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EFFECT OF BAKING AND FRYING METHODS ON QUALITY CHARACTERISTICS OF POTATO CHIPS

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Abstract

Effect of cooking method (baking and frying) on quality attributes of potato chips was investigated in this study. Baking and frying experiments were conducted at 170, 180, 190˚C using potato slices with a thickness of 1.4 mm. Texture and color measurements were carried out and surface and internal temperatures of potato slices were monitored during the experiments. F_{max} values of potato chips were found around 2.5 N for both treatments, deformation values of baked samples (0.91 mm at 170°C, 0.65 mm at 180°C 1.14 mm for 190°C) were lower than fried ones (1.77 mm at 170˚C, 1.09 mm at 180°C, 2.24 mm for 190°C). Hardness values of baked samples (3.90 N/mm at 170˚C, 3.17 N/mm at 180°C, 2.33 N/mm at190°C) were higher than fried ones (1.88 N/mm at 170˚C, 2.85 N/mm at 180°C, 0.99 N/mm for 190°C). Colors of fried and baked potato chips were orange yellow and brilliant yellow, total color changes were determined in the range of 16.7 - 22.3 and 21.7 – 37.4, respectively. The results showed that baking process failed to provide acceptable quality attributes although it is considered as healthy alternative to frying due to its potential to provide texture and color with existence of less oil.

Keywords: Potato chips, frying, baking, quality properties

KIZARTMA VE FIRINLAMA YÖNTEMLERİNİN PATATES CİPSLERİNİN KALİTE ÖZELLİKLERİ ÜZERİNE ETKİSİNİN İNCELENMESİ

Özet

Bu çalışmada patates cipsi üretiminde kullanılan kızartma ve fırınlama yöntemlerinin patates cipsinin kalite özellikleri olan rengi ve tekstürü üzerine etkisi incelenmiştir. Fırınlama ve kızartma işlemleri belirli kalınlıktaki (1.4 ± 0.1 mm) patates dilimlerine 170, 180 ve 190˚C'de uygulanmıştır. Kızartma ve fırınlama işlemi süresince patates cipslerinin iç kısmı ve yüzey sıcaklıklarındaki değişimi ölçülmüş ve sonrasında tekstür ve renk ölçümleri gerçekleştirilmiştir. Deformasyon değerleri, fırınlanan örneklerin (0,91 mm, 170°C; 0,65 mm, 180°C; 1,14 mm, 190°C) kızartılmış örneklerden (1,77 mm, 170°C; 1,09 mm, 180°C; 2,24 mm, 190°C) düşük, sertlik değerleri fırınlanan örneklerin (3,90 N/mm, 170˚C; 3,17 N/mm, 180°C; 2,33 N/mm, 190°C) kızartılmış örneklerden (1,88 N/mm, 170˚C; 2,85 N/mm, 180˚C; 0,99 N/mm, 190°C) yüksek ve F_{max} değerlerinin her iki örnek için benzer olduğu görülmüştür. Renk değerleri incelendiğinde fırınlanmış örnekler turuncumsu sarı, kızarmış örnekler parlak sarı olarak tanımlanmış ve toplam renk değişimin kızarmış ürünlerde 16,7 - 22,3, fırınlanmış örneklerde ise 21,7 - 37,4 aralığında olduğu görülmüştür. Sonuçlar, daha az yağ kullanılması nedeni ile sağlıklı bir pişirme yöntemi olarak önerilen fırınlama işleminin patates cipsi üretiminde arzu edilmeyen tekstür ve renk oluşumuna neden olduğunu göstermiştir.

Anahtar kelimeler: Patates cipsi, kızartma, fırınlama, kalite özellikleri

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INTRODUCTION

Potato chips are popular for their unique characteristics such as flavor and crispy texture. However, due to their oil content ranging from 35% to 45% by weight (1), they have a negatively perceived image. Furthermore, among the foods tested up to date, potato chips appear to have the highest levels of acrylamide (2, 3). In recent years, increasing consumer awareness of the relationship between nutrition and health has led to demand for high quality foods that are also healthy. Therefore, making potato chips with low oil and acrylamide content and good sensory quality has been a great interest to researchers. Impingement drying (4, 5), vacuum frying (1, 6), low-pressure superheated steam drying (7, 8), and baking are the prominent methods that have been studied. Among these methods, baking is considered as a viable alternative to frying due to its potential to provide a similar product with no added fat (9), and baked version of potato chips has been marketed by several manufacturers.

The characteristic crispy texture of potato chips is one of the most important quality indicators of the finished product, and is the result of changes in the original structure of potato tissue during heating. Development of this crispy texture is highly related to the rate of heat transfer. Deep fat frying can impart this characteristic thanks to the high rate of heat transfer associated with hot frying oil. Rapid escape of water from potato slices as a result of high heat transfer rates during frying is responsible for the expanded and crispy texture (10, 11). Low rate of heat transfer associated with baking leads to slow cooking and hence long processing times, and fails to provide the desired expanded texture and crispiness desired by consumers.

In addition to the changes related to texture, color changes also take place during both cooking methods. Color of fried potato products is described as one of the most significant quality factors determining their acceptance (12-14). A strong relationship was also reported between color development and drying rate (15). Although baking is a healthier alternative to frying, it fails to provide quality attributes similar to that of fried chips; therefore objective of this study was to investigate the effect of cooking method (baking and frying) on quality attributes (texture and color) of potato chips.

MATERIALS and METHODS

Materials

Potatoes (Lady Claire) were provided Anka Tohumculuk, Nevsehir, Turkiye. Potato slices were prepared as explained in (8). Firstly, potatoes were cut into thin slices (1.4 ± 0.1 mm) using an electric slicer (GE300, Celme, Italy) and then circular slices with a diameter of 36 mm were cut out using a plastic cutting mold. Slices were washed for 1 min in distilled water using a magnetic stirrer to remove surface starch. Then, the slices were gently dried with paper towel.

Frying and Baking Experiments

Potato slices (2 slices at a time) were fried in an electrical fryer (Precisterm, J.P. Selecta, Spain) at 170, 180 and 190°C by immersing in sun flower oil (5 L) completely. For baking experiments, potato slices were coated with sunflower oil and oil-coated slices (2 slices at a time) were placed on a stainless steel wire mesh inside the oven (ULP600, Memmert, Germany) so that drying could take place from both sides. Frying and baking times at different temperatures were selected as to reach a final moisture content of less than 2% by weight. Frying times were determined 130 s; 110 s; 85 s and baking times were 22 min; 20 min; 16 min for 170, 180, 190°C, respectively. Moisture content of samples was determined by drying the samples to constant weight at 105±1°C (16).

Temperature Measurement

Temperature measurements were performed as explained (9). Surface and internal temperatures of potato slices were monitored during frying and baking experiments using type-T thermocouples (diameter 0.22 mm, Omega Engineering, Inc., Stamford, Conn., U.S.A.). Time and temperature data were collected every second by using a data acquisition system, comprising a digital multimeter and a 20-channel multiplexer (Keithley, Model 2700 DMM and Model 7700, Cleveland, Ohio, U.S.A.). Surface thermocouple was placed so that the tip of the thermocouple was flushed with the surface. Location of the surface thermocouple was verified by visual observation after each experiment. A second thermocouple was placed inside the slice (toward the center) to measure the internal temperature. Air temperature was recorded using another thermocouple which was placed 10 cm above the samples. Temperature measurement of the frying oil was performed by immersing a thermocouple in the fryer. Since 2 potato slices were fried at a time, no change in oil temperature was observed. A sudden drop in air temperature was inevitably experienced in baking experiments when the oven door was opened to place the slices inside the oven. It was, however, observed that the temperature inside the oven reached the set temperature within the 1st minute of the baking experiments.

Texture Measurements

Texture measurements were performed using a Texture Analyzer (TA-XT2i, Stable Micro Systems Ltd., Surrey, UK). A crisp fracture rig (HDP/CFS) and a 6.35 mm ball probe (P/0.25S) were used. Tests were carried out by placing the fried or baked potato samples on the rig and by driving perpendicularly a ball probe (6.35 mm) attached to the crosshead at a speed of 1 mm/s. Texture measurements were performed after 2 minutes that potato chips were removed from the frying oil or the baking oven. Two potato chips were analyzed for each frying and baking experiments and repeated five times. From the force-deformation curve the following parameters were obtained; maximum force value (force at the first major drop, Fmax, N) and deformation value (deformation induced at maximum force, mm), hardness (ratio of maximum force value to deformation value, N/mm).

Color Measurement

Machine vision system was used for color analysis. A color image obtained with a digital camera under controlled and defined illumination conditions (D65 illumination in a light box described by Luzuriaga et. al. (17)) was analyzed using software developed for this purpose. Average color method was used to determine average L^* (lightness), a^* (redness), b^* (yellowness) values for each potato chips. In the average color method, the individual L^*, a^*, and b^* values of each pixel in an object are averaged (18). Ten samples were analyzed for each temperature for baking and frying. Total color difference (ΔE) between raw (L_0, a_0, b_0) and fried/baked potato slices (L, a, b) was defined by Equation 1.

$$\Delta E = \left((L^*_0 - L^*)^2 + (a^*_0 - a^*)^2 + (b^*_0 - b^*)^2\right)^{1/2} \qquad (1)$$

DSC Analysis

DSC analyses were performed using a Perkin-Elmer DSC-6 differential scanning calorimeter (Perkin-Elmer Corp., Norwalk, CT, USA). Nitrogen was used as the purge gas at a flow rate of 20 mL/min. After weighing samples of 5-6 mg into aluminum pans, the pans were hermetically sealed. An empty, hermetically sealed aluminum pan was used as reference. The samples were subjected to a temperature program during which heating took place from 20 to 110°C at a scan rate of 5°C/min.

Statistical Analysis

All the experiments were performed in five replicates for each temperature. The differences in color, texture of baked and fried samples were statistically evaluated by independent sample t-test (α=0.05) using SPSS (SPSS for Windows, Release 11.5, 2002, LEAD Technologies Inc.).

RESULTS AND DISCUSSION

Texture of Baked and Fried Potato Chips

Texture parameters (F_{max}, deformation, hardness) of baked and fried potato chips and statistical results were showed in Table 1. Typical force-deformation curve of baked and fried potato chips were depicted for 170°C in Figure 1. Maximum force values of baked and fried potato chips were significantly different only at 180°C (P<0.05). F_{max} values of baked and fried potato chips were observed similar and ranged between 2-3 N at all temperatures. This observation was in agreement with the results obtained by (1, 19, 20). Research in the literature showed that cutting force of commercial potato chips is 1.9 N (7). In the light of this observation, baked and fried potato chips could be evaluated as commercial potato chips in terms of maximum force values in the present study.

Deformation values of baked and fried potato chips were significantly different at all temperatures (P<0.05). Baked potato chips had lower deformation values for all temperatures and their hardness values, which were obtained by dividing deformation value by maximum force value, are higher than fried samples. The hardness values were significantly different at 170°C and 190°C (P<0.05). It was observed that these values

Table 1. Texture parameters of potato chips prepared by frying and baking at 170,180,190°C.

Texture parameter	Temperature (°C)	Frying	Baking	p (α=0.05)
F_{max} (N)	170	2.74 ± 1.04	2.88 ± 0.45	0.692
	180	2.66 ± 0.79	2.02 ± 0.33	0.029
	190	2.02 ± 0.73	2.41 ± 0.67	0.233
Deformation (mm)	170	1.77 ± 0.92	0.91 ± 0.65	0.027
	180	1.09 ± 0.51	0.65 ± 0.10	0.015
	190	2.24 ± 0.87	1.14 ± 0.42	0.002
Hardness (N/mm)	170	1.88 ± 1.06	3.90 ± 1.45	0.002
	180	2.85 ± 1.32	3.17 ± 0.62	0.500
	190	0.99 ± 0.41	2.33 ± 0.86	0.000

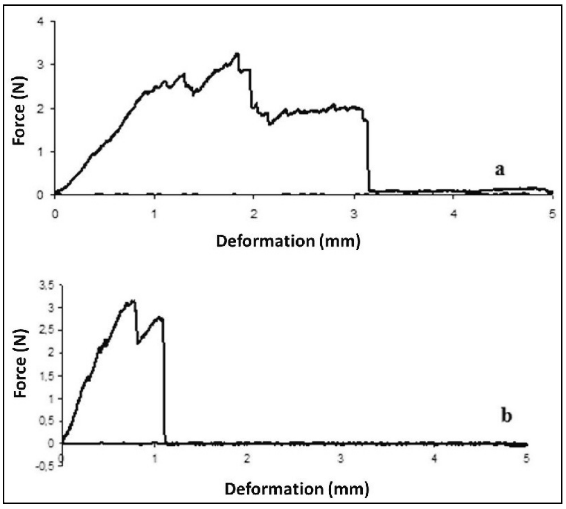

Figure 1. Typical force- deformation curves of baked (a) and fried (b) chips at 170 °C.

of both samples had no differences at 180˚C (P>0.05). This suggests that texture formation may have been limited due to the termination of treatment. It is therefore presumed that the combined effect of time and temperature on texture formation at 170°C and 190°C was greater than at 180°C as explained in a previous study by (9).

A higher hardness value indicates that material requires a higher force treatment for breaking and this can be explained as brittle. Higher hardness values and sharp vertical drop in force-deformation curve (Figure 1b) demonstrated that baked potato chips were less flexible (more brittle) than fried potato chips. According to the results fried potato chips had more flexible texture than baked ones. In contrast, frying takes place rapidly (due to much higher heat transfer coefficients associated with hot frying oil) and is a much more efficient heat transfer process than baking. Although it has been reported that not all starch may gelatinize in case of rapid dehydration (21, 22), the DSC analysis revealed that no ungelatinized starch was present within the potato slice after frying at 180°C for 1 min and 40 s in this study. Furthermore, the DSC thermogram of the potato slice fried at 180°C for only 30 s showed no gelatinization peak. From this, it was concluded that although dehydration took place rapidly, all starch was able to gelatinize even within the limited time of frying. In frying process, existence of oil acts as a plasticizer in the system and provides flexibility to the product (21). Limited heat transfer due to the low heat transfer coefficient may not have generated energy requirement for all starch gelatinization during baking process. Many researches in the literature related to harder texture of baked potato chips as incomplete starch gelatinization during baking process (7, 23, 24). This can cause less delamination into the potato chips and tough structure since not occurring intercellular separation.

Although a sensory assessment was not a goal of the study, sensory evaluations were performed in order to supplement instrumental measurements by the authors of this article. As regards visual observations, volume of baked potato chips was smaller than fried ones and had no bubbles. Hardened surface of baked chips may have increased the resistance to volume change that consequently caused more shrinkage of volume during baking process. This may prevent the intercellular seperation thus, the bubble formation on the product surface which is formed by gas expansion inside the pores, as explained (1).

Surface and Internal Temperatures

Baking time was longer than frying times probably because the formation of a dry skin that acted as a barrier to heat transfer to the core of potato slices. At the same time low heat transfer coefficient of air may have decreased heat transfer rate and further it may be lowered moisture loss rate from potato chips as explained by (23, 24).

Temperature profiles during baking and frying processes were depicted for 170°C in Figure 2. Time-temperature profile of the baking process markedly differed from frying. The difference between surface and center temperature was quite high (~50°C) at the beginning of frying process (Figure 2a). In contrary to frying, baked samples internal and surface temperatures increased together and those were 100°C for a long time during baking. It started to rise when drying was completed (Figure 2b). These differences in temperature profiles may have caused because of lack of lamination between layers of potato slice during baking process.

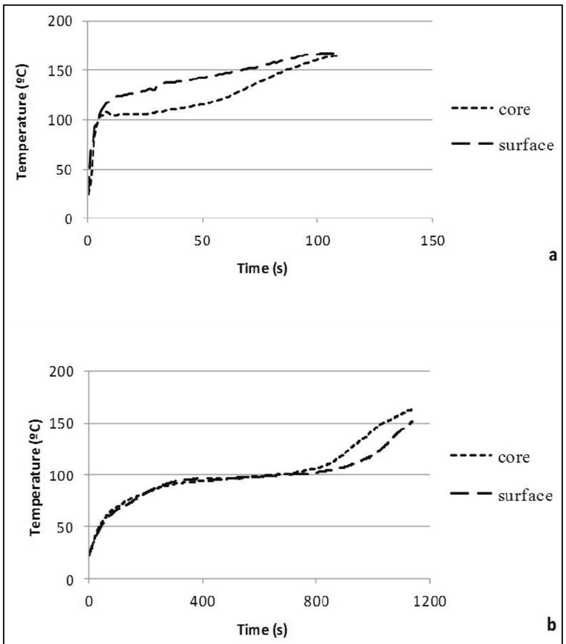

Figure 2. Surface and internal temperature profiles of potato slices during frying (a) and baking (b) at 170°C.

Color of Baked and Fried Potato Chips

Lightness, redness, yellowness (L^*, a^*, b^*) and ΔE values of fried and baked chips were shown in Table 2. Color parameters of baked and fried potato chips were significantly different for all temperatures ($P<0.05$). Lightness (L^*) and yellowness (b^*) values of baked chips were lower and redness (a^*) values were higher than their fried counterparts. Figure 3 presented the images of baked and fried potato chips at 170, 180, 190°C. Machine vision system determined color of baked and fried potato chips as orange yellow and brillant yellow, respectively.

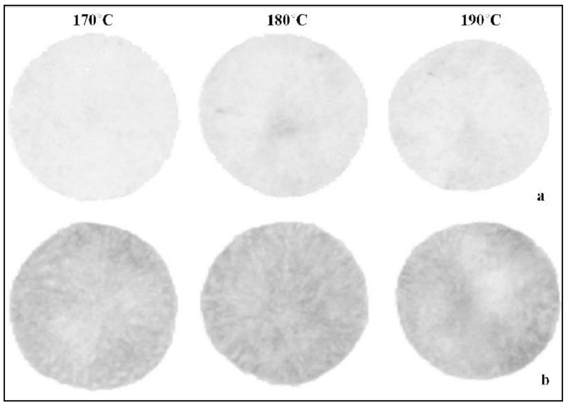

Figure 3. Image of fried (a) and baked (b) potato chips at 170, 180, 190°C.

Colors of baked potato chips were indicated darker than fried ones with respect to the color parameters and image of chips. Total color change (ΔE) gives information about the change of color during process (25, 26). According to the results baked samples had higher ΔE values for all temperatures. Greater change of color during baking can be explained by the formation route of color. Existence of oxygen during baking process

Table 2. Color parameters of potato chips prepared by frying and baking at 170, 180, 190°C.

Color parameter	Temperature (°C)	Frying	Baking	p (α=0.05)
L^*	170	93.7 ± 1.9	80.5 ± 2.5	0.000
	180	87.9 ± 3.5	75.3 ± 4.4	0.000
	190	92.2 ± 1.2	83.9 ± 2.8	0.002
a^*	170	-13.4 ± 3.0	8.7 ± 3.3	0.000
	180	-2.1 ± 7.0	20.0 ± 5.7	0.000
	190	-9.9 ± 2.4	4.2 ± 5.5	0.000
b^*	170	61.3 ± 2.2	57.5 ± 2.3	0.000
	180	64.9 ± 1.5	55.0 ± 2.6	0.000
	190	62.6 ± 1.7	57.5 ± 1.5	0.000
ΔE	170	15.7 ± 1.8	26.3 ± 3.3	0.000
	180	22.3 ± 4.4	37.4 ± 6.4	0.000
	190	16.7 ± 1.7	21.7 ± 5.4	0.025

leads to ascorbic acid oxidation in addition to Maillard reaction. Many scientific articles (4, 7, 26, 27) reported that air causes higher degree of ascorbic acid loss because of low convective heat transfer coefficient and existence of oxygen in medium. Since frying medium has no oxygen, color formation occurs only via Maillard reaction. This caused lighter color of chips during frying in present study. Redness (a^*) parameter changed significantly during frying while L^* and b^* values had no significant change as explained by (28). The linear relationship between acrylamide content and a^* value caused by the same formation mechanism, was reported (28, 29). A previous study (9) showed that acrylamide content of baked potato chips was lower than fried ones at 170°C in spite of having a higher value of a^* value. This observation showed that acrylamide content and a^* value may not always be directly related when color formation takes place via both enzymatic and non-enzymatic reactions. Higher a* and ΔE values were indicated for both baked and fried potato chips at 180˚C. This observation might be about limited color formation due to termination of both processes. These results may be better explained by detailed study about time-temperature effects on color formation of potato chips which was beyond scope of this study.

CONCLUSIONS

Baked and fried potato chips were investigated in terms of their color and textural properties. Color parameters of baked and fried potato chips were significantly different and baked chips had darker color for all temperatures. Hardness of these samples showed importance of combined effect of time and temperature on baked chips. According to the results it can be concluded that baking process failed to provide acceptable quality attributes although it is considered as a healthy alternative to frying due to its potential to provide texture and color with existence of less oil. Determining color and texture formation kinetic of potato chips and acrylamide content and using alternative technologies instead of oven baking and the combined effect of some alternative technologies with oven baking could be subject of further research.

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