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Permittivity Measurement of Edible Food Materials: A Review Paper

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ABSTRACT:
This study investigates the dielectric characteristics of a range of food items, such as potatoes, apples, chicken breast meat, quinoa seeds, Carasau bread dough, coconut oil, turmeric, jamun, tamarind, vegetables, beef, cheddar cheese, wheat grains, and dairy products. A variety of techniques, including the vector network analyser, planar transmission line sensor, Marconi instrument, and novel planar double spiral sensor, are used to do measurements over a range of frequencies. This study also explains how dielectric characteristics are affected by temperature, frequency, moisture content, and density. In order to address particular applications like food quality monitoring, adulteration detection, and process optimization, the research also introduces novel sensors and techniques, such as a complementary Meta resonator, the Cavity Perturbation Technique, an ultra-broadband characterization method, and metamaterial-based microwave sensors. The results provide important new information for a variety of businesses and further our understanding of the dielectric characteristics of food products.

Keywords: Adulteration,dielectric constant,permittivity, edible food materials,

I. INTRODUCTION:

Dielectric property evaluation as a means of evaluating food quality is a rapidly developing subject of study with significant implications for the food sector. Dielectric characteristics, which include things like permittivity and loss factor, offer a special perspective on how electromagnetic fields interact with certain foods. This work begins a thorough investigation of dielectric reactions in a variety of dietary items, including dairy, cereals, meats, fruits, and vegetables. Understanding the nuances of dielectric characteristics is essential for optimizing food processing procedures, maintaining product integrity, and satisfying strict quality requirements as the globe experiences a paradigm shift towards more advanced and technologically driven approaches.

The modern food business must become more accurate and efficient in many areas of manufacturing, such as identifying adulteration, monitoring freshness, and refining processing methods. Dielectric characteristics are sensitive markers that show variations in composition, moisture content, and general quality. The evaluation of food quality might be revolutionized by using this data, having ramifications for both consumer-level applications and large-scale industrial operations.

The study explores the dielectric characteristics of a wide range of food products with the goal of advancing both the fundamental knowledge of these characteristics and the creation of novel techniques and sensors. These techniques, which range from conventional vector network analysers to state-of-the-art devices like microwave sensors based on metamaterials, aim to improve the accuracy and sensitivity of measurements of dielectric properties. In doing so, they open up new avenues for food science and technology applications and provide answers to problems pertaining to adulteration detection, process optimization, and quality monitoring.

Additionally, the introduction of new sensors and methods takes into account how the food sector is changing due to issues like digitization, globalization, and shifting customer tastes, which call for sophisticated and flexible methods. The incorporation of dielectric studies into this wider framework places this study at the forefront of advances that have the potential to completely change our understanding of, approaches for handling, and guarantees for the quality of our food supply.

Essentially, this work is a timely investigation into the unexplored possibilities of dielectric characteristics in the field of food science. The research aims to contribute to academic knowledge as well as the practical advancement of food technology by revealing the electromagnetic subtleties of various food products and introducing state-of-the-art measurement techniques. This will enable the research to provide solutions that meet the demands of a dynamic and rapidly evolving food industry.

II. LITERATURE SURVEY:

An extensive collection of earlier studies examined the dielectric characteristics of various dietary ingredients. [15]Fruits and vegetables have been the subject of several studies, which have highlighted the distinct electromagnetic signatures that correlate to changes in moisture content, maturity, and general quality. These investigations employ techniques like cavity perturbation and dielectric spectroscopy to measure over a wide range of frequencies and capture subtle reactions. The resulting insights may be applied to many fields, such as monitoring fresh food products and refining processing procedures.

[7]Research on chicken breast and other meat varieties demonstrates a sophisticated knowledge of complicated permittivity in the field of meats, which helps to design sensors that can accurately determine freshness, identify abnormalities, and improve overall quality control in the meat sector. [1] Beyond conventional grains, the investigation of dielectric characteristics in cereals includes knowledge of local cereals' responses to electromagnetic fields in the audio frequency range. This creates opportunities for advancements in agro-food technology, where it becomes critical to measure impedance precisely using specialized tools like the Marconi 0.1% universal impedance bridge.

The study of pseudocereals, like [2] quinoa, expands the focus to include bulk density, moisture content, and temperature. The results clarify how dielectric characteristics change under various circumstances, providing essential knowledge for the creation of efficient food processing and storage techniques. [3] The analysis of traditional breads, such as Sardinian Carasau, highlights how microwave technology may be used to determine the composition of food at various stages of manufacture. In addition to taking into account dielectric characteristics, the study looks at how important variables like salt, water content, and yeast concentrations affect the microwave response, opening the door to more accurate quality control procedures throughout the bread-making process.

The existing knowledge is based on dielectric properties in food materials, while also demonstrating the variety of applications and approaches used. The combined results add to a thorough knowledge of how dielectric studies may transform raw material characterization, quality evaluation, and processing optimization, among other aspects of the food business.

III. EXISTING METHODS:

The field of dielectric property measurements in food science comprises a range of well-established techniques, each specifically designed to capture particular facets of food ingredients' electromagnetic reactions. Using a Vector Network Analyzer (VNA), a flexible device that enables accurate measurements over a variety of frequencies, is one often-used method. Experiments on the freshness of potatoes and apples demonstrate how this technique enables thorough evaluations of dielectric characteristics in the microwave frequency range (4.9–7.05 GHz). The Nicholson-Ross-Weir New Non-Iterative Method and a waveguide approach are used to evaluate permittivity values, which improves the accuracy of describing changes in dielectric characteristics related to food freshness.

When it comes to [7] planar transmission line sensors, a thorough examination of chicken breast flesh requires assessing complicated permittivity between 0.5 and 5 GHz. In comparison to an open-ended coaxial line probe that is sold commercially, this approach demonstrates the benefits of the planar sensor in terms of reducing variances for various sample orientations. Because of its capacity to deliver accurate data across a wide range of frequencies, the planar sensor is a useful instrument for evaluating meat's dielectric characteristics, which helps the meat processing sector maintain quality control.

A 0.1% universal impedance bridge, a Marconi device, is used in studies on indigenous [1] cereals (corn, beans, and rice) to provide accurate impedance measurements. By maintaining uniform conditions throughout the measurement process, the coaxial sample holder enables researchers to investigate the frequency dependence of dielectric characteristics. This methodological decision lays the groundwork for comparable studies in other biological and agro-food materials, in addition to furthering our understanding of the dielectric behaviour of cereals.

Dielectric permittivity tests are performed at 2.45 GHz with the purpose of evaluating quinoa, a nutrient-richpseudocereal [2], taking into account several characteristics such as bulk density, moisture content, and temperature. By illuminating the differences in permittivity under various settings, this technique provides insights into how these factors affect the dielectric characteristics of quinoa seeds. This study not only adds to the body of information about pseudocereal qualities, but it also shows how versatile dielectric measurements are for evaluating the quality of various food products.

[3] The evaluation of Sardinian flatbread, or Carasau bread, makes use of microwave technology. Dielectric permittivity measurements are carried out up to 8.5 GHz, and the impact of concentrations of yeast, salt, and water on the microwave response is investigated. This approach offers a thorough analysis of the ingredients in Carasau bread dough, highlighting the significance of mathematical models like the Cole-Cole model and dielectric spectroscopy for interpretation. The results provide important new information for the development of microwave sensors capable of accurately characterizing the composition of bread dough while it is being made.

A new method is introduced by the inventive planar double spiral sensor[4] , which is intended for use in dielectric characterization and adulteration detection in coconut oil. This sensor has an asymmetric coplanar strip (ACS) architecture and deliberately divides its antennae to function as a measurement and reference sensor. It operates in the 2.4 GHz ISM frequency range. When the sensor is manufactured with certain parameters, its resonant characteristics change according to the liquid samples' dielectric qualities. Because of its ability to identify adulteration at a variety of concentrations, the sensor is a useful instrument for guaranteeing product safety and integrity in the food business. This paper discusses the application of electromagnetic (EM) fields in the food sector by means of an experimental framework for food powder dielectric property characterization. This work uses waveguide systems and the open-ended coaxial probe method to investigate powdered meals in the 500 MHz–20 GHz frequency range. In addition to highlighting the appropriateness of the suggested configuration, the study sheds light on flour permittivity, highlighting a density-dependent connection and indicating the possibility of useful applications in the food sector.

A thorough comprehension of the dielectric characteristics of food ingredients is essential for the several electromagnetic-based treatments used in food preparation. Three characterization techniques are used in studies on instant mashed potatoes: a bespoke stripline resonator, a broadband dielectric broadband spectrometer, and an open-ended coaxial dielectric probe. Instant mashed potatoes, a standardized meal, enable insightful comparisons by displaying similar dielectric characteristics at varying moisture amounts. In order to cook food evenly and efficiently, it is essential to build sophisticated microwave heating equipment, and this research offers priceless insights into this process.

Methods for ultra-broadband characterization[8] are presented to investigate food materials' dielectric characteristics between 1 Hz and 1.6 GHz. This study uses an adaptable technique that enables quick testing of instant mashed potatoes with different moisture and salt content combinations. In addition to ultra-broadband measurements, the system enables automatic temperature sweeps, providing comprehensive knowledge of the relationship between temperature and dielectric characteristics. The extensive datasets obtained further advance our comprehension of the complex processes affecting changes in the dielectric properties of dietary ingredients. The system's adaptability to various heating applications, such as microwave, radio frequency, and ohmic, has implications for imaging and measurement.

The complementary Meta resonator is presented as a useful instrument in the study of vegetable oils in the C and X bands. [9] The selected complementary mirror-symmetric S resonator (CMSSR) is used to measure the dielectric constant of the oil being tested. It operates in the microwave frequency range and makes use of dual-notch resonance phenomena. The suggested complementary Meta resonator sensor's precise performance and small size make it a potential tool for characterizing vegetable oils in microwave frequency bands, which will boost food technology.

[10] The Cavity Perturbation Technique (CPT) at 2.4 GHz is used to detect adulterated turmeric. The study focuses on two prevalent adulterants: starch and egg yellow colouring.

IV. INFERENCES:

The study on the dielectric properties of [13] tamarind and a green drink yields valuable insights into the electromagnetic behavior of these beverages.The findings carry practical implications for optimizing microwave-assisted pasteurization processes, emphasizing the significance of precise temperature control for consistent results. Furthermore, the study contributes to the broader understanding of dielectric properties in food science and technology, with potential applications in the development of novel food processing techniques. However, the complexity of the green drink, attributed to multiple ingredients and potential interactions, underscores the need for further research and a comprehensive consideration of factors influencing food properties and processing outcomes.

The efficacy of the [10] Cavity Perturbation Technique (CPT) at 2.4GHz is underscored, demonstrating its reliability in discerning adulteration when a single contaminant is introduced. However, the research aptly identifies challenges associated with complex adulteration scenarios involving multiple adulterants, emphasizing the need for more advanced methodologies. In response, the introduction of an automated machine learning flow proves pivotal in significantly enhancing the accuracy of adulteration detection, showcasing the potential of integrating experimental techniques with sophisticated data analysis approaches.

The uniqueness of this approach lies in its ability to optimize the predictive model based on the chosen hardware platform, addressing both technology-independent and technology-dependent considerations. The study's practical relevance is evident in its application to the spice industry, offering a promising solution for improving the precision and reliability of turmeric adulteration detectiona critical aspect of quality control.

[15] The chosen frequency range of 500–2500 MHz, though relevant for certain applications, might not encompass the full spectrum needed for all food processing scenarios. Additionally, the examination of flour slurry concentrations at 20, 30, and 50 g per 100 g water, while informative, may not cover the entire range of concentrations encountered in practical food processing. The study's focus on individual ingredients (salt and butter) and their combination simplifies the complexity of real-world food formulations, potentially overlooking interactions in more intricate compositions. The explored temperature range of 30 to 80 °C, though suitable for understanding certain thermal effects, might not be representative of higher-temperature food processing methods. Furthermore, the study's concentration on a specific rice variety, Indian Basmati, limits the generalizability of its findings to other rice varieties. The lack of real-time monitoring capabilities and the need for further validation of the identified relationships also underscore the study's limitations in immediate practical application. As with any research, these drawbacks provide valuable insights for refining methodologies and prompting future investigations to enhance the applicability and robustness of the study's findings in diverse food processing contexts.

The narrow frequency range may limit its ability to fully capture the diverse spectrum of frequencies relevant to practical applications. Also, the study mentions twowheat [18] varieties, but the variability across different wheat varieties is not thoroughly accounted for. Sole reliance on the dielectric constant, without a comprehensive analysis of other electrical properties, could potentially overlook important factors influencing electrostatic separation. Furthermore, the effectiveness of the method in real-world impurity removal scenarios needs validation. The scalability and practical applicability of the electrostatic separation method on a larger scale, beyond laboratory conditions, remain to be explored.

[23]The chosen frequency range (4.9–7.05 GHz) might capture relevant characteristics for the selected products, but a broader spectrum could provide a more comprehensive characterization of dielectric responses. The assumption of homogeneity within food samples overlooks potential variations, especially in complex structures. Additionally, while temperature and moisture content are considered, a deeper exploration of their effects on dielectric properties would contribute to a more nuanced understanding. The limited details on the methodology, particularly regarding the Nicholson-Ross-Weir New Non-Iterative Method, pose challenges for result reproducibility. Furthermore, the study does not explicitly correlate dielectric properties with specific quality indicators, and a comparative analysis with established quality assessment methods could enhance the study's robustness. Considering these limitations provides a balanced perspective on the study's findings and suggests avenues for future research to refine dielectric measurements as a tool for assessing food freshness and quality.

V. CONCLUSION:

A wide range of sectors can benefit from the thorough investigation of dielectric characteristics in food items. The novel sensors and methods presented in this study have the potential to improve the sensitivity and accuracy of dielectric property measurements, which will improve the processing and monitoring of food quality. The results have ramifications for the food sector and provide answers for issues with product development, quality control, and standard-setting.

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