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Electrical impedance spectroscopy for the detection of adulterants in foods. A pilot study in cocoa oil

Espectroscopia de impedancia eléctrica para la detección de adulterantes en alimentos. Piloto en aceite de cacao

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

Abstract

Nowadays, in order to ensure human health and well-being, it is essential that food has a high purity and safety in its processing, these must have the highest standards of production quality. When we refer to food adulteration, we are talking about the intentional addition of prohibited or undeclared substances in them, which can have serious effects on the health of those who consume them. The use of artificial additives, thickeners, preservatives, hormones, antibiotics, among others, can cause food adulteration and this in turn can become an important factor in human health.

Pure cocoa oil is an excellent example of an unadulterated food that offers numerous benefits for health and personal care. It is a natural oil rich in antioxidants and anti-inflammatory, which makes it beneficial for heart health, as well as being an excellent moisturizer for the skin and can be used in a variety of sweet and savory recipes. Palm oil is an inexpensive and easily accessible vegetable oil, but consuming large quantities is harmful to health.

[1] Ingeniería de Alimentos, Facultad de Ingeniería, , Universidad de Caldas. Manizales, Colombia. Correo: camilo.art3@gmail.com ORCID: https://orcid.org/0009-0001-8463-5147

[2] Professor Universidad de Caldas, Facultad de Ingeniería, Departamento de Sistemas e Informática. Manizales, Colombia. Correo: julioc.caicedo@ucaldas.edu.co ORCID: https://orcid.org/0000-0003-4073-9152

[3] Professor Universidad de Caldas, Facultad de Ingeniería, Departamento de Ingeniería. Manizales, Colombia. Correo: felix.diaz@ucaldas.edu.co ORCID: https://orcid.org/0000-0002-1202-2376

However, adulterated cocoa oil, especially with palm oil, can have negative effects on consumer health and on the taste of the original product. Adulterations with industrial formulations are a risk in the early degradation of the food matrix.

For the detection of adulterants, there are traditional methods such as physicochemical tests, which, although they present an adequate analysis, have drawbacks such as: destruction of the sample, high operating cost or long processing times. A modern alternative could be electrical impedance spectroscopy (EIS), a non-destructive technique for the evaluation of food and which has shown utility in determining the quality and freshness of some foods. It is less expensive than some physicochemical tests and the analysis requires a minimum amount of time.

The objective of this research focuses on using EIS for the possible detection of palm oil adulterant in cocoa oil.

Keywords: Adulteration, Electrical impedance spectroscopy, Cocoa oil, Health, Non-destructive.

Resumen

En la actualidad para asegurar la salud y el bienestar humano es esencial que los alimentos posean una alta pureza y seguridad en su procesamiento, estos deben contar con los más altos estándares de calidad de producción. Cuando nos referimos a la adulteración de los alimentos estamos hablando de la adición intencional de sustancias prohibidas o no declaradas en ellos, lo que puede tener graves efectos en la salud de quienes los consumen. El uso de aditivos artificiales, espesantes, conservantes, hormonas, antibióticos, entre otros, puede provocar la adulteración de los alimentos y está por su parte puede constituirse en un factor importante en la salud humana.

El aceite de cacao puro es un excelente ejemplo de un alimento sin adulterar que ofrece numerosos beneficios para la salud y el cuidado personal. Es un aceite natural rico en antioxidantes y antiinflamatorio, lo que lo hace beneficioso para la salud del corazón, además de ser un excelente hidratante para la piel y se puede utilizar en una variedad de recetas dulces y saladas. El aceite de palma es un aceite vegetal económico y de fácil acceso, pero consumir grandes cantidades es perjudicial para la salud.

No obstante, el aceite de cacao adulterado, especialmente con aceite de palma, puede tener efectos negativos en la salud del consumidor y en el sabor del producto original. Las adulteraciones con formulaciones industriales son un riesgo en la degradación temprana de la matriz alimenticia.

Para la detección de adulterantes, existen métodos tradicionales como las pruebas fisicoquímicas, que, aunque presentan un análisis adecuado, poseen inconvenientes como: destrucción de la muestra, costo elevado de funcionamiento o tiempos de largos de procesamiento, una alternativa moderna podría ser la espectroscopia de impedancia eléctrica (EIS, por sus siglas en inglés), técnica no destructiva para la evaluación de alimentos y que ha mostrado utilidad para determinar la calidad y frescura de algunos alimentos, es de menor costo que algunas pruebas fisicoquímicas y el análisis require una mínima cantidad de tiempo. El objetivo de esta investigación se centra en utilizar la EIS para la posible detección del adulterante de aceite de palma en el aceite de cacao.

Palabras clave: Adulteración, Espectroscopia de impedancia eléctrica, Aceite de cacao, Salud, No destructivo.

1. Introduction

Food adulteration is a problem in the food industry that can have serious economic and health implications. Adulterants are added to food products to increase their volume, weight or shelf life, or to reduce their cost. Detecting adulterants in food products is a crucial step in ensuring food safety and quality [1, 2, 3, 4].

On the other hand, one can also mention the limitations of current technologies for detecting adulterants in food, such as liquid chromatography and mass spectrometry, which can be expensive, time-consuming and require specialized personnel; the acquisition of equipment and line management is limited by commercial companies and payment to external laboratories can lead to a leak of confidential information when developing a new product.

In recent years, electrical impedance spectroscopy (EIS) has emerged as a promising tool for food analysis. EIS is a non-destructive analytical technique that measures the electrical properties of a sample as a function of frequency. The principle of EIS is based on the fact that different components of a sample have different electrical properties, and by measuring the impedance of a sample over a range of frequencies, it is possible to obtain information about the composition and properties of the sample [1, 2]. In addition, EIS can be a rapid and accurate technique for detecting adulterants in food, which can save time and money for the food industry.

EIS can be used to detect common adulterants such as water, starch and sugars in different types of foods, such as oils, milk and fruit juices [1]. In addition, EIS can be a rapid and accurate technique to detect adulterants in foods, which can save time and money for the food industry [1]. For this test, a cocoa oil matrix was used, which was adulterated using different concentrations of palm oil (the most commonly used compound for commercial adulteration of cocoa oil).

2. Objectives

Accurate detection of adulterants in food has become a critical concern nowadays, in a context where the globalization of the food industry and the complexity of supply chains have created opportunities for food adulteration and fraud on an unprecedented scale. In this regard, the present research acquires significant relevance by highlighting the fundamental role played by EIS as a highly effective tool in the detection of adulterants. This technique offers the advantage of being non-destructive, meaning that it does not alter or damage the samples, thus allowing their subsequent chemical and microbiological analysis to determine the exact nature of the adulteration.

The inclusion of adulterants in food can have serious legal implications, as it violates labelling regulations and is subject to significant legal penalties. Furthermore, the risks to public health should not be underestimated, as adulteration can introduce undeclared components or harmful substances into food products, which can lead to unforeseen illnesses and allergies.

3. Materials and methods

This research focuses on the application of electrical impedance spectroscopy (EIS) for the detection of adulterants in food, with a pilot focus on cocoa oil. The electrical impedance of the samples was measured using an impedance meter (3522-50 LCR Hitester, HIOKI, Japan, 2006) in the frequency range of 1 Hz to 1 MHz. The measurements were performed at room temperature in the city of Manizales – Caldas- Colombia.

The selected adulterants consist of palm oil, incorporated into cocoa oil at concentrations of 0%, 25%, 50%, 75% and 100% in constant volumes of 10 ml total. The fundamental purpose of this study is to analyse the capacity of HIA to identify and quantify the presence of adulterants in cocoa oil, highlighting the relevance of this technique in the early detection of possible food fraud and underlining the legal and medical implications that may arise from such practices.

The methodology followed is similar to that used in cases of oil adulteration present in the market, where representative samples of cocoa oil adulterated with palm oil in the proportions mentioned were extracted. These samples were subjected to electrical impedance measurements in the same frequency range of 1 Hz to 1 MHz, using the 3522-50 LCR Hitester impedance meter from HIOKI, Japan. The measurements were carried out at room temperature using 1 cm^3 of sample in a cylinder with two conductive tips, according to the configuration shown in Figure 1.

Figure 1. Dials used for EIS measurement in cocoa oil samples.

Source: own.

4. Results

The statistical results provided show notable differences in electrical impedance (Z) depending on the different proportions of palm oil and cocoa oil in the samples tested. The sample sets are described as follows:

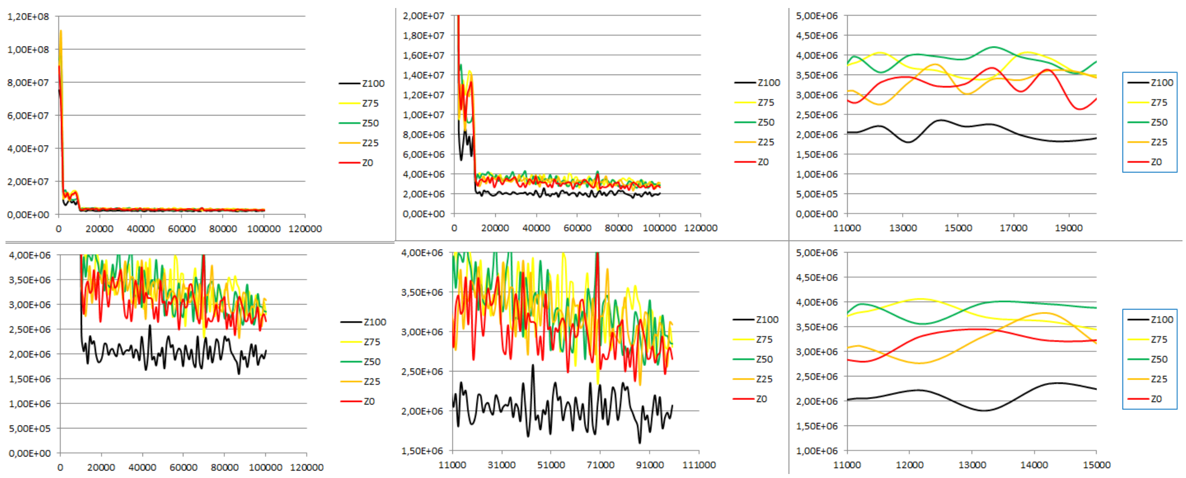
Table 1. Variable versus concentrations.

Variable	Concentrations
Z0	100% pure palm oil
Z25	75% palm oil and 25% cocoa oil
Z50	50% palm oil and 50% cocoa oil
Z75	25% palm oil and 75% cocoa oil
Z100	100% pure cocoa oil

Source: own.

The graphical representation of these data, in the form of a comparison of impedance (Z) located on the "Y" axis versus the frequency located on the "X" axis, is a fundamental resource for the visualization and understanding of the variations observed in the electrical properties of the different sets of samples. In Figure 2, it has been repeatedly highlighted that the line corresponding to Z100 (100% pure cocoa oil) remains systematically far from the other curves that represent the sets adulterated with palm oil.

Figure 2. Impedance (Z) vs Frequency



Source: own.

The persistent distance between the Z100 line and the others along the graph initially suggests that the adulterated cocoa oil samples exhibit different electrical properties than pure cocoa oil. However, a statistical analysis is proposed through the analysis of variance (F Test), using the differences in the means of electrical impedance (Z) between these sets of samples shown in Table 2.

Table 2. F Test for Two-Sample Variances.

Prueba F para varianzas de dos muestras					
	Z0	*Z75*		*Z25*	*Z50*
Media	5171866	5838478	Media	5746381	5814440
Varianza	1,1231E+14	1,62412E+14	Varianza	1,7953E+14	1,7678E+14
Observaciones	100	100	Observaciones	100	100
Grados de libertad	99	99	Grados de libertad	99	99
F	0,69150474		F	1,01559684	
P(F<=f) una cola	0,03396916		P(F<=f) una cola	0,46939139	
Valor crítico para F (una cola)	0,71732859		Valor crítico para F (una cola)	1,39406126	
	Z0	*Z50*		*Z100*	*Z0*
Media	5171866	5814440	Media	3817972	5171866
Varianza	1,1231E+14	1,76775E+14	Varianza	9,4309E+13	1,1231E+14
Observaciones	100	100	Observaciones	100	100
Grados de libertad	99	99	Grados de libertad	99	99
F	0,63531826		F	0,83973196	
P(F<=f) una cola	0,01249462		P(F<=f) una cola	0,193178	
Valor crítico para F (una cola)	0,71732859		Valor crítico para F (una cola)	0,71732859	
	Z0	*Z25*		*Z75*	*Z100*
Media	5171866	5746381	Media	5838478	3817972
Varianza	1,1231E+14	1,79532E+14	Varianza	1,6241E+14	9,4309E+13
Observaciones	100	100	Observaciones	100	100
Grados de libertad	99	99	Grados de libertad	99	99
F	0,62556148		F	1,72212297	
P(F<=f) una cola	0,0102418		P(F<=f) una cola	0,00366952	
Valor crítico para F (una cola)	0,71732859		Valor crítico para F (una cola)	1,39406126	
	Z50	*Z75*		*Z50*	*Z100*
Media	5814440	5838478	Media	5814440	3817972
Varianza	1,7678E+14	1,62412E+14	Varianza	1,7678E+14	9,4309E+13
Observaciones	100	100	Observaciones	100	100
Grados de libertad	99	99	Grados de libertad	99	99
F	1,08843832		F	1,87442463	
P(F<=f) una cola	0,33707117		P(F<=f) una cola	0,00099121	
Valor crítico para F (una cola)	1,39406126		Valor crítico para F (una cola)	1,39406126	
	Z25	*Z75*		*Z25*	*Z100*
Media	5746381	5838478	Media	5746381	3817972
Varianza	1,7953E+14	1,62412E+14	Varianza	1,7953E+14	9,4309E+13
Observaciones	100	100	Observaciones	100	100
Grados de libertad	99	99	Grados de libertad	99	99
F	1,10541451		F	1,90365973	
P(F<=f) una cola	0,30951381		P(F<=f) una cola	0,00076802	
Valor crítico para F (una cola)	1,39406126		Valor crítico para F (una cola)	1,39406126	

Source: own.

The table above shows the F test for the different concentrations of palm oil in cocoa oil. The highest values are shown in green and the lowest values in yellow, that is, when F is greater than the critical value there is a significant difference in their variance. While in the opposite case, if F is less than the critical value the difference is not significant. For example, in the analysis of Z25 and Z100 it is observed that F has a value of 1.9037 being greater than the critical value 1.3940 which suggests a significant difference between both. Likewise, in other cases of concentration comparisons they have a similar behavior with respect to the 100% pure cocoa sample.

5. Conclusions

Electrical impedance spectroscopy (EIS) as a food analysis tool allows the measurement of the electrical properties of a sample based on frequency. In this case study, an analysis was carried out between palm oil and commercial cocoa oil. The purpose was to demonstrate the presence of palm oil in cocoa oil at different concentrations in order to identify values that would allow the separation of samples with a higher cocoa concentration.

When comparing the adulterated pools and pure palm oil (Z0, Z25, Z50 and Z75) no statistically significant differences in electrical impedance (Z) were observed, as in all comparisons the value of F remained below the critical value for F (one-tailed). Comparison of Z100 with the adulterated pools (Z25, Z50 and Z75) revealed statistically significant differences in electrical impedance. In all the above comparisons the value of F exceeded the critical value for F (one-tailed), demonstrating the existence of substantial differences in impedance between Z100 and the adulterated pools.

The results of the variance tests highlight the initial assumption that electrical impedance varies significantly depending on the adulteration and the pure sample analyzed. This confirms the usefulness of electrical impedance spectroscopy as an effective tool for the detection of adulterants in this food matrix.

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