EFFECTS OF FRYING TEMPERATURE AND TIME ON MOISTURE LOSS AND OIL ABSORPTION OF COLOMBIAN *QUESO COSTEÑO*

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SUMMARY

Frying is one of the most widely used food transformation processes in the world, due to its speed and the sensory characteristics acquired by fried products. Advances in food technology have helped to describe the mass transfer processes that occur during the frying of some products. However, although these properties are described in most foods for industrial use, few studies have been carried out on artisanal products such as Colombian Queso Costeño*. Therefore, the main objective of this work was to evaluate the processes of moisture and oil transfer during the frying of this product, using a multilevel design 32, with two factors and three levels each other: temperature (140°C, 160°C and 180°C) and frying time (60, 120 and 180 seconds). The results obtained showed that the moisture content is reduced with increasing time and temperature, and on the contrary, the amount of oil increased under the same physical conditions, which may be due to the high moisture fraction and the short processing time. In conclusion, the increase in temperature and frying time resulted in lower moisture content and higher oil absorption.*

Introduction

Cheese is defined as a fresh or matured product, traditionally obtained by converting fluid milk into a semi-solid mass by coagulating the proteins due to the reduction in pH as a result of the use of an acid, or a coagulating agent, in the presence of heat and acid or a combination of them (Fox *et al*,, 2004; Santiago *et al*., 2018). This product's nutritional and sensory properties depend on the quality of the milk and the processing operations (i.e., the type of coagulation and pasteurization) (Bertuzzi *et al*., 2018; Fox *et al*., 2015). Cheese is also used as an ingredient in the preparation of a wide range of homemade culinary preparations in the prepared food sectors and industrial areas, its application will depend on the properties of each type of cheese (Ramírez-Navas, 2010), and its production can be industrial or artisanal, as is the case of *Queso Costeño* (Ruíz Pérez *et al*., 2017).

KEYWORDS / Frying / Mass Transfer / Moisture / Oil / *Queso Costeño* /

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Queso Costeño is a local product of the Colombian Caribbean Region, semi-hard, high in salt and fat, and low in moisture, so its conservation is greater than that of other cheeses (Acevedo *et al*., 2015). The informal production of *Queso Costeño* has been the main cause of its low production at the industrial level (Quintero *et al*., 2017).

On the other hand, frying is one of the most common methods of food preparation worldwide (Li *et al*., 2019), whether traditional or industrial, which allows extending the shelf life of products and is characterized as a fast dehydration process that involves the simultaneous transfer of heat and mass (Tirado *et al*., 2015) resulting in two flows in opposite directions of water vapor and oil (Morales and Santa Cruz, 2017).

Thermophysical properties such as specific heat, density, thermal conductivity, and thermal diffusivity influence heat transfer and are determined based on the chemical composition of the food or the process temperature and in turn are essential for the design, evaluation, and optimization of heat transfer operations (Carson *et al*., 2016).

Therefore, in recent years, studies have emerged that seek to analyze the physical processes occurring in fryings, such as the effect of time, temperature, and other factors on the kinetics of moisture loss and oil absorption in foods, since these can improve the sensory attributes of the products. However, very few studies have been directed to the investigation of cheese and the modification of its properties by frying and its effect on mass transfer. Therefore, the objective of this research was to evaluate the effect of frying temperature and time on the mass transfer of *Queso Costeño*.

Materials and Methods

Raw material

The raw material used for the production of *Queso Costeño* included whole cow's milk, received in a cistern and pasteurized at 63°C to avoid contamination by microorganisms. It was then stored refrigerated at 4°C until use. Commercial palm oil was used for the frying process. The material was purchased in local markets in the county of Rocha (Arjona-Bolívar, Colombia), and transported to laboratories at the Universidad de Cartagena, (Cartagena de Indias, Colombia) where the experimental process was carried out.

Elaboration of Queso Costeño

For the production of the *Queso Costeño*, the milk was first preheated to 32°C. After that, calcium chloride (20 % w/v) was added as a technological adjuvant to aid clotting, and it was left to stand for 2 minutes. Next, for the coagulation process, rennet was added at the strength of 1:150 and left to rest for 40 minutes. The curd was then cut into cubes of approximately 1 cm^3 and left to rest for 5 minutes. Once the viscous product was obtained, it was left to rest at 45°C for 15 minutes. Finally, the curd was completely drained and the product was salted (salt % 2 w/w) (Ramírez-Navas *et al*., 2016). The product obtained was molded and pressed in a pneumatic press at 2 bars for 14 hours. After this time, the finished product is obtained which was cut into flat plates of 2 cm^3 for further processing.

Physicochemical characterization of Queso Costeño

To verify whether the cheese produced complies with the characteristics of a semi-hard product, bromatological tests were performed on raw samples to determine the amount of moisture (969.19) protein (976.14), fat (933.05), total chlorides (935.43), acidity (920.12) and ashes (935.42) using the methodology proposed by the Association of official analytical chemists (AOAC, 2012). Once these results were obtained, the carbohydrate content was determined using Equation 1.

$$\text{Carbohydrates} = 100 - [(\%\ \text{moisture}) + (\%\ \text{protein}) + (\%\ \text{fat}) + (\%\ \text{ashes})] \quad (1)$$

Immersion frying process

Immersion frying was carried out in a Waring Pro Df250b, 1800 watt, 5-liter capacity, professional digital fryer. Frying times were 60, 120 and 180 seconds, and oil temperatures were established by preliminary tests at 140°C, 160 and 180°C (Montero *et al*., 2021). Frying was carried out in batches as shown in Table I. Once the frying process was finished, the cheese chip samples remained for 5 minutes on absorbent paper. Finally,

TABLE I
EXPERIMENTAL DESIGN

Experimental test	Temperature (°C)	Time (s)
1	140	60
2	140	120
3	140	180
4	160	180
5	180	60
6	160	60
7	180	180
8	160	120
9	180	120
10	140	60
11	140	60
12	140	120
13	140	180
14	140	180
15	160	60
16	160	60
17	140	120
18	180	60
19	160	120
20	180	60
21	160	120
22	160	180
23	180	120
24	180	120
25	160	180
26	180	180
27	180	180

Completely randomized experimental design (CRD) with a multilevel design 3^2 with its factors of temperature and immersion frying time.

the samples were stored and sealed in polyethylene bags.

Experimental design

Prior to the frying process, a completely randomized experimental design (CRD) was carried out with a multilevel design 3^2, where two factors and three levels were used for each factor. Experimental test was carried out in triplicate, for a total of 27 experimental trials (Table I). The mean and standard deviation for each experiment were calculated in Microsoft Excel, Windows 10. The factors were temperature at 140°C, 160°C, and 180°C and time at 60, 120 and 180 seconds, the response variables were: moisture loss (%) and oil absorption (%). The selection of the response variables was based on preliminary frying trials and on bibliographic references on previously studied fried products (Acevedo *et al*., 2018; Torres-Gonzalez *et al*., 2018).

Determination of moisture and oil absorption

Moisture loss and oil content were calculated according to AOAC 925.10 and AOAC 920.85 (AOAC, 2012), respectively. To determine the fat content, the Soxhlet method with petroleum ether extraction was applied (Montero *et al*., 2021). All measurements were performed in triplicate.

Thermophysical properties such as specific heat (Cp), density (ρ), conductivity (k), and thermal diffusivity (α) were calculated based on the correlations obtained by Choi and Okos, (1985) based on the data of the bromatological composition of the cheese at 25°C. The calculation was performed using the computer program called CTCIA (Coefficients of Heat Transfer in Food Engineering) by (Tirado *et al*., 2015).

Kinetics of mass transfer

The data obtained for moisture loss and oil absorption in the different experimental tests were processed in Microsoft Office Excel, in which the average values and standard deviation were coded. Graphs of kinetic behavior as a function of time were also obtained.

Statistical analysis

Statistical analyses were performed using StatGraphics® Centurion 16.1.15 (Corp., Herndon, VA, USA), in which the existence or not of statistically significant differences ($p \leq 0.05$) between samples was determined through simple ANOVA analysis of Variance, and for tests with significant differences in any factor, Tukey HSD Multiple Range Analysis was used.

Results

Physicochemical characterization

The bromatological characteristics for the cheese, together with the statistical data corresponding to moisture, fat, protein, chlorides, acidity, carbohydrates and ashes are described in Table II, where the moisture content of *Queso Costeño* corresponds to more than half of the raw product.

The analysis was carried out according to the Colombian Technical Standard ICONTEC, (2000), which establishes the requirements to be met by cheese varieties or groups of varieties. The content of moisture without fat is within the range established by the NTC 750 (54.0-69.0% w/w), considering that the cheese under study is in the firm/semi-hard classification. On the other hand, in the analysis carried out, it was found that the fat content in dry matter was 23%, being within the semi-skimmed classification (≥10.0 -<25.0% w/w). The milk protein content was 19% and the amount of chloride present in the final product corresponds to the average total chloride used and does not exceed 4% according to the requirements of (ICONTEC, 2000). The average of acidity, carbohydrates, and ash is within the permitted levels according to regulations and current good manufacturing practices (CGMPs). It should be noted that the composition of the different types of cheese depends on the quality and chemical composition of the fresh milk, the type of process used to manufacture the different types of cheese, and the use of food additives.

Determination of thermophysical properties

Table III shows the values of conductivity, density, heat capacity, and thermal diffusivity of the unfried cheese pieces. The values shown were obtained at 25°C, being necessary to calculate the thermophysical properties in the CTCIA program. Thermal diffusivity was evaluated from the experimental data of thermal conductivity, density, and heat capacity, as shown in Equation 2.

$$\alpha = \frac{k}{C_p \rho} \tag{2}$$

Kinetics of moisture

Figure 1 shows the moisture content of *Queso Costeño* as a function of time subjected to immersion frying. The results show the behavior of

TABLE II
COMPONENTS OF *QUESO COSTEÑO*

Component	(%w/w)
Moisture	54.67±0.78
Fat	23.00±0.32
Protein	19.00±0.18
Chlorides	2.02±0.05
Acidity	0.60±0.01
Carbohydrates	1.40±0.03
Ash	1.93±0.23

The mean and standard deviation data correspond to experimental tests performed in triplicate.

TABLE III
THERMOPHYSICAL PROPERTIES OF *QUESO COSTEÑO*

Thermophysical properties	Result at 25°C	Measurement Units
Conductivity	0.4092	W/m°C
Density	1039.63	kg/m^3
Heat capacity	3176.82	J/kg°C
Thermal Diffusivity	1.24×10^{-7}	m^2/s

Results correspond to the mean and standard deviation of three replicates for each experimental test.

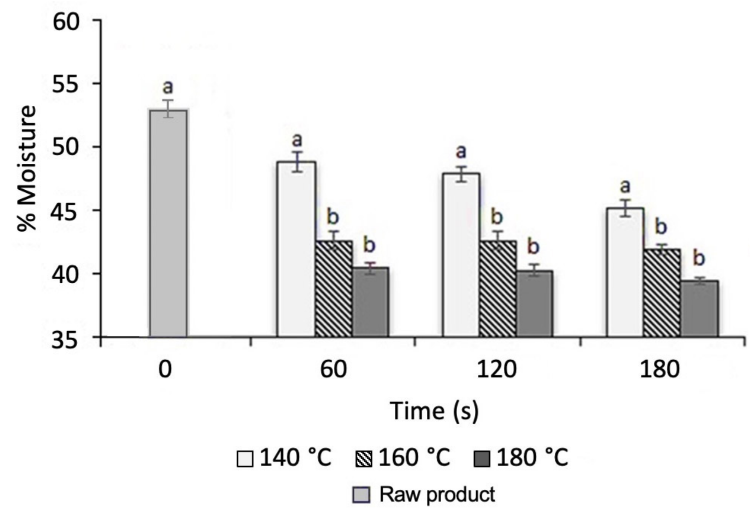

Figure 1. Moisture loss as a function of time for the three temperatures under study. Average and standard deviation of three replicates per experimental test. Different letters between temperature columns indicate significant difference at 95% confidence.

moisture loss for the three experimental temperatures at 140°C, 160°C and 180°C with a time between 60 and 180 seconds. A decrease from 54.67% of the initial moisture content to 46.18%, 42.58% and 39.91% is observed at 140°C, 160°C and 180°C, respectively. In general, a directly proportional relationship can be observed in the loss of moisture concerning to the time of the process at the three temperatures applied. Considering the initial moisture content of the cheese (54.67%), a rapid drop is observed the first time at 60 seconds and subsequently, the reduction of water becomes constant. This moisture loss process was more noticeable when a temperature of 180ºC was applied ($p≤0.05$).

Similarly, according to these results, we can state that the higher the temperature, the kinetics tend to take lower moisture values ($p≤0.05$). This behavior is observed between temperatures of 160°C and 180 C at a time of 180 seconds.

Kinetics of oil absorption

The oil absorption kinetics of the cheeses subjected to frying is presented in Figure 2, where the relationship of % oil versus time (seconds) is observed for each temperature (140°C, 160°C, and 180°C). It can be observed that the oil gradually impregnated the samples during frying with time and temperature, where the highest values were obtained when a temperature of 180°C was applied.

Performing a detailed analysis, a higher oil absorption rate is observed as the temperature increases, where in the first time of 60 seconds there was a higher absorption at 160°C with an oil content of 27.32%, however, this value is similar to that obtained when a temperature of 180°C was applied (26.84%). It can also be observed that oil absorption tends to be constant at 160ºC ($p≤0.05$), between 60 and 180 seconds. On the other hand, the final absorbed oil content (final product-crude product) of each process at the maximum time of 180 seconds was 4.76%, 5.67%, and 10.74% at 140°C, 160°C, and 180°C, respectively.

Taking into account, the moisture content of the cheese and the time, in which the samples were subjected to the frying process, it is considered that the progressive release of moisture gave way simultaneously to the penetration of oil, a fact that could explain the increase in the oil content of the cheese chips.

Discussion

Our results indicate that the analysis of mass transfer phenomena, including different times and temperatures of fried products, could help us to obtain a better quality of the product, since they indicate the loss or gain in the content of its components, such as lipid fraction and moisture, thus modifying the sensory attributes of the final product.

Moisture and oil content in frying cheese could be affected by processing conditions, type of coagulant, oil used for frying, and type of cheese. Yusufu *et al*., (2018) reported that soft cheese samples after frying at 180°C for 10 min showed moisture content between 45.60 - 51.08% and oil content between 25.00 - 28.50%, which compared to the results shown in Figures 1 and 2 at the same temperature showed lower values than the reported range in terms of moisture content, while oil content showed higher values.

In previous studies, the effect of deep frying on the properties of cheese has been investigated. Ansarifar *et al*., (2018) evaluated the effect of chitosan on mass transfer during deep frying of Kurdish cheese nuggets and observed a loss of moisture during frying with increasing frying time, and also showed

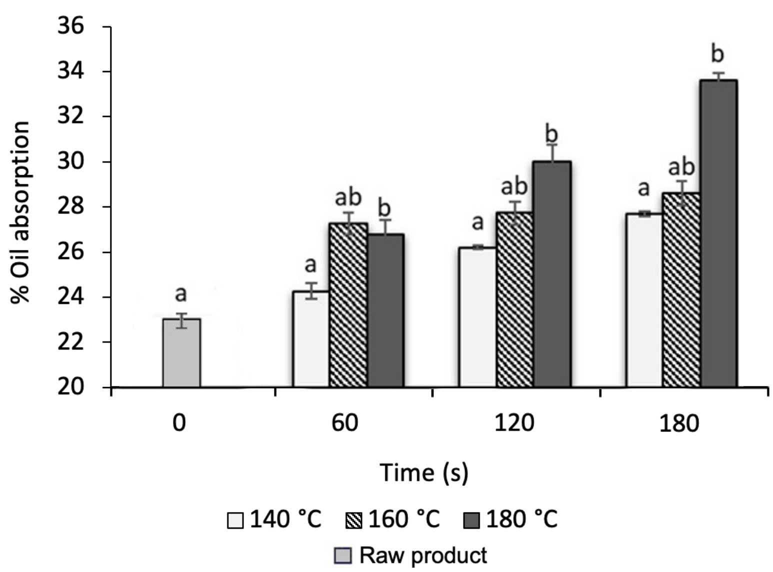

Figure 2. Oil absorption as a function of time for the three temperatures under study. Mean and standard deviation of three replicates per experimental test. Different subscripts between rows indicate significant difference at 95% confidence.

that for this type of food matrices, oil absorption increases with frying time and temperature. On the other hand, Ansarifar *et al*., (2013) studied the effect of frying time and chitosan on moisture and oil content of fat-fried cheese nuggets, and modelled the frying kinetics, the results showed that with increasing frying time, moisture content decreased and oil content increased.

About to the content of biomolecules such as milk protein, calculated at 19%, the result was similar to that found by Politis and Ng-Kwai-Hang, (1988), who analyzed the composition of standardized fresh milk and subsequently analyzed the fat, protein, total solids and salt of the cheese produced at the laboratory level. These authors found a protein content of 24.86%, while the fat content was 29.51%, higher than those found in this study and classified by NTC 750 as a semi-fat cheese.

On the other hand, the thermal conductivity values found in this study were similar to the values found by Machado and Vélez, (2008) in tortilla dough, poblano chile, and fresh Oaxaca cheese, the values were 0.40, 0.40 and 0.41W/m°C, respectively. These same authors reported heat capacity values of Oaxaca cheese of 2.37kJ/kg°C, lower than the value obtained in this study, perhaps this fact is due to the availability of moisture, density, and structure of the food, highlighting that Oaxaca cheese is "harder" than *Queso Costeño*, which is attributed to the porous character of this type of cheese.

In general, a directly proportional relationship of moisture loss concerning processing time can be observed for the three temperatures applied. Tirado *et al*., (2015) reported that the rate of moisture loss of tilapia and breadfruit decreases with increasing frying time and temperature, with higher losses at the beginning of the process for tilapia, attributing this fact to the nature of the food.

Similarly, according to these results, we can state that at higher temperatures, the kinetics tend to take lower moisture values. A similar result is obtained when a time of 180 seconds is applied. This fact is attributed to the formation of a crust that prevents moisture from escaping from the center of the product, since as the food is fried for longer, the moisture content of the crust is slowly reduced, resulting in fewer steam bubbles escaping through the surface (Mellema, 2003). Zhang *et al*., (2020) note that the decrease in moisture loss as the end point of the frying process approaches may be related to crust formation.

Regarding the oil absorption rate, it was found that it is directly proportional to the temperature, it is evident in the first time (60 s) a higher absorption at 160°C with an oil content of 27.32%, but this value is similar to that obtained when a temperature of 180°C was applied (26.84%). It can also be observed that the oil absorption at 160°C tends to be constant between 60 and 180s.

On the other hand, the oil content is absorbed at the end of each process (180 seconds). The above was similar to the work done by Math *et al*., (2004) during the frying of flour rolls, where the absorption was 42.22%, 45.70%, and 50.36% at 165°C, 175°C, and 185°C, respectively. It should be noted that several studies have shown that the highest oil penetration during frying occurs during the cooling phase, i.e. when the product is removed from the hot oil, the pores of the food are more open and the surface fat penetrates much more easily than during immersion. Taking into account the moisture content of the cheese and the time during which the samples were subjected to the frying process, it is considered that the progressive release of moisture gave way simultaneously to the penetration of oil, a fact that could explain the increase in the oil content of the cheese chips.

Conclusions

The thermophysical properties of *Queso Costeño* were similar to those found in other fresh foods. Temperature and processing time affected the moisture and oil content of the cheese pieces. The moisture content decreased with increasing time and frying temperature from 140 to 180°C. It is also concluded that the oil content is directly proportional to the processing time and temperature, i.e. the oil content is higher as these two factors increase.

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EFECTOS DE LA TEMPERATURA Y TIEMPO DE FRITURA EN LA PÉRDIDA DE HUMEDAD Y ABSORCIÓN DE ACEITE DEL QUESO COSTEÑO COLOMBIANO

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RESUMEN

La fritura es uno de los procesos de transformación de alimentos más utilizados en el mundo, debido a su rapidez y a las características sensoriales que adquieren los productos fritos. Los avances en tecnología alimentaria han ayudado a describir los procesos de transferencia de masa que se producen durante la fritura de algunos productos. Sin embargo, aunque estas propiedades están descritas en la mayoría de los alimentos de uso industrial, pocos estudios se han realizado en productos artesanales como el queso costeño colombiano. Por ello, el objetivo principal de este trabajo fue evaluar los procesos de transferencia de humedad y aceite durante la fritura de este producto, utilizando un diseño multinivel 3^2*, con dos factores y tres niveles cada uno: temperatura (140°C, 160°C y 180°C) y tiempo de fritura (60, 120 y 180 segundos). Los resultados obtenidos mostraron que el contenido de humedad se reduce al aumentar el tiempo y la temperatura y, por el contrario, la cantidad de aceite aumentó en las mismas condiciones físicas, lo que puede deberse a la elevada fracción de humedad y al corto tiempo de procesado. En conclusión, el aumento de la temperatura y del tiempo de fritura dio lugar a un menor contenido de humedad y a una mayor absorción de aceite.*

EFEITOS DA TEMPERATURA E DO TEMPO DE FRITURA NA PERDA DE UMIDADE E ABSORÇÃO DE ÓLEO DO QUEIJO COSTEÑO COLOMBIANO

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RESUMO

A fritura é um dos processos de transformação de alimentos mais utilizados no mundo, devido à sua rapidez e às características sensoriais adquiridas pelos produtos fritos. Os avanços na tecnologia de alimentos têm ajudado a descrever os processos de transferência de massa que ocorrem durante a fritura de alguns produtos. No entanto, apesar dessas propriedades estarem descritas na maioria dos alimentos industrializados, poucos estudos foram realizados em produtos tradicionais como o Queso Costeño *colombiano. Assim, o principal objetivo deste trabalho foi avaliar os processos de transferência de umidade e absorção de óleo durante a fritura deste produto, utilizando um desenho multinível* 3^2*, com dois fatores e três níveis entre si; temperatura (140 °C, 160 °C e 180 °C) e tempo de fritura (60, 120 e 180 segundos). Os resultados obtidos mostraram que o teor de umidade diminui com o aumento do tempo e da temperatura e, pelo contrário, a quantidade de óleo aumentou nas mesmas condições físicas, o que pode ser devido ao maior teor de umidade e ao pouco tempo de processamento. Em conclusão, o aumento da temperatura e do tempo de fritura resultou num menor teor de umidade e numa maior absorção de óleo.*