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Effects of pre-drying on the quality of frying oil and potato slices

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RESEARCH ARTICLE

Abstract

The effects of pre-drying on the quality of frying oil and potato slices were investigated. Potato slices were air-dried at 60 °C for 15, 30, 45, 60, 90, 120 min before frying. The pre-dried potato slices were deep-fried in sunflower oil at 180 °C for 5, 10, 13 min and sampled. For the oil sampling, the frying procedure was repeated five times using dried potato slices without oil replenishment. Oil samples were removed at the end of successive frying operations (13 min-1st, 39 min-3rd, 65 min-5th) and analysed. The moisture content, colour and oil intake of the potato slices and the colour, peroxide value, free fatty acid, fatty acid composition and viscosity of the oil samples were evaluated. Pre-drying treatment had a significant effect on the physicochemical properties of potato slices and frying oil. Pre-drying decreased the oil absorption. The oil content for the 5 min frying was found as 4.46% and 2.93%, respectively, for the control and 120 min pre dried samples. Free fatty acid levels and viscosity of the oil decreased depending on the pre-drying time. The highest level of free fatty acid (0.42%) was found at the end of the 5th frying operation in control samples. The viscosity of oil increased during frying. In control samples, the viscosity of oil was found 82.47 and 85.8 Pa s, respectively, at the 1st and 3rd frying operations. Pre-drying did not affect the fatty acid composition of the frying oil when compared with fresh oil.

Keywords*:* potato, drying, deep-frying, oil uptake, quality

1. Introduction

Potatoes are the fourth most important vegetable crops in the world in terms of consumption. Table stock (31%), frozen French fries (30%), chips and shoestrings (12%), and dehydrated items (12%) are the main utilisation of processed potatoes (Miranda and Aguilera, 2006). Potatoes are also used in the production of potato flour, and starch in developed countries. Fried potatoes constitute a significant portion of processed potato products. Deep-fat frying is one of the oldest and most popular food preparation methods.

Deep-fat fried food is very popular for consumers because of their desirable flavour, colour and crispy texture (Boskou *et al.*, 2006). Frying is the process of immersing food in hot oil at high temperatures ranging from 150 to 190 °C. Frying oil acts as a heat transfer medium and contributes to the texture and flavour of fried food. Frying time, food surface area, moisture content of the food, types of breading or battering materials, and frying oil influence the amount of absorbed oil by foods (Choe and Min, 2007).

Deep-fat frying produces desirable and undesirable flavour compounds, and changes the flavour stability and quality, colour, and texture of the fried food. The frying oil can deteriorate as a result of various complex physical and chemical reactions. As such, these reactions can cause volatile and nonvolatile compounds (Bensmira *et al.*, 2007; Karoui *et al.*, 2011). Most of the volatile compounds evaporate into the atmosphere with steam and the remaining volatiles in the oil undergo further chemical reactions or they are absorbed by fried food. The non-volatile compounds found in the oil change the physical and chemical properties of the oil and fried foods (Choe and Min, 2007).

Deep frying decreases the unsaturated fatty acids in the oil and increases foaming, colour, viscosity, density, specific heat, and contents of free fatty acids, polar materials, and polymeric compounds. Degradation of oil not only affects the usability and frying life of the oil, but may also contribute over time to health hazards, such as potential gastrointestinal disorders and mutagenesis in the human body (Dana and Saguy, 2001).

In deep fried potato products, both health and sensory aspects should be addressed to meet consumer demand. Consumer trends are moving towards healthier food and low-fat products, thus creating the need to develop technologies to reduce the amount of oil in the fried end-products (Ouchon *et al.*, 2003). There are alternative methods to the manufacturing of fried products with reduced fat, which are based on partial moisture removal before or after frying. The most commonly used methods are as follows: (1) conventional frying with premature removal of potatoes from the fryer at high moisture content (approximately 10%) and finishing the process by using superheated steam (Li *et al.*, 1999); (2) hot air and microwave finishing (Blau, 1965; Blau *et al.*, 1965; Smith and Davis, 1965); (3) pre-drying of potatoes before frying (Gamble and Rice, 1987; Gupta *et al.*, 2000; Krokida *et al.*, 2001d; Moyano *et al.*, 2002); and (4) osmotic pretreatment of potatoes by immersion or spraying with sugar solutions (Krokida *et al.*, 2001b).

Air drying can be used as a pre-treatment before the frying operations, and some studies have reported that the air drying significantly reduces oil absorption and improves texture in potato chips (Pedreschi and Moyano, 2005). Today's consumer expectations for better quality, safety and nutritional value have driven researchers to find out methods for improving food properties. Therefore, the purpose of the present study was to investigate the effects of pre-drying treatment over: (1) the colour quality and oil uptake of potato slices; and (2) the free fatty acid content, peroxide value, colour, viscosity and fatty acid composition of oil during frying. Sunflower oil was used for frying.

2. Materials and methods

Preparation of potato slices

Arya varieties of potatoes were used for this experiment. Potatoes were washed, peeled and sliced in the form of 10×10×30 mm. Drying pre-treatment was carried out in an air dryer at 60 °C. Potato slices were air dried at 60 °C for 15, 30, 45, 60, 90 and 120 min., respectively. Potato slices without pre-drying treatment were considered as the control variable.

Frying and frying oil sampling

Sunflower oil was supplied from a commercial market and used for the frying process. Table 1 shows some physical and chemical properties (viscosity, peroxide value, free fatty acid, fatty acid composition and colour parameters) of this fresh oil. Frying was carried out in an electronic fryer (model Serie F 48-RA; Tefal Minuto, Groupe Seb,

Table 1. Physical and chemical properties of fresh sunflower oil.

Properties	Sunflower oil
Viscosity (Pa s)	76.27±0.12
Peroxide value (PV, meq O_2/kg)	39.55±5.51
Free fatty acid (%)	0.19±0.00
L* value	95.88±0.01
a* value	-1.80±0.00
b* value	7.65±0.01

Istanbul, Turkey). 12 slices of pre-dried (control, 15, 30, 45, 60, 90, 120 min) potato samples were fried for 5, 10 and 13 min per sample. For each frying time, 4 potato slices were sampled and analysed. After the cooling of oil, 60 ml of oil was sampled and the remaining oil was used for the frying operations. This procedure was followed for five times without oil replenishment. Oil sampling procedures for the analysis were performed following cooling stages at the end of the 1st, 3rd and 5th frying operations.

Oil uptake

The oil contents of the potato slices were determined by the Soxhlet extraction method with petroleum ether (AOAC, 1990).

Moisture content

The moisture contents of the potato slices were measured by conventional drying method as described in the AOAC method (AOAC, 1990).

Peroxide value

The peroxide value was measured by using the iodometric titration method (AOAC, 1990). For this purpose, approximately 5 g oil was weighed into a flask (250 ml) and dissolved in 10 ml chloroform. Then, 15 ml acetic acid and 1 ml saturated potassium iodide (KI) were added and mixed. The mixture was left in the dark at room temperature for 5 min. Distilled water (75 ml) was added and the mixture was shaken vigorously. 1 m of the prepared starch solution (1%) was added and the resulting solution was titrated with 0.01 mol/l sodium thiosulfate ($Na_2S_2O_3$) until the colour became clear. The peroxide value was calculated using the following equation:

$$\text{Peroxide value} = \frac{[(V_1 - V) \times N]}{M}$$

Where, V_1 is the amount of $Na_2S_2O_3$ used for the titration of the sample (ml), V is the amount of $Na_2S_2O_3$ used for the titration of the blank (ml), N is the normality (mol/l) of $Na_2S_2O_3$ and M is the weight of the sample (g) (Gordon, 1991). Peroxide value is expressed as milliequivalents (meq) of active oxygen per kilogram of oil. Peroxide value analysis was repeated for 5 times.

Free fatty acid content

The free fatty acid values of the samples were examined by biochemical analysis according to AOAC (AOAC, 1990). For this purpose, 5-10 g oil was weighed into a flask and dissolved in 100 ml ethanol-diethyl ether (1:1, v/v). A few drops of phenolphthalein (1%) were added and the resulting solution was titrated with 0.1 mol/l sodium hydroxide (prepared in ethanol) until the colour became permanently pink. The free fatty acid value was calculated using the following equation:

$$\text{Free fatty acid \%} = \frac{V \times 2.82}{M}$$

Where, V is the amount of NaOH used for titration of the sample (ml); 2.82 is the gram molecules of oleic acid; M is the weight of the sample (g). FFA% was expressed as oleic acid (Matalgyto and Al-Khalifa, 1998). Free fatty acid content analysis was repeated for 5 times.

Colour measurement

The colour values of the potato and oil samples were analysed by using an automatic colorimeter (Lovibond RT Series Reflectance Tintometer; Lovibond, Amesbury, UK). The Lovibond tintometer gives three values: L*, a*, b*. The L* values measure the level of black to white (0-100), a* shows the degree of red to green (+ = red and − = green), and b* shows the degree of yellow to blue (+ = yellow and − = blue). Colour measurement of samples was repeated for 5 times.

Viscosity

The viscosity values of the oil samples were determined at 25 °C using a strain/stress controlled rheometer (RheoStress 1; Thermo Scientific Haake, Karlsruhe, Germany) equipped with a temperature-control unit (Haake, Karlsruhe, Germany), and a cone-plate configuration with a cone radius of 35 mm and a gap of 1.00 mm between the cone and the plate. Viscosity measurements were repeated for 5 times.

Fatty acid composition

The fatty acid composition of the samples was determined according to the Agilent application catalogue (David *et al.*, 2005). The oil (100 mg) was saponified with 100 µl 2 N KOH, and 3 ml hexane was added to the mixture. The mixture was then vigorously shaken with a vortex for 1 min, and then centrifuged at 6,000 rpm for 5 min. The fatty acid compositions were analysed by gas chromatography (Agilent 6890; Agilent, Chandler, AZ, USA), equipped with a flame ionisation detector and 100 m × 0.25 mm HP-88 column. The injector temperature was 250 °C. The oven temperature was kept at 103 °C for 1 min, and then programmed from 103 to 170 °C at 6.5 °C/min, from 170 to 215 °C for 12 min at 2.75 °C/min, and finally, at 230 °C for 5 min. The carrier gas was helium with a flow rate of 2 ml/min; the split rate was 1/50. Fatty acid composition was identified by comparison of retention times to known standards. The results were expressed as g of fatty acid/100 g total fatty acids (%). The analysis of fatty acid composition was repeated for 2 times.

Statistical analysis

Statistical analyses were performed by using the Statistical Analysis System software. The effects of drying time and frying time on the oil uptake, colour and moisture content of potato slices were determined by using two-way analysis of variance. Also, the effects of pre-drying and frying time on the quality of oil samples were determined by using two-way analysis of variance (SAS Institute, 2001). Significant differences between the means were further analysed by using the Tukey test. Post-hoc power analysis was conducted by using the statistical software Sigmaplot 11.0 (Systat Software GmbH, Erkrath, Germany).

3. Results and discussion

The experimental moisture and oil content values are shown in Table 2 and 3. The pre-drying treatment reduced the initial moisture content of the potato slices (Table 2). Increased length of pre-drying, therefore, implies that a smaller amount of free moisture is available for removal during frying.

Table 2. The moisture content of the potato slices after frying (%).[1]

Drying time (min)	Frying time (min)		
	5	10	13
0	67.46±0.53^{Aa}	61.14±0.67^{Ba}	50.71±0.96^{Ca}
15	63.10±0.20^{Ab}	57.81^{a}±0.29^{Bb}	49.64±0.33^{Cba}
30	62.26±1.07^{Ab}	56.17±0.24^{Bb}	47.34±0.32^{Cb}
45	58.57±1.34^{Ac}	55.23±0.13^{Abc}	43.89±0.07^{Bc}
60	54.07±0.90^{Ad}	51.93±0.08^{Bc}	43.85±0.12^{Cc}
90	49.97±0.17^{Ae}	48.09±0.67^{Bd}	42.96±0.01^{Cc}
120	45.13±0.21^{Af}	42.58±0.53^{Be}	41.11±0.05^{Bc}

[1] Values within a column with different lowercase letters were significantly different at *P*<0.05; values within a row with different capital letters were significantly different at *P*<0.05.

Table 3. The oil content of the potato slices after frying (%).[1]

Drying time (min)	Frying time (min)		
	5	10	13
0	4.46±0.53^{Ba}	9.8±0.67^{Aa}	11.29±0.96^{Aa}
15	4.81±0.20^{Ba}	4.36±0.29^{Bb}	6.99±0.33^{Ab}
30	4.27±1.07^{Aa}	4.12±0.24^{Ab}	5.56±0.32^{Acb}
45	4.00±1.34^{Aa}	3.97±0.13^{Ab}	5.61±0.07^{Acb}
60	4.04±0.90^{Aa}	3.75±0.08^{Ab}	5.43±0.12^{Acb}
90	3.57±0.17^{Ba}	3.69±0.67^{BAb}	5.31±0.01^{Ac}
120	2.93±0.21^{Ba}	3.45±0.53^{Bb}	5.08±0.05^{Ac}

[1] Values within a column with different lowercase letters were significantly different at P<0.05; values in the row with different capital letters were significantly different at P<0.05. Post-power of performed test with alpha = 0.050: for dry: 1.000; for fry: 1.000; for dry×fry: 1.000.

As shown in Table 3, pre-drying decreased the oil content of the potato slices during frying. However, increasing the frying time caused more oil uptake by the potato slices. According to statistical analyses, pre-drying had a significant effect on the oil uptake and moisture content of potato slices (P<0.05). Many factors affect the oil uptake of foods, such as pre-drying treatment, frying time, surface treatments, crust size and initial interfacial tension (Dobarganes *et al.*, 2000; Moyano and Pedreschi, 2006; Pedreschi and Moyano, 2005; Ross and Scanlon, 2004). During frying, inner moisture of food converts to steam and causes a pressure gradient. As the surface gets dry, the oil penetrates the food (Innawong, 2001). Decreased moisture content results in lower oil uptake of food (Krokida *et al.*, 2001b; Pedreschi and Moyano, 2005). Rimac-Brnčić *et al.* (2004) indicated that oil deterioration during frying increases the oil uptake of food. These reasons may explain the increased fat percentage of the potato slices during frying in our study. Similar results were found by Daniel *et al.* (2005), and Gupta *et al.* (2000). As the pre-drying time increased, the oil content of the potato slices decreased (Table 3). Krokida *et al.* (2001b), Pedreschi and Moyano (2005), Moyano *et al.* (2002) and Gupta *et al.* (2000) reported that the pre-drying process reduces oil uptake during the frying of potatoes. Song *et al.* (2007) studied the effect of vacuum microwave pre-drying on the quality of fried potato chips. They showed that vacuum microwave pre-drying significantly reduced the oil uptake of potato chips. Many researchers have investigated the lowering of oil uptake by using hydrocolloids, such as cellulose derivates, gellan gum, arabic gum, alginate and carrageenan (Falguera *et al.*, 2011; Garcia *et al.*, 2002; Garmakhany *et al.*, 2008; Rimac-Brnčić *et al.*, 2004). These coating materials prevent moisture evaporation and reduce the oil uptake due to their strong water holding capacity and high firmness (Pinthus *et al.*, 1992, 1995).

The experimental data for the colour parameters of the potato samples are presented in Figure 1A-C. The L* value of the potato slices decreased significantly due to the pre-drying treatment (Figure 1A). It increased during the frying process, reaching values that ranged between 50.30 and 72.75. The L* value of the potato slices increased as the frying time increased. A similar trend for L^* has been found for the frying of potato strips and potato slices (Krokida *et al.*, 2001b). Figure 1B shows the a* values for pre-dried and fried potato slices. The chromatic parameter a* of the pre-dried potato slices increased considerably during frying due to browning reactions. Colour is one of the important quality parameters of fried potatoes (Pedreschi *et al.*, 2007). The fried potato colour is associated with the amount of reduction in its sugar content (Krokida *et al.*, 2001a). The a* value increased during the frying in a range between -1.75 to 7.52. Similar results were found by Krokida *et al.* (2001a,b) and Song *et al.* (2007). Figure 1C represents the b* values. The b* parameter of the samples

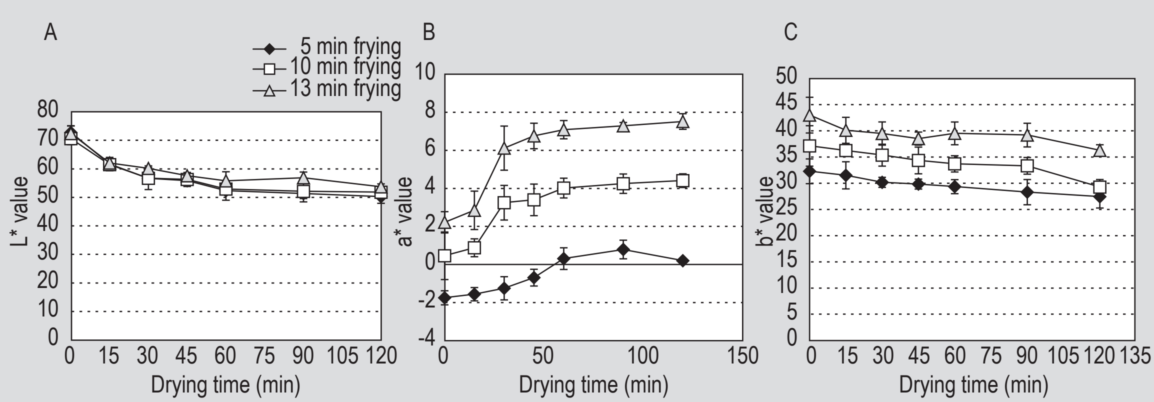

Figure 1. Colour parameters of the potato slices. (A) L* values present the level of black to white (0-100), (B) a* values the degree of red to green (+ = red and − = green), and (C) b* values the degree of yellow to blue (+ = yellow and − = blue).

decreased due to the browning reactions that took place during the drying process. Decrease in b* parameter was more remarkable in the 13 min than the 5 min of frying. The b* values were found as 43.02 and 32.3 for 5 min and 13 min frying, respectively, for the control samples. However, the b* values were increased with the increase in frying time. 120 min pre-dried samples that were fried for 5 and 13 min, the b* values were found as 27.45 and 36.29, respectively. This clearly indicated that the frying time significantly affects the b* values of the samples (Table 4) (P<0.05). The potato variety used for frying also affects the colour parameters of the potato slices during the frying (Krokida *et al.*, 2001c; Pedreschi *et al.*, 2007). Paul and Mittal (1996) examined how degradation of canola oil affected the colour of fried products. They concluded that there was a high correlation between the oil degradation and colour of fried products. Krokida *et al.* (2001c) indicated that colour parameters of potato slices were affected by oil temperature and sample thickness. According to the results of colour parameters, it may be concluded that by increasing redness, and decreasing yellowness and lightness, the pre-drying treatment before frying has a negative effect on the colour of potato slices.

The viscosity increased as the frying time increased. In fact, the viscosity increased from 82.4 to 90.03 Pa s (i.e. about 8.47% increase) for 65 min frying, 78.1 to 84.7 Pa s (i.e. about 7.79% increase) for 39 min frying, and 77.03 to 82.1 Pa s (i.e. about 6.18% increase) for 13 min frying when the drying was varied from 15 to 120 min, respectively. Pre-drying decreased the viscosity of oil that was sampled from 45 min pre-dried frying potato slices (Table 5). In addition, the statistical analysis results indicated a significant difference between the viscosity of untreated (without pre-drying treatment) and treated (pre-drying treatment) samples during frying (Table 5) (P<0.05). In deep-frying operations, the viscosity of the oil changed significantly with frying time and temperature. This change must be taken into consideration when designing frying operations so that product quality could be controlled. The viscosity of the oil is strongly affected by its degradation products as a result of the formation of dimers, trimers, polymers, epoxides, alcohols and hydrocarbons, all of which contribute to the increase in viscosity (Stevenson *et al.*, 1984). The oil is a real heat transfer medium during the frying process. It may thicken and become more viscous as it is heated. Thickening reduces the rate of heat transfer and it takes longer to cook and to colour the food. The viscosity of the frying oil is an important factor in determining the total volume of oil sticking in large cavities in the crust of the food product. Higher viscosity results in a larger volume of oil in the fried food (Clark and Serbia, 1991).

Determination of free fatty acid appears to be the method favoured by many operations for quality control evaluation of used frying oil (Sumnu and Sahin, 2008). The content

Table 4. Colour parameters of potato slices.[1]

Drying time (min)	Frying time (min)								
	5 min frying			10 min frying			13 min frying		
	L*	a*	b*	L*	a*	b*	L*	a*	b*
0	72.75±2.39^{Aa}	-1.75±0.37^{Cd}	32.30±2.36^{Ba}	70.61±2.08^{Aa}	0.46±1.25^{Bb}	37.14±3.86^{Ba}	72.38±2.67^{Aa}	2.22±0.56^{Cb}	43.02±3.41^{Aa}
15	61.71±2.34^{Ab}	-1.56±0.35^{Cdc}	31.53±2.59^{Cba}	61.51±1.69^{Ab}	0.88±0.47^{Bb}	36.26±0.84^{Ba}	62.05±1.68^{Ab}	2.85±1.01^{Ab}	40.12±2.48^{Aba}
30	56.64±3.87^{Acb}	-1.25±0.61^{Cdc}	30.19±0.96^{Cbac}	56.71±1.62^{Ac}	3.25±0.91^{Ba}	35.38±2.09^{Ba}	60.17±0.90^{Acb}	6.12±1.16^{Aa}	39.51±2.21^{Aba}
45	55.88±2.04^{Acd}	-0.69±0.44^{Cbc}	29.86±0.95^{Cbac}	56.30±1.38^{Ac}	3.40±0.83^{Ba}	34.37±2.55^{Ba}	57.58±1.19^{Acd}	6.76±0.67^{Aa}	38.34±1.25^{Ab}
60	52.37±3.34^{Acd}	0.31±0.57^{Ca}	29.37±1.34^{Cbac}	52.94±0.60^{Acd}	4.02±0.52^{Ba}	33.72±1.55^{Ba}	55.80±3.21^{Ad}	7.09±0.48^{Aa}	39.54±2.17^{Aba}
90	51.35±1.74^{Bcd}	0.79±0.49^{Ca}	28.32±2.41^{Cbc}	52.11±3.66^{Bd}	4.25±0.51^{Ba}	33.34±1.59^{Bba}	56.89±2.02^{Acd}	7.29±0.18^{Aa}	39.21±2.26^{Aba}
120	50.30±2.36^{Bd}	0.20±0.06^{Cba}	27.45±2.16^{Bc}	51.82±0.90^{BAd}	4.41±0.36^{Ba}	29.28±1.45^{Bb}	53.70±1.05^{Ad}	7.52±0.41^{Aa}	36.29±1.08^{Ab}

[1] Values within a column with different lowercase letters were significantly different at P<0.05; values within a row with different capital letters were significantly different at P<0.05.

Table 5. Viscosity of frying oil (Pa s).[1]

Drying time (min)	Frying time (min)		
	13	39	65
0	82.47±0.06^{Ba}	86.07±0.15^{Aa}	85.8±0.10^{Ae}
15	78.13±0.06^{Be}	78.10±0.00^{Bg}	87.00±0.10^{Ac}
30	77.23±0.06^{Cf}	83.33±0.15^{Bc}	86.33±0.06^{Ad}
45	77.03±0.06^{Cg}	80.23±0.06^{Bf}	82.4±0.17^{Ag}
60	81.6±0.10^{Bc}	81.57±0.06^{Be}	84.8±0.10^{Af}
90	81.3±0.06^{Cd}	82.7±0.10^{Bd}	87.3±0.06^{Ab}
120	82.10±0.00^{Cb}	84.7±0.00^{Bb}	90.03±0.06^{Aa}

[1] Values within a column with different lowercase letters were significantly different at $P<0.05$; values within a row with different capital letters were significantly different at $P<0.05$.

Table 6. Free fatty acid content of frying oil (%)[1]

Drying time (min)	Frying time (min)		
	13	39	65
0	0.23±0.00^{Cb}	0.36±0.00^{Ba}	0.42±0.01^{Aa}
15	0.27±0.02^{Aa}	0.28±0.00^{Ac}	0.31±0.00^{Acb}
30	0.28±0.04^{Aa}	0.28±0.00^{Ac}	0.30±0.02^{Ac}
45	0.28±0.00^{Ca}	0.34±0.00^{Bb}	0.39±0.00^{Aa}
60	0.28±0.00^{Ba}	0.28±0.00^{Bc}	0.34±0.00^{Ab}
90	0.22±0.00^{Ab}	0.23±0.00^{Ad}	0.24±0.02^{Ad}
120	0.20±0.00^{Bb}	0.22±0.00^{Ad}	0.22±0.00^{Ad}

[1] Values within a column with different lowercase letters were significantly different at $P<0.05$; values within a row with different capital letters were significantly different at $P<0.05$.

of the free fatty acids in the oil increased with continued frying (Table 6). While the amount of free fatty acids in 120, 90 and 30 min pre-dried samples rose to about 0.02%, the highest amount was found at 0.42% for samples which were not pre-dried. Similar results were obtained by Chung *et al.* (2004) and Man and Hussin (1998). In fact, the statistical analysis results shown in Table 5 revealed the existence of a significant difference between the pre-dried and undried samples. Drying had a significant effect on the free fatty acid content of frying oil (Table 6) ($P<0.05$). During frying, the oil is continuously and repeatedly used at elevated temperatures (160-180 °C) in the presence of air and moisture. Drying has a reducing effect on the moisture content of the food because it decreases the amount of water that goes from food to oil. This also reduces the formation of free fatty acids by hydrolysis. Hydrolysis occurs at relatively high temperatures and in an aqueous medium by the formation of glycerol and fatty acid from the triglyceride molecule (Maskan, 2003).

Peroxide value is an important parameter from the point of view of rancidity and toxicology. Food lipid oxidation products such as peroxides, the free radicals involved in their formation and propagation, malonaldehyde, and several cholesterol oxidation products are reported to promote atherosclerosis and coronary heart disease (Subramanian *et al.*, 2000). The effect of pre-drying and frying time on peroxide values of oil is shown in Figure 2. Statistical results showed that pre-drying had a significant effect on peroxide values (Figure 2) ($P<0.05$). However, frying for 13 and 39 min showed no significant difference in the peroxide values of the frying oil. Pre-drying caused irregular ups and downs on the peroxide value. The peroxide values at the end of the 1st, 3rd and 5th frying operations for the control samples were found as 37.64, 65.53, and 51.20 Pa s, respectively. During frying, peroxide forms hydroperoxides which are not generally stable during deep-frying. Therefore, they are not a good index for measuring oxidation (Damy and Jorge, 2003; Maskan and İ. Bağcı, 2003). Hydroperoxide, which is a major oxidation product, decomposes to secondary products, such as esters, aldehydes, alcohols, ketones, lactones and hydrocarbons (Choe and Min, 2007). These results may be explained by the decomposition of the peroxides to secondary products or by higher peroxide formation rate rather than breaking them down (Saguy and Dana, 2003).

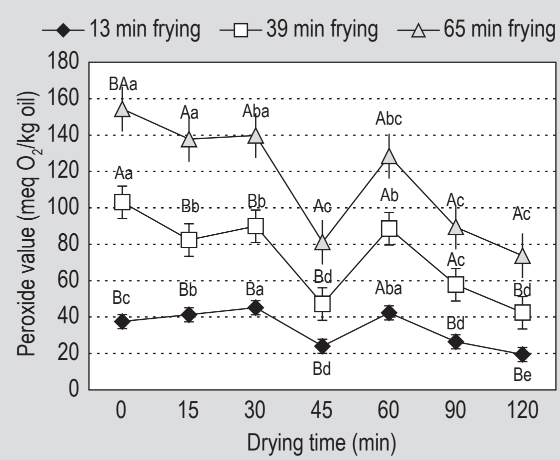

Figure 2. Peroxide value of frying oil (meq O_2/ kg oil). Significant differences in the same style of bar are shown by different small letters (a-e; comparison between drying time; *P*<0.05). Significant differences in the different style of bar are shown by different capital letters (A-B; comparison between frying time; *P*<0.05).

The fatty acid composition of the sunflower oil (used in frying) is presented in Table 7. Palmitic, stearic, elaidic and eicosapentaenoic acid percentages increased at all frying times for control samples ($P<0.05$). The palmitic acid percentage was found as 6.3 and 6.42% at the end of the 1st and 5th frying operations, respectively. Stearic acid composition also increased from 3.26 to 3.32% for the undried samples. High temperature, air and moisture cause autooxidation during the frying process, result in breakage of the double bonds of the unsaturated fatty acids, and form small molecular weight components. Autooxidation reactions are reported to be responsible for palmitic acid increase (Onal-Ulusoy *et al.*, 2005). The linoleic acid content decreased in all types of pre-drying treatments during the frying process. The proportion of linolenic acid decreased by 3.47 and 1.00%, respectively, in 90 min pre-dried and undried samples for 39 min frying. Frying for a long time significantly increased the amount of elaidic acid (Figure 3) ($P<0.05$). The trans-fatty acid content of frying oil is important because high intakes of trans-fatty acids have been recognised as a risk factor for coronary heart disease (Kannel *et al.*, 1986). Recent studies have showed a link between consumption of elaidic acid and risk of cardiovascular disease (Mozaffarian *et al.*, 2004; Oh *et al.*, 2005). During frying, elaidic acid content increased as the frying time increased. The increase in elaidic acid content was more remarkable at the 1st and 3rd frying. However, at the 5th frying, there were irregular ups and downs. Also, pre-drying did not cause significant changes on elaidic acid level. Several studies reported that elaidic acid level increased slightly depending on frying temperature and time (Bansal *et al.*, 2009; Tsuzuki *et al.*, 2010). Continuous frying and higher temperatures promote the formation of trans-fatty acids due to exchange of fatty acids between the fried food and the oil (Saguy and Dana, 2003). The formation of elaidic acid level did not exceed 5 mg/g oil and consumption of one portion of fried potatoes has a little importance on trans-fatty acid intake (Romero *et al.*, 2000).

The lightness of frying oil changed significantly due to pre-drying treatment (Figure 3A). The L* value of the oil samples decreased as the frying time increased. However, The L value did not regularly increased as the pre-drying time increased. The L* values of the 120 min pre-drying, 13 and 39 min oil samples were almost the same as the L* values of fresh oil at 95.87, 95.86 and 95.88, respectively. The colour of fresh oil is normally very light yellow (Warner and Eskin, 1995). According to our results, the colour of frying oil was nearly the same as the fresh oil even though potato slices were fried for 13 and 39 min. As the frying time increased, the a* parameter increased dramatically for the same drying time (Figure 3B). The b* parameters

Table 7. Fatty acid composition of frying oil (%)

Frying time (min)	Drying time (min)	Proportion (relative percentage)											
		$C_{14:0}$	$C_{16:0}$	$C_{16:1}$	$C_{18:0}$	$C_{18:1}$	$C_{18:1}$(trans)	$C_{18:2}$	$C_{20:0}$	$C_{20:1}$	$C_{18:3}$	$C_{22:0}$	$C_{20:5}$
0	0	0.07	6.26	0.12	3.22	37.03	0.62	51.09	0.26	0.13	0.18	0.75	0.27
13	0	0.07	6.30	0.12	3.26	37.34	0.65	50.64	0.26	0.12	0.18	0.77	0.28
	15	0.07	5.93	0.13	3.54	36.22	0.57	51.95	0.27	0.14	0.17	0.72	0.29
	30	0.07	5.92	0.13	3.48	36.00	0.62	52.18	0.28	0.14	0.17	0.73	0.29
	45	0.08	5.92	0.13	3.50	35.96	0.71	52.10	0.27	0.14	0.18	0.72	0.28
	60	0.08	6.14	0.14	3.53	35.88	0.72	51.54	0.27	0.14	0.18	0.73	0.28
	90	0.07	6.51	0.13	3.36	35.32	0.75	52.21	0.27	0.13	0.19	0.78	0.29
	120	0.07	6.33	0.12	3.27	37.30	0.75	50.55	0.26	0.12	0.19	0.75	0.28
39	0	0.09	6.51	0.13	3.32	37.58	0.61	50.13	0.27	0.12	0.19	0.76	0.28
	15	0.07	5.96	0.13	3.52	36.17	0.73	51.81	0.28	0.14	0.17	0.73	0.28
	30	0.07	5.96	0.13	3.51	36.11	0.74	51.85	0.28	0.14	0.17	0.74	0.29
	45	0.08	5.95	0.13	3.50	36.06	0.75	51.92	0.27	0.14	0.18	0.73	0.28
	60	0.08	5.98	0.13	3.52	36.13	0.74	51.80	0.28	0.14	0.17	0.74	0.29
	90	0.07	6.35	0.12	3.29	37.46	0.69	50.40	0.27	0.12	0.19	0.76	0.28
	120	0.07	6.40	0.13	3.30	37.61	0.75	50.13	0.26	0.13	0.19	0.75	0.28
65	0	0.07	6.42	0.12	3.32	37.71	0.72	49.99	0.27	0.12	0.19	0.77	0.29
	15	0.07	6.03	0.13	3.55	36.40	0.61	51.58	0.28	0.14	0.18	0.74	0.29
	30	0.08	6.12	0.12	3.54	36.50	0.72	51.49	0.27	0.14	0.17	0.74	0.26
	45	0.08	6.00	0.13	3.53	36.26	0.75	51.64	0.28	0.14	0.18	0.74	0.29
	60	0.08	6.02	0.13	3.55	36.27	0.75	51.51	0.28	0.14	0.18	0.75	0.29
	90	0.08	6.40	0.12	3.31	37.61	0.75	50.09	0.27	0.12	0.19	0.77	0.28
	120	0.07	6.44	0.12	3.31	38.02	0.52	49.99	0.26	0.12	0.19	0.73	0.24

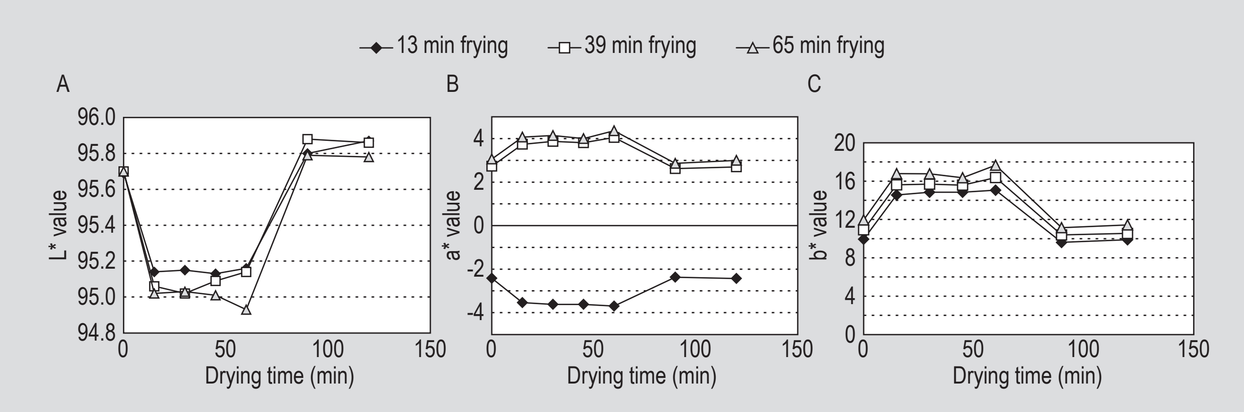

Figure 3. Colour parameters of frying oil. (A) L* values present the level of black to white (0-100), (B) a* values the degree of red to green (+ = red and − = green), and (C) b* values the degree of yellow to blue (+ = yellow and − = blue).

of oil samples increased significantly during the frying process (Figure 3C). As the frying time increased, this phenomenon became more intense. Pre-drying and frying time had a significant effect on the colour parameters of frying oil ($P<0.05$). Colour is an index that is commonly used to determine quality. Oil colour may be influenced by a number of factors including the type and amount of food being fried. Frying oil colour changes from yellow to orange-brown with continuous frying. This change occurs as a result of oxidation, polymerisation and other chemical modification (Takeoka *et al.*, 1997; Tan *et al.*, 1985). The compounds that are formed as a result of oil degradation during frying cause darkening and result in an increase in a* and b* values. Man *et al.* (2010), Jaswir and Man (1999) and Irwandi *et al.* (2000) reported that the colour of frying oil was darkened due to oxidation and the formation of browning pigments when potato chips were fried.

Conclusions

The pre-drying effects on the quality of frying oil and potato slices were examined in this study. Oil uptake in fried potato slices diminished as the drying time increased, whereas increased frying times promoted oil uptake. Pre-dried potato samples presented oil content much lower than the control sample (34% decrease for 5 min frying). The colour deterioration that took place during drying affected the colour of fried products, which became browner. Frying time becomes a key point during frying due to the fact that it affects the oil uptake and colour of potato slices, the peroxide value, free fatty acid content, colour and fatty acid composition of frying oil. The lightness of the potato slices decreased, a* values of the potato slices increased and b* value of the potato slices decreased by the pre-drying treatment. The viscosity of the frying oil increased as the frying time increased whereas it was decreased by pre-drying treatment. The content of the free fatty acids of the frying oil increased with continued frying. The peroxide value showed irregular ups and downs during frying. The fatty acid profile did not alter by drying.

In conclusion, the drying pre-treatment decreases the oil content of potato slices, while the quality of potato slices can be controlled by choosing the appropriate drying time. In today's society the consumption of deep-fat fried foods is increasing. The possible health hazard effects of fried foods may be reduced by pre-drying the potato slices before frying.

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