Producing Lower-Calorie Deep Fat Fried French Fries Using Infrared Dry-blanching as Pretreatment

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Abstract

The main objectives of this work were to study the suitability of using infrared (IR) heating as a dry-blanching pretreatment prior to frying and to investigate its potential to reduce the oil uptake in French fry production. It was observed that by using IR heat complete inactivation of polyphenol oxidase enzyme could be achieved in 3 min with 4.7% moisture loss for 9 mm French fries. Following IR dry-blanching, the samples were fried at 146, 160, and 174°C for 1, 3, 5, and 7 min. At the end of 7 min frying, compared to unblanched samples, dry-blanched samples had 37.5, 32 and 30% less total oil at the frying temperatures of 146, 160 and 174°C, respectively. The final moisture contents of unblanched and dry-blanched samples were between 50-60% after 7 min frying. The L*a*b* color values of both unblanched and dry-blanched samples decreased initially and then increased as the frying progressed. The sensory evaluation revealed that panelists mostly favored the IR dry-blanched French fries in terms of taste, texture, color and appearance.

Highlights

- Infrared heat successfully inactivated polyphenol oxidase enzyme in 3 min.
- Oil uptake of French fries was significantly reduced.
- No significant difference in sensory properties of infrared dry-blanched and unblanched fries.

Introduction

Potatoes, available all around the world, provide a substantial contribution to the daily supply of minerals, vitamins, carbohydrates and proteins. One of the most popular processed potato products is French fries which are appreciated because of their characteristic taste and texture (Van Loon, Linssen, Legger, Posthumus & Voragen, 2005). French fries are among the major commercial fried foods and account for 44% of processed potatoes in the US (Moreira, Castell-Perez & Barrufet, 1999). The globally expanding quick-serve restaurants (QSRs) are common places for consumption of French fries. In the most popular QSRs a large serving of French fries could contain 519±30 calories, where 45.5±1.7% calories come from the fat (USDA, 2011). It has been evidenced by many epidemiological studies that the consumption of foods rich in oil causes obesity and development of many cardiovascular diseases (Kaiyala, Prigeon, Kahn, Woods, & Schwartz, 2000; Buettner, Schölmerich, & Bollheimer, 2007; USDA & USDHHS, 1990). Therefore, due to increased health awareness, the quality of food is judged by the consumers not only on the basis of color, odor, and taste, but also on the fat content.

Many QSRs seek ways to produce lower oil containing French fries and as a result, there has been a strong incentive to introduce technologies that could produce French fries with lower oil contents and with desirable sensory quality characteristics. In recent years, several new techniques have been proposed to reduce oil uptake in fried potatoes, such as dipping in sugar or salt solutions (Bunger, Moyano & Rioseco, 2003; Nonaka, Sayre & Weaver, 1977; Tran, Chen & Southern, 2007), coating with cellulose derivatives (Garcia, Ferrero, Bertola, Martino & Zaritzky, 2002; Kelleher & Williamson, 2005; Khalil, 1999; Rimac-Brncic, Lelas, Rade & Simundic, 2004), or vacuum frying (Garayo & Moreira, 2002; Troncoso & Pedreschi, 2009). However, although these proposed methods have reduced the oil content to some extent, they have found limited application due to use of synthetic chemicals, high energy consumption or unsatisfactory final product quality.

Infrared radiation is energy in the form of a band of electromagnetic wave, which is more efficient in heat transfer than convection and conduction. The efficient heat transfer can provide a high heating rate and reduce the heating time to reach the desired product temperature (Chou & Chou, 2003; Jones, 1992; Sandu, 1986). Several studies have shown that treating foodstuffs with infrared yielded higher quality products (Hebbar, Vishwanathan & Ramesh, 2004; Sharma, Verma & Pathare, 2005; Yang, Bingol, Pan, Brandl, McHugh & Wang, 2010; Zhu & Pan, 2009; Zhu, Pan, McHugh & Barrett, 2010). Up to now, the only employment of infrared technology during French fry production was reported by Lloyd, Farkas and Keener (2004) who used infrared heating to produce finished product from the deep fat par-fried French fries. The overall acceptability and final quality of French fries were reported to be comparable to that from traditional immersion frying methods.

Strong (1968) and Moyano and Pedreschi (2006) showed that the dehydration of potato strips after blanching reduced the oil uptake during frying. Furthermore, Pan and McHugh (2006) illustrated that during infrared blanching partial dehydration could also be achieved. Since infrared blanching does not need water or steam, it is also called infrared dry-blanching. Moreover, due to above-mentioned efficiencies in heat delivery, which could save time and energy, infrared technology possesses a potential for blanching potato strips prior to frying while reducing the oil uptake. However, so far, the application of infrared blanching during French fry production and its effects on final French fry quality have not been studied. Therefore, the objectives of the present work were to (i) investigate the effectiveness of infrared dry-blanching on enzyme inactivation; (ii) study the oil uptake and color change of infrared dry-blanched potato strips under different frying conditions; and (iii) evaluate the sensory quality of the French fries.

Materials and methods

Materials

Potatoes (Russet Burbank) were provided by Washington State Potato Commission. They were stored in a cold room (9±1 °C, 85±3 % relative humidity) and were taken out at least 12 h prior to experiments. The potatoes were washed and hand peeled. A French fry cutter (French Fry Cutter, Progressive International Corp., Washington, USA) was used to obtain square strips with cross section of 9.43±0.43 mm from the parenchymatous region of the potato tubers. Immediately after cutting, the strips were dipped into water mainly to prevent enzymatic browning reactions and also to remove the surface starch. The initial moisture contents (MCs) of strips before and after dipping into water were 78.75±0.20 and 82.1±0.6% (w.b.), respectively (AOAC, 1984).

Blanching pretreatment

Blanching pretreatment was done prior to deep fat drying using a pilot scale catalytic infrared device with double-sided heating (Catalytic Industrial Group Inc., Independence, KS). Infrared intensity was measured as 11080 W/m^2 using Ophir FL205A Thermal Excimer Absorber Head (Ophir Optronics Inc., Wilmington, MA). The potato strips were heated from both bottom and top for various time periods, 30, 60, 90, 120, 150, and 180 s. The samples after blanching treatment were frozen immediately for enzyme inactivation analysis. The surface and center temperatures of potato strips were measured using type T thermocouples, (response time < 0.15 s), and were recorded every 1 s with a data logger thermometer (HH147, Omega Engineering Inc., Stamford, CT, USA). Temperature measured just beneath the surface of potato strips was considered to be the surface temperature. Each experiment was repeated at least 5 times.

Polyphenol Oxidase Assay

To analyze the heating effect on polyphenol oxidase (PPO), a major enzyme that could cause browning in potatoes, the unblanched (control) and infrared dry-blanched potato strips were thawed and then were homogenized with chilled phosphate buffer solution (0.1 M, pH 6.0) in a ratio of 1:10 in a blender (Warring 38BL54 LB10, Waring Laboratory & Science, CT, USA) for 3 min. The homogenate was centrifuged at 12,000 rpm for 10 min, and stored in an ice bath until being assayed. The activity of PPO was measured by using spectrophotometer (UV-1700, Shimadzu, Kyoto, Japan) following the method of Espin, Morales and Varon. (1995). One unit of PPO activity was defined as an increase of 0.001 unit of absorbance per min.

Frying

A commercial deep-fat fryer (Professional Deep Fat Fryer, Euro-Pro Corporation, West Newton, USA) was used for the frying tests. The fryer was filled with 3.5 L of soybean oil and potatoes-to-oil ratio was maintained at 1:30 w/v. The fryer was preheated for approximately 1 h prior to frying experiments and the frying oil was discarded after 10 h of use. Only the samples blanched for 3 min were used for frying since PPO was completely inactivated. Infrared dry-blanched and unblanched samples were fried at 146, 160, and 174°C for 1, 3, 5, and 7 min. At the end of frying, the fryer basket was shaken for approximately 10 s and an additional 2 min draining was applied to remove the excess oil on the French fry surface. The samples were allowed to cool at room temperature for further analysis. A random experimental design was employed and all experiments were run in triplicate.

Total Oil Content Determination

Total oil content (TOC) was measured using the Soxhlet extraction method (AOAC, 1995). Samples were dried to a constant weight in a convection oven at 70°C for at least 12 h prior to extraction. The dehydrated French fries were ground in a blender (Warring 38BL54 LB10, Waring Laboratory & Science, CT, USA) for 2 min and were extracted by *n*-hexane for 3 h in a Soxhlet extractor. The *n*-Hexane was recovered under vacuum at 40°C by a rotary evaporator (Büchi Labortechnic AG, Flawil, Switzerland). To further remove the possible residual *n*-hexane the oil was left in a convection oven at 80°C for 1 h and then sample was weighed to determine the oil gained. TOC is expressed as g oil/g dry matter.

Color Analysis

Color is considered as an important indicator for the acceptability of French fries by consumers. For each experiment the surface colors of at least 5 samples were measured using a colorimeter (Minolta Chroma Meter CR-200, Minolta Co., Ltd., U.S.A.). For each sample the average of 8 readings along a randomly chosen face were measured and reported in CIE L*a*b* color space. The experiments were done in triplicate.

Sensory evaluation

In separate research, we have observed that the French fries produced with the industrial procedure (Sanz, Primo-Martín & Vliet, 2007), including water blanching (70°C, 14 min), air drying (60°C, 5 min), par-frying for 1 min and finish frying for 3 min at 174 °C, had MC of approximately 57 % (w.b.). The French fries had the characteristic golden-brown color when the values of a* and b* were approximately -0.8 and 15, respectively. These MC and color values were used as reference for ideal French fries. Since the required times to reach the aforementioned a*-value and the MC were similar compared to the required time to reach the b*-value, the required frying times for producing sensory evaluation samples at different frying temperatures were obtained from the average frying times to reach the a*-value and MC and are presented in Table 1.

A sensory panel evaluation was carried out for the finished fries for each frying temperature. The sensory attributes were evaluated by a total of 77 panelists. The panelists were asked whether there were differences between blanched and unblanched French fries in terms of taste, texture, color, appearance and overall. Regardless they see a difference or not, panelists were required to choose either of the treatments as their preference.

Statistical analysis

The differences between blanched and unblanched French fry color, moisture and oil content data were analyzed by Analysis of Variance (ANOVA) using Minitab® (Release 14, Minitab Inc., PA, USA) at a significance level of α=0.05. The sensory data were analyzed using binomial distribution test by using the BINOMDIST built-in function in MS Excel (Microsoft Co. Ltd., Redmond, WA, USA) to determine any significant difference.

Results and Discussion

Infrared dry-blanching

The temperature profiles of the surface and center of potato strips under infrared treatment are presented in Fig. 1. Similar to conventional blanching, in the early stage of infrared blanching surface temperatures were found to be slightly higher than the center temperatures due to high heat delivered by infrared radiation to the surface layers which then were transferred to the center with the conduction mechanism. Due to partial shielding effect of the tray on the strips, the bottom surface temperature of potato strips rose slower than the top surface and center temperatures after 90 s. Unlike conventional blanching, after approximately 100 s of infrared treatment the center temperatures of potato strips rose slightly faster than their surface temperatures due to moisture losses at the surface layers and possibly due to changes in surface properties of the potato strips, such that swelling and slight baking of the of top surface were visually observed. It was also observed that the surface and center temperatures increased to slightly above 100°C at the end of infrared heating which could be due to dried surface and vapor pressure generated in the center, respectively.

Unlike the other blanching methods, the infrared dry-blanching combines blanching and drying into one single step, wherein the process has been named as simultaneous infrared dry blanching and dehydration by Pan and McHugh (2006). It was observed that the complete inactivation of PPO was achieved in approximately 3 min with only 4.7% moisture loss (w.b.). Therefore, the samples blanched for 3 minutes were used for further studies. It can also be seen from Fig. 1 that significant inactivation of PPO mainly occurred when the center and surface temperatures were higher than 60°C, which is in accord with the findings of Zhu and Pan (2009) for inactivation of PPO in apple slices under IR heating.

Moisture and oil contents of finished French fries

As was expected, longer frying times and higher frying temperatures led to lower moisture contents for French fries (Fig. 2). Within the frying time and temperature range of this study, two-way ANOVA revealed that frying temperature and time significantly affected ($P < 0.05$) the moisture contents of both control and blanched samples. These findings are in agreement with other authors (Garayo & Moreira, 2002; Moyano & Pedreschi, 2006).

The total oil contents of all French fry samples generally increased with the increase of frying time and frying temperature (Table 2) and with the decrease of moisture content (Fig. 3). For control samples, it was also observed that except one data point, namely 160°C 1 min, for the same frying time there were no significant ($P > 0.05$) differences between oil contents of French fries fried at 146 and 160 °C. However, at 174°C for all frying times the oil contents were significantly higher ($P < 0.05$) than those of 146 and 160°C. Moreover, inverse, almost linear, relationships were found between moisture and oil contents (Fig. 3) of control samples, with coefficients of determination of 0.98, 0.99 and 0.94 for 146, 160 and 174°C, respectively.

Significant oil uptake of infrared blanched samples took place within the first minute of frying (moisture contents less than 70%); such as, 72.5, 77.9 and 72.1% of the total oil uptake at 146, 160 and 174°C, respectively. Then the oil uptake rate was much slower during the rest of frying process. This is in accord with Moyano and Pedreschi (2006) who also found that significant oil uptake of blanched and pre-dried samples occurred within 1 and 3 min of frying at 120 and 150°C, respectively. This observation is also in agreement with the findings of Toma, Leung, Augustin and Iritani (1986) who observed that compared to untreated samples, partially (surface) frozen potato strips absorbed similar or more amount of oil during par frying.

The high oil absorption rate at the initial frying stage could be mainly due to dry-surface resulted from infrared dry-blanching. Compared the unblanched samples, which had higher moisture contents, due to reduced water vapor pressure during frying the dry surface could allow oil to quickly penetrate to the layers close to the surface of French fries. Therefore blanched samples had higher oil contents at the initial stage of frying compared to unblanched samples. During infrared blanching, the formation of an elastic whitish skin was observed when the surface temperature was higher than

60°C. Moreover, Pan, Shih, McHugh and Hirschberg (2008) showed that IR pre-treated and then freeze-dried banana slices (5 mm thick) had higher crispness than those processed only by freeze-drying. The authors related the higher crispness to the crust formation and structural changes caused during IR pretreatment. It is also reported that gelatinization of starch reduced the oil uptake during frying (Pedreschi and Moyano, 2005) and it is known that gelatinization of potato starch ranges from 65 to 75°C depending on moisture content. O'Connor, Fisk, Smith and Melton (2001) also found that after finish frying the outer layers of French fries absorbed significantly more oil compared to its inner core. Therefore, it could be concluded that the reduced oil uptake of infrared blanched samples in the later stages of frying was due to both gelatinization of the inner core and the formation of the crust which together protected the inner layers from absorbing oil and was also due to the formation of the elastic whitish skin which decreased the diffusion rate of oil. In this study only two sides of the potato strips were directly exposed to infrared emitter; however, it is expected that more oil reduction in finished French fries could be achieved if all four major sides are exposed infrared emitters to form similar skins and crusts.

Compared to unblanched samples blanched samples had significantly lower ($P < 0.05$) total oil contents after 7 min of deep-fat frying. At the end of 7 min frying, infrared blanched samples had 37.1, 32.8 and 30.2% less oil compared to control samples at 146, 160 and 174°C, respectively. This is similar to what Moyano and Pedreschi (2006) found that blanching and convective pre-drying of potato strips prior to frying reduced the total oil uptake at the end of the frying process.

Color of infrared blanched and control French fries

Figure 4 (a-f) shows the changes in L*, a*, and b* values of unblanched and blanched samples at different frying times and temperatures. The color of French fries is formed as a result of Maillard reaction which's extent is dependent on the frying time and temperature (Márquez & Añón, 1986). Although we have used parenchymatous region of potato tubers, it was observed that color distribution along the strips were not uniform, especially at longer frying times and higher frying temperatures, which could be due to heterogeneous distribution of reducing sugars in potato tissue (Talburt, Schwimmer & Burr, 1987; Thompson, Love, Sowokinos, Thornton & Shock, 2008).

At all frying temperatures, for both blanched and unblanched samples, we have observed that there was a slight initial decrease in the L* values in the first 1 min of frying; however, the L* values increased as the frying continued (Fig. 4, a and b). In literature, the L* values of French fries is reported to either decrease (Márquez & Añón, 1986) or increase that is preceded by a slight initial decrease, (Krokida, Oreopolou, Maroulis & Marinos-Kouris, 2001a; Krokida, Oreopolou, Maroulis, & Marinos-Kouris, 2001b) during the initial stages of frying and then to become constant as the frying proceeded.

The initial decrease in L* values could be due to either development of a micro-ridges or -pores on the surface, which can cause the light to scatter differently, thus causing a lower L* value. It was reasoned by Sotome, Takenaka, Koseki, Ogasawara, Nadachi, Okadome et al. (2009) that changes in surface reflectance properties of potato tubers during super heated steam blanching caused a decrease in L* values, because the authors used reflected light in the color measurement. Similarly the colorimeter used in this study also uses reflected light to measure the color values of objects. Moreover, Krokida, Oreopoulou and Maroulis (2000) showed that during frying the porosity of French fries increases. Vitrac, Trystram and Raoult-Wack (2000) reported that a large porous structure was formed inside the cassava slices after 1 min frying at 160°C. In accord with the rationale of these findings, we first measured the L* value of untreated potato strip, 60.59±0.53, and then the surface of potato strip was punctured randomly many times with a needle (diameter, 0.93 mm). The potato strip was dried at 60°C for 3 min and then the strip was dipped in oil for 1 min. It was seen that L* value decreased significantly ($P < 0.05$) to 58.48±0.16. In another experiment, we dipped the untreated potato strips in oil and found that there was no significant difference ($P > 0.05$) in L* due to merely dipping in oil. Therefore, the initial decrease in L* value could mainly be due to the change of surface characteristics of French fries in the initial stages of frying.

For French fries, consumers mostly expect golden-brown color (Jensen, 2011). The +a* and +b* values are indicators of the redness and yellowness of the product, respectively. Higher +b* values and lower +a* values are desirable for French fries. Similar to L* values, except one treatment of blanched samples fried at 160°C, the a* values decreased within the first min of frying (Fig. 4 c and d) which was possibly due to removal of air between the cells that led to a change in the surface reflecting properties (Lau, Tang & Swanson, 2000; Brewer, Klein, Rastogi and Perry, 1994). As the frying continued due to possible conversion of chlorophyll to pheophytins the a*-value increased. In most cases, for the same frying time the higher frying temperatures led to significantly ($P < 0.05$) higher a* values for both unblanched and blanched samples. Compared to L* and a* values, the b* values considerably increased after 1 min of frying (Fig. 4, e and f.) which could be due to increase in concentration of carotenoids at the layers close to the surface as the frying progressed. The initial decrease in b* value could be due to leaching of carotenoids into oil. This rationale is in accord with assumptions of Sotome, Takenaka, Koseki, Ogasawara, Nadachi, Okadome et al. (2009).

Many authors showed that as the frying progresses the thickness of crust formed on the surface increases (Du Pont, Kirby & Smith, 1992; Ziaiifar, Courtois & Trystram, 2010). Therefore, as the crust thickness increases, which is mainly formed of oil, the concentration of dry matter components of potato could also be increasing which is resulting in an increase of a* and b* values as the frying continues.

Sensory quality evaluation

Table 1 shows the oil and moisture contents of finished fries, fried for a certain time to achieve a similar product characteristics of targeted of a MC of nearly 57 % and an a* value of approximately -0.8, used for sensory evaluation at different frying temperatures. On average, infrared blanched samples had 33.4% less oil than the unblanched samples.

The probability values of sensory attributes such as taste, texture, color and appearance of French fries and in the case of a statistical significant difference ($P < 0.05$) between unblanched and blanched samples, the percentage of panelists preferring blanched samples are given in Table 3. It is seen from Table 3 that at 174°C the texture, color and appearance of blanched samples were significantly different than those of unblanched samples wherein more than half of the panelists preferred blanched French fries. At all frying temperatures there were significant differences in textural properties and except 160°C frying temperature more than 50% of the panelists favored the texture of IR blanched samples due to their crunchier texture. There was no significant difference ($P > 0.05$) between taste and color of blanched and unblanched samples at 146°C.

Although at all frying temperatures the total oil contents of blanched samples were less than the unblanched samples, at 160°C the appearance of blanched samples was less appealing to the panelists than the control samples due to the oily appearance of surface. However, since the oil could be loosely attached to the surface of French fries the oily appearance of French fries could be eliminated by using mechanical shakers. We have experimentally observed that shaking the fryer pan for 180 s decreased the total oil content by 11.73% compared to 10 s shaking. The sensory evaluation at 3 different frying temperatures revealed that IR technology mostly improved the taste, texture and color of the French fries.

Conclusions

This study showed that infrared heating was an effective method for blanching of regular cut fries. Moreover blanching potato strips with infrared heat prior to deep fat frying significantly reduced the total oil content of French fries. The results of sensory evaluation revealed that blanching potato strips with infrared yielded a desirable taste, texture and color to the French fries, and furthermore panelists mostly preferred infrared blanched French fries. This research demonstrated that blanching of potato strips with infrared would produce lower-calorie French fries.

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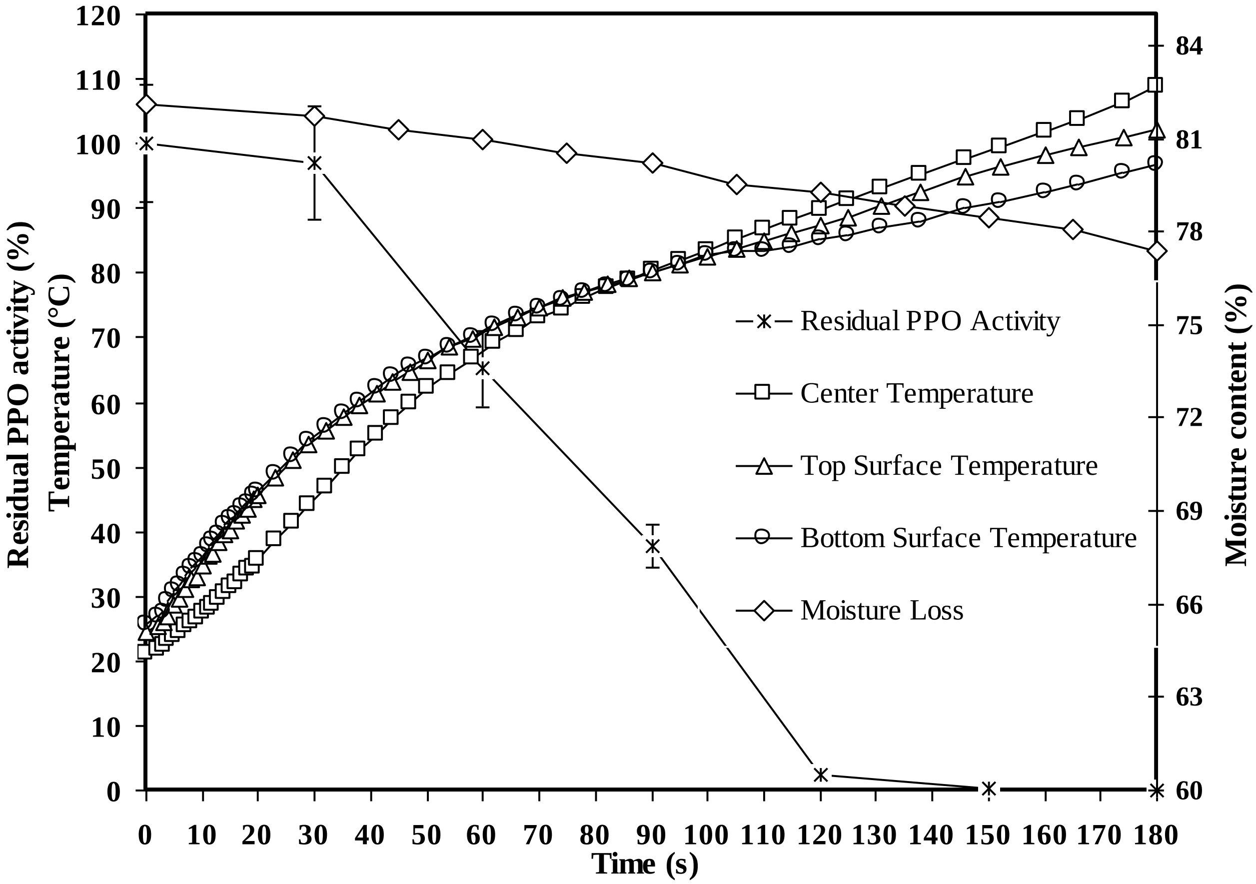

Figure 1. Residual PPO activities, temperature profiles and moisture loss of infrared dry-blanched potato strips

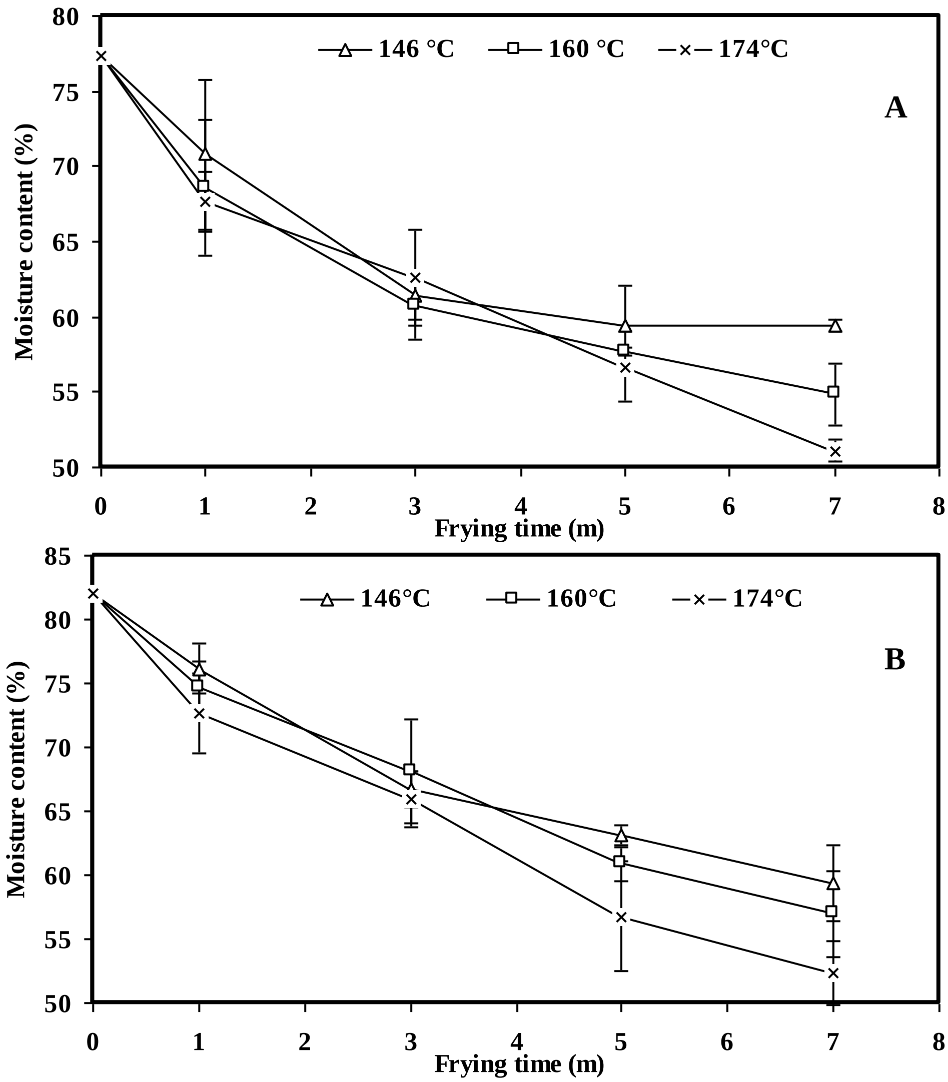

Figure 2. Moisture contents of a) infrared blanched and b) unblanched (control) French fries

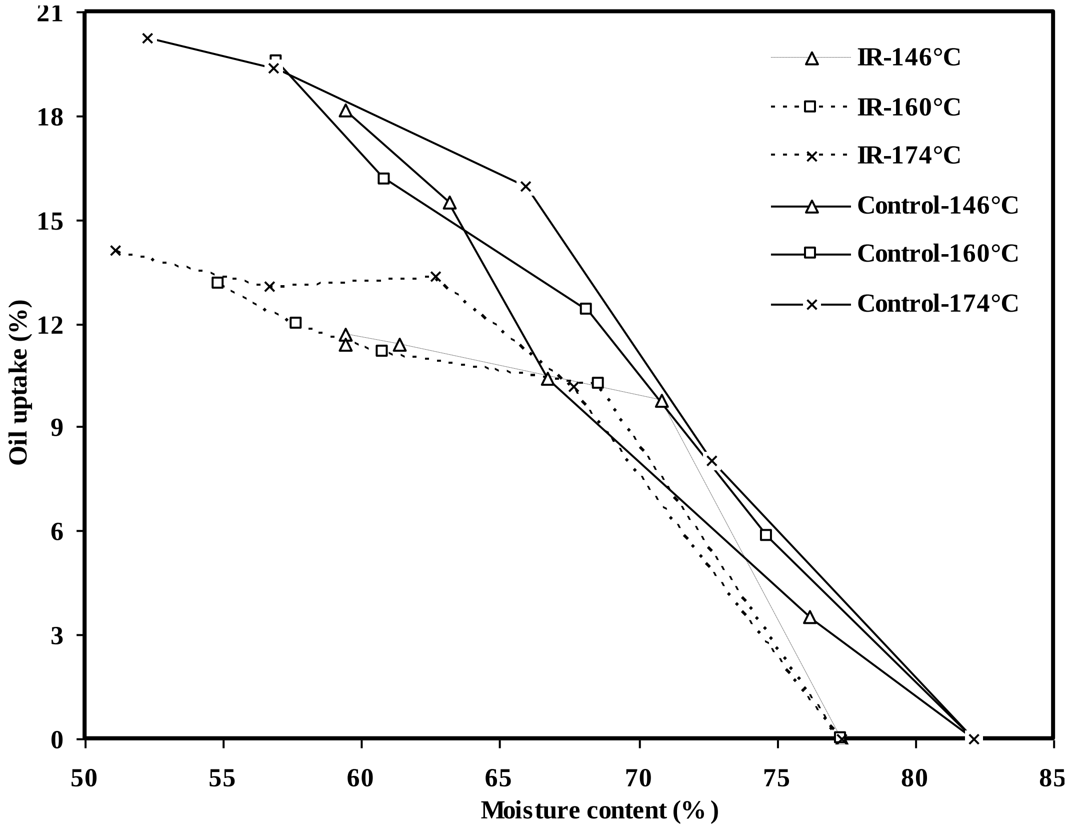

Figure 3. Relationship of oil content to moisture of infrared dry-blanched (dotted lines) and control (solid lines) French fries

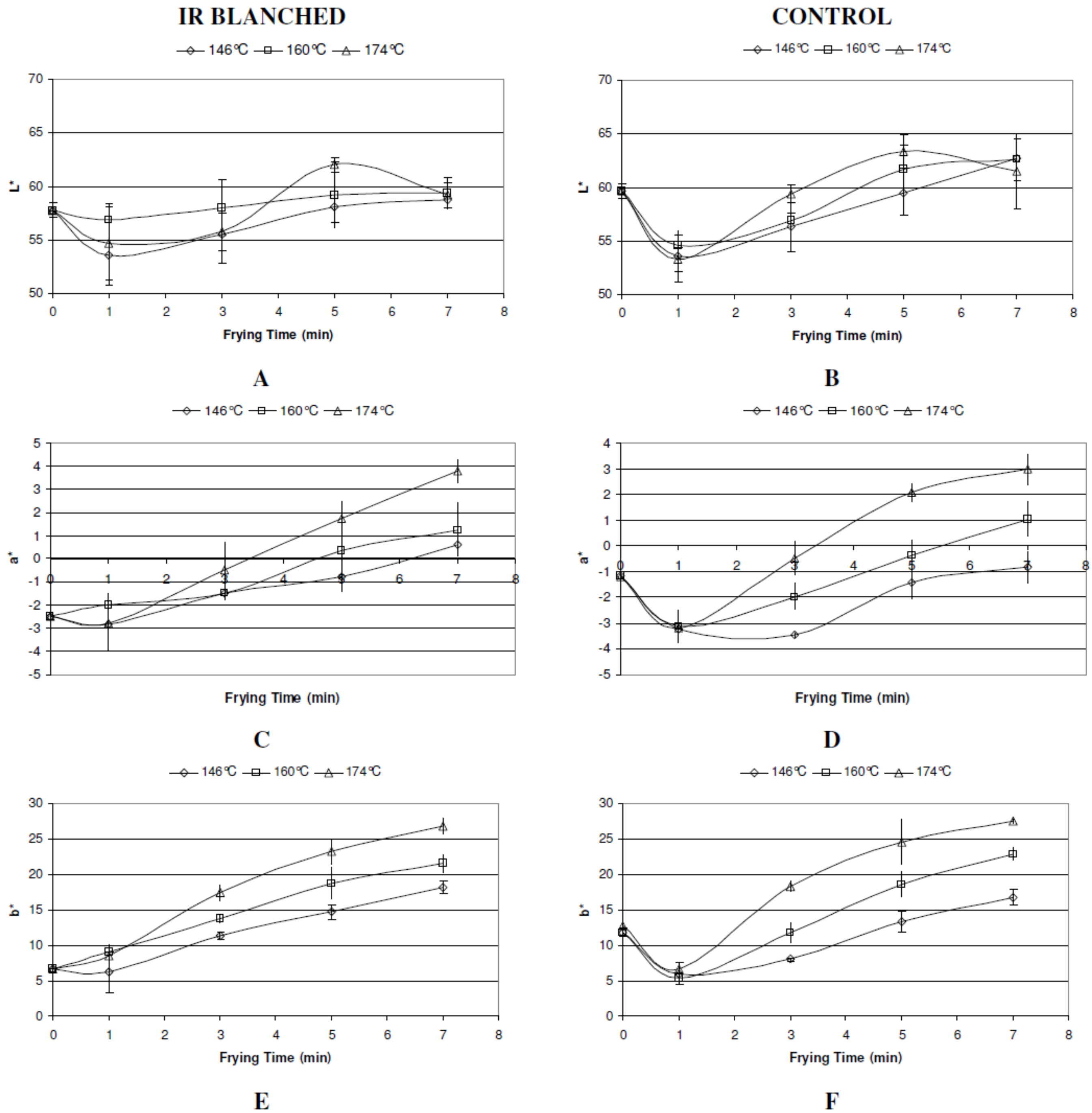

Figure 4. Color values of infrared blanched and control samples after frying

Table 1. Oil (g oil g^{-1} dry basis) and moisture (% wet basis) contents of infrared blanched and control samples prepared for sensory analysis under different frying conditions

Frying Temperature	Control			Infrared Blanched		
	Frying Time (s)	Oil Content	Moisture Content	Frying Time (s)	Oil Content	Moisture Content
146°C	447	22.77	63.89	330	13.93	58.25
160°C	333	21.74	59.13	270	15.30	60.96
174°C	241	20.79	63.1	228	14.23	57.76

Table 2. Oil contents (g oil g^{-1} dry basis) of infrared blanched and control French fries under different frying temperatures (Mean value ± S.D.)

Frying time (min)	Control			Infrared Blanched		
	146°C	160°C	174°C	146°C	160°C	174°C
1	3.51 ± 0.85a	5.82 ± 0.99b	8.05 ± 0.21c	9.75 ± 1.33a	10.25 ± 1.21a	10.19 ± 1.14a
3	10.43 ± 0.95a	12.40 ± 0.56a	15.98 ± 1.65b	11.40 ± 0.70a	11.19 ± 1.39a	13.38 ± 0.31b
5	15.49 ± 0.24a	16.14 ± 0.37a	19.37 ± 2.18b	11.67 ± 0.92a	11.95 ± 0.41a	13.05 ± 1.24b
7	18.16 ± 0.80a	19.58 ± 2.09a	20.27 ± .015a	11.42 ± 0.33a	13.16b ± 1.16b	14.13 ± 0.68b

For each treatment, means in the same row with different letters are significantly different (P < 0.05).

Table 3. P-values of sensory attributes and percentage preferring infrared blanched samples

Sensory Attribute / Frying Temperature (°C)	Taste	Texture	Color	Appearance
146	P=0.168	P=0.0003	P=0.118	P=0.017
	N/A	59.1%	N/A	50%
160	P=0.113	P=0.0003	P=0.113	P=0.0003
	N/A	46.4%	N/A	39.3%
174	P=0.149	P=0.0020	P=0.0001	P=0.0001
	N/A	59.3%	55.6%	51.9%

N/A: Not applicable since there is no significant difference between the blanched and unblanched samples for the respective sensory property.