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Color Changes Kinetics and Heat Transfer during Deep Fat Frying of Garlic Slice

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ABSTRACT: Heat and mass transfer phenomena that take place during frying cause physicochemical changes, which affect the colour and surface of the fried products. The effect of frying temperature on the colour changes and heat transfer during deep fat frying of garlic has been investigated. The colour scale parameters redness (a*), yellowness (b*) and lightness (L*), and color change intensity (ΔE) were used to estimate colour changes during frying as a function of oil temperature and time. L* value of fried garlic decreased during frying but a* and b* values were increased. A first-order kinetic equation was used for each one of the three colour parameters, in which the rate constant is a function of oil temperatures. The results showed that oil temperature have a significant effect on the colour parameters. Different kinetic models were used to fit the experimental data and the results revealed that the power model was the most suitable to describe the color change intensity (ΔE). Center temperature of garlic slice increased with increase in oil temperature and time during frying.

Keywords: *Colour Parameters, Frying, Garlic, Kinetic Equation. Power Model.*

Introduction

Frying is a complex unit operation that is widely used in the food industry. During the process, food is immersed in an oil bath at a temperature above the boiling point of water. This results in counter flow of water vapour (bubbles) and oil at the surface of the product (Dueik *et al.*, 2010).

Garlic (*Allium sativum*) is a plant known for its antimicrobial, antithrombotic and antiatherosclerotic properties. Also, cloves of garlic are used for consumption in various regions of the world, either raw, cooked or fried. Garlic is applied to spice dishes due to its specific pungent flavour and used to preserve meat and vegetables because of its antimicrobial properties. Garlic is the food with the highest number of organosulfurous compounds. Thirty-three of these compounds have been identified, and the biological activity of several is known. (Olech & Zaborska, 2012; Prati *et al.*, 2014). Comparison of the main bioactive compounds and antioxidant activities in garlic after treatment protocols (blanching, boiling, frying, and microwaving) was studied by Gorinstein *et al.* (2008). It was found that blanching and frying and then microwaving of garlic did not decrease significantly the amounts of its bioactive compounds and the level of antioxidant activities.

Heat and mass transfer phenomena that take place during frying cause physicochemical changes, which affect the colour and surface of the fried products. Process variables such as oil temperature

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and oil type are expected to affect the colour of the fried products. Although, the investigation on colour properties of fried products has started many years ago, it has continued with increasing interest in recent years.

Krokida *et al.* (2001) studied the effect of oil temperature, oil type and sample thickness on colour changes during deep fat frying of french fries. They reported that oil temperature and thickness of potato strips have a significant effect on the colour parameters, which are not affected by the use of hydrogenated oil in the frying medium. Paul and Mittal (1996) examined how the degradation of oil during frying of canola affected the colour of the fried product. They noted high correlations between the colour parameters and oil degradation during frying. Kozempel *et al.* (1995) developed a simulator for food processes such as blanching, drying and frying of potatoes. The model was also used to control the colour of fried potatoes. Khalil (1999) examined the quality of french fried potatoes as influenced by the coating with hydrocolloids. They noted that coated french fries exhibited higher red and yellow colours. The effect of frying temperatures and durations on the quality of vacuum fried jackfruit chips was evaluated by Maity *et al.* (2014). Jackfruit chips fried at higher temperature resulted in maximum shrinkage (48%). The lightness in terms of hunter value decreased significantly during frying. Frying at lower temperatures was found to retain bioactive compounds such as total phenolics, total flavonoids, and total carotenoids in jackfruit chips. Effects of frying treatments on texture (hardness) and colour parameters (L^*, a^*, b^* and ΔE) during deep fat frying of yellow fleshed cassava root slices were investigated by Oyedeji *et al.* (2017). The overall colour change in chips fried under vacuum conditions at 118°C for 8 min was the least (21.20) as compared to the fresh and atmospherically pre-dried ones (16.69 and 14.81, respectively).

The aim of this research is to study the effect of changes in frying temperature on the colour parameters, surface changes and heat transfer during deep fat frying of garlic slice and to specifically investigate changes in these quality attributes at each frying time, and determine kinetic parameters for these changes.

Materials and Methods

- *Frying of garlic*

Garlic was purchased from a local supermarket and stored at 7°C and 90–95% relative humidity. Slices of garlic with 10 mm thickness were prepared with the aid of a steel cutter and were immediately placed into the fryer. A fryer with temperature control of ±1°C was used (Lutron, TM-916). Refined sunflower oil (Ladanoil, Iran) was used as the frying media. Frying temperatures of garlic slices were set at 130, 150, 170 and 190°C. All experiments were performed in triplicate order and the present results are the average of the obtained individual values.

- *Color measurement*

In order to investigate the effect of frying temperature on color changes of fried garlic, a computer vision system was applied. Sample illumination was achieved with HP Scanner (Hp Scanjet 300). Since the computer vision system perceived color as RGB signals, which is device-dependent, the taken images were converted into $L^*a^*b^*$ units to ensure color reproducibility (Salehi, 2017). In the $L^*a^*b^*$ space, the color perception is uniform, and therefore, the difference between two colors corresponds approximately to the color difference perceived by the human eye. L^* (lightness/darkness that ranges from 0 to 100), a^*(redness/greenness that ranges from -120 to 120) and b^* (yellowness/blueness that ranges from -120 to 120) were measured in this study (Salehi & Amin Ekhlas, 2018).

The calculation of color changes (ΔE) for total color difference was made with the following equations:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \tag{1}$$

The change in the surface of the garlic slice during frying, is calculated using the following equation:

$$\Delta A = \frac{A_0 - A_t}{A_0} \times 100 \tag{2}$$

Where ΔA is the surface change percent (dimensionless), A_0 and A_t (m^2) are surface of garlic at first time (fresh garlic) and frying period, respectively.

In this study, the image analysis of dried gums was performed using Image J software version 1.42e, USA.

- *Mathematical modelling*

A first-order kinetic model was chosen to describe the colour changes within the frying process.

$$\frac{dC}{dt} = -K_c(C - C_e) \tag{3}$$

Where C is the colour parameter (L*, a*, b*), C_e the equilibrium value, K_C the rate constant (min^{-1}) of each colour parameter, t is the frying time (min).

At zero time each colour parameter (L*, a*, b*) has an initial value C_i. The effect of process variables on the colour parameters during frying can be embodied into the following empirical equations, which are similar to those proposed for frying kinetic equations (Krokida *et al.*, 2001; Salehi, 2018):

$$\left(\frac{C - C_e}{C_i - C_e}\right) = \exp(-K_c t) \tag{4}$$

$$C = C_i + a(1 - \exp(K_c t)) \tag{5}$$

The estimation of the above parameters for each one of the colour parameters was carried out using a non-linear regression analysis method, separately for each colour parameter during frying of garlic.

In addition, power and quadratic models were chosen to describe the colour changes intensity (ΔE) within the frying process:

Power model:

$$\Delta E = at^b \tag{6}$$

Quadratic model:

$$\Delta E = a + bt + ct^2 \tag{7}$$

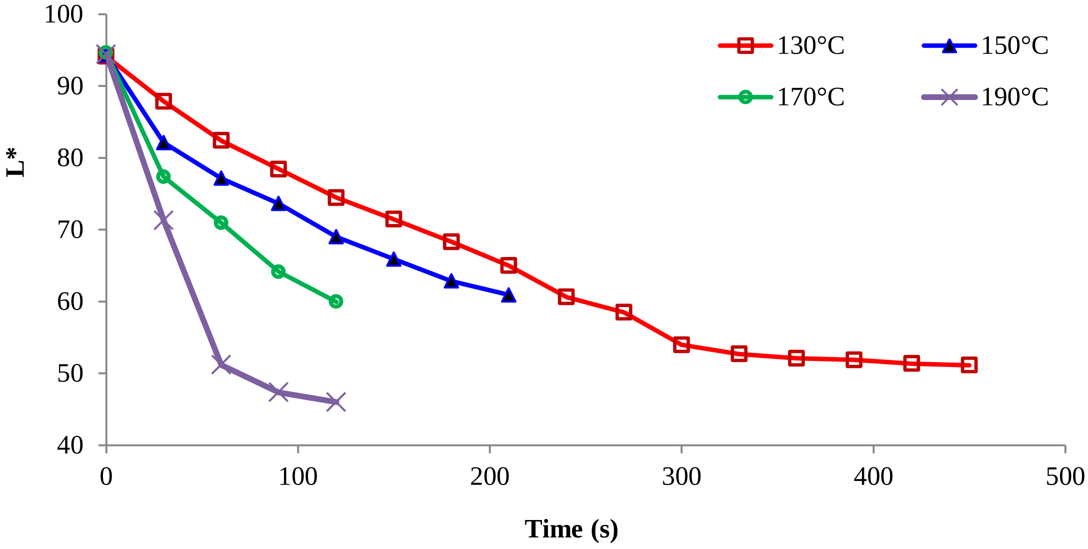
The experimental data were modeled by using non-linear regression in Curve Expert 1.34 software.

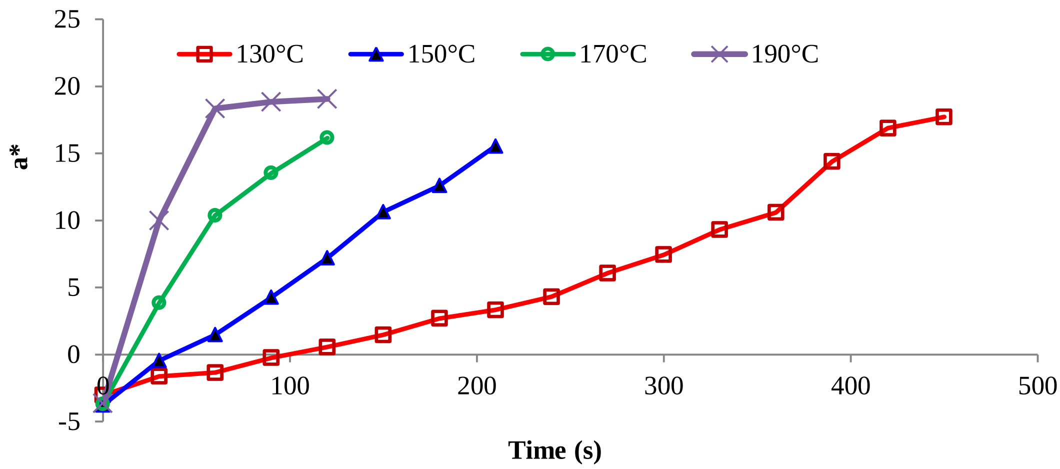
- *Temperature profiles*

A thin thermocouple (Type K) was inserted in the center of the garlic samples, assuring the position by measure of the sample dimensions. The temperatures at the geometric center of the sample and bulk oil were measured, with sampling time (t) frequency of 5 s by means of the thermocouples (Lutron, TM-916, Taiwan).

Results and Discussion

Figure 1 shows changes in L*, a* and b* values of garlic slices for increasing frying times and temperature during frying. L* is a critical parameter in the frying industry as it is usually the first quality attribute evaluated by consumers when determining product acceptance. Low L* values indicate a dark colour and are mainly associated with non-enzymatic browning reactions (Dueik *et al.*, 2010). The results of the experimental lightness data are shown in Figure 1. As shown in Figure 1, L* value of fried garlic decreased during frying. For instance, L* value diminished from L_0^* = 94.42 to L* = 46.00 at end point (much darker) when frying at 190°C. Oil temperature has a negative effect on the lightness of fried garlic. The change in L* value was less at lower frying temperature. As the temperature of frying increased from 130 to 190 °C, the lightness of garlic decreased from 51.14 to 46.00, respectively. In general, an L* parameter decrease is not desired because that means a more dark product, which is not acceptable for fried garlic. Decrease in L* value has been linked with nonenzymatic browning reactions which accelerates at high temperatures (Dueik *et al.*, 2010; Mariscal & Bouchon, 2008).





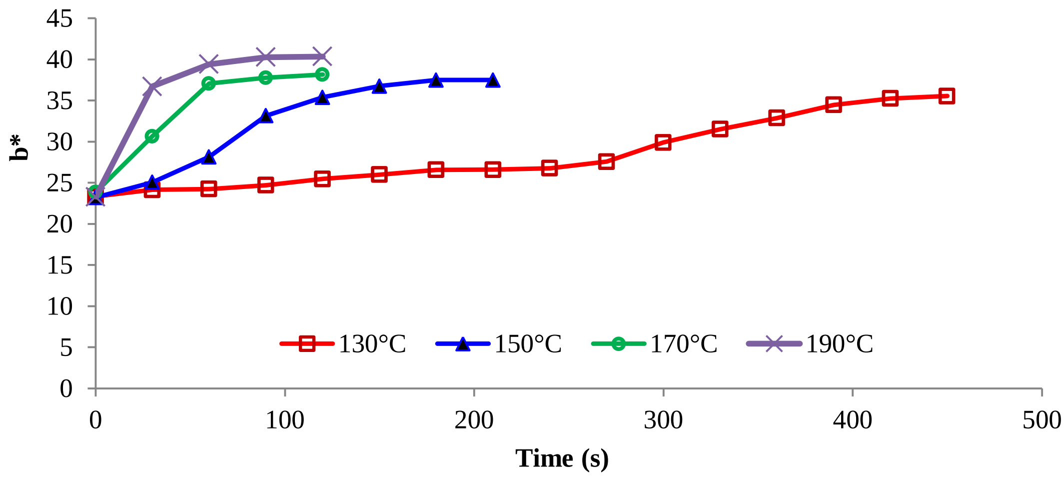


Fig. 1. The effect of temperature on lightness (L*), redness (a*) and yellowness (b*) parameters during frying of garlic.

It was also observed that the rate of reduction in the values for lightness parameter at lower frying temperatures is slower as compared to the rate observed at higher frying times across all the frying temperatures. Similar behavior in fried potato chips was reported by Nourian *et al.* (2003). Since lightness is a very important colour quality parameter, lower frying temperatures with lower boiling point of water are preferable to preserve the lightness and hence the attractiveness of fried products (Oyedeji *et al.*, 2017).

The reduction in L* may be attributed to intense browning reaction and increase crust formation due to exposure to high temperature (Mariscal & Bouchon, 2008).

As with the case of the redness parameter, a* is also affected by the oil temperature and frying time (Figure 1). As shown in this Figure 1 the redness of fried garlic increased during frying.

As shown in Figure 1 the yellowness of fried garlic increased during frying. In general, higher b* parameter values give more yellow products, which is desirable for fried products.

Garlic slices fried under different oil temperature showed a significant decrease in their colour coordinates, reaching the final values of a*=19.05 and b*=40.36, when frying at 190°C.

The mathematical model was fitted to the experimental colour data simultaneously for process variable examined and the parameter estimation resulted from fitting Eq. 5 to the experimental data. The results of fitting the proposed first-order kinetic model to the experimental data are reported in Table 1. The elimination of parameters K_C and a for each colour parameter gave an acceptable agreement between experimental and calculated values, as found by comparison of the values R and SE.

In Figure 2 colour change (ΔE) is presented as functions of frying time. As shown in Figure 2 the ΔE, increased frying during. The colour change intensity (ΔE) gets more intense at higher temperatures. Vacuum frying of potato chips was studied by Garayo and Moreira (2002) they reported that the change in total colour difference was affected by frying conditions and there was a change observed in total colour during deep fat frying of potato chips at atmospheric and vacuum conditions.

The mathematical models were fitted to the color change (ΔE) data and the parameter estimation resulted from fitting Eqs. 6 and 7 to the experimental data. The results of fitting the proposed power model to the experimental data are reported in Table 2.

Table 1. The values of the colour kinetic model coefficients during frying of garlic.

Parameters	Temperature (°C)	a	K_C	R	SE
L*	130	168.927	0.037	0.908	6.149
	150	127.723	0.076	0.889	5.520
	170	129.626	0.134	0.912	6.425
	190	266.490	0.101	0.860	12.21
a*	130	-7.237	0.183	0.996	0.579
	150	-83.222	0.060	0.997	0.487
	170	-122.208	0.082	0.952	2.809
	190	-179.776	0.074	0.878	5.101
b*	130	-3.475	0.209	0.987	0.697
	150	-53.666	0.087	0.966	1.641
	170	-91.448	0.088	0.892	3.747
	190	-153.093	0.067	0.848	3.385

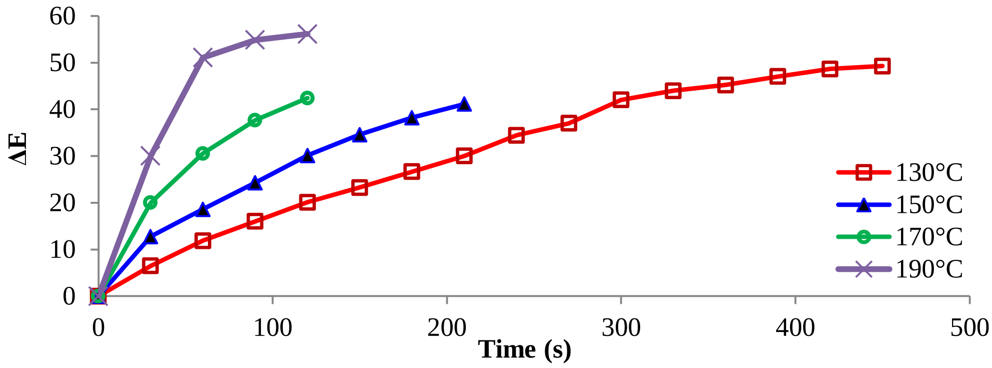


Fig. 2. The effect of temperature on color change (ΔE) during frying of garlic.

Table 2. The values of the kinetic model coefficients of color change (ΔE) during frying of garlic

Temperature (°C)	a	b	R	SE
130	12.509	0.709	0.995	1.461
150	19.243	0.619	0.998	0.622
170	29.890	0.527	0.996	0.952
190	45.271	0.395	0.920	5.830

Kinetics of moisture loss and oil uptake during deep fat frying of Gethi (*Dioscorea kamoonensis Kunth*) strips was studied by Manjunatha *et al.* (2014). The hunter colour parameters were significantly affected by frying temperature and frying time. The L* value increased with respect to frying time initially, followed by decline and same trend was observed at higher temperatures of frying with elevated rate, whereas a* value increased with time as well as temperature of frying and obeyed zero order rate equation. In addition, chroma, hue angle and total colour difference were markedly affected by frying temperature as well as frying time. In another study, the total colour change of tofu during frying at different temperatures was studied and it increased exponentially and followed first order kinetic equation. The increase in magnitude of total colour difference values could be attributed to the high temperature and low moisture content, which initiated the nonenzymatic browning such as Maillard reaction and caramelisation of sugars (Baik & Mittal, 2003).

Surface change % (shrinkage) is a common phenomenon during frying. Rapid water loss resulted in significant shrinkage in chips during frying (Canadian Institute of Food Science and Technology JournalMaity *et al.*, 2014). In Figure 3 surface change is presented as functions of frying time and oil temperature. As shown in Figure 3, the surface change % was increased with the progression of frying time. As soon as the garlic slices were introduced in the low frying medium, the slices shrunk. As the temperature of frying increased from 130 to 190 °C, the surface change % of garlic slices decreased from 23.66 to 7.82 %, respectively. At the end of frying the % surface change in garlic slices was 23.66, 11.52, 9.65 and 7.82 % at 130, 150, 170, and 190 °C, respectively. High surface change was observed in garlic slices fried at 130 °C that might be due to low removal of moisture. Similar behavior was also reported in change in shrinkage during vacuum frying of banana chips (Yamsaengsung *et al.*, 2011). Higher shrinkage in potato chips was also reported during high temperature frying (Yagua & Moreira, 2011).

The effect of oil temperature on center temperature change of garlic during frying is shown in Figure 4. Center temperature of garlic slice increased with increase in oil temperature (faster heat transfer) and time during frying. The center temperature increased rapidly at the beginning. This profile is basically due to the sample unstable heating and water evaporation phenomenon from the surface. Within the experimental conditions studied, a difference between the maximum sample temperature and the oil temperature was recorded, in which the center temperature of most of the samples reached 99 for 130 °C, 125 for 150 °C, 133 for 170 °C and 141 for 190 °C, respectively.

The frying time to get desirable colour of the garlic slice was different for each oil temperature; the characteristic time decreased with increasing temperature, which is to be expected since the rate of heating is higher.

The effect of temperature on physical properties of chicken strips during deep-fat frying studied by Vélez-Ruiz *et al.* (2002). The center temperature of chicken strips increased quickly at the beginning and had a plateau at around 95-105°C from 1-4 min, for the oil temperature equal 130-150 °C.

Conclusion

Colour parameter (L*, a*, b*) changes of garlic that take place during frying can be described by an empirical first-order kinetic model. Oil temperature and frying time are the process parameters that affect the colour parameters during frying. The colour change phenomenon gets more intense at higher temperatures. Garlic slices fried under different oil temperature showed a significant decrease in their colour coordinates, reaching the final values of a*=19.05 and b*=40.36, when frying at 190°C. Different kinetic models were used to fit the experimental data and the results revealed that the power model was the most suitable to describe the color change intensity (ΔE). The center temperature of garlic slice increased rapidly at the beginning of frying process.

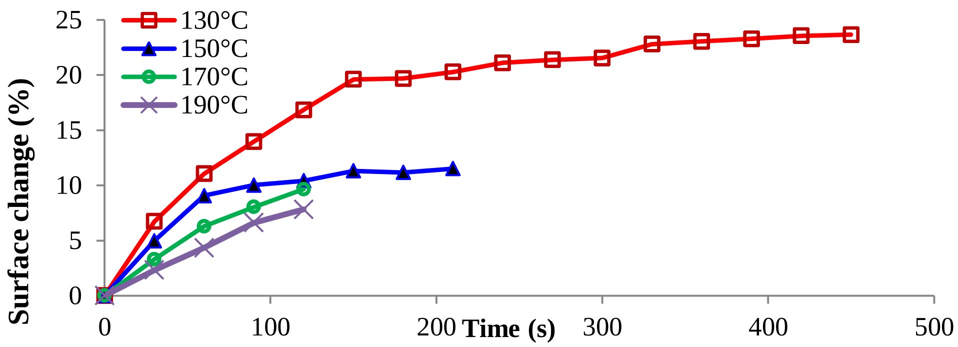


Fig. 3. The effect of temperature on surface change during frying of garlic.

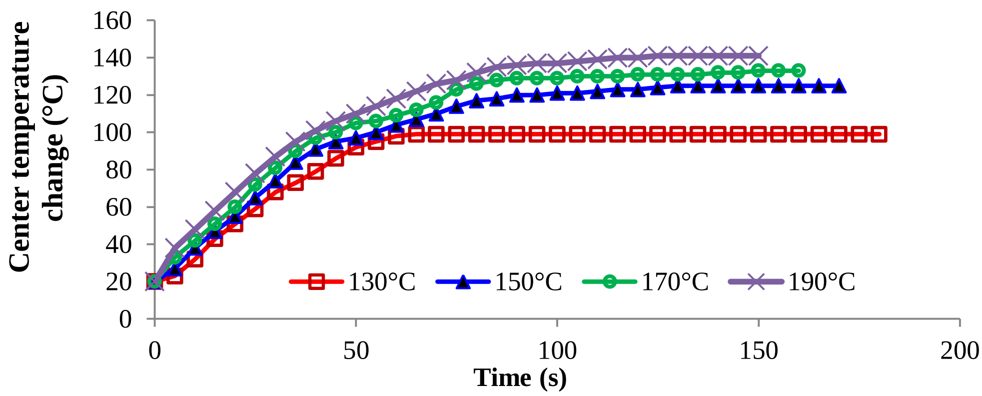


Fig. 4. The effect of oil temperature on center temperature change of garlic during frying.

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