for Tea using Electrical Impedance Spectroscopy

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Abstract— *Moisture is the most essential parameter for tea leaves for storage and consumption stage as it affects the physical and chemical aspects of tea leaves with which it relates the stability and freshness the tea leaves for a long time. The most essential parameter which affects the quality of tea leaves is moisture for post harvesting, processing, storage and transport. The main aim of this study is to development procedure for moisture content measurements of fresh tea leaves using measurement acquired by electrical properties. Method This relation is obtained the frequency range within between 100 kHz to 300 MHz and moisture content ranges between 2%-75%. A good relation between moisture content and correlate with variations in electrical properties viz. IZI, Ѳz, R, Cp, Cs has been observed by partial least square regression technique. Result Moisture prediction model was developed by applying electrical properties and that the new technique it was observed more accuracy obtained using a single parameter as compared with that moisture measurement. Conclusion the model which is developed can evaluated with in performance the moisture content a commercial moisture meter which is expected.*

Keywords— Moisture content, electrical properties variation, impedance analyzer, partial least square regression, moisture prediction model.

I. INTRODUCTION

Yoshitomi et al. (2000) worked with production of tea consist of manufacturing techniques, determination of moisture content the drying rate and endpoint at every step seriously tea quality affected in terms of leaf taste , shape, aroma, and colour of liquor. Tea leaves moisture content has been accepted actually progressively at every step, and has been accepted to be 50% wet base when 30% wet base using primary stage tea roller, when 13 % wet base using Secondary stage drying tea roller, when tea roller using final stage drying and drying 5% wet base. A overall of moisture content (5–80% wet base.) is essential to the tea producing process. In given moisture range, actually required precision of the moisture content is below 3% wet base of the excellence delusion. Trabelsi et al. (1998) worked with moisture measurement can be makes independent of density with the help of a new independent of density function reported in literature. This new density independent function determines the relationship of two components bulk density and complex permittivity. Trabelsi et al. (1998) studied the new density independent calibration functions integrate effect of both temperature and frequency and accounts the energy distribution. Researchers reported calibration equation for moisture determination at different temperatures, frequencies and bulk density. The accuracy of determination of both entity depends on accuracy with which ε' and ε" are determined. Kraszewski et al. (1999) carried out their study with several equations for calibration based on measurements taken 1.5GHz for various densities, temperature and moisture contents.

Grain bulk density cannot be resolved, but determination of moisture content for bulk density independence of material and temperature for compensation can be done. Phase shift and attenuation were considered as a function of moisture content. One researcher revealed that density independent and temperature compensated determination were obtained with 15.2 GHz measurement on shelled corn [4]. Kandala et al. (2004) studied the complex impedance technique could be further used to find the moisture content of single in-shell peanuts. Parallel plate capacitor arrangement was used to measure the phase angle, dissipation factor and capacitance and at 1 MHz and 5 MHz frequencies. Hewlett- Packard Impedance Analyzer 4192A LF was used to make measurements. Electrical equation was developed using multi linear regression for MC determination in the range 5-20%. Kandala et al. (2006) worked with moisture content determination and used non-conducting cylindrical capacitor arrangement at 1 MHz and 9MHz frequencies.

The technique was extended to bulk sample as well as single pod. The results were found using six-variable equation and MC was accurately determined for 5 to 22% of MC value. Agilent 4285A Precision LCR meter was used to make measurements of impedance, dissipation factor, and phase angle. Practical instrument could be made based on this technique for in- shell peanuts. Kandala et al. (2012) studied the complex impedance

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technique to six different variation of wheat using parallel plate capacitor arrangement, low cost complex impedance analyzer and a computer. A sample of 150 grams of wheat was placed between parallel plate electrode assembly and variations in capacitance, phase angle and of impedance were found to compute the semi-empirical equation for wheat samples at 1 MHz and 5 MHz frequencies. The measured values were applied to computer for the calculation of MC using multi-linear regression method. The moisture range of tested samples varied from 9 to 25% and the results were independent from the variations of weight and volume of the samples. The performance of meter for all the six varieties of wheat.

Hazarika et al. (2006) worked at the final stage the moisture content of tea leaves, drying plays an essential role in product quality and durability. The two methods for this propose are weight method and human taster. They found these methods are not suitable for online monitoring of MC of tea leaves. Mizumuki et al. (2006) carried out their work with four steel electrodes and an LCR meter was used for the measurement of resistance, reactance and capacitance in figure S1. They found low level of correlation coefficient in between the moisture ranges from 1.2% to 80 % wet basis. Rehman et al. (2011) investigations on a nondestructive impedance spectroscopic technique, is made with the help of probe of two terminals and precise LCR meter. The ratio in middle of raw and ripe mango, measured 1 KHz frequency. Optimum frequency selected for repeatability and dependability. Ritula et al. (2012) worked with precise moisture prediction model of grain has been described based on the electrical properties variations. Moisture content of wheat sample range started from 7.1% to 34.5% was used to report in different electrical properties variations viz. DF, Z, and C in the ranges between 1 KHz–1 MHz. A better relation found between corresponding variations in electrical properties and moisture values has been found at 251.58 KHz frequency using partial least square regression (PLSR) method [11].

In this report, a new technique for moisture determination enclosing a range of wide moisture content is 2–75 %wet base has been observed. The relation between tea leaves moisture content and the electrical properties of were enquired from 100 kHz to 300 MHz frequency range applying electrical spectroscopy. Electrical properties have an impact on the moisture content at frequency range 121.5595 MHz. However, the parameters approximations were observed to be inadequate for tea producing process. Hence, a new developed equation which satisfies electrical properties simultaneously. That equation can evaluates the performance of moisture content of tea leaves which is predicted from a commercial moisture meter.

II. MATERIALS AND METHODS

Fresh green tea shoots for their moisture content and variation in electrical properties. The electrical properties are affected by the variations in weather conditions during four harvesting flush seasons from April to October and to corroborate health claims associated with tea consumption. Samples of fresh tea shoots were collected from Wah Tea Estate, Rajpura, Palampur various stages of growth of tea leaves having various grades of tea such as the smaller leave is considered best for the manufacturing of fine tea.

These samples were concerned to plucking, dried and analyzed. All analytical approximations were carried out in triplicate to minimize the error. The data on analytical approximations were pooled and analyzed statistically. Fresh Tea leaves of black tea were mechanically plucked from Wah Tea Estate, Rajpura, Palampur in the month of april 2016. Samples of fresh tea shoots were wrapped in aluminium foil and store in refrigerator for freshness. Tea leaves were bringing to CSIO Lab Chandigarh for experiment.

The initial moisture content of tea sample was measured using microwave oven method. For moisture content measurement and electrical property 5 gm of samples approximately were weighted by using electronic balance. Total of 18 samples were prepared in Triplicate. The stored samples were always dried completely prior to aqueous extractions for analytical estimations. The samples were subjected to microwave oven method IFB convection microwave oven model: 30SC2 (30 L capacity, microwave 1.4 KW, frequency 2450 MHz), Sample (5 g) of dried green tea shoots stored in air-tight container was taken in a pre-weighed Petri dish and placed in microwave oven maintained at different temperature levels for drying. The Petri dish was taken out in desiccators after regular intervals of 2 h till a constant temperature are reached. The difference in initial and final weight was taken as the moisture content of the sample. Samples were again weighted to determine moisture content. Samples were processed for electrical properties measurement in impedance analyzer.

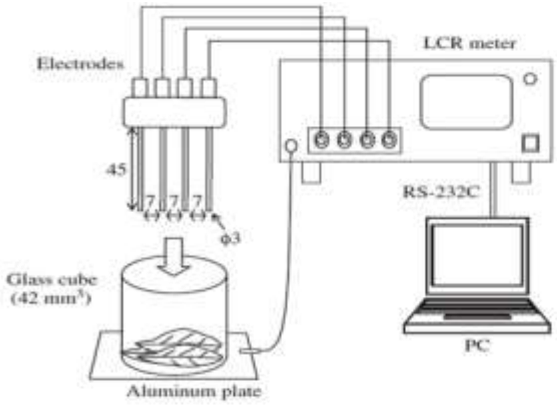

Fig. S1 LCR meter

The 4396B, when combined with the 43961A, uses an I-V measurement method to measure the impedance of a DUT. Through the software intuit Link can import data from 4396B data to computer. The Intuit Link 4294A/4395A/4396B software provides an easy-to-use toolbar that enables to connect to analyzer from either Microsoft Excel or Microsoft Word. Once connected, can perform simple trace data capture and instrument display image transfers directly into spreadsheet or document.

III. RESULTS

3.1 Dependence of moisture on electrical properties

For this prediction model system realized a suitable measurement frequency, the dependence of electrical properties IZI, ϴz, R, Cp, and Cs on the moisture content of the tea leaves was examined by PLSR(partial least squares regression) method in the frequency range of 100 KHz to 300 MHz. This study could well organize the mutual relation between moisture content and resistance at any frequency.

3.2 Data acquisition from impedance analyzer

For the electrical properties measurement, 5gm sample of tea leaves was used. The impedance measurement using parallel plate capacitor for the system is shown in figure S2.

Fig.S2 Sample holder connections

The measurements are seriously affected by residual admittance and impedance of electrodes and also electrodes and cable. For more precision in measurements, it is important to apply improvement to the electrical properties measurement. There are almost two calibration performances that automatically improve the measurements acquired using an impedance analyzer. The electrical properties IZI, ϴz, R, Cp, and Cs were measured using Agilent 4396b impedance /network/spectrum analyzer. The measurement statics is transmitted from to the Personal computer across interface which links serially to personal computer and instrument and give the results in graphical and numerical values as shown in Figure S3. Data analysis by the (PLS) partial least squares method was executed The Unscrambler X software on the measurement data.

3.3 Chemo -metric analysis of data

The multivariate calibration of partial least square (PLS) for impedance analyzer spectral data was done by The Unscrambler X. The spectra were automatically imported to. XLS spread sheet of MICROSOFT EXCEL. The spectral data imported in The Unsrambler was then analyzed using PLS technique. Before PLS the spectral data need to be pre-processed

Analytical study by the (PLS) partial least squares method was operated using The Unscrambler X software on the measurement data. The better relation for validation and calibration data observed at F7 frequency is 121.559500MHz in table S4. Further, the root mean square error (RMSE) values for validation and calibration are observed to be least at that frequency value. Hence, the frequency of 121.559500MHz has been selected for analyze of electrical properties of tea leaves and successive expansion of moisture prediction model.

3.4 PLS Plots Explanation

Score plot

This is a two-dimensional scatter plot of scores for two named factors from PLSR (partial least square regression). The plot gives report about patterns in the samples.

The scores plot for (factor 1, factor 2) is specifically useful, these two components sum up more change in the data than any other combination of components. It can be recognized from the score plot in Figure S5 that the sum of the explained deviations for different axis of two parts is large (X-: explained 99%, 1% and Y- explained: 88%, 5%).

Loading plot

With spectroscopic data 1 vector loading weight plot is often very useful for understanding and identifying the wavelengths in which there is significant absorption related to the constitute of interest.

Predicted vs. Reference plot shows the results for the first Y-variable. The selected predicted Y-value from the model is plotted against the reference Y-value.

Explained Variance

This plot shows the related variance for each model complexities. It can be used to identify which variables are described by the different components in a model.

3.5 Fitness Measurement Plot (Calibration)

The measured versus predicted plot of moisture for calibration data is shown in Figure S6.

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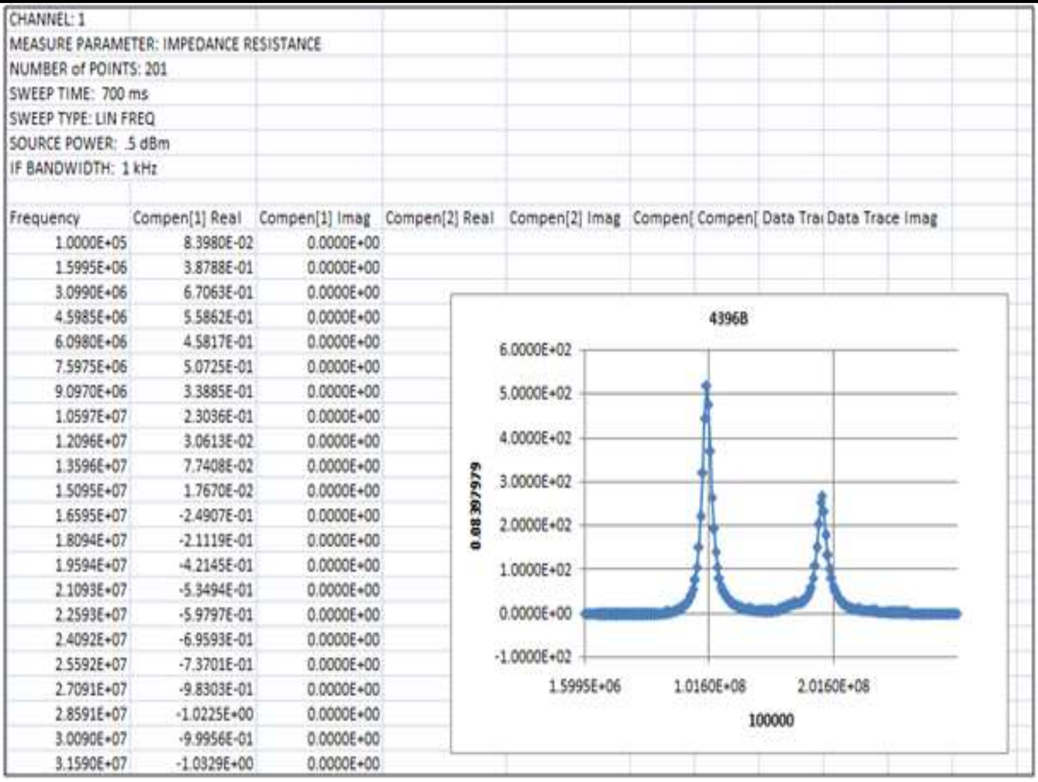

CHANNEL: 1
MEASURE PARAMETER: IMPEDANCE RESISTANCE
NUMBER of POINTS: 201
SWEEP TIME: 700 ms
SWEEP TYPE: LIN FREQ
SOURCE POWER: .5 dBm
IF BANDWIDTH: 1 kHz

Frequency	Compen[1] Real	Compen[1] Imag	Compen[2] Real	Compen[2] Imag	Compen[	Compen[	Data Trac	Data Trace Imag
1.0000E+05	8.3980E-02	0.0000E+00						
1.5995E+06	3.8788E-01	0.0000E+00						
3.0990E+06	6.7063E-01	0.0000E+00						
4.5985E+06	5.5862E-01	0.0000E+00						
6.0980E+06	4.5817E-01	0.0000E+00						
7.5975E+06	5.0725E-01	0.0000E+00						
9.0970E+06	3.3885E-01	0.0000E+00						
1.0597E+07	2.3036E-01	0.0000E+00						
1.2096E+07	3.0613E-02	0.0000E+00						
1.3596E+07	7.7408E-02	0.0000E+00						
1.5095E+07	1.7670E-02	0.0000E+00						
1.6595E+07	-2.4907E-01	0.0000E+00						
1.8094E+07	-2.1119E-01	0.0000E+00						
1.9594E+07	-4.2145E-01	0.0000E+00						
2.1093E+07	-5.3494E-01	0.0000E+00						
2.2593E+07	-5.9797E-01	0.0000E+00						
2.4092E+07	-6.9593E-01	0.0000E+00						
2.5592E+07	-7.3701E-01	0.0000E+00						
2.7091E+07	-9.8303E-01	0.0000E+00						
2.8591E+07	-1.0225E+00	0.0000E+00						
3.0090E+07	-9.9956E-01	0.0000E+00						
3.1590E+07	-1.0329E+00	0.0000E+00						

Fig.S3 Data acquisition from impedance analyzer

It presents a linear line relation between measured values and predicted, with slope and relation very near to 1, which is 0.9631488, and, 0.9276556 respectively.

Table S7 shows that fitness measurement validation for frequency 121.559500MHz.

Table.S4 Statistical fitness measure values at each frequency

Frequency(Hz)	RMSEC (Calibration)	RMSEP (Validation)	Correlation (calibration)	Correlation (validation)
1599500(F1)	0.0745556	0.0833518	0.8671957	0.8560761
3099000(F2)	0.0740382	0.0837463	0.8969032	0.8555181
6098000(F3)	0.0735411	0.0830467	0.8707854	0.8577219
18094000(F4)	0.0735742	0.0830327	0.8706691	0.8579698
19593500(F5)	0.0735232	0.0829662	0.8708481	0.8581973
36088000(F6)	0.0738201	0.0832666	0.8698032	0.8571686
121559500(F7)	**0.0550271**	**0.0621978**	**0.9276556**	**0.9203047**
126058000(F8)	0.0580022	0.0691604	0.9196214	0.9014634
127557500(F9)	0.0610764	0.0734191	0.9108753	0.8889548
151549500(F10)	0.0646138	0.0822584	0.9002525	0.8602672
300000000(F11)	0.0713574	0.0869645	0.8782381	0.8442006

3.6 Predicted versus measured plot (validation)

The measured versus predicted plot of moisture for validation data is shown in Figure S8.

It presents a linear line relation between predicted and measured values, with slope and relation very near to 1, that is, 0.9276555 and 0.9977872, respectively.

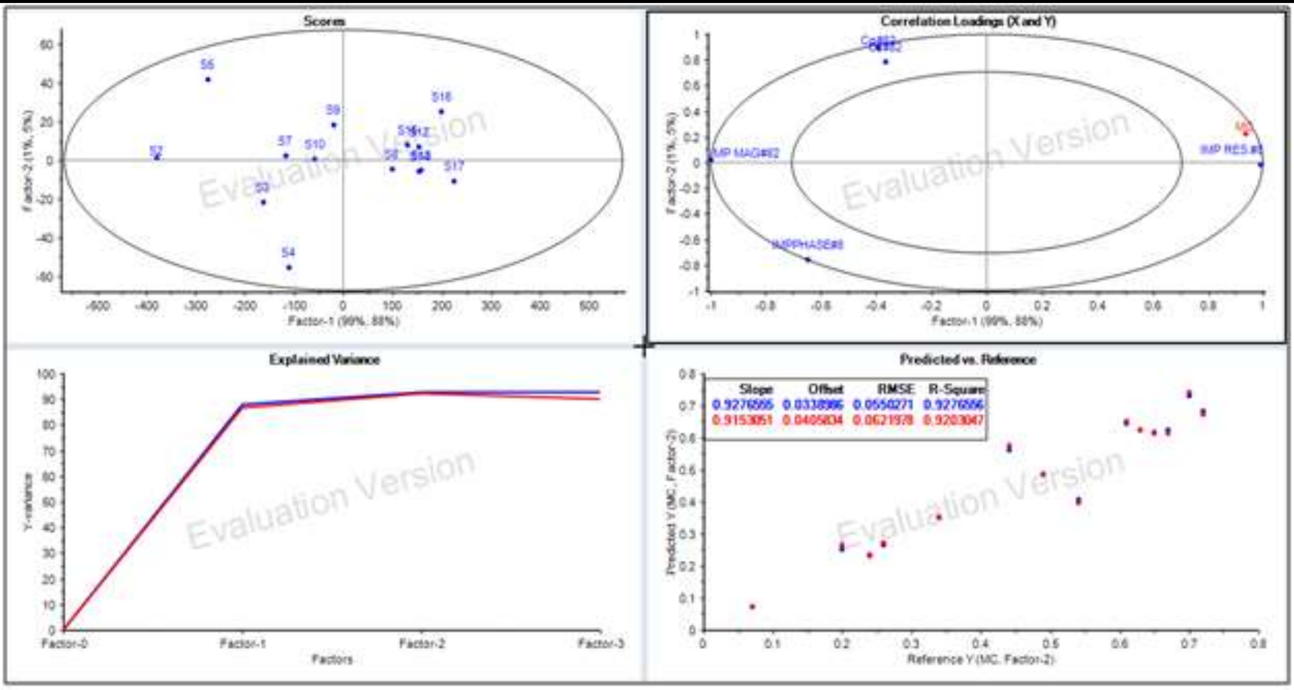

Fig. S5 PLS Plot of at Frequency 121.559500 MHz

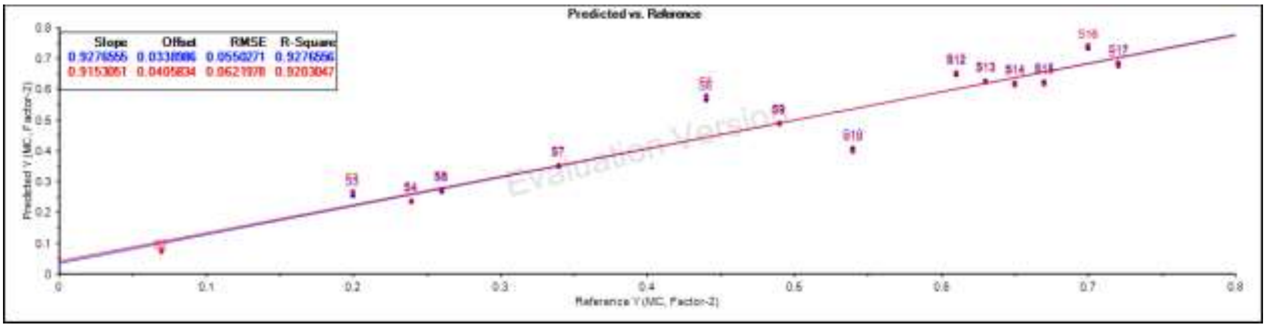

Fig.S6 Predicted versus reference of at 121.559500 MHz (calibration)

Table. S7 Fitness measurement calibration

Correlation	Slope	R^2	RMSEC	SEC	Bias
0.9631488	0.9276555	0.9276556	0.0550271	0.0571043	0

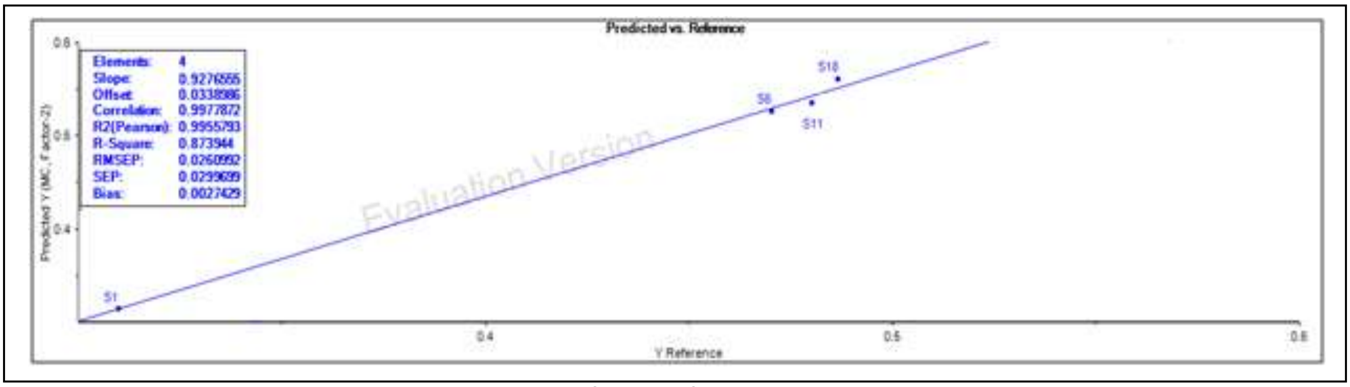

Fig.S8 Predicted versus reference of at 121.559500MHz (validation)

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Table.S9 Fitness measurement validation

Correlation	Slope	R^2	RMSEP	SEP	Bias
0.9977872	0.9276555	0.873944	0.0260992	0.0299699	0.0027429

The prediction equation is follows:

$$MC=0.46857-0.0008IZI-0.0022(\Theta_Z)+0.0001(R)+8.695(C_P)+2.6393(C_S) \quad (1)$$

However, a compact desired measurement between accuracy and computational difficulty has to be continued. The prediction model which is developed can be helpful for the development of better technology for valid, precise moisture measurement in tea leaves.

IV. CONCLUSION

In this study, a precise moisture prediction model of tea leaves has been developed based on the electrical properties variations with respect to moisture. The tea leaves samples having moisture content ranging from 2% to 75% were used to report the different electrical properties variations viz.

IZI, ϴz, R, Cp, and Cs in the frequency ranges of 100 KHz–300 MHz. A capable relation between moisture values and corresponding electrical properties variations has been found at 121.559500MHz frequency.

The results were found to have better for calibration set corresponding to validation set. PLSR (partial least square regression) can be used as full spectrum calibration methods to evaluate electrical properties with respect to moisture content from their spectra. All the factors like slope, correlation, RMSE, R-Square are close to 1 shows best predictive quality. The developed model can be applicable for the evolution of better technology for valid, precise moisture measurement in tea leaves.

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