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ORIGINAL PAPER

Effect of frying time on acrylamide content and quality aspects of French fries

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Abstract The effect of frying time on quality and acrylamide (AA) content of French fried potatoes, obtained simulating home-cooking practices, was studied in order to investigate the optimal conditions to minimize the amount of produced toxicant together with the maintenance of good culinary quality. French fries were obtained from fresh potatoes using a domestic fryer with static basket; a 4:1 oil:product ratio and a fixed initial oil temperature of 180 °C were used. Several batches were fried at different times (3, 4, 5, 6, 7, 8, 9 min). During frying tests the oil, the sticks surface and core temperatures were measured by thermocouples. Analysis of water removal, oil uptake, colour, texture and AA content were carried out on fried final products. AA content increased exponentially increasing the frying time. In our working conditions after around 4 min of frying, when the temperature of potato surface and the oil bath reached, respectively, 120 and 140 °C, the increase of time became a key factor in terms of the quantity of AA and its formation rate. On the basis of colour, oil content and AA level the best culinary product was obtained after 5 min of frying.

Keywords Acrylamide · French fries · Frying time · Frying temperature · Home-cooking practices · Quality

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Introduction

In April 2002, Tareke et al. [1] reported that several heat-processed foods contained relatively high amounts of acrylamide (AA), known to be a neurotoxic, genotoxic and carcinogen compound in animals [2] classified by IARC [3] as a probable human carcinogen. AA is present at high concentration in certain fried, roasted and baked products. It is mostly formed by thermal degradation of free amino acid asparagine that reacts with the carbonyl groups of reducing sugars, mainly glucose and fructose, during Maillard reaction [4–6].

Potato (*Solanum tuberosum*) is one of the world major agricultural crops, consumed daily by millions of people. Raw potatoes do not contain AA but high amounts of its precursor, reducing sugar and free amino acids [7], responsible for AA formation during the Maillard reaction, but also for flavour and browning compounds [8].

The AA concentration in potato foods depends on the quantity of free aspargine and reducing sugars present in the raw material as well as on the cooking condition [9]. The level of asparagine in raw potato varies only within a narrow range [10]; therefore the amount of reducing sugars becomes the limiting factor. Ensuring a low sugar content means mostly starting from suitable potato cultivars and preventing the ‘‘low-temperature sweetening’’ by storing at temperature around 8–12 °C [11–14].

As far as the cooking conditions are concerned, the typical high temperatures of frying, roasting or baking, favour the formation of AA. French fries and potato chips, in particular, could contain more than 2,000 μg/kg of this compound [15, 16]. Temperature and time of frying process have been shown to be significant factors affecting the amount of AA formed in potato foods [16] as well as the development of desirable aroma compounds typical of high-quality food. It is know that French fries cooked lowering the frying temperature from 190 to 150 or 120 °C are characterized by decreased level of AA [16]. Anyway, the culinary quality of the product is rarely considered. Texture, colour and oil content are the main quality characteristics of French fries directly bound to the acceptance of the product by the consumers.

The frying equipment used for French fries preparation also plays an important role for both home and industrial practices. Actually, for the majority of domestic or catering fryers, the initial oil temperature dramatically decreases when potato sticks are immersed into the oil bath and few minutes are necessary to recover the initial temperature. The length of this period strictly depends on the oil:product ratio and the heating power of the fryer [17]. Moreover, it has been already described that (a) the rate of AA formation in French fries is not the same for surface and core of potato, as a consequence of the different heat transfer and evaporation of water from the sticks. Actually, the core never exceeds 100 °C even for prolonged cooking at 190 °C [15]; (b) AA is formed during the end of the frying process, when the temperature of oil and potato strip surface reaches almost 120 °C. As a consequence the critical point for frying process is not only represented by the initial oil temperature but also by the possibility of maintaining a constant selected temperature during the whole cooking process [15, 17].

The purpose of this study was to investigate the effect of frying time and temperature on AA formation together with the changing of colour, texture, moisture and oil content of French fries obtained from raw potatoes, using a domestic fryer simulating home-cooking conditions. This is in order to define the appropriate conditions to minimize the amount of toxicant and obtain a good culinary quality of the final product.

Materials and methods

Frying

Fresh potatoes (*Solanum tuberosum* L. cv. ''Vivaldi''), bought on the local market and sold for frying use, were used. Potatoes were washed and cut into strips (9.0 mm × 9.0 mm) using a hand-operated French fry cutter. The sticks were washed in tap cold water and blotted with absorbing tissue paper. Frying of potato strips was performed using peanut oil and a domestic scale fryer ''easy clean system'' 1800 W, Mod. F989 (DeLonghi, Italy) equipped with a static basket and a regulating thermometer. A 4:1 oil:product ratio, and a fixed initial oil temperature of 180 °C were used in order to simulate real frying conditions (home and catering practices). Several batches were fried in duplicates at the following durations: 3, 4, 5, 6, 7, 8, 9 min. Frying time was prolonged until the product became over fried and not acceptable.

Measurement of temperature

Temperature data were recorded every 5 s during the experiment using a digital multimeter mod. 2700 (Keithley, Cleveland, OH, USA) coupled with thermocouples mod. GG–30-KK (Tersid, Milano, Italy) and a personal computer. During all frying tests two thermocouples were inserted into a strip: one under the surface and a second one inside the strip to measure both surface and core temperature. A third thermocouple was used for oil temperature measurement.

After each frying test the following analytical determinations were carried out in triplicate on potato samples:

Moisture content

The moisture content was determined gravimetrically as described in AOAC-925.10 [18].

Total oil content

Total oil content was determined by solvent extraction using the Soxhlet method [19], performing the extraction procedure with petroleum ether. Oil content was reported as a percentage on a moisture-free basis.

Colour analysis by computer vision system (CVS)

The colour of ten fried potato sticks were measured for each frying test. French fries were placed on a matte black background and the excess of oil was removed from the surface with tissue paper.

Images were captured using the image acquisition system developed by Mendoza and Aguilera [20] with slight modifications. The samples were illuminated using two parallel lamps (with two fluorescent tubes by lamp, model TL-D Deluxe, Natural Daylight, 18W/965, Philips, NY, USA) with a colour temperature of 6,500 K (D_{65}, standard light source commonly used in food research) and a colour-rendering index (Ra) close to 90%. A colour digital camera (CDC), mod. PowerShot A70 (Canon, NY, USA) was located vertically over the sample at a distance of 12.5 cm. Lamps and CDC were inside a wood box with internal walls that were painted black in order to exclude surrounding light and external reflections.

Images from one side of potatoes were taken on the matte black background and saved in JPG format in a PC.

The algorithms for pre-processing of full images, image segmentation and colour quantification were written in MATLAB 6.5 (The MathWorks, Inc.). The average value of the segmented pixels in CIE (Commission International de l'Eclairage) $L^*a^*b^*$ colour space was registered as the colour of the sample.

Numerical values of a* and b* were converted into hue angle: $h° = \tan^{-1}$ (b*/a*) [21].

Texture

Texture measurement was performed at room temperature (23 ± 2 °C) after frying. Cutting tests were carried out by measuring the maximum shear force (F_{max}) necessary to cut the potatoes strips, using a Texture Analyser mod. TA-HDi (Stable Micro Systems, Surrey, UK), equipped with a 50-kg load cell. A rectangular attachment for cutting and 10 mm/s test speed was used. For each frying batches, 21 potato slices were measured.

Acrylamide content

Extraction

The amounts of acrylamide have been determined according to the method of Ahn et al. [22]. Briefly, 10 g of French fries were grinded using a food processor, and placed in a flask added with 100 mL of hot water. AA was extracted swirling the flask immersed for 2 h in a water bath at 80 °C. The flask was cooled before filtering the aqueous extract through a sintered-glass filter. The sample was added with an internal standard, methacrylamide. A portion of the filtered sample was spiked with AA.

GC/MS analysis

AA was detected using GC/MS (Agilent-5973 Network) equipped with a capillary column DB17 (50% phenil, 50% methylsilicone) Agilent (length 30 m × I.D., 0.25 mm × D.F. 0.25 μm). Before GC/MS analysis, 10 mL of sample were treated with a brominating solution (15 mL) overnight at 4 °C in the dark [22, 23]. The excess of bromine was precipitated using few drops of 0.1 M sodium thiosulphate solution. The brominated acrylamide and methacrylamide were extracted with ethyl acetate. The organic solution was evaporated and made up to 1 mL of ethyl acetate.

The ions monitored for the brominated product of AA were 106, 108, 150 and 152, while 120 and 122 for brominated methacrylamide.

The calibration graphs for standards were obtained by plotting the ratio of 152/122 amu peak area against AA concentration.

Results and discussion

The obtained temperature profiles (mean values of duplicate cycles) of frying until 9 min (540 s) is reported in Fig. 1. At the beginning of frying the initial oil temperature rapidly and strongly decreased from 180 to 130 °C as a consequence of potato sticks immersion.

The temperature inside potato strips never exceeded the water boiling point even after 9 min of frying. During the first 4 min of frying potato surface and oil temperatures were respectively lower than 120 and

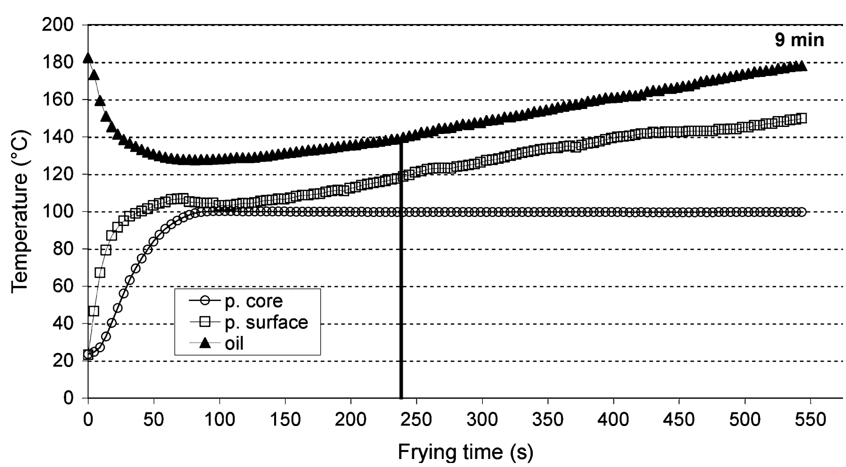

Fig. 1 Temperature profiles of oil bath, surface and core of potato strips during the frying process

140 °C. At these temperatures AA levels lower than 50 µg/kg were detected. As reported in Table 1 after four min of frying potato surface temperature was on the average of 125, 130 and 137 °C and oil temperature of 145, 152 and 160 °C, respectively, for 5, 7 and 9 min of frying. At the same cooking times there was a substantial increase of AA content.

In our experimental conditions, the temperature of potato surface and oil had to be higher than 120 and 140 °C, respectively, for 2 min in order to have a level of above 200 µg/kg of AA. Additional 2 min of frying time led AA content to reach 830 µg/kg.

As shown in Fig. 2, AA content increased exponentially with the increasing of frying time with enhanced slope at longer times.

These results are in disagreement with those of Matthäus et al. [9] and Gökmen et al. [15] that found a linear relationship between frying time and AA content. As we already shown in Table 1, the rate of AA formation suddenly increased from 5 to 7 min of frying, also as a consequence of the increase of oil and potato surface temperature. AA was found to be 830 µg/kg after 9 min of frying, about 12 times higher than that after 5 min, becoming 2 times higher from 8 to 9 min of frying.

Figure 3 shows an exponential relationship also between AA levels and the oil temperatures registered at the end of each frying test.

At a final oil temperature above 150 °C the rate of AA formation increased. This result is in agreement with those of other researchers [24, 25].

Table 1 Average potato surface and oil temperatures and AA content after the first 4 min of frying

Frying time (min)	Average *T* of potato surface (°C)	Average *T* of oil bath (°C)	Acrylamide (µg/kg)
5	124.08 ± 2.02	145.36 ± 2.47	68.14 ± 8
7	131.19 ± 6.33	152.59 ± 6.59	280.09 ± 20
9	136.74 ± 8.43	160.28 ± 10.96	830.10 ± 100

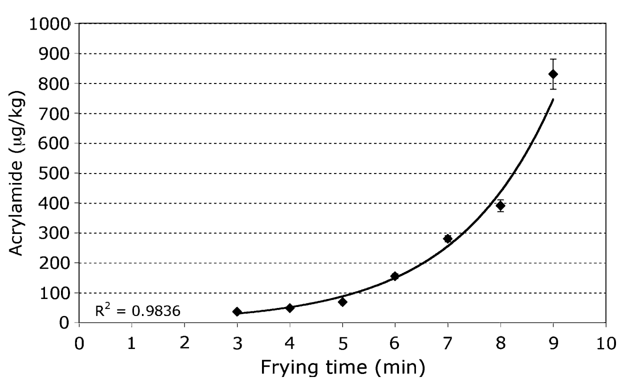

Fig. 2 Acrylamide content in French-fries versus frying time

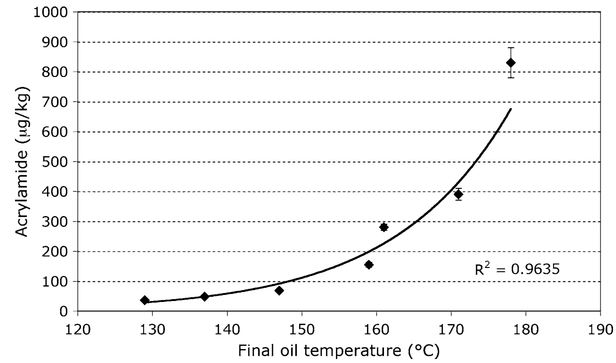

Fig. 3 Dependence of acrylamide levels on the final oil temperature of the oil bath in French fries during frying

Actually, it seems that the time of exposure to a certain temperature, directly bound to the oil:potato ratio, influences AA formation more than the only magnitude of the initial frying temperature.

Quality characteristic results of potatoes at different frying time are reported in Figs. 4, 5 and 6.

As shown in Fig. 4 oil uptake started after 3 min of frying together with the product dehydration; at this time the temperature of oil and potato surface reached values higher than 100 °C. Prolonging the frying time the sticks dried out and became oily. Fat absorption was almost on the same level, around 13%, from 5 to 9 min of frying. This value of oil content is defined good for French fries culinary quality [17]. As far as the water content is concerned, the industry suggests a range between 38 and 45% for an ideal French fries product [9]. However, after 5 min of frying our fried potatoes had a too high amount of water, of about 65%.

In spite of that, after 6 min of frying, French fries had a crispy crust, reaching texture values around 13 N in terms of F_{max} (Fig. 5), that was defined a suitable value for consumption by Lisinska and Golubowska [26]. This was probably due to the quickly superficial crust formation from 5 to 6 min of frying, caused by the increase of about 10 °C of oil and potato surface temperature. Until 5 min of frying French fries tended to remain soft due to the initial drop of temperature.

As far as colour results are concerned (Fig. 6), French fries get more red and darker as the frying time increase. In particular, during 9 min of frying, lightness (L*) and hue angle (h°) decreased exponentially, respectively from 76.13 to 47.75 and from 97.58 to 69.01, while redness (a*) increased from –6.59 to 13.57.

These findings suggest that final product underwent more and more brown proportionally to the frying time and AA formation. AA data showed a good linear

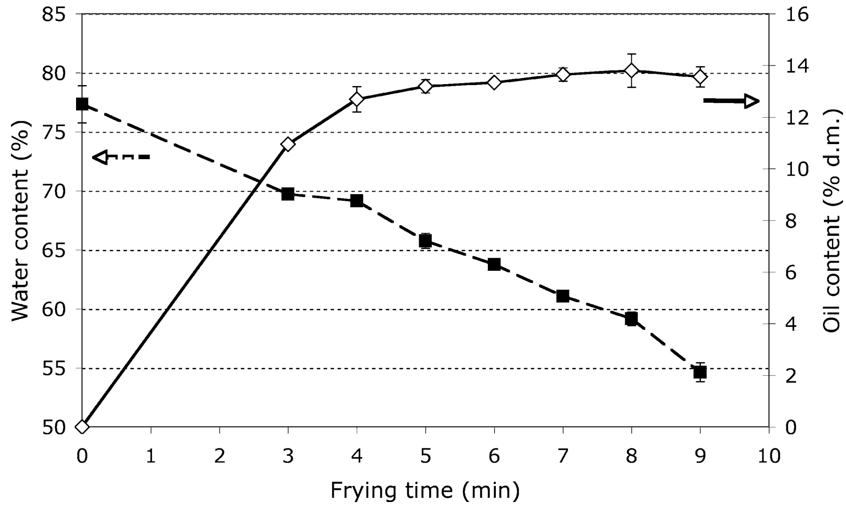

Fig. 4 Changes in oil and water content of potato sticks during frying

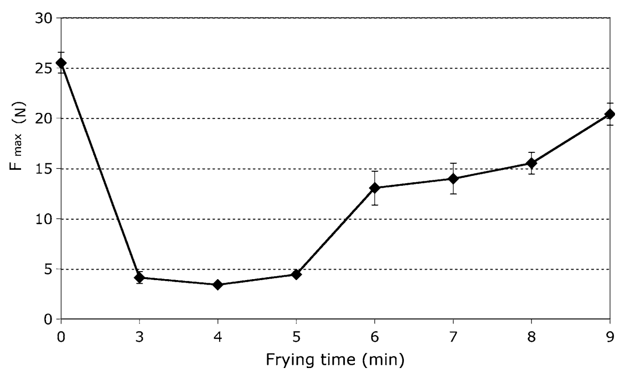

Fig. 5 Changes of texture (maximum shear force F_{max}) of potato sticks during frying

correlation, respectively with lightness ($r^2 = 0.768$, $P < 0.01$), redness ($r^2 = 0.848$, $P < 0.001$) and hue angle ($r^2 = 0.897$, $P < 0.001$) values.

On the basis of colour results, it seems that the best culinary product was reached after 5 min of frying; one more minute led browning spread over the whole pieces. At 5 min of frying French fries contained low level of AA (68 μg/kg), but they showed a poor texture quality.

Conclusion

In order to have a good culinary quality and a low content of AA, temperature and heating time to which French fries are subjected during home-frying conditions seemed to be more important than initial oil temperature.

In our working conditions, after 5 min of frying the temperature of potato surface and the oil bath was, respectively, higher than 120–140 °C. Increasing of frying time caused an obvious increment of these temperatures and at the same times an exponential increase of AA level and of its formation rate.

After 5 min of frying, the best culinary product was reached in terms of colour, oil content and AA level (68 μg/kg), but the texture quality was poor.

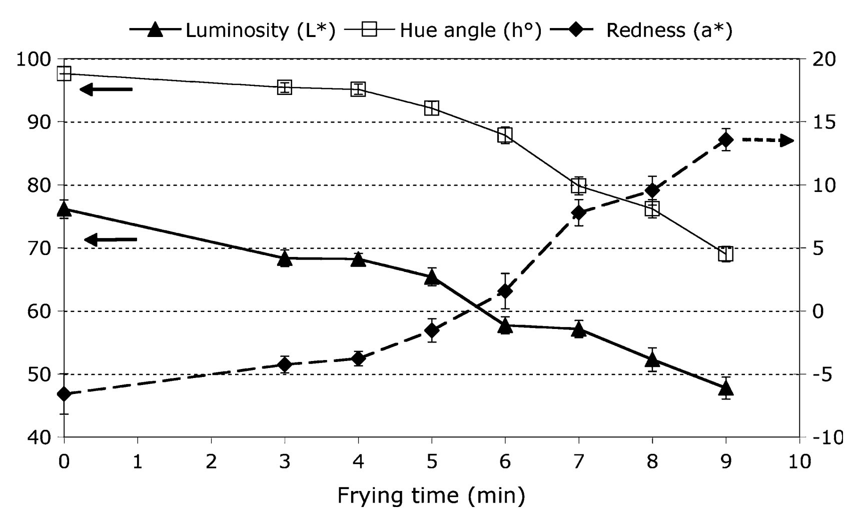

Fig. 6 Changes of colour parameters (L*, a*, h°) of potato sticks during frying

The oil and surface product temperatures reached during the second half of frying, and the duration of this step of the process (depending also on the amount of potatoes added in relation to the oil volume) are crucial for its quality characteristics. This suggests that when we fry in home-cooking conditions (high initial oil temperature and high amount of potatoes) it would be very important to use equipments with an efficient heating power in order to quickly get over the initial drop of temperature and make shorter the frying time.

In this way it could be possible to avoid that the product become good coloured before getting crispy, and to obtain low content of AA in respect of total culinary quality.

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References

1. Tareke E, Rydberg P, Karlsson P, Eriksson S, Törnqvist M (2002) J Agric Food Chem 50:4998–5006
2. Friedman M (2003) J Agric Food Chem 51:4504–4526
3. IARC (1994) Acrylamide. In: IARC monographs on the evaluation of carcinogen risk to humans some industrial chemicals. International Agency for Research on Cancer, Lyon, 60, pp 389–433
4. Mottram DS, Wedzicha BL, Dodson AT (2002) Nature 419:448–449
5. Stadler RH, Blank I, Varga N, Robert F, Hau J, Guy PA, Robert MC, Riediker S (2002) Nature 419:449–450
6. Yaylayan VA, Wnorowski A, Locas CP (2003) J Agric Food Chem 51:1753–1757
7. Williams JSE (2005) Food Chem 90:875–881
8. Whitfield FB (1992) Crit Rev Food Sci Nutr 31:1–58
9. Matthäus B, Haase NU, Vosman K (2004) Eur J Lipid Sci Technol 106:793–801
10. Amrein TM, Bachmann S, Noti A, Biedermann M, Ferraz Barbosa M, Biedermann-Brem S, Grob K, Keiser A, Realini P, Escher F, Amadò R (2003) J Agric Food Chem 51:5556–5560
11. Biedermann-Brem S, Noti A, Grob K, Imhof D, Bazzocco D, Pfefferle A (2003) Eur Food Res Technol 217:369–373
12. Grob K, Biedermann M, Biedermann-Brem S, Noti A, Imhof D, Amrein TM, Pfefferle A, Bazzocco D (2003) Eur Food Res Technol 217:185–194
13. Olsson K, Svensson R, Roslud CA (2004) J Sci Food Agric 84:447–458
14. De Wilde T, De Meulenaer B, Mestdagh F, Govaert Y, Vandeburie S, Ooghe W, Fraselle S, Demeulemeester K, Van Peteghem C, Calus A, Degroodt JM, Verhé R (2005) J Agric Food Chem 53:6550–6557
15. Gökmen V, Palazoğlu TK, Şenyuva HZ (2006) J Food Eng 77:972–976
16. Pedreschi F, Kaack K, Granby K (2006) Food Res Int 39:40–46
17. Fiselier K, Bazzocco D, Gama-Baumagartner F, Grob K (2006) Eur Food Res Technol 222:414–419
18. AOAC (1990) Official methods of analyses. Association of Official Analytical Chemist, Washington
19. AACC (1986) Approved methods of the American Association of Cereal Chemists. Minneapolis
20. Mendoza F, Aguilera JM (2004) J Food Sci 69:E471–E477
21. McGuire RG (1992) Hortic Sci 27:1254–1255
22. Ahn JS, Castle L, Clarke DB, Lloyd AS, Philo MR, Speck DR (2002) Food Addit Contam 19:1116–1124
23. Castle L (1993) J Agric Food Chem 41:1261–1263
24. Pedreschi F, Moyano P, Kaack K, Granby K (2005) Food Res Int 38:1–9
25. Fiselier K, Grob K (2005) Eur Food Res Technol 220:451–458
26. Lisinska G, Golubowska G (2005) Food Chem 93:681–687