195
Annals
Agric. Sci.,
Ain Shams Univ.,
Cairo, 53(1), 195-206, 2008

REDUCTION OF OIL CONTENT FROM FRIED POTATO CRISPS: KINETICS OF MOISTURE LOSS, OIL UPTAKE AND COLOR CHANGES DURING FRYING

[16]

Khalil[1], H.I. and I.S. Ashoush[1]

1- Food Science Department, Faculty of Agriculture, Ain Shams University, Shoubra El-Kheima, Cairo, Egypt

Keywords: Potato crisps; Pre-drying; Oil absorption; Water loss; Potato color & texture; Kinetics

ABSTRACT

Pre-drying and subsequent dipping in both a salt and sugar solution is a potentially effective process for reducing the oil content of potato crisps. The effect of various pretreatments on oil uptake; moisture loss; color parameters (L, a & b) and textural changes of fried potatoes was investigated. The highest values (≈ 27% reduction) in oil uptake observed for samples pretreated with sugar solution followed by those samples pretreated by dipping in salt solution (≈ 22% reduction). The reaction rate constant (κ) of oil uptake for control sample was 0.009 s^{-1} while it was for the pretreated potato crisps in the range of 0.007 to 0.017 s^{-1}. The potato crisps pretreated by both salt and sugar solution had greater values of total color change (ΔE) compared with the control samples. The reaction rate constant of color change for sugar treated potato crisps recorded higher values (0.009 to 0.011 s^{-1}) compared with that of salt treated (0.005-0.006 s^{-1}) and control samples (0.002 s^{-1}). There were no differences in textural values between both salt and sugar treated potato crisps during frying process at 180 °C.

INTRODUCTION

Deep-fat frying is a widely used food process, which consists basically of immersion of food pieces in hot vegetable oil. The high temperature causes partial evaporation of the moisture, which moves away from the food and through the surrounding oil, and a certain amount of oil is absorbed by the food. Frying is often selected as a method for creating unique flavors and texture in processed foods that improve their overall palatability. The high temperature of the frying fat, typically leads to the appreciated textural characteristics of fried foods. Besides, heating of reducing sugars effects a complex group of reactions, termed caramelization, leading to browning development (**Mellema, 2003 and Pedreschi *et al* 2007b**).

Gamble *et al* (1987) indicated that as the food material fries, the inner moisture is converted to steam causing a pressure gradient and as the surface dries out, the oil adheres to the product surface and enters the surface at damaged areas. They suggested that most of the oil enters the chips from the adhering oil being pulled into the chips when they are removed from the fryer due to accumulation of steam.

Potato crisps (thin circular slices) are also among the most popular consumer snack products throughout the world. However, oil fried potato chips contain up to 39% oil, which are of concern to health conscious consumers. In many countries, medical authorities have implicated a high fat diet as being one of the major factors causing increased incidence of cardiovascular disease (**Glew, 1988**).

(Received March 9, 2008)
(Accepted March 22, 2008)

Dana and Saguy (2006) stated that there are three main possible mechanisms to describe oil absorption phenomena during deep-fat frying namely, water replacement, cooling-phase effect and surface-active agents. Coating techniques with an aqueous hydrocolloid solution of potato chips lead to high water content over 10% by weight compared to only 4% or less in uncoated chips. This high water content exhibited a soggy texture which is unacceptable to the consumer **(Prosise, 1990)**. In the potato chip process, raw potatoes are washed, peeled, sorted and cut into slices. Some potato processing plants use blanching in hot water and drying with warm air until reach a moisture content of 60% (wet basis) prior to frying **(Califano and Calvelo 1987)**. After this, potato slices are usually fried in continuous friers with hot oil (170 - 190 °C), where they remain until the moisture level is less than 2% of the total weight **(Pedreschi *et al* 2007b)**.

Krokida *et al* (2001a) used osmotic dehydration as a pre-treatment to produce low-fat french fries where potato strips were immersed into different solutions, which were sugar, Nacl, maltodextrine 12 and maltodextrine 21, for 3h before frying. **Pedreschi *et al* (2007a)** mentioned that soaking in Nacl solution of potato slices before frying improve not only their color (less browning) after frying but also reduce dramatically the amount of acrylamide formation using a different frying temperatures.

Tran *et al* (2007) demonstrated that the pre-drying followed by dipping potato crisps in a sugar solution can reduce the oil content of the fried crisps with an increased sweetness. This procedure has been shown to be capable of significantly reducing the oil uptake in the crisps during frying and there was a significant 30% oil reduction compared with the control samples. The moisture contents were not different when compared with the control. The crisps that had gone through the pretreatment procedure had some changes in color and seemed to shrink more. Color of potato chips is an extremely important criterion for the potato processing industry and it is strictly related to consumer perception. On the other hand, acrylamide has recently been reported as a critical compound for human health that is formed in potatoes during frying and that is highly related to the color of the chip **(Mottram and Wedzicha 2002; Pedreschi *et al* (2006) and Pedreschi *et al* 2007a)**.

Moyano *et al* (2002); Krokida *et al* (2001b); Pedreschi *et al* (2005) and Pedreschi *et al* (2007a) assumed that the change in color parameters (L, a & b) followed a first-order kinetics during frying of potato chips.

The principal objectives of the present study were to study the effects of pre-drying and pretreatments on the oil reduction, water loss phenomena and also the color and the textural changes during deep fat frying at 180 °C of potato crisps. And also to apply a first-order kinetic model to fit the oil uptake, moisture loss and color change data during frying process.

MATERIALS AND METHODS

2.1. Materials

Potato tubers (*Solanum tuberosum* L., CV. Sponta) weighed about 200-300g each with a diameter larger than 50 mm were obtained from the local market. Sunflour oil (the frying oil) was also purchased locally. Analytical grade hexane solvent was purchased from El-Gomhoreya Company, Cairo, Egypt, while sugar and salt were obtained from the local market.

2.2. Potato crisp preparation

Potato tubers were washed, peeled and manual sliced. Slices (thickness of 2.0 mm) were cut from the center region. Slices were rinsed immediately after cutting for 1 min in tab water to eliminate some starch adhering to the surface prior to frying. To minimize enzymatic browning, slices were blanched by heating raw slices in 5 l of hot water at 80 °C for 3.5 min and then cooled down to 25 °C. A single layer of blanched potato slices were placed on aluminum foil covered stainless steel trays and then dried in a convection oven at a temperature of 60 °C to a final moisture content of 26%.

2.3. Pretreatments

The air dried potato slices were left to cool down to ambient conditions (25°C) for 1 h and then they were subjected to the following treatments: control (No pre-drying, no dipping); pre-drying, no dipping and pre-drying, with dipping. Slices were immersed in sucrose solutions (15, 20 and 25% w/w), Nacl (2, 4 and 6% w/w) and their combination of (20% sucrose and 2% Nacl w/w) at 40 °C for 30 s.

2.4. Frying conditions

About 100 g of slices per sample were deep-fried in 3 l of hot sunflour oil contained in an electric fryer (Moulinex, Model 880, France) at 180 °C. During frying, ten slices were removed every minute for 6 min. After frying, samples were wrapped on absorbing tissue paper for 5 min prior to testing (**Tran *et al* 2007**).

2.5. Analyses

2.5.1. Oil content was measured by Soxhlet extraction using hexane. The test was performed in triplicates and average values were taken (**AOAC, 2000**).

2.5.2. Moisture content of potato crisps was measured by drying the samples in a convection oven until constant weight at 105 °C; the tests were done in triplicates (**AOAC, 2000**).

2.5.3. Color of potato chips was measured using a Hunter lab DP 9000 D 52L optical sensor using L*, a* and b* color scale. The instrument was standardized each time with a white and a black ceramic plate. The samples were scanned at five different locations and the mean values of L, a, b were recorded. The total color change (ΔE) of each crisp was calculated as described by **Tran *et al* (2007)** as follows

$$\Delta E = [(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2]^{1/2} \quad (1)$$

Where L_0, a_0 and b_0 are the lightness, redness and yellowness color score respectively at time zero. The L, a & b represented the instantaneous individual reading during frying process.

2.5.4. Texture measurements of the crisps were carried out at room temperature (25 °C) using hand flat penetrometer with a diameter of 0.8 cm (D. Ballauf Manufacturing Company, Washington D.C., USA) as described by **Pedreschi *et al* (2007b)**.

2.6. First-order model kinetics

2.6.1. Kinetics of oil uptake

An empirical model of first-order kinetics was applied to describe oil uptake during frying (**Durán *et al* 2007**) as follows

$$O = O_{eq}[1 - \exp(-\kappa t)] \quad (2)$$

Where O is the oil content at time t (g oil / g dry solids); O_{eq} is the oil content at equilibrium (or maximum oil content on dry basis) at t = ∞, t is the frying time and κ is the reaction rate constant (s^{-1}) for this model.

2.6.2. Kinetics of moisture loss

A first order kinetic model was chosen to describe the moisture loss during the frying process (**Krokida *et al* 2001a**) as follows

$$(x - x_e)/(x_0 - x_e) = \exp(-\kappa t) \quad (3)$$

Where x is the moisture content at time t (g/g dry solids); x_e is the moisture content at an infinite process time; x_0 is the moisture content at zero time and κ is the rate constant of moisture loss (s^{-1}).

2.6.3. Kinetics of color change

A first order kinetic model was adopted to describe the color change during the frying process (**Krokida *et al* 2001a**) as follows

$$(c - c_e)/(c_0 - c_e) = \exp(-\kappa t) \quad (4)$$

Where c is color parameter (L,a,b); c_e is equilibrium color parameter; c_0 initial color parameter and κ is the rate constant of color change (s^{-1}). This model of first order kinetic could be simplified as follows

$$(c/c_0) = \exp(-\kappa t) \quad (5)$$

RESULTS AND DISCUSSION

3.1. Oil Uptake

Oil uptake profiles for no pre-drying, no dipping (control sample); pre-drying, no dipping; pre-drying, with dipping in 2, 4 & 6% Nacl solution; 15, 20 & 25% sugar solution and combination of Nacl-sugar solution are shown in (**Fig. 1**). The oil content was dependent on the frying time. The pre-dried and dipped potato crisps had lower oil contents compared with the untreated ones (the control). The lowest values (≈22% reduction) ware observed for samples pre-treated with Nacl solution, while dipping sugar solutions resulted in ≈27% reduction in oil content. The same trend was obtained by **Tran *et al* (2007)**, who found that pre-dried and dipped samples in sugar solution

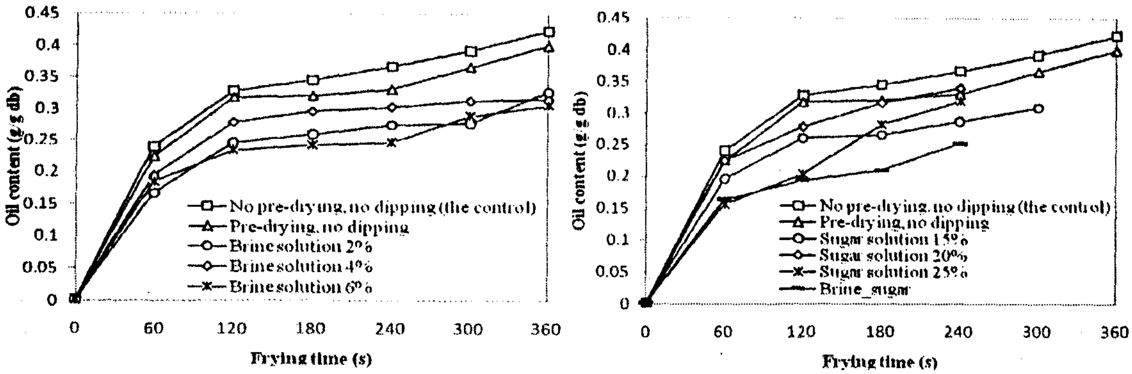

Fig. 1. Effect of pre-drying and pretreatments on oil uptake of potato crisps during frying process

before frying had lower oil contents (oil reduction of ≈30%) compared with untreated samples, while the Nacl soaking method only had 22.2% reduction in oil content. **Pedreschi *et al* (2007b)** reported that salt soaking of potato slices reduced oil absorption after frying at 180°C with 10% compared with blanched samples.

From a nutritional and healthy point of view this fact is very interesting since it has been demonstrated that the salt soaking process before frying could reduce acrylamide formation in potato chips in about 80% reduction at 160°C (**Pedreschi *et al* 2007a**).

Dana and Saguy (2006) proposed that higher oil uptake during extended frying is probably related to increased oil viscosity caused by polymerization reactions taking place in the degrading oil.

3.2. Moisture loss

Moisture content is an important parameter of quality control of fried potato crisps. Moisture content data of control, salt and sugar treated samples are shown in (**Fig. 2**). From the point of view of heat and mass transfer, the behavior of control, Nacl and sugar soaked potato slices was quite similar. The initial moisture content of potato after blanching was 5.67 g/g db (85 wt %) and the percentage of the final moisture content for the fried control sample was 2.2% (0.023 g/g db) at 6 min. of frying time, while it was lower for pre-dried, no dipping and also for salt & sugar treated samples (1.2 wt%). The same results were observed by **Tran *et al* (2007); Krokida *et al* (2001a) and Pedreschi *et al* (2007b),** who found that the good quality of potato crisps, could be attained when the moisture content was finished at 1.5 wt%.

The lowest moisture content values were given by the pretreatment with sugar solution followed by Nacl solution and combined salt-sugar solution as shown in (**Fig. 2**). The same trend was obtained by **Krokida *et al* (2001b)**.

3.3. The relationship of oil uptake and moisture loss

Figure (3) shows the relationship of oil uptake and moisture loss of control, salt and sugar pretreatment of potato slices. This relationship during immersion frying has been studied previously by **Tran *et al* (2007); Moyanoa and Pedreschi (2006) and Southern *et al* (2000)**. A linear moisture-oil relationship was also obtained in this study (**Fig. 3**). The data have also demonstrated that the initial moisture content (5.67 g/g db) and the final oil content of control samples (0.424 g/g db) were in the range shown by **Tran *et al* (2007)**. The coefficient of determination (R^2) of relationship between oil uptake and moisture loss was in the range of 0.80 to 0.978 for control and all pretreatments at different concentrations of salt and sugar solution.

3.4. Kinetics of oil uptake

First-order kinetics model was used to describe oil uptake of potato crisps during frying process at 180°C. **Fig. (4) shows** the use of this model for control, salt and sugar dipped potato crisps and **Table (1)** illustrates the reaction rate constant (κ) in s^{-1} and coefficient of determination (R^2).

The specific rate (κ) for control sample was 0.009 s^{-1} and for salt dipped samples ranged between 0.007 to 0.016 s^{-1} and for sugar dipped samples it was in the range of 0.01-0.017 s^{-1}. **Moyanoa and Pedreschi (2006)** found that the

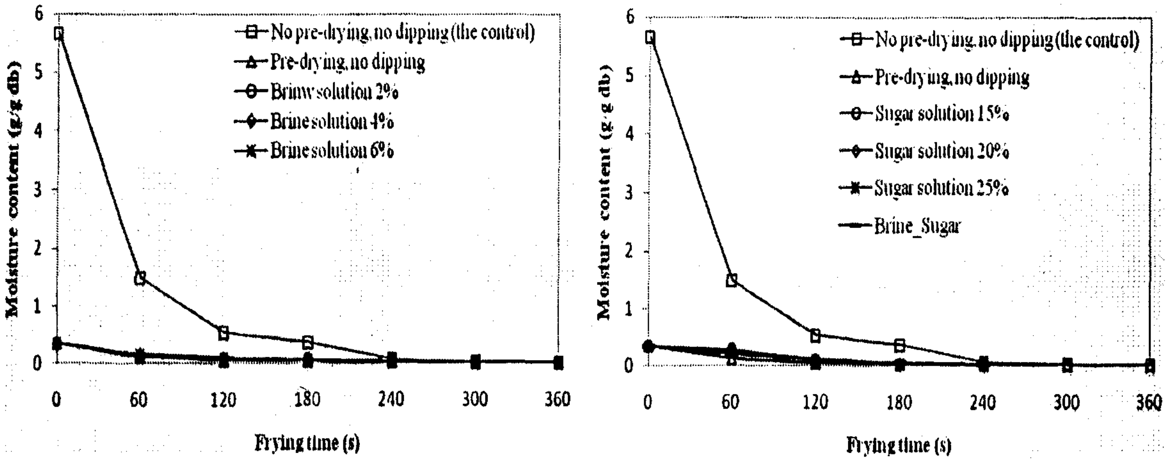

Fig. 2. Effect of pre-drying and pretreatments on moisture loss of potato crisps during frying process

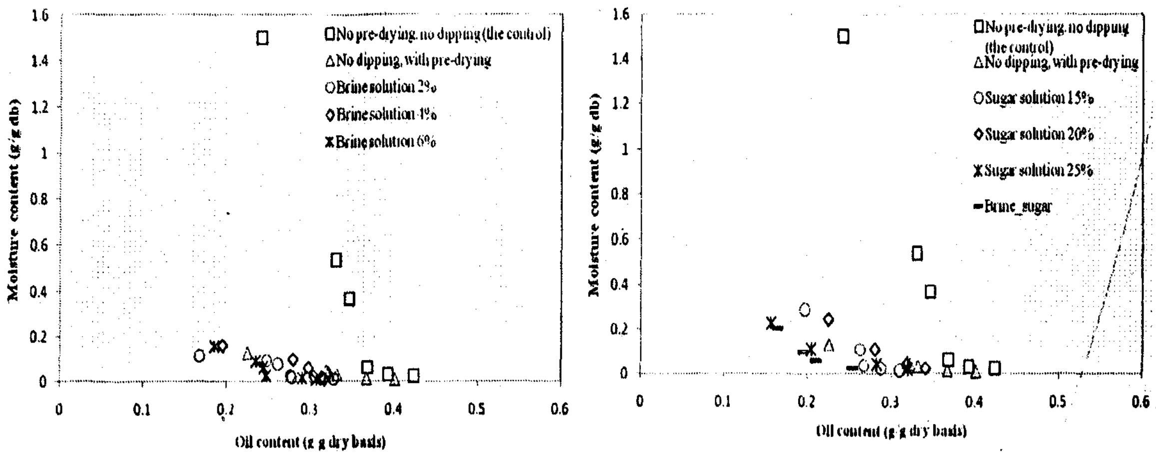

Fig. 3. Effect of brine and sugar pretreatments on the relationship of oil uptake and moisture loss for potato crisps

Table 1. Reaction rate constant (κ) values (s^{-1}) of oil uptake for control and pretreatment potato crisps during frying at 180 °C

Treatment	A	K	R^2
No pre-drying, no dipping (the Control)	0.058	0.009	0.954
Pre-drying, no dipping	0.048	0.008	0.864
Brine 2%	0.014	0.007	0.812
Brine 4%	0.243	0.016	0.962
Brine 6%	0.079	0.009	0.842
Sugar 15%	0.105	0.010	0.916
Sugar 20%	0.359	0.016	0.995
Sugar 25%	1.235	0.017	0.947
Brine & Sugar (2% & 20%)	0.153	0.008	0.985

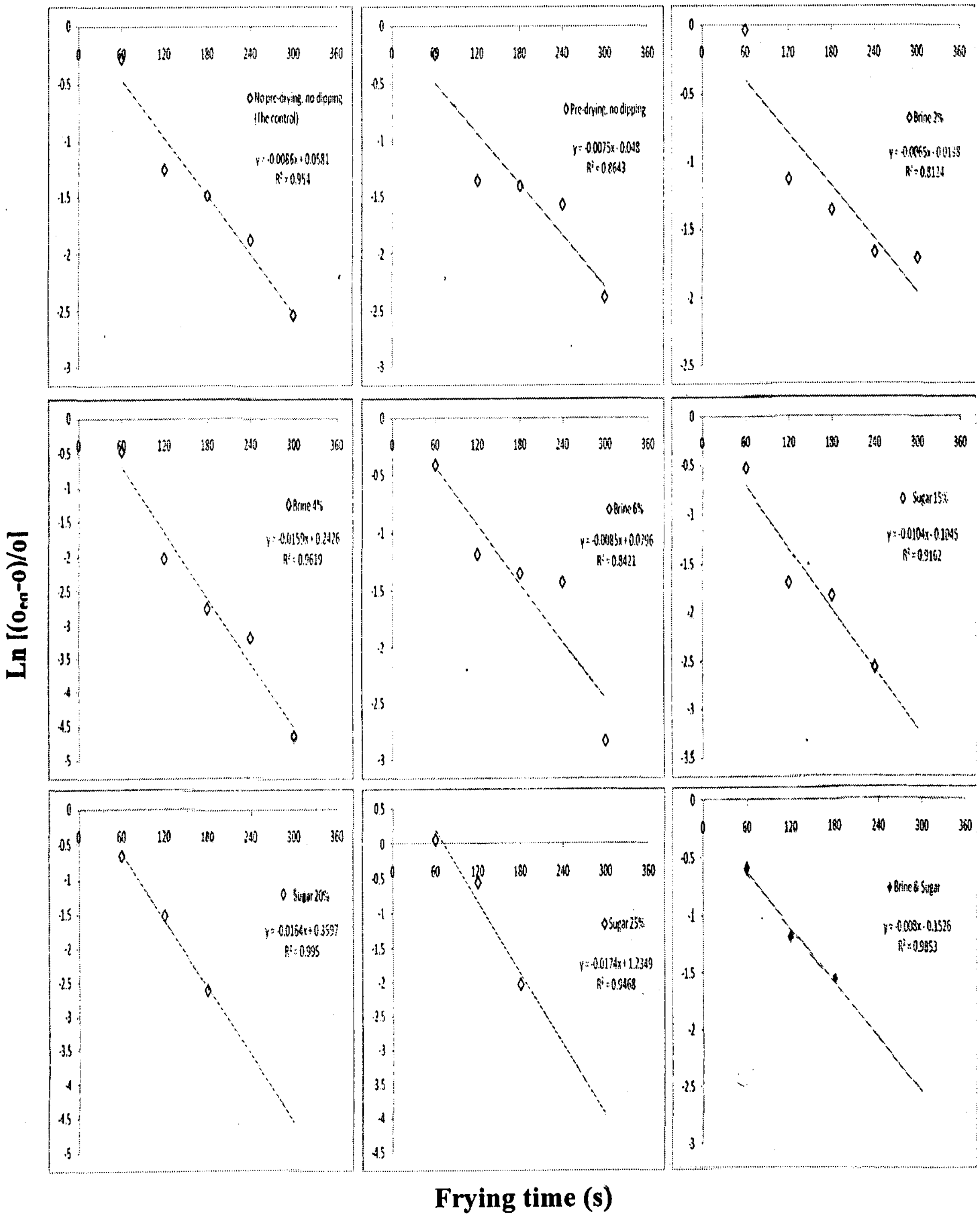

Fig. 4. First-order kinetics model for oil uptake of potato crisps during frying at 180 °C

reaction rate constant (κ) for control, blanched and blanched-dried samples were 0.06, 0.05 and 0.22 s^{-1}, respectively.

Durán ***et al*** **(2007)** reported that the specific rate (κ) values were 1.25 and 2.00 min^{-1} for control (blanched) and blanched-Nacl samples, respectively at 180 °C and the oil content at equilibrium values were 0.61 and 0.59 g oil/g db, respectively.

3.5. Kinetics of moisture loss

Fig. (5) illustrates the use of first order kinetics model for moisture loss of potato crisps during frying at 180°C. The results of parameter estimation (κ) for moisture content kinetics are summarized in **Table (2)**. The corresponding values of coefficient of determination (R^2) are also given in **Table (2)**. The reaction rate constant (κ) values ranged between 0.012 – 0.022 s^{-1} for pretreated potato crisps and the R^2 values ranged between 0.90-0.98 as shown in **Table (2)**. A similar results were found for the specific rate (κ) in potato slices **(Krokida** ***et al*** **2000 and Krokida** ***et al*** **2001b)**.

3.6. Color

Color experimental data are presented in **Fig. (6)**.

3.6.1. Lightness

As shown in **Fig. (6)**, the lightness (L) of potato crisps decreases due to the pre-drying process and the values of L ranged between 60 to 40 in pre-drying process. **Bunger** ***et al*** **(2003)** found that for French fried potatoes at frying time of 5 min., lightness values of 50 were obtained considered adequate in order to obtain an acceptable color.

The samples prepared with different concentrations of sugar solutions showed the lowest lightness values compared with the samples treated with Nacl solutions **(Fig. 6)**. "L" values trended lower as frying time increased. The same trend was observed by **Krokida** ***et al*** **(2001a)**, due to loss in glossity of the fried potato samples.

3.6.2. Parameter "a"

As shown in **Fig. (6)**, the "a" parameter of potato crisps was increased due to the browning reactions that take place during frying of the pretreated samples, reaching values in the range of -5 to 8 in salt treated potato crisps and in the range of -3.8 to 11.8 in sugar treated ones.

The sugar solution resulted in the highest "a" value, followed by salt solutions as expected since salt does not participate in browning reactions and parameter "a" trended higher as frying time increased. These results agree with the data obtained by **Krokida** ***et al*** **(2001a) and Bunger** ***et al*** **(2003)**.

3.6.3. Parameter "b"

The results for the "b" parameter are also presented in **Fig. (6)**. Higher "b" values mean more yellow color, which is desirable for a fried product. The salt solution resulted in the highest "b" values, reaching values in the range of 16 to 23 with different concentrations of salt solutions, while the sugar solution treatment gave the lowest "b" values (14 to 19). The same findings were observed by **Krokida** ***et al*** **(2001a)**. An overall consideration of the effect of pretreatments on color parameter showed that salt solutions results in the most acceptable, light colored and yellow products. **Pedreschi** ***et al*** **(2007a)** mentioned that soaking in Nacl lead to paler potato chips (lighter in color) than those of the control after frying.

3.6.4. The Color change (ΔE)

The total color change (ΔE) of potato crisps is shown in **Fig. (7)**. The color change was directly related to the frying time at different pretraetments. Obviously, the potato crisps with predried treatment and both salt and sugar dipping had greater change in color compared with the control samples. At the end of frying time, the ΔE values were 9.56, 20.56 and 25.52 for control, 2% salt pretreated and 15% sugar pretreated samples, respectively as shown in **Fig. (7)**. The same trend was observed by **Tran** ***et al*** **(2007)**.

3.6.5. Kinetics of Color change

Kinetics of the color change of the fried potato crisps has been shown to follow a simplified first-order model **(Table 3)**. The reaction rate constant (κ) values of control samples was 0.002 s^{-1} and at different concentrations of salt solutions, it ranged between 0.005 to 0.006 s^{-1} and recording values in the range of 0.009 to 0.011 s^{-1} for different concentrations of sugar solutions (higher values), with reasonable high coefficient of determination (R^2 were in the range of 0.794 to 0.995) as shown in **Table (3)**. **Tran** ***et al*** **(2007)** found that the

Table 2. Reaction rate constant (κ) values (s^{-1}) of moisture loss for control and pre-treated potato crisps during frying at 180 °C

Treatment	A	K	R^2
No pre-drying, no dipping (the Control)	0.305	0.022	0.948
Pre-drying, no dipping	0.334	0.012	0.904
Brine 2%	0.152	0.012	0.897
Brine 4%	0.045	0.013	0.941
Brine 6%	0.069	0.013	0.976
Sugar 15%	0.912	0.019	0.987
Sugar 20%	1.009	0.021	0.974
Sugar 25%	0.706	0.018	0.985
Brine & Sugar (2% & 20%)	0.213	0.014	0.997

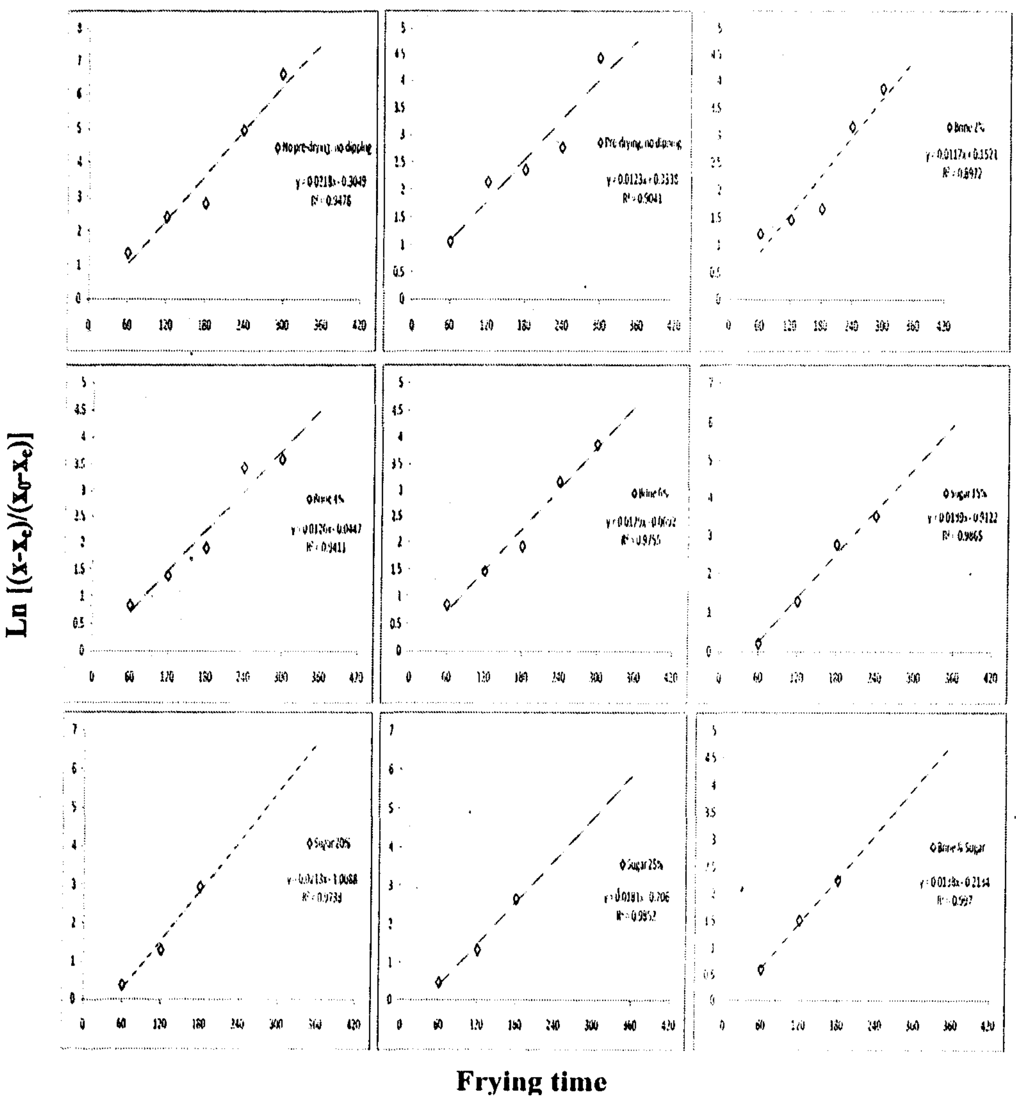

Fig. 5. First-order kinetics model for moisture loss of potato crisps during frying at 180 °C

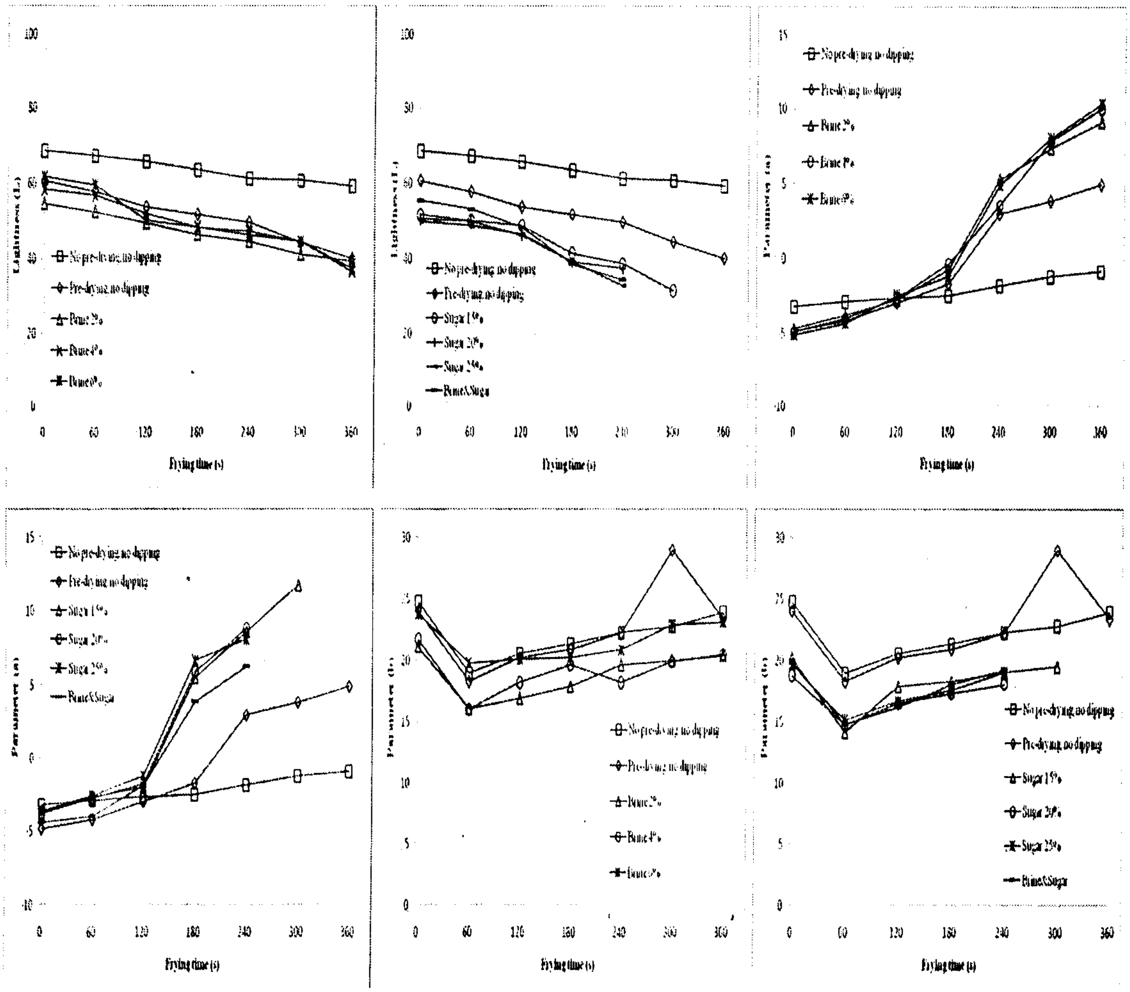

Fig. 6. Color changes versus frying time for potato crisps.

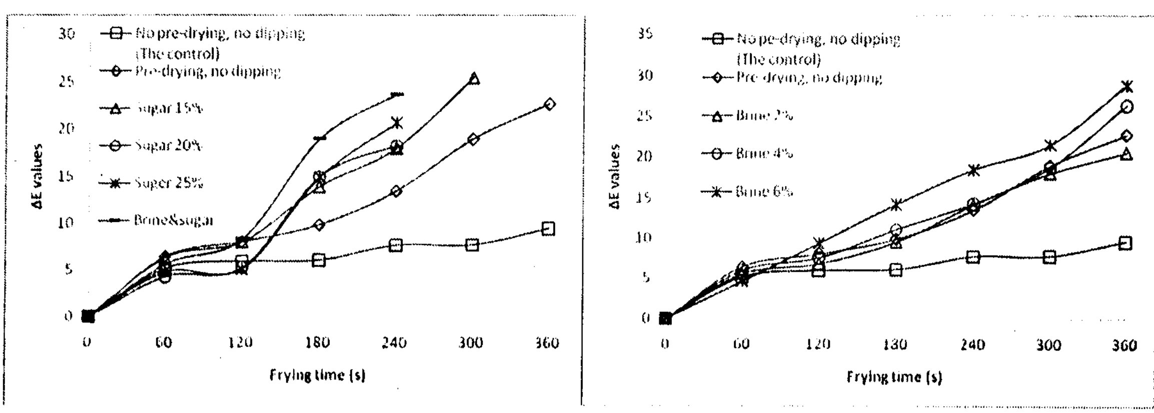

Fig. 7. Total color change in potato crisps during frying at 180 °C

Table 3. Values of reaction rate constant (κ) for color change of potato crisps during frying at 180 °C

Treatment	A	K	R^2
No pre-drying, no dipping (the Control)	0.719	0.002	0.918
Pre-drying, no dipping	1.569	0.005	0.987
Brine 2%	1.665	0.005	0.991
Brine 4%	1.789	0.005	0.995
Brine 6%	2.003	0.006	0.923
Sugar 15%	1.972	0.009	0.938
Sugar 20%	2.221	0.011	0.871
Sugar 25%	2.204	0.009	0.794
Brine & Sugar (2% & 20%)	2.126	0.010	0.961

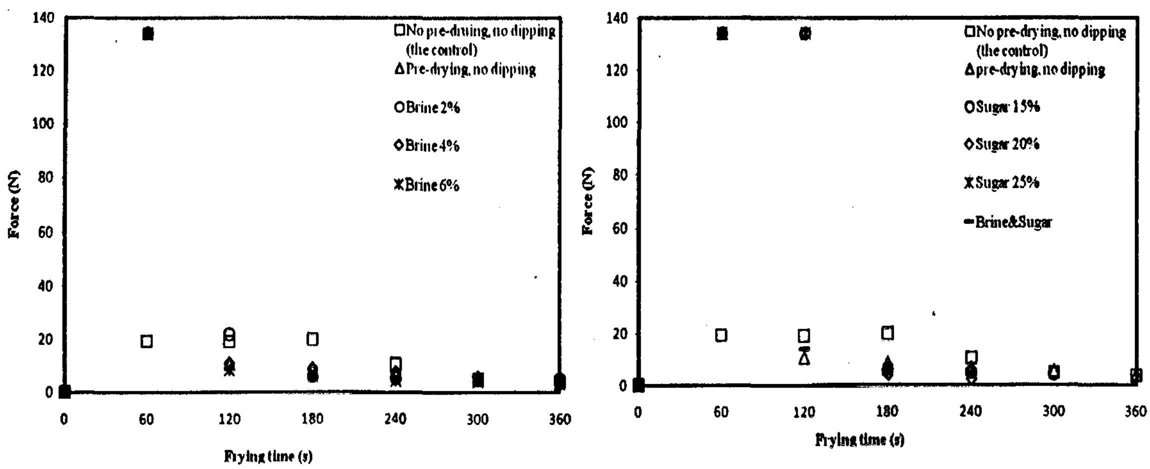

Fig. 8. Texture changes of potato crisps during frying at 180 °C

κ values of control, pre-drying with dipping and pre-drying without dipping were 0.006, 0.007 and 0.007 s^{-1}, respectively and the R^2 values were 0.82, 0.90 and 0.81, respectively.

3.7. Texture analysis

Texture of the control, different pretreated potato samples are shown in **Fig. (8)**. Peak force is defined as the force at which the punch penetrates the outer layer of the surface of fried potato crisps and could describe properly the crispness of fried potato crisps. The force to penetrate the upper crust decreased as frying time was increased from 1 to 6 minute. **Fig. (8)** indicating the beginning of the starch gelatinization and softening prior to the formation of a thick and rigid crust. A similar observation was found for texture changes of potato slices by **Pedreschi *et al* (2007b)** and **Bunger *et al* (2003)**.

CONCLUSION

Potato crisps dipped in a sugar solution followed by samples pretreated with salt solutions showed reduction in the oil content of the fried crisps. Also, pre-drying without dipping of the blanched samples produced fried crisps with less oil content than control. This procedure has been shown to be capable of reducing the oil uptake in the crisps during frying. There was a 27% and 22% oil reduction for sugar and salt pretreated samples respectively compared with the control samples. Moisture loss profiles of salt and sugar pretreated potato crisps showed almost no differences during frying at 180 °C.

Salt treated samples have the most acceptable color, while in sugar treated ones, a browing reactions takes place during frying resulting in more dark and red colored fried product. Both mass transfer phenomena (moisture loss and oil uptake) and color changes that take place during frying of potato crisps can be described by an empirical first order kinetic model. Salt and sugar pretreatments were the parameters that affect reaction rate constant (κ) of water loss, oil uptake and color changes during frying.

These findings open an interesting possibility in order to produce a healthier product introducing a simple soaking step into the potato fries processing line.

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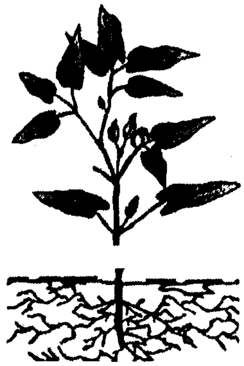

حوليات العلوم الزراعية
جامعة عين شمس ، القاهرة
مجلد(٥٣)، عدد (١)، ١٩٥-٢٠٦، ٢٠٠٨

خفض محتوى رقائق البطاطس المقلية من الزيت: دراسة حركيات فقد المحتوى الرطوبى وإكتساب المحتوى الزيتى والتغيرات اللونية أثناء عملية القلى

[١٦]

هانى إدريس خليل[١] - إيهاب صلاح عشوش[١]
١- قسم علوم الأغذية - كلية الزراعة - جامعة عين شمس - شبرا الخيمة - القاهرة - مصر

إستهدف هذا البحث دراسة خفض المحتوى من الزيت لرقائق البطاطس المقلية على درجة حرارة ١٨٠مْ بإستخدام عملية السلق والتجفيف المبدئى (العينة الضابطة) وإستخدام كل من معاملة النقع فى محاليل بتركيزات مختلفة من كلوريد الصوديوم (٢ ، ٤ ، ٦%) والسكروز (١٥ ، ٢٠ ، ٢٥%) . وقد وجد أن هذه المعاملات ذات تأثير فعال فى خفض المحتوى الزيتى لرقائق البطاطس.

وأظهرت النتائج المتحصل عليها إنخفاض فى المحتوى الزيتى بنسبة ٢٧% ، ٢٢% لكلا من المعاملة بمحاليل السكروز وكلوريد الصوديوم على التوالى، كما أوضحت نتائج جهاز هنتر لقياس الألوان إنخفاض قيم L وإرتفاع قيم a, b, ΔE لرقائق البطاطس أثناء القلى.

عند دراسة حركيات التغير فى المحتوى من الزيت والمحتوى الرطوبى وكذلك معدل التغير فى اللون وجد أن نموذج التفاعل من الدرجة الأولى أثبت أفضليته عند إستخدامه لدراسة حركيات التغير حيث كان ثابت معدل التفاعل للمحتوى الزيتى فى مدى يتراوح من ٠,٠١٧ - ٠,٠٠٧ لكل ثانية (حيث يتراوح معامل التقدير من ٠,٩٩٥ - ٠,٨٦)، أما بالنسبة لحركيات التغير فى معدل اللون تراوح معامل التقدير بين ٠,٩٩٥ - ٠,٨٧ وأوضحت شرائح البطاطس المقلية المعاملة مبدئياً بمحاليل السكروز إرتفاعاً فى قيم ثابت معدل التفاعل مقارنة بالمعاملة بمحاليل كلوريد الصوديوم. ولم يتضح من المعاملات المختلفة لشرائح البطاطس المقلية أى تغير فى التركيب أو القوام.

تحكيم: أ.د أحمد فريد السهريجى
أ.د عادل زكى محمد بديع