New Insights on Application of Return Loss Measurement for Starch Content Estimation in Cassava

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***Abstract*—This research explores the use of radio frequency (RF) return loss measurement to characterize cassava quality and estimate the starch content of cassava roots, with new equivalent circuit models presented. While pure starch is non-conductive, the content of charged ions in the raw composite cassava flour provides a potential marker for estimating the starch content of cassava, which is important for the design of quality measurement devices based on the return loss method. The study also raises questions for further exploration, such as understanding the pattern of distribution of the electrolytic components in a fresh root and exploring the relationships between these ions and other properties of cassava. Overall, these new findings offer new directions for research and development in the field of food quality assessment.**

***Index Terms*—Equivalent circuit modelling, food and crop quality estimation, cassava, electrical impedance spectroscopy, return loss.**

I. Introduction

Electrical impedance spectroscopy (EIS) is a powerful analytical technique that provides non-destructive and non-invasive means for assessing the quality of organic and inorganic materials, including food products [1]. The technique involves measuring the electrical impedance of food samples at different frequencies, providing information about the physical and chemical properties of the sample [2]. By analyzing the impedance spectrum of a food product, researchers and food manufacturers can obtain valuable insights into the composition, texture, and freshness of the product [3], [4], [5]. The technique has emerged as a promising tool for food quality analysis, offering a rapid, accurate, and cost-effective alternative to traditional methods [6], [7].

Cassava is a starchy root vegetable that provides staple food to 800 million people globally [8]. The tropical crop is highly valued because of its peculiar climate resilience, drought tolerance and relative resistance to weeds and insect pests [9]. The bulk of the dried cassava root consists of carbohydrates, over 80% of which is pure starch [10], [11]. Pure cassava starch is typically constituted of 16–18% of amylose and 82–84% amylopectin [12]. In [13] the viability of starch content estimation in cassava using electrical return loss measurement was demonstrated. The return loss, which is the amount of RF power reflected after an RF signal is injected into a sample, was shown to be a good predictor of both the dry matter and starch content in a cassava sample. The utility of the return loss method for the quality characterisation of cassava has also been verified for cassava flour suspensions and fresh roots [14].

, Ali This paper introduces a new and precise electrical circuit model for the frequency response of cassava flour, based on return loss measurements of suspensions containing varying cassava flour concentrations. The model offers new insights into the electrochemical properties and attributes of pure cassava flour, which could lead to the development of more reliable characterization tools for cassava and other food products. This is a key step in the development of low-cost, field-deployable devices for food quality estimation. Also included in the proceedings of AFRICON 2023 is another paper, which focuses on the evolving design philosophy of a portable test instrument used for estimating the starch content of cassava roots, and details the approaches employed to enhance the functionality and user-friendliness of the instrument [15].

The outline of the paper is as follows: Section II describes the experimental setup used to capture the frequency response data from the cassava suspension samples. In Section III, the results of the measurement are presented, and the equivalent circuit model and parameter extraction are described. Section IV presents the discussion and Section V concludes the paper.

II. Experimental Setup for Model Extraction

Cassava flour obtained by finely grinding peeled and dried cassava chips was dissolved in deionised water at quantities of 5g, 7.5g, 10g, 12.5g, 20g and 30g. The cassava flour in this form is a composite that retains the constituents of raw cassava, which is primarily starch (which is non-conductive [16]) but also includes water-soluble, electrically conductive, constituents such as potassium and sodium [17]. As a control experiment, the return loss of deionised water, which is used as the solvent in these experiments, was also measured. The return loss measurements were carried out using a Keysight FieldFox Microwave Analyzer N9917A (a vector network analyzer - VNA [18]) and a specially designed coaxial probe to measure the one-port reflection coefficient from 30 kHz to 500 MHz (measurement setup is shown in Fig 1) [19], [13]. All the samples were thoroughly stirred before each measurement was taken. Pure cassava starch, which is extracted by wet milling of fresh, peeled cassava roots, and processed to remove fibres and all the water-soluble constituents of the cassava is also measured using the same test setup at 10g and 20g. This is

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done to observe the difference in electrical response between the composite cassava flour and its pure starch extract.

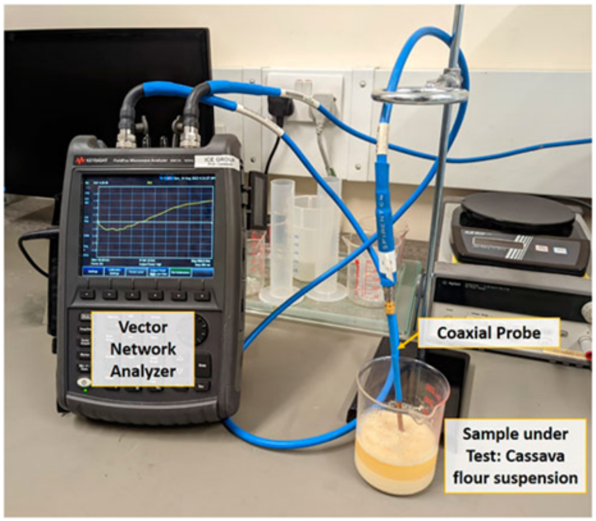

Fig. 1. Measurement setup for testing samples with different concentration levels of cassava flour and starch.

III. Results and Equivalent Circuit Extraction

The return loss plots from 30 kHz - 500 MHz from the measurement of the cassava flour composite and extracted pure cassava starch are shown in Fig. 2. The increase in the magnitude of the return loss (dB) with increased concentration of the cassava flour may be observed. It may also be observed that while 20g of cassava flour results in -9.3dB of return loss at low frequencies, the return loss measured for the same quantity of cassava starch is less than -1dB which is quite similar to the response of pure deionised water.

A. Equivalent Circuit Model

An equivalent circuit consisting of resistances and capacitances is developed to model the frequency response curves in Fig. 2. This model is a modification of the classical 1969 Hayden's equivalent electric circuit model [20] and the double-shell equivalent electrical circuit model [21], which were developed to model the electrical response of plant tissue. The equivalent model developed is shown within the dotted lines in Fig. 3 with the voltage source V_s representing the single port excitation from the VNA for the frequency response measurement as shown in the setup in Fig 1. C_s, C_d and R_d were found to be associated with the starch content in the cassava flour, while R_s models the losses associated with the soluble conductive components of the cassava flour.

The values for the components in the model, at different levels of cassava flour concentration, are shown in Table 1. The model matched the measured response within a 1% margin of difference across all the measured frequencies.

R_s is found to be the dominant contributor to the overall frequency response and reduces with increasing flour concentration, reflecting the increase in the conductivity of the suspension. Importantly, C_s, C_d and R_d, which are associated

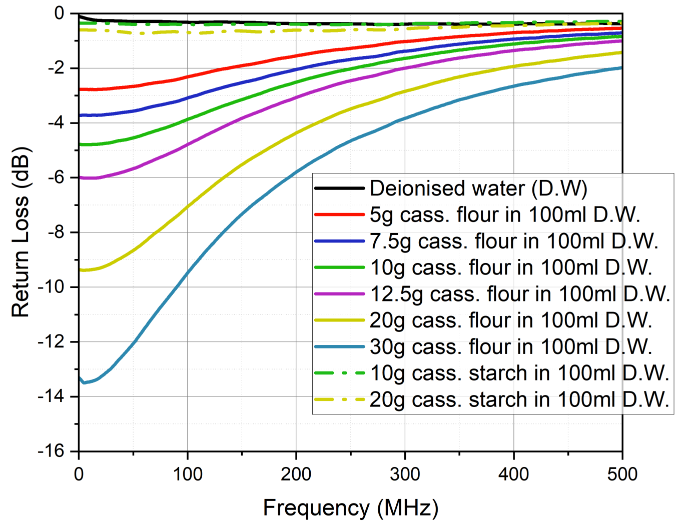

Fig. 2. Solid lines show the return loss plots of deionised water (used as the solvent for the experiments) and suspensions of cassava (cass.) flour. Dashed lines show the return loss plots of suspensions of pure cassava starch.

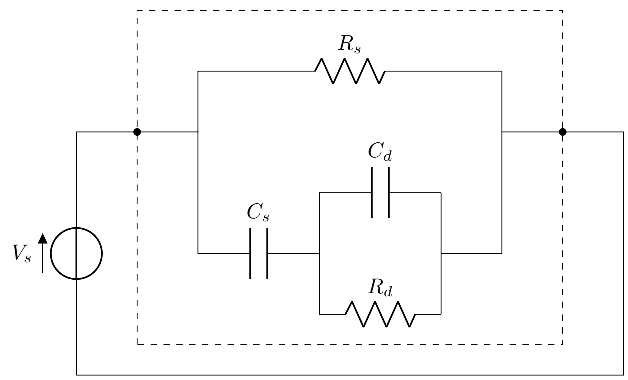

Fig. 3. Equivalent circuit of cassava flour suspension. The component values for different concentrations is shown in Table 1

with the starch component of the cassava flour, contribute to the overall frequency profile, with extracted values and effects only changing slightly with changing the concentration of the cassava flour.

IV. Discussion

From Fig. 2 it is observed that the magnitude of the return loss does not change in proportion to the content of

TABLE I
Parameters for the Cassava Flour Equivalent Circuit

Flour Concentration	Equivalent Circuit Parameters			
	C_s (pF)	C_d (pF)	R_d (Ω)	R_s (Ω)
5g	15	500	1	315
7.5g	15	500	1	236
10g	15	550	1	185.5
12.5g	15	500	1	150
20g	15	550	1	101.2
30g	14.3	500	0.5	76.7

starch flour in the suspension. This observation agrees with the understanding that at room temperature (24^{o} C), pure starch does not dissociate into ions when suspended in water, hence it does not conduct electricity [16]. However, from Fig. 2, it may be observed that the magnitude of the return loss increases with increasing flour concentration, with the difference clearly discernible from 30kHz to 300 MHz. This shows that the changing electrical impedance is due to the presence of dissolved, conductive substance(s) present in the cassava flour and not the starch constituent. Furthermore, while starch suspends in water, the electrically conductive component of the cassava starch composite is soluble, such that the measured frequency response is consistent even when the measurement is conducted on the solution above after the suspension has settled.

This observation is of particular interest considering that previous studies have demonstrated the viability of estimating the starch content of cassava (both fresh roots and flour) using the return loss measurement [13], [14]. These new findings suggest that the return loss approach to measuring starch content actually measures the water-soluble conductive components that are present in the cassava flour, which is proportional to the starch content, thus providing a good measurement proxy.

These findings raise a few key questions for further exploration. The first is to understand if the aggregation of the conductive components in the cassava dry matter composite is generally proportional to the starch content of a cassava root sample. This question is essential to ascertain the viability of the return loss method of starch estimation. Preliminary results indicate this to be true in fresh cassava root [13], however, more extensive studies are required to establish this. The second key question is to understand the pattern of distribution of these conductive components in fresh cassava roots. Research reported in [14] showed that probing the roots at different locations will yield different reflection curves, which indicates different concentrations of the conductive components across the cassava root. Understanding the nature and pattern of this distribution in concentration will enable accurate and repeatable estimations of starch content in cassava and other starchy food crops, such as potatoes and yams.

V. Conclusion

This paper presents a new electrical equivalent circuit model for cassava and sheds new light on the use of the electrical property of return loss to characterise cassava quality, specifically with regard to measuring the starch content of cassava roots. While starch is non-conductive, the content of charged ions in the raw composite cassava flour (Potassium, Phosphorus, Calcium etc) appears to be correlated with the amount of starch in the cassava. This provides a potential marker for estimating the starch content of cassava, which is important for the design of quality measurement devices based on the return loss method. Moreover, this discovery opens up new avenues for further research in the field of cassava quality assessment. Future studies could explore the relationships between these ions and other properties of cassava, as well as investigate the potential applications of this method for other types of food products.

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