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Research Article

Kinetics of Color Change in Squash (*Cucúrbita maxima*) During Frying by Immersion at Atmospheric Pressure and Vacuum Pressure

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Abstract: The goal of this study was to determine the kinetics of the change of color in squash (*Cucúrbita maxima*) during frying by immersion under conditions of atmospheric pressure and vacuum. Methodologically, the color of the rind of the external surface of the product conditioning in geometry of cylinders circulars, was evaluated in terms of the parameters CIELAB concerning L*, a* and b* post-process of frying under conditions of temperature of 150, 170 and 190°C, pressure of 40 and 80 kPa and during the time of processing time of 30 to 270 sec in intervals of 60 sec. The darkening of the surface of the product by effect of the process of frying in both procedures was evident in the decrease of the parameter L* as well as the parameters a* and b*, being more severe effect of darkening of the frying atmospheric higher temperature and experiencing changes of zero order for L*, zero for a* and first order for b*. The unit of the temperature and the speed of the reaction is explained by the Arrhenius equation. The activation energy obtained for the parameters of L*, a* and b* were 58.050, 13.709 and 53.545 kJ/mol and 32.082, 13.336 and 63.768 kJ/mol for the process of frying to the vacuum and frying in atmospheric conditions respectively.

Keywords: Color in food, deep fat frying, osmotic dehydration, squash, vacuum frying, vegetable oils

INTRODUCTION

The squash is a Cucurbitaceae vegetable that is characterized by an important level of tolerance to environmental stress, an aspect that favors its easy adaptation to different agro-ecological conditions; it is considered as a product with excellent characteristics of culinary quality (Goldman and Schrager, 2004). This vegetable has a wide medicinal potential, agro-industrial and is renowned for its high nutritional value. Over time has been highlighted in the national production (Vinasco *et al*., 1998). The squash is an excellent supplier of crude protein (4,4-14,5%) and same of components such as pro-vitamin A in the form of total carotenes (490,1-1365.8 μg/g), elements such as ascorbic acid (vitamin C), minerals (calcium, iron, phosphorus) and amino acids as thiamine and niacin, with a digestibility of dry matter more than 80%. This vegetable is also used in the agro-industry of the crafts and the decor (Cabrera *et al*., 2010).

The production of the squash relates historically crops "pancojer", on production systems in small and medium-sized segments of land productive, being cultivated as the main product or in partnership with another crop type; it highlights as a product of high relevance in the food security of the country (Estrada, 2003; Jaramillo, 1980). Therefore, the relative importance of this vegetable in the food security of the population of Colombia demand analysis and study of the various processes of transformation of the same, in order to diversify their presentation forms for the consumption, since the squash has traditionally been consumed in the Colombian households cooked and in other cases has been submitted the alternative of frying this vegetable, in such a way as to present other options of consumption.

For its part, the frying is an intensive process of temperatures and energies, an aspect that results in the evaporation unchanged of significant quantities of water in the food (Wu *et al*., 2013). The management of this type of variables, converted to the frying in a complicated process of control, aspect that makes it possible to determine in most of the cases the quality of the final product; therefore, the frying is an operation that helps food develop desirable characteristics in the product according to the requirements of the consumer. The process of frying regularly usually accompanied by various chemical reactions such as the oxidation, hydrolysis, polymerization and fission (Li *et al*., 2008; Sebastian *et al*., 2014). These reactions have fundamental effect on components of oil, as the decrease of the unsaturated fatty acids and contribute to the generation of physical phenomena such as the production of foam, color variation in the matrix in the

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process, changes in viscosity, density, heat specific between other aspects (Choe and Min, 2007; Nayak *et al*., 2016). In line with the oil, the process of frying causes chemical changes in the food, which are promoted by reactions as the denaturation of the proteins, the caramelization of sugars and tanning no enzymatic NEB; which are essential aspects for the shaping and development of attributes in the food that can be determined way sensory, such as the flavor, color and texture (Wang *et al*., 2013).

In the frying procedures, the vacuum application has been highlighted as an alternative that allows the reduction of undesirable effects, thereby reducing the boiling point of the water with the vacuum application, it makes it easier to extract this component from the food in process, using lower operating temperature and also getting decreased oil absorption between a 69.8 and 80% (Mir-Bel *et al*., 2009; Yagua and Moreira, 2011). Bibliographic reports mention that in vacuum-fried products, the acrylamide content is reduced and they generate desired results in aspects of color, texture, organoleptic quality, nutritional and sensory attributes (Granda *et al*., 2004; Shyu and Hwang, 2001; Da Silva and Moreira, 2008; Troncoso *et al*., 2009).

On the other hand, it is necessary to mention that during the processes of frying a fundamental parameter that evaluate consumers as an attribute of product quality fried is the final color of the food. With the color is possible correlate visually subjective quality of the first sensation that the consumer will experience, which uses as a decision criterion for the acceptance or rejection of the same one (Dhaiban *et al*., 2014; Du and Sun, 2004). It is, therefore, have established instrumental methods for the measurement of color, where they have used color spaces in a set of numeric values that are used to represent shades in two and three spatial dimensions (Trussell *et al*., 2005). Since the color in the frying is conditioned by some process parameters as the immersion time of the product in the heating medium, the type of oil used to perform the process, the type of fried (atmospheric or vacuum) and the different temperatures of operation that is used for effects of cooking (Arreola and Rosas, 2007). Because of the above, is necessary to consider the impact of critical parameters of operation for processes of modeling to estimate or predict changes in this attribute of quality during frying by immersion (Yildiz *et al*., 2007). Taking into account the foregoing, the determination of the kinetics of the change of color in the squash (*cucúrbita maximum*), during frying by immersion under atmospheric conditions of pressure and vacuum conditions is the aim of this study.

MATERIALS AND METHODS

In the laboratories of the Universidad de Cordoba was carried out the present study, Berastegui-Colombia headquarters. There, squashes were upgraded in geometry of cylinders circulars of dimensions of 2.0±0.5 cm and 0.8±0.1 cm diameter and thickness respectively, were then subjected to a process of osmotic dehydration using a solution ternary constituted by sucrose, sodium chloride and water to 60% p/p, in proportions of 55% of the sweetener, 5% of the salt and 40% of water. The pretreatment was carried out until reach 150 min of processing time, under a relation product-solution of 1:20 p/v and constant agitation 100 rpm.

Completed the process of osmotic dehydration, cylinders of squash were subjected to a process of frying by immersion at atmospheric pressure of 80kPa and a vacuum pressure of 40 kPa. The frying temperature used were 150, 170 and 190°C, the process time used was 30, 90, 150, 210 and 270s. The middle convective heat used was a mixture of vegetable oils composed of soya and palm olein. The system of measurement of the parameters color that was used was the scale CIELAB, where the chromaticity L*, a* and b* was determined using a colorimeter Konica Minolta brand of reference CM-5 in triplicate. For the modeling of the parameters of the color is used the method of Singh (1994):

$$\pm\frac{dP}{dt} = kP^n \quad (1)$$

where,

P = The quality of the attribute
k = Kinetics constant
n = The order of the equation
t = The time

It should be mentioned that the rate constant typically depends on the temperature and can be modeled in a Arrhenius Eq. (2):

$$k = k_0 \exp\left[-\frac{E_a}{RT}\right] \quad (2)$$

where,

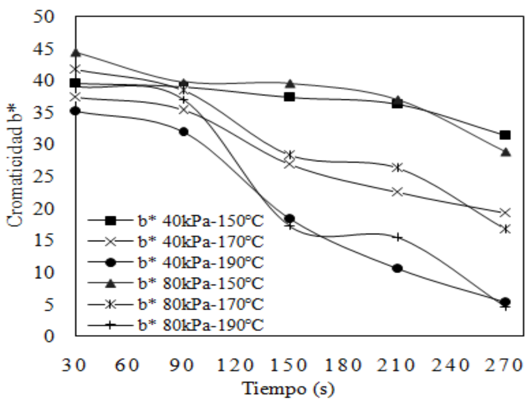
k = The constant kinetics that depends on the temperature
k_o = The factor of the frequency of collisions
R = The universal constant of the gases
T = The absolute temperature
E_a = The activation energy

With the data captured was possible to make the graphs to the kinetics of color for the squash fried with prior osmotic dehydration. The accuracy of the adjustment was calculated by the percentage of the mean quadratic error (%RMS) using Eq. (3):

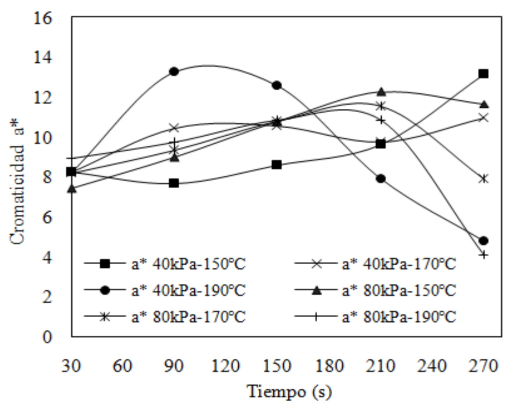
$$\%RMS = \sqrt{\frac{1}{N}\left[\sum_{1}^{N}\left(\frac{P_{Exp} - P_{Cal}}{P_{Exp}}\right)^2\right]} \times 100 \quad (3)$$

RESULTS AND DISCUSSION

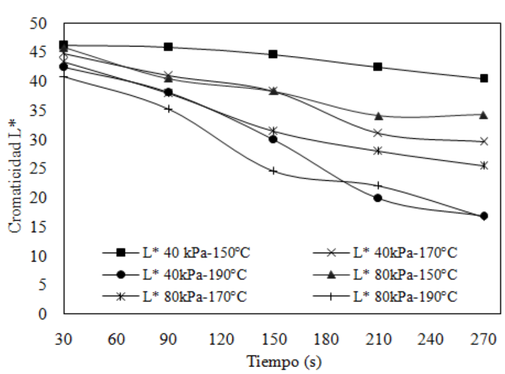
In Fig. 1, illustrates the kinetics of the color parameters relating to luminance (L*), chromaticity a* and chromaticity b*, where it can be observed that in the frying atmospheric (80 kPa) as the processing time and the temperature of frying increase, the average values of L* presented greater reduction. This phenomenon is attributable to the fact that with the increase of temperature is exercised greater driving force on the array in the process, causing a greater concentration of total solids in the outer surface of the product.



(a)



(b)



(c)

Fig. 1: The kinetics of the change of the parameters L*, a*, b*. (a): Kinetic of b*; (b): Kinetic of a*; (c): Kinetic of L*

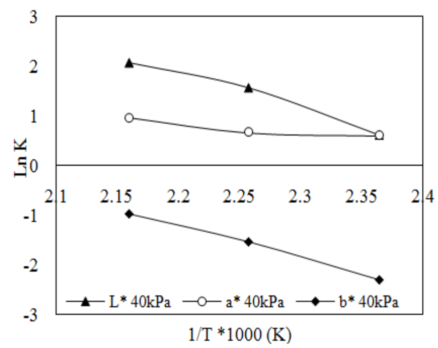
This phenomenon is directly on the reactions of non- enzymatic (Krokida *et al*., 2001; Gazmuri and Bouchon, 2009). In contrast, in the process of frying with a vacuum application the trend of parameter L*it was similar that the one presented with frying under atmospheric conditions, but the effect on the decrease of L* is much lower, with which yields products less dark and with better visual appearance. This is attributable to the fact that with the implementation of vacuum decreases the temperature of evaporation of the water contained in the squash and therefore the output of this component is done with greater ease, generating the dehydration of the cells under conditions of process less severe, which restricts the development of reactions do not enzyme develop under conditions of high temperatures its effect will not be so severe on which alters the porosity of the array, giving as a result products less dark and with better visual appearance (Quan *et al*., 2016; Bunger *et al*., 2003). Related results were obtained in chips of corn, where lightness values declined much more under the conditions of frying atmospheric that under conditions of frying to a vacuum (Xu and Kerr, 2012).

For its part, in relation to the chromaticity a* under conditions of atmospheric frying, the trend indicated a slight increase and then decrease with the passing of time of the process, being more severe than the decline in the average values of this parameter with the temperature of 190°C. This phenomenon can be attributed to that with the income of solids by the effect of the osmotic dehydration, catalyze the reactions of browning not enzyme in the matrix, which facilitates the reduction of shades of red saturated to shades less red and darker characteristics of the reactions of caramelization. In the case of the process that is used conditions of vacuum, the trend recorded teaches that to working temperature lower (150°C) there is an increase in this parameter indicating shades redder, but with the temperature of frying 190°C the trend was different, where to higher process times the tonalities became less red. This phenomenon is attributable to the fact that with this last temperature is exercised greater influence envelopes total sugars of the squash and it generates the greatest emergence of dark tonalities due to browning no enzymatic characteristic of the processes of frying by the reaction of sucrose with amino acids common (Mottram *et al*., 2002; Coughlin, 2003).

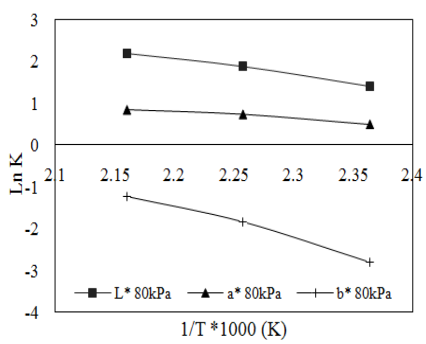
Regarding the chromaticity b*, can be identify that there was a reduction in the scale of this parameter, finding that in all the processes analyzed both in atmospheric conditions such as in conditions when

Table 1: Summary of color kinetics of squash during atmospheric and vacuum frying

Pressure (kPa)	Parameter	Orden of reaction	Ea (kJ/mol)	k_o	% RMS
40	L*	Zero	58.05	4.046×10^{-7}	0.474
	a*	Zero	13.70	0.093×10^{-4}	0.479
	b*	First	53.54	5.783×10^{-5}	1.609
80	L*	Zero	32.08	4.588×10^{-4}	0.501
	a*	Zero	13.33	0.008×10^{-4}	0.529
	b*	First	63.76	6.927×10^{-6}	1.864



(a)



(b)

Fig. 2: Constants of the kinetic parameters of Arrhenius

empty, the result found was a decrease of this value. This indicates that there was a reduction of the pigment of β-carotene, studies have shown that the β-carotene in processing conditions of hot temperatures experienced a degradation is degraded by the heat and this can change through the isomerization, oxidation and the Division (Archir *et al*., 2011; Mendoza-Corvis *et al*., 2015). These reactions are directly affected by the temperature which, to have an increase in the matrix of the process resulted in a doubling of the links trans type to links cis, originating with this the appearance of shades less yellow and bluer (Meléndez-Martínez *et al*., 2004).

Figure 2 shows the Arrhenius plot of rate constants for L*, a* and b* changes during frying of squash.

Table 1 shows the activation energy values obtained for the parameters of L*, a* and b* which are 58.050, 13.70 and 53.54 kJ/mol and 32.0829, 13.3367 and 63.768 kJ/mol, for the process of frying in vacuum and frying under atmospheric conditions, respectively, in the kinetics of zero order for L*, in order zero for a* and of the first order for b* in both processes.

The behavior presented in the activation energy (Ea); in the phenomena studied, both to atmospheric conditions such as to conditions of vacuum, it is possible to identify that there is a noticeable difference in the parameter of luminance (L*), being much more the energy required for the reactions of darkening in the process of frying under vacuum that in atmospheric conditions, this is consistent with the trends in the Fig. 1, where it is well known that under conditions of vacuum the absence of air inhibits the oxidation reactions of lipids in the oil and with this the browning in the surface of the products for which it will be necessary to higher energy consumption to achieve change notorious in the darkening the squash fried (Fan *et al*., 2005; Shyu *et al*., 2005). For its part, in the other parameters evaluated of chromaticity a* and chromaticity b*, the behavior obtained in the energy levels of activation does not presents a variation very high, appearing then similar values between the operations of vacuum and frying atmospheric, considering that in the samples remained the same the content of sugars by the osmotic effect and thus the occurrence of reaction of darkening with very similar energy requirements under both conditions. In the same way with the frying to vacuum is required much less power in frying under atmospheric conditions to achieve a thermal degradation in the β-carotene that represent variations in parameter b* of the squash.

CONCLUSION

The factors of temperature and time meet a direct action on the parameters of luminance (L*), chromaticity to* and chromaticity b* under conditions of operation atmospheric and vacuum. The process of dehydration, the reactions of caramelization and degradation of natural pigments present in the squash as the β-carotene, are the main affectations that experiences the squash to be subjected to prosecutions of frying and thus be modified color characteristics relating to L*, a* and b*, being more noticeable effects on products subject to frying in atmospheric conditions to empty. Similarly, confirms that the unit of the temperature and the speed of the reaction can be explained by the Arrhenius equation. The activation energy obtained for the parameters of L*, a* and b* were 58.050, 13.70 and 53.54 kJ/mol and 32.0829, 13.3367 and 63.768 kJ/mol for the process of frying in vacuum and frying in atmospheric conditions, respectively, following kinetics of zero order for L*, order zero for a* and of the first order for b* in both processes.

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