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Effect of Frying Temperature and Time on the Thermophysical Properties and Texture Profile of Arepa Con Huevo

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Abstract : Deep fat frying is a widely used and industrially important food process, nowadays fried foodstuffs are consumed by their characteristics of palatability and texture. The aim of this research was to evaluate the effect of frying temperature and time on the thermophysical properties and texture profile of arepacon huevo.The samples were made with 81.4 % of corn dough and 18.6 % of hen's egg,this was 10 cm in diameter and 2.5 cm thick. The temperatures used were 170 °C, 180 °C and 190 °C, with times of 300 s, 360 s and 420 s. The product/oil ratio was 1:4 weight/volume (250 g/L). The moisture of the arepas decreased as the process temperature increased ($p<0.05$).An increase in oil content was found as the processing time increased ($p<0.05$). The protein, dietaryfibre, ash and carbohydrate contents of arepascon huevo were not significantly affected by processing conditions ($p>0.05$). Conductivity and thermal diffusivity increased with temperature, with maximum values of 0.79 W/m °C ± 0.05 W/m °C and 2.96 x 10^{-7} m^2 s^{-1}. Hardness increased with temperature ($p<0.05$) varying from 13.41 to 27.34 N. The understanding thermal and texture properties are important in order to improve the frying processing and physicochemical parameters of arepa con huevo.
Key words : arepacon huevo, deep fat frying, oil uptake, thermal diffusivity, hardness.

1. Introduction

Deep fat frying is one of the oldest food preparation processes, which was originated in the Mediterranean area, due to the influence of olive oil on African, Arab and European food (1; 2). The unique combination of flavor and texture of the fried foodstuffshas made these products one of the most desirable choices for consumers worldwide. Among the most common are potatoes, donuts, corn snacks, and chicken nuggets, also fish chopsticks (3). From an engineering point of view, frying is a complex unit operation that simultaneously involves heat transfer through conduction-convection and mass transfer mechanisms, which manifested in moisture diffusion and surface oil uptake(1, 2, 3, and 4).

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During the process, the oil temperature is always above the boiling point of the water, normally around 120 °C to 190 °C (4, 5). These temperatures cause dehydration of the microstructure and the formation of a porous crunchy surface layer, which provides open canals and forms that facilitate oil input(6). Several researchers have suggested that oil uptakedepends to a large extent on the amount of moisture loss, as well as the temperature, process time, surface treatments, porosity, initial interfacial tension (food-oil), oil quality and nature of the fried product (protein or starchy) etc.(1, 2, 4, 6).

The texture profile analysis (TPA) is an excellent instrumental procedure, which consists of subjecting samples of a foodstuffs to a double uniaxial compression with respect to its initial height, simulating the effort of the human jaw when biting, without breaking the food matrix in order to calculate the basic parameters of texture (7, 8).

The texture obtained during frying is a consequence of changes in the composition of foods, mainly in proteins and carbohydrates, which are modified by the effect of heat transferred and the elimination of water from them(8).On the other hand, thermophysical properties are essential parameters in the modelling and design of heating systems in the food industry, where the main considerations are energy costs, food quality and safety(9).These properties provide useful information for the design of equipment as well as for economic and efficient thermal processes (9, 10).

The arepa con huevo is an autochthonous, popular and widely consumed foodstuff in Colombia, especially in the Caribbean coast (11). Its shape consists of a rounded disc, made from corn doughs, which is mixed with water and a minimum amount of salt to guarantee its flavor; it is then molded, a raw whole hen's egg without shell is added and completely immersed in hot oil for an empirically fixed time (4, 11). So far, there are few studies that have analyzed the physical and chemical characteristics of this product during frying. An understanding of the behavior of physicals features of this foodstuff during frying can be useful in order to improve its acceptability and consume. Hence, the objective of this research was to evaluate the effects of frying parameters (temperature and time) on the thermophysical properties and texture profile of arepa con huevo.

2. Materials and Methods

The preparation of the product, the frying process, the bromatological and texture analysis, were carried out in the research laboratories of the Processes and Agro-Industries of Vegetables Group of the Food Engineering Program of the Universidad de Córdoba, at an average temperature of 25 ºC, relative humidity of 80% and a height of 20 msnm.

2.1 Formulation of the product

The arepas with pre-cooked corn dough of the yellow variety ZmCol-CIM-3132 were made. It contained 59.04% ± 4.38% moisture and was supplied by a company located in the city of Cartagena (Colombia). Upon receipt, the doughswere stored under refrigeration conditions at 12 °C using a Frigobar Igloo 1.7 ft stainless steel FR-180 refrigerator(Daewoo, Electronics USA).The traditional techniques observed from traders and sellers of the product in the municipality of Luruaco (Atlántico) were used and modified with a single frying stage (Figure 1).The arepas were made with 81.4 % by dough and 18.6 % of eggs, which came from hens and were acquired ensuring that they had a commercial size AA (66.52 g ± 2.64 g) in shell and without shellof 45.31 g ± 1.82 g according to the provisions of NTC-1240 (12). Salt was added to the dough to flavor it, as well as water at 15°C to soften its structure slightly and form the circular plates; this was homogenized in its entirety for 10 min, using a food mixer (Kitchen Aid, Model 5K5SS, USA) equipped with a 5KAB flat beater at 40 rpm. Immediately the product was molded with the dimensions of 10 cm in diameter and 2.5 cm thick, geometry that was selected due to the traditional shape of the product. In this research a circular mold was used, which had a concave area to place the dough and add the egg.

2.2 Deep fat frying process

Commercial palm oil was used because of its good resistance to oxidation during the thermal treatment and low cost, which was obtained from a local supermarket located in the city of Cartagena. A 7L capacity stainless steel electric deep fryer with three thermocouples (Type J stainless steel 304) with a diameter of 0.25 mm for oil temperature control, the center and the product surface (with an accuracy of ± 0.05 °C) was used, coupled with a data acquisition system (INTECH Micro 2100-A16 Rev 1.3) and a PID controller (RKC HA 900 Instrument). Before frying, the circular corn plates were placed in the concave mold for one min at room temperature (25 °C) and a raw shelled whole creole hen egg was added to it; immediately other circular corn plates were used to seal the product and leave the egg inside the layers of dough (Figure 1).A completely randomized experimental design with a unifactorial structure was used, where the factor was temperature at levels (170°C, 180°C and 190°C) with three replicates in each treatment for a total of 9 experimental units (EU) per analysis. The oil was heated to the required temperatures of 170°C, 180°C and 190°C, with times of 300s, 360s and 420s. The arepas were submerged with the help of a metal basket, which was covered with a grid of the same material to ensure total immersion of the product. The ratio of product to oil was 1:4 weight/volume (250g/L).Subsequently, the arepascon huevo were removed from the fryer and placed in a wire mesh basket in which they were allowed to drain by gravity for two minutes at room temperature (25°C) and placed in the desiccators for 10min until final quality analysis.

(a) (b) (c) (d)

Figure 1. Synthesis of the process of making the arepas con huevo: (a) receipt of the raw material (corn doughs); (b) mixing the components, kneading, moulding and incorporation of the raw whole egg without shell; (c) deep fat frying; (d) registration of weights and packaging of the arepas for the final analyzes.

2.3 Bromatological analysis

The measurements on the arepascon huevofried at a fixed time of 300 s were made. Compared to the data obtained from a control without frying. The following determinations were made, following the AOAC (13) methodology for cereals and derivatives: moisture (%) by drying to steady weight at 105 °C (Method, 925.09); fat by Soxhlet (Method, 945.38); proteins by acid digestion with the Kjeldahl method (Method, 920.87). Ashes by total incineration at 550 °C (Method, 923.03).Total dietary fibre using the determining equipment (TE-149 TECNAL) (Method, 991.43).Once obtained these percentages, the difference of 100 to find the carbohydrates content was used, and calories (kcal/100 g) through empiric ratio as reported by Alvis et al., (14) and González et al., (10)was determined. All data were expressed as the mean with their respective standard deviation.

2.4 Determination of thermophysical properties

The specific heat (*Cp*), density (ρ), conductivity (*k*) and thermal diffusivity (α) of the whole samples were determined using the formulas used by Alvis et al. (9), based on the composition of the product and the processing temperatures (170 °C, 180 °C and 190 °C) at a fixed time of 300 s. These models were systematized in the computer program DEPROTER (Determination of Thermophysical Properties) developed by Alvis et al. (9) (Table 1). The calculations were made in triplicate and the results were expressed as the mean with their respective standard deviation.

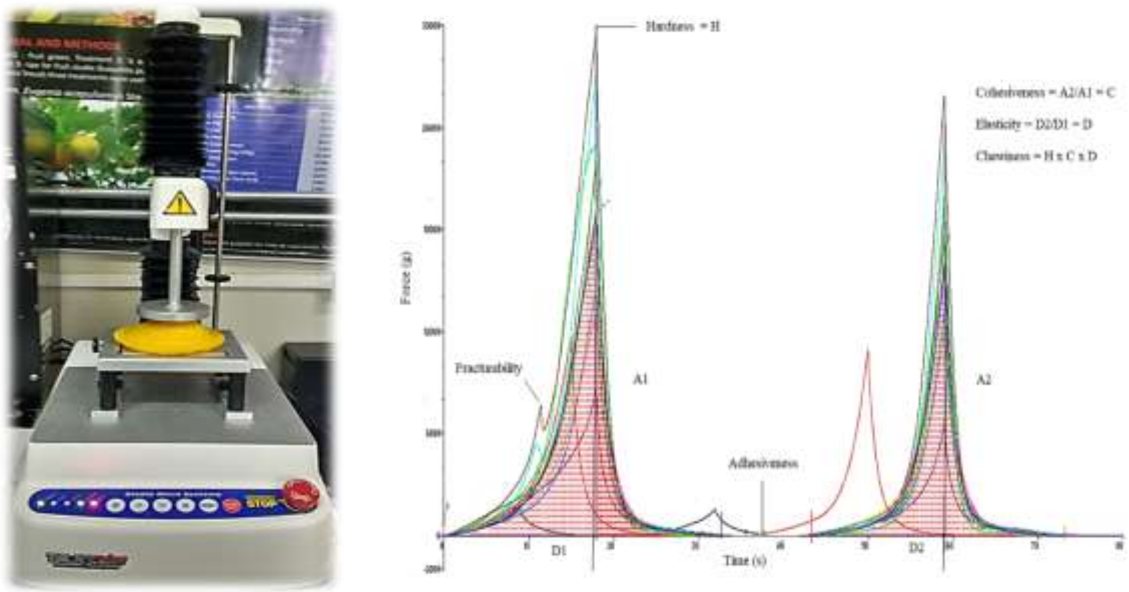
Table 1: Models to calculate the thermophysical properties of arepas con huevo

Parameters*	**Units**	**Models***
Thermalconductivity (k)	W/m °C	$k = 0{,}25\ X_{HC} + 0{,}16\ X_P + 0{,}16\ X_{GR} + 0{,}14\ X_{CZ} + 0{,}48\ X_{H2O}$
Specificheat (Cp)	kJ/kg °C	$C_p = 1{,}42\ X_{HC} + 1{,}55\ X_P + 1{,}68\ X_{GR} + 0{,}85\ X_{CZ} + 4{,}18\ X_{H2O}$
Thermaldiffusivity (α)	$10^{-7}\ m^2/s$	$\alpha = k/\rho * Cp$

*ρ = product density and X_{HC}, $X_{P,}$ X_{GR}, X_{CZ} and X_{H2O} represent the mass fractions of carbohydrates, proteins, fats, ash and moisture.

2.5 Texture profile analysis

Samples of whole and freshly fried arepascon huevo (with a cooling time of no more than 15 min) were subjected to a double uniaxial compression test, using a texture analyzer (model TA. TX2i ®.Plus, Stable Micro System, coupled with Texture Expert Exceed software version 2.64). The equipment was equipped with an aseptic aluminium platform (on which the sample was placed) and a 75 mm circular attachment that moved vertically (Figure 2).The speed of the tests and the percentage of compression with respect to the initial height of the product were fixed by means of preliminary tests on the equipment and by bibliographical references, remaining at 10 mm/s and 50 %, levels that allowed to calculate adequately all the textural parameters(8, 10, 15). For the measurements a completely randomized experimental design (DCA) with a 3^2factorial treatment structure was used, i. e. two factors, time with the levels of 300 s, 360 s and 420 s and temperature whose respective levels were 170 °C, 180 °C and 190 °C. All the treatments were carried out in triplicate.



(a) (b)

Figure 2. Texture analyzer used during the texture profile tests in the arepas con huevo: (a) equipment and accessories. (b) Typical graph obtained with the software connected to the equipment. Courtesy: Grupo GIPAVE, Universidad de Córdoba (Colombia).

2.6 Statistical Analysis

To find the statistical differences between the data of the variable responses, two-way ANOVAwas performed and to compare the mean of the treatments, Tukey's HSD multiple comparisons test was used with a significance level of 5%. Likewise, a multiple linear regression analysis was carried out among the parameters of instrumental texture, in order to understand the relationships between these variables as a function of frying temperature and time. Data were processed in STATGRAPHICS Centurion 16.1.15 program. (Keygen, USA).

3. Results and Discussion

3.1 Chemical composition analysis

The Table 2shows how the moisture content of the product decreased as process temperatures increased at the same frying time, which was statistically significant ($p < 0.05$). An increase in oil content was also found as the processing temperature and time increased ($p < 0.05$) (all data not shown). When comparing the conditions of 170 °C and 190 °C, it was observed that the amount of oil was slightly lower ($p < 0.05$) in the last treatment; this is explained by the fact that at a higher temperature there was more formation of the surface crust, which possibly acted as a physical barrier to the oil inlet (4, 11). Various studies attribute the formation of crust on the surface of fried products to the gelatinization of starches and denaturation of proteins; it has also been found in starchy products that the crust increases notably with the increase in frying temperature (5, 6, 10 and 16).

In arepas con huevo, a decrease in the total fat content could be favourable, from the point of view of product preservation, owing to the lower propensity to oxidative rancidity during the storage period, and a greater acceptability on the part of consumers (4, 11). Nowadays trends point to the processing of low-fat fried products, because of the excessive fat intake has been associated with the increase in the risk of cardiovascular diseases, as well as some types of cancer (2, 5), for that reasons, is desirable to obtain arepascon huevothe minimum amount of fat possible.

Table 2: Bromatological composition of fried arepas at 170, 180 and 190 ° C and 300s.

Components (drybasis)		**Temperaturas***			**ANOVA**	
	Non-Fried (25 °C)	**170 °C**	**180 °C**	**190 °C**	**Value-F**	**p-value**
Moisture **	59.04 ± 4.38^{d}	40.21 ± 1.74^{c}	34.85 ± 2.13^{b}	29.77 ± 2.96^{a}	136.77	p<0.05
Oil**	9.88 ± 0.66^{a}	28.04 ± 0.30^{d}	23.65 ± 0.08^{c}	21.59 ± 0.77^{b}	94.26	p<0.05
Proteins	11.27 ± 0.05^{a}	11.31 ± 0.05^{a}	11.58 ± 0.05^{a}	11.97 ± 0.33^{a}	2.71	p>0.05
Ashes	0.67 ± 0.08^{a}	0.62 ± 0.03^{a}	0.63 ± 0.08^{a}	0.59 ± 0.04^{a}	1.67	p>0.05
Dietaryfiber	0.71 ± 0.15^{a}	0.47 ± 0.15^{a}	0.53 ± 0.11^{a}	0.55 ± 0.13^{a}	0.37	>0.05
Carbohydrates	18.43 ± 2.36^{a}	19.35 ± 2.51^{a}	28.76 ± 3.02^{a}	35.53 ± 8.27^{a}	9.31	p>0.05
Calorías (kcal/100 g)	399.13 ± 12.44^{a}	385.21 ± 11.87^{a}	365.73 ± 19.36^{a}	383.36 ± 9.36^{a}	0.95	p>0.05

* The data represent the average of three determinations with their respective standard deviation, rows with different letters indicate significant differences (p<0.05). DB: dry basis ** Values calculated on dry basis oil-free.

On the other hand, the total protein, dietary fibre and carbohydrate content in arepa con huevo were not significantly affected by the processing conditions used during frying ($p>0.05$), reflecting the stability of these components. It has been reported that frying brings about changes in the native structures of food proteins, especially in their tertiary, quaternary and secondary structures (a process known as denaturation), which is attributed to the breaking of hydrogen bridges and decreasing electrostatic attractions that hold together the folded double helix structures of molecules(16, 17, 18). Dietary fiber on the microstructure of fried starchy products, such as arepas con huevo, could influence lower oil uptake, reducing of gelatinization temperature and therefore decrease starch digestibility of crustal, and perhaps inhibits rate of formation of toxic components such as acrylamide, furan or hydroxymethylfurfural (4, 11, 17, and 18).Regarding the mineral content of fried products similar to arepacon huevo, most reports indicate that these nutrients are not affected during heat treatment, given their high stability (18, 19).

3.2 Thermophysical properties analysis

Table 3 shows the thermophysical properties of arepascon huevo, obtained on the basis of chemical composition and frying temperature.The thermal conductivity and diffusivity depend on the microstructure of the product, as well as the chemical constituents (9, 17). In the arepas a slight increase in these parameters was observed, proportional to the temperature. With values of 0.49 ± 0.04 W/m °C -1.08 ± 0.09 x 10^{-7} m^2/s at 25 °C and 0.79 ± 0.05 W/m°C- 2.96 x 10^{-7} m^2/s, which could be due to the fact that under these conditions the product lost more moisture and therefore, there was a process of solids concentration that would facilitate heat diffusion, especially on the microstructure of the crunchy porous crust (4, 6, 11, 17 and 18).Yildiz et al. (20) in potato pieces, obtained thermal conductivity values of 0.40 W/m °C, at 0.60 W/m °C. While the thermal diffusivity was 9.2 x 10^{-9},11.2 x 10^{-9} and 18.2 x 10^{-9} m^2/s at temperatures of 150 °C, 170 °C and 190 °C, respectively.Bouchon and Pyle (21) during the cooling of fried potato-chip, reported that (k) was higher in the dry porous crust where the temperature was higher, compared to the cooked center that had more moisture and less oil compared to the surface. It has been indicated that while water is present in liquid form, it absorbs most of the energy in the form of heat, preventing its rapid conduction into food structures (16, 17, and 18).This would explain the behavior of thermal conductivity found in arepascon huevo at low temperatures. In relation to the specific heat of fried arepascon huevo and control (un-fried sample), statistically significant differences were found ($p<0.05$). This parameter decreased with the temperature increase, obtaining average values of (2672.88 ± 42.29kJ/kg°Cto 170 °C and 2274.14 ± 77.94 kJ/kg°C to 190 °C. This behavior may be due to the decrease in moisture in the microstructure(7, 10, and 17).

Table 3:Thermophysical properties of the arepas con huevo after the frying process

Product\Properties *	k (W/m°C)	Cp (kJ/kg°C)	ρ (kg/m^3)	α ($x10^{-7}m^2/s$)
Non-Fried (25 °C)	0.49 ± 0.04a	3187.51 ± 98.56a	1010.05 ± 90.61a	1.08 ± 0.09a
170 °C	0.66 ± 0.05b	2672.88 ± 42.29b	1009.68 ± 20.38a	2.55 ± 0.81b
180 °C	0.72 ± 0.08b	2539.11 ± 61.07c	1111.97 ± 32.84b	2.68 ± 0.04b
190 °C	0.79 ± 0.03c	2274.14 ± 77.94d	1079.33 ± 95.55a	2.96 ± 0.41b
Average	0.67 ± 0.05	2668.41 ± 69.96	1052.76 ± 59.85	2.32 ± 0.34

*Data represent the mean with its standard deviation

3.3 Texture changes of arepa con huevo

Table 4, schematizes the results obtained from the texture profile of the samples of arepascon huevo. It can be seen that in treatments one, three, four there were no statistically significant differences ($p>0.05$) in all the textural parameters evaluated. In terms of hardness, there was an increase as the temperature and frying time increased, with statistically significant differences in all the treatments analyzed ($p<0.05$) varying from 13.41± 1.94 N to 170 °C - 360 s to 27.34 ± 0.75 N to 190 °C - 420 s.The most adhesiveness treatments were those processed at the shortest time and temperature (170 °C - 300 s and 170 °C - 360 s) with averages of - 1.50 ± 0.03 N and - 1.41 ± 0.08 N respectively. These values are high compared to samples processed at a higher temperature ($p<0.05$). This is attributed to the superficial moisture of the arepas, which was more abundant at low temperatures and this may have influenced the softening of the microstructure, compared to those treatments where the product was drier and with more crunchy crust formation, therefore less adhesive (17, 22).

No statistically significant differences in elasticity ($p>0.05$) were found between all the treatments evaluated. This indicates that the product recovered its initial height very well during the time of the measurements, i. e. that the force applied during deformation was not sufficient to completely destroy the original structure of the food and therefore, this allowed all texture parameters to be properly calculated. The arepascon huevo showed differences in cohesiveness ($p<0.05$), being this smaller in the lower temperature and time treatments (0.56 ±0.08 to 170 °C - 360 s and 0.58 ±0.03 at the respective conditions of 170 °C and 300 s). This indicates that the intermolecular forces that held together the structure of the product in those treatments were relatively weaker, which was also possibly influenced by moisture content and would be related to what was found for the adhesiveness of these treatments(6, 10, 23).

Table 4. Texture profile of arepas con huevo

Treatments*	Time (s)	Temperature (° C)	Hardness (N)	Adhesiveness (N)	Elasticity	Cohesive ness	Chewiness (N)
1	300	170	15.75±1.44a	-1.50±0.03a	0.92±0.01a	0.58±0.03a	8.41±0.41a
2	300	190	18.09±0.33b	-1.02±0.08a	0.95±0.01a	0.68±0.04a	11.68±1.04a
3	300	180	16.91±0.25a	-0.99±0.09a	0.89±0.01a	0.64±0.05a	9.63±0.59a
4	360	170	13.41±1.94a	-1.41±0.08a	0.85±0.05a	0.66±0.08a	7.52±2.85a
5	360	180	16.65±2.79a	-0.92±0.23b	0.87±0.02a	0.89±0.11c	12.89±2.66a
6	360	190	19.09±0.05b	-0.27±0.04c	0.88±0.04a	0.66±0.19a	11.09±2.45a
7	420	170	15.45±2.26a	-0.64±0.14b	0.95±0.05a	0.71±0.13b	10.42±2.93a
8	420	180	22.64±1.12c	-0.51±0.05b	0.92±0.01a	0.69±0.01ab	14.37±0.85c
9	420	190	27.34±0.75d	-0.53±0.13b	0.95±0.03a	0.63±0.11a	16.36±3.47c
	ANOVA		p<0.05	p<0.05	p>0.05	p<0.05	p<0.05

* Different letters in the same column represent statistically different data (p <0.05).

In the case of chewiness, the values found in the arepas con huevo were proportional to the increase in hardness, obtaining an average of 16.36 ± 3.47 N, under frying conditions at 190 °C and 420 s, with respect to the lowest values of 8.41 ± 0.41 and 6.38 ± 2.85 N, which were observed in the treatments at 170 °C with the times of 360 s and 300 s respectively. These results indicate that the arepas processed at a higher temperature were more difficult to deform (higher hardness) than those where the heat treatment was low (lower hardness). This is possibly due to the greater dehydration of the internal structure and the concentration of solids in the external cortex (4, 5, 11, 17, and 22). Kumar et al. (23) found a gradual increase in the hardness value with the increase of frying time and temperature. They explained that a higher temperature caused a rapid loss of moisture from the surface, resulting in higher hardness, which was initially 0.17 N and increased to 3.19 N in 25 min, 2.24 N and 3.94 N in 20 min at temperatures of 120, 130, 140 ° C, respectively.

3.4 Correlations of texture parameters

In Table 5, the data obtained from the correlations of the texture parameters of the arepas con huevo are schematized. Between the hardness and the frying temperature there was a direct and highly significant correlation (rho> 0.75 and p <0.01). Between the adhesiveness and the hardness, an inverse and significant relationship was found (p <0.05). This indicates that the arepas of greater surface crust were less adhesive (4, 22, 24, and 25). Hardness also showed a direct and significant relationship with elasticity and cohesiveness, owing to the greater resistance of the structure when the product was dehydrated. The samples with greater adhesiveness were less chewable and deformed faster, between these two parameters there was an inverse and highly significant correlation (rho = -0.561 y and p <0.09).

Table 5: Correlations of the texture parameters of arepas con huevo

Parameters		**Time (s)**	**Temperature (° C)**	**Hardness (N)**	**Adhesiveness (N)**	**Elasticity**	**Cohesiveness**	**Chewiness (N)**
Time (s)	r-Pearson	1						
	p-valor	0,99						
Temperature (° C)	r-Pearson	-	1					
	p-valor	-	-					
Hardness (N)	r-Pearson	0.822*	0.796**	1				
	p-valor	0.001	0.001	-				
Adhesiveness (N)	r-Pearson	-0.545	-0.559*	-0.624	1			
	p-valor	0.021	0.023	0.025	-			
Elasticity	r-Pearson	0.079	0.462*	0.638*	0.295	1		
	p-valor	0.481	0.031	0.032	0.561	-		
Cohesiveness	r-Pearson	0.035	0.394	0.597	-0.935	0.687**	1	
	p-valor	0.742	0.048	0.022	0.001	0.004	-	
Chewiness (N)	r-Pearson	0.662*	0.494*	0.972*	-0.561	0.851*	0.743**	1
	p-valor	0.002	0.011	0.001	0.009	0.001	0.002	-

*Significant correlation (p <0.05). * Highly significant correlation (p <0.01).

4. Conclusions

Based on the results found, frequent intake of arepas with eggs is recommended and it is feasible to classify this food such as nutritionally complete. The conductivity and thermal diffusivity increased with temperature. The specific heat of the samples decreased with temperature increase. Hardness increased with temperature and frying time. The chewiness of the samples was proportional to the increase in hardness. The understanding the texture changes of the arepa con huevo, as well as the behavior of thermophysical properties during deep fat frying, would help to improve the quality and acceptability of this product.

Conflict of interest and Acknowledgment

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