UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

Visión Electrónica
https://doi.org/10.14483/issn.2248-4728

VISIÓN ELECTRÓNICA

A RESEARCH VISION

Electrical impedance spectroscopy for food characterization. Case study: cocoa butter extracted at different pressing temperatures

Caracterización de aceite de cacao a diferentes temperaturas de prensado: análisis por espectroscopía de impedancia eléctrica

Camilo Hernando Arteaga Erazo[1], Julio César Caicedo Eraso[2], Felix Octavio Diaz Arango[3]

INFORMACIÓN DEL ARTÍCULO

Historia del artículo:
Enviado: 05/08/2025
Recibido: 15/09/2025
Aceptado: 17/11/2025

Keywords:
quality evaluation
electrical impedance spectroscopy
cocoa butter
traditional methods
non-destructive

Palabras clave:
evaluación de calidad
espectroscopia de impedancia eléctrica
aceite de cacao
métodos tradicionales
no destructivo

ABSTRACT

The evaluation of food quality is a crucial aspect for both the food industry and public health. Food quality can directly impact the health and safety of consumers, as well as the reputation and profitability of the food industry. Although traditional methods for evaluating food quality have proven effective, new techniques and technologies are being developed to enhance and complement these methods. One non-destructive technique being used in food evaluation is electrical impedance spectroscopy (EIS).

This technique measures the electrical impedance of a sample as a function of frequency and is useful for determining the quality and freshness of products. In this regard, EIS has been successfully used to evaluate the quality of cocoa butter and provide additional information about the composition and electrical properties of its components.

Compared to traditional physical-chemical methods for evaluating cocoa butter quality, such as acidity determination and refractive index, EIS is a non-destructive, faster, and more sensitive technique for evaluating the quality and stability of cocoa butter, mainly during its processing and storage. The objective of this research focuses on characterizing cocoa butter extracted at different temperatures of mechanical extrusion using EIS as an alternative method.

RESUMEN

La evaluación de la calidad de los alimentos es un aspecto crucial tanto para

1. Student, Faculty of Engineering, Food Engineering, Universidad de Caldas. Manizales, Colombia. Email: camilo.art3@gmail.com. Orcid: https://orcid.org/0009-0001-8463-5147
2. Associate Professor, Universidad de Caldas, Faculty of Engineering, Department of Systems and Informatics. Manizales, Colombia. Email: julioc.caicedo@ucaldas.edu.co. Orcid: https://orcid.org/0000-0003-4073-9152
3. Associate Professor, Universidad de Caldas, Faculty of Engineering, Department of Engineering. Manizales, Colombia. Email: felix.diaz@ucaldas.edu.co. Orcid: https://orcid.org/0000-0002-1202-2376

Cite this article as: C. H. Arteaga-Erazo, J. C. Caicedo-Eraso, F. O. Diaz-Arango, "Electrical impedance spectroscopy for food characterization. Case study: cocoa butter extracted at different pressing temperatures", Visión Electrónica, vol. 19, no. 2, 2025.

la industria alimentaria como para la salud pública. La calidad de los alimentos puede impactar directamente la salud y seguridad de los consumidores, así como la reputación y rentabilidad de la industria alimenticia. Aunque los métodos tradicionales de evaluación de la calidad de los alimentos han demostrado ser efectivos, nuevas técnicas y tecnologías están siendo desarrolladas para mejorar y complementar estas técnicas. Una técnica no destructiva que se está utilizando en la evaluación de alimentos es la espectroscopia de impedancia eléctrica (EIS). Esta técnica mide la impedancia eléctrica de una muestra en función de la frecuencia y es útil para determinar la calidad y frescura de los productos. En este orden de ideas, particularmente la EIS se ha utilizado exitosamente para evaluar la calidad del aceite de cacao y proporcionar información adicional sobre la composición y propiedades eléctricas de sus componentes. En comparación con los métodos fisicoquímicos tradicionales para evaluar la calidad del aceite de cacao, como la determinación de la acidez y el índice de refracción, la EIS es una técnica no destructiva, más rápida y sensible para evaluar la calidad y estabilidad del aceite de cacao, principalmente durante su procesamiento y almacenamiento. El objetivo de esta investigación se centra en caracterizar el aceite de cacao extraído a diferentes temperaturas de extrusión mecánica utilizando la EIS como método alternativo.

1. Introduction

Electrical Impedance Spectroscopy (EIS) is an advanced analytical technique that has emerged as a crucial tool in food characterization. Distinguished by its non-destructive nature, EIS is used to identify various properties of materials, including food products, by inducing alternating electrical signals at different frequencies and measuring the corresponding response signals [1]. This technique has been employed to assess fruit ripeness, detect adulteration in meat and dairy products, determine physicochemical properties across a wide range of food matrices, and even to quantify microorganisms present in foods and on work surfaces [2].

EIS is considered a promising detection technology due to its multiple advantages: it is rapid, cost-effective, portable, easy to implement, non-invasive, and environmentally friendly. These features make it a method with great potential for application in the food industry for quality control and process monitoring [1].

Understanding the variations in the electrical characteristics of cocoa butter as a function of processing conditions is of great relevance for both the food industry and food science research. Although no specific studies have been found addressing the use of electrical impedance spectroscopy to characterize cocoa butter extracted at different pressing temperatures, similar techniques have been applied to the characterization of other foods and biotechnological products [1][2][3].

This study focuses on the application of EIS to investigate the properties of cocoa butter extracted at varying pressing temperatures. The central hypothesis is that electrical impedance spectroscopy can be used to analyze the electrical properties of the oil and to determine how these properties change with processing temperature. This could potentially lead to the optimization of the pressing process and improvement of oil quality.

This approach provides a unique perspective on the molecular and structural transformations occurring during cocoa butter extraction, enabling comparisons with similar matrices and potentially impacting the quality and applications of the final product. Through the meticulous application of EIS, this study aims to make a significant contribution to the field of food characterization, promoting a better understanding of production processes and their implications for food quality.

2. Objective

This research undertakes a detailed analysis of the electrical properties of cocoa butter extracted under various pressing temperature conditions. The investigation is grounded in the premise that variations in extraction temperature may influence the composition and characteristics of the resulting oil, potentially exerting a significant impact on the quality of products derived from it [2]. In this context, Electrical Impedance Spectroscopy (EIS) is applied as a key analytical technique due to its potential to detect and quantify underlying changes in the electrical attributes of samples, thereby offering a valuable opportunity to enhance and refine laboratory analysis practices.

The approach is directed toward identifying electrical markers or distinctive signatures capable of revealing subtle transformations in the cocoa butter food matrix. Achieving this goal may not only shed light on the intrinsic relationship between processing conditions and the properties of the final product but also provide critical insights for the food and chocolate industries in terms of quality control and process optimization. Furthermore, the findings may extend to other sectors utilizing this matrix. Ultimately, this study aims to contribute to the advancement of scientific knowledge in the field of food characterization and to provide valuable input for the continuous improvement of industrial practices in the production and processing of cocoa-related products.

3. Materials and Methods

To characterize cocoa butter extracted at different pressing temperatures using Electrical Impedance Spectroscopy (EIS), samples of cocoa butter were obtained under controlled pressing temperatures ranging from 140°C to 180°C, with increments of 10°C between each sample. This resulted in five samples to be evaluated: 140°C, 150°C, 160°C, 170°C, and 180°C. The electrical impedance of each sample was measured using an impedance analyzer (3522-50 LCR HiTester, HIOKI, Japan, 2006) over a frequency range of 1 Hz to 1 MHz. All measurements were conducted at room temperature, using 1 cm^3 of oil placed in a cylindrical cell equipped with two conductive electrodes, as illustrated in Figure 1.

Figure 1: Electrodes used for EIS measurements in cocoa butter samples.

Source: Own

4. Results

The statistical results obtained show variable differences in electrical impedance (Z) as a function of the different cocoa butter extraction temperatures in the samples evaluated. The sample sets are described as follows:

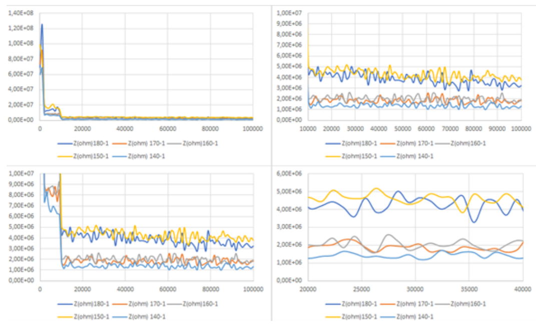
Table 1: Variable versus Extraction Temperatures

Variable	Extraction Temperature
Z (ohm)180-1	Cocoa butter extracted at 180°C
Z (ohm)170-1	Cocoa butter extracted at 170°C
Z (ohm)160-1	Cocoa butter extracted at 160°C
Z (ohm)150-1	Cocoa butter extracted at 150°C
Z (ohm)140-1	Cocoa butter extracted at 140°C

Source: Own

The graphical representation of these data, in the form of a comparative plot of impedance (Z) on the Y-axis versus frequency on the X-axis, serves as a fundamental tool for visualizing and understanding the variations observed in the electrical properties across the different sample sets. In Figure 2, it is consistently observed that the grouping of the samples remains stable throughout the plot.

Figure 2: Impedance (Z) vs. Frequency



Source: Own

The distance between the lines corresponding to Z(ohm)180-1 and Z(ohm)150-1, and those corresponding to Z(ohm)140-1, Z(ohm)160-1, and Z(ohm)170-1, remains consistent throughout the frequency range represented in the graph. This observation suggests a preliminary clustering of cocoa butter samples that exhibit distinct electrical properties.

However, a statistical analysis was conducted using an analysis of variance (ANOVA, F-test) to evaluate the differences in the mean electrical impedance (Z) among these sample groups, as presented in Table 2.

In the previous table, the F-test results for cocoa butter extracted at different pressing temperatures are presented. The green-highlighted values represent the highest F-values, while the yellow-highlighted values indicate the lowest. A statistically significant difference in variance is considered when

the calculated F-value exceeds the critical value. Conversely, when the F-value is lower than the critical value, the difference is not statistically significant.
For example, in the comparison between Z(ohm)180-1 and Z(ohm)150-1, the F-value is 1.2545, which is lower than the critical value of 1.3940. This indicates that there is no significant difference in variance between these two samples, suggesting homogeneity in their electrical properties.

5. Conclusions

Electrical Impedance Spectroscopy (EIS) is a valuable analytical tool in food analysis, enabling the measurement of a sample's electrical properties as a function of frequency. In this case study, an analysis was conducted on cocoa butter extracted at different pressing temperatures to determine whether a consistent relationship exists between processing temperature and electrical impedance.

When comparing the cocoa butter sample sets Z(ohm)180-1 and Z(ohm)150-1, no statistically significant differences in electrical impedance (Z) were observed, as all F-test values remained below the critical threshold for a one-tailed test. Similar results were found for the group comprising Z(ohm)140-1, Z(ohm)160-1, and Z(ohm)170-1. However, comparisons between the sets Z(ohm)180-1 and Z(ohm)150-1 against Z(ohm)140-1, Z(ohm)160-1, and Z(ohm)170-1 revealed statistically significant differences in impedance.
Nevertheless, the variance test results were not conclusive overall, as electrical impedance varied significantly only within specific temperature groups. The observed variation was neither consistent nor followed an increasing, decreasing, or otherwise standardized pattern. Therefore, no definitive relationship between the variables can be established at this stage. Further studies are necessary to determine which factors are more closely related to electrical impedance in cocoa butter.

Table 2: F-Test for Variances Between Two Sample Sets

Comparison	**F Value**	**F Critical** ($\alpha = 0{,}05$)	**P-value**	**Conclusion**
Z(180) vs Z(170)	1.4881	1.3941	0.5977	Variances are not significantly different
Z(180) vs Z(160)	2.4897	1.3941	0.8430	Variances are not significantly different
Z(180) vs Z(150)	1.2545	1.3941	0.6101	Variances are not significantly different
Z(180) vs Z(140)	2.4392	1.3941	1.0207	Variances are not significantly different
Z(170) vs Z(160)	1.0000	1.3941	0.7173	Variances are not significantly different
Z(170) vs Z(150)	0.8430	1.3941	0.7173	Variances are not significantly different
Z(170) vs Z(140)	1.0207	1.3941	1.0207	Variances are not significantly different
Z(160) vs Z(150)	0.8430	1.3941	0.7173	Variances are not significantly different
Z(160) vs Z(140)	1.0207	1.3941	1.0207	Variances are not significantly different
Z(150) vs Z(140)	1.0000	1.3941	0.7173	Variances are not significantly different

Source: Own

References

[1] J. C. Caicedo-Eraso, F. O. Díaz-Arango, and A. Osorio-Alturo, "Espectroscopia de impedancia eléctrica aplicada al control de la calidad en la industria alimentaria," 2019. [Online]. Available: http://www.scielo.org.co/pdf/ccta/v21n1/0122-8706-ccta-21-01-00100.pdf

[2] L. M. Montes, L. F. Mejía-Gutiérrez, and J. C. Caicedo-Eraso, "Espectroscopia de impedancia eléctrica, una herramienta para aplicaciones biotecnológicas con *Lactobacillus casei* ATCC 393," 2021. [Online]. Available: http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S0123-34752021000100055

[3] Ó. H. Ocampo Hernández, C. A. Ruiz Villa, W. Aristizábal Botero, G. Olarte Echeverri, and P. A. Gallego, "Caracterización del tejido columnar del cérvix mediante espectroscopia de impedancia eléctrica y modelado computacional," *Biosalud*, 2017. [Online]. Available: https://www.semanticscholar.org/paper/216f9823cf95e0f9043636a052f656c4d318eed1