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THE INFLUENCE OF POTATO SLICE SIZE ON THE ACRYLAMIDE LEVEL OF POTATOES FRIED UNDER FAST FOOD CONDITIONS

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Abstract
The aim of this study was to investigate the influence of potato slices (7, 9, 11 mm- Queen Anne variety) fried in palm oil in a fryer set at 190°C, for different periods of time (6, 8, 11 min) on the acrylamide level and color parameters of French fries. The experimental samples were prepared by the SPE technique and analyzed in terms of acrylamide content by GC-MS/MS. Results showed that the acrylamide content is significantly affected by the size of the potato slices and by the frying times: for 6 min of frying it varied from 222.90 µg/kg (7 mm) to 217.81 µg/kg (9 mm) and 192.36 µg/kg (11 mm), respectively; for 8 min of frying it ranged from: 842.44 µg/kg (7 mm) to 416.23 µg/kg (9 mm) and 343.19 µg/kg (11 mm); for 11 min of frying it was between 2636.06 µg/kg (7 mm), 1114.41 µg/kg (9 mm) and 906.70 µg/kg (11 mm), respectively. A reduction in the acrylamide level was obtained by about 14%, 59%, 66% for 6, 8, 11 min of frying at the size of 11 mm, compared to those divided at the size of 7 mm. The acrylamide formation in French fries was significantly reduced with larger the size of the potato slices and with shorter periods of frying. When increasing the potato slice size, positive linear correlations were obtained between the acrylamide level and the color parameters a and b* (R^2 = 0.54 - 0.99) and negative linear correlations with the color parameter L* (R^2 = 0.684-0.998).*

Keywords: acrylamide, fast food, French fries, GC-MS/MS.

1. INTRODUCTION

Potato (*Solanum tuberosum*) is one of the most cultivated vegetables and its consumption is high. Potato-based products are highly consumed in Romania in different forms, especially as French fries and chips.

The frying process to obtain French fries is used both in households and in industrial sectors, as it can create unique sensory characteristics in food products. By thermal processes, the sensory properties of end products are improved, the color, taste, aroma and texture are changed compared to the raw materials from which are obtained (Capuano and Fogliano, 2011). During frying, chemical reactions occur (Maillard) which can cause the formation of chemical contaminants in the process, such as acrylamide. Acrylamide is produced at temperature above 120°C, in low moisture conditions, as a product of the reaction between reducing saccharides and amino acids, mainly asparagine.

Potato-based products are considered to be one the main contributors to acrylamide intake due to the high content of asparagine, an amino acid found naturally in potatoes and to the processing

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conditions (EFSA, 2015). The frying time and temperature influence the acrylamide content of French fries, also the color, texture and flavour (Gőkmen et al., 2006; Yang et al., 2016; Tepe and Kadahal, 2019). In the study realized by Gőkmen et al. (2006) it was showed that the frying temperature has a higher impact on the acrylamide content of French fries than frying time. Tepe and Kadahal (2019) showed that besides the frying temperature and frying time, the potato slice size also has an effect on the acrylamide content of French fries, the thicker the size, the more acrylamide is formed.

In addition to frying parameters, other factors influence the acrylamide content of French fries, like the pH, the surface-to-volume ratio of the product, the potato cultivar (Yang et al., 2016). In other studies, was as well investigated the effect of the type of oil and lipid oxidation profile on the acrylamide content of French fries (Mesias et al., 2020; Abd Razak et al., 2021; Başaran and Turk, 2021) and it was showed that the unsaturated fatty acid ratio of oil affects the acrylamide content. A higher acrylamide content was obtained when vegetable oils with high unsaturated fatty acids were used, these oils being more susceptible to oxidation compared with the ones with an equilibrated ratio of saturated and unsaturated fatty acids.

Taking in considerations that acrylamide is considered by the International Agency for Research on Cancer (IARC) (1994) a "probable carcinogen for human" (group 2A), its reduction in food products is necessary. In 2017, European Commission has implemented the Regulation 2158 which establish the mitigation measures and benchmark levels for the reduction of this process contaminant in food (EC, 2017). Also, in order to ensure food safety, Food Drink Europe (2019) set a toolbox with steps to prevent and reduce the formation of acrylamide in food products. One way to mitigate the acrylamide in French fries is to reduce the size of potato strips. An important parameter in acrylamide control is the color of end-products. In the study realized by Kammound et al. (2022) it was showed that by increasing the frying conditions (temperatures and time) of potatoes deep-fried the color parameters were influenced, French fries became darker, redder and yellower. Also, Yang et al. (2016) showed that by increasing the frying temperature from 150 to 190°C the values of L^* parameter decreased, French fries becoming darker, while b^* parameter increased.

EC (2017) and the toolbox of Food Drink Europe (2019) specifies that the color of French fries should be golden-yellow. A lighter color of French fries can be accepted by some consumers but some other sensorial properties cannot be obtained, such as flavor and texture.

The aim of this study was to investigate the influence of potato strips size (7, 9, 11 mm) and frying conditions (190°C/6, 8, 11 min) on the acrylamide content of French fries obtained by deep-frying in palm oil and to establish the correlations between the acrylamide content and color parameters.

2. MATERIALS AND METHODS

Chemicals, reagents and standards

For this study, native acrylamide (min. 99% purity) acquired from Restek (Benner Circle, Bellefonte, USA) and internal standard (IS) of labeled acrylamide (1,2,3-^{13}C labeled acrylamide, min. 99% purity) purchased from Cambridge Isotope Laboratories (Andover, MA, USA) were used. All chemicals, reagents and solvents were of analytical grade. Isolute® Multimode (1000 mg, 6 mL) and Isolute® ENV$^+$ (500 mg, 6 mL) SPE cartridges supplied by Biotage (Uppsala, Sweden) were used in this study.

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Samples

Potatoes used in this study were from *Queen Anne* variety and were purchased from a local supermarket from Bucharest, Romania. The producer label stated that potatoes are „special for frying”. Refined non-hydrogenated palm oil used in this study was purchased from the same supermarket.

French fries preparation

Potatoes were peeled and cut at the dimension of 7, 9 and 11 mm with a length between 60 and 80 mm. Potato strips were rinsed in tap water, and the excess water from the surface was removed using absorbent paper. Palm oil was weighted and transferred in the fryer up to the low level.

The frying process was realized in a temperature-controlled fryer with two units of customized 4 L capacity stainless (Hendi Blue Line). Oil was gradually heated at 190°C, and maintained at this temperature for 30 min before frying the potatoes. For each frying cycle a ¼ potato/oil ratio (w/w) was used, which was chosen so the potatoes to be deep fried. Potatoes were fried at 190°C, for 6, 8 and 11 min. After potato strips were fried, the frying basket with the sample was taken out and shaken to eliminate the oil in excess. French fries were let to cool and after this it were ground and homogenized in a laboratory mixer (Büchi, Labortechnik AG, Germany) and then it was transferred in a 50 mL centrifuge tube and kept at -20°C before analyses.

Sample preparation for acrylamide analysis

For the acrylamide determination the method described by Negoiță et al. (2022) was used. Briefly, 1g homogenized sample of French fries, spiked with 440 µL internal standard of 1 mg/L concentration on which was added 20 mL water and 10 mL hexane was vortexed in centrifuge tubes for 60 min. After this step, sample was centrifugated at 5°C, 6000 x g for 20 min (5804R Eppendorf centrifuge with cooling, Eppendorf, Hamburg, Germany). The aqueous extract obtained was collected (10 mL) and acrylamide extraction was performed by using the HyperSep Universal Vacuum Solid Phase Extraction Manifold (Thermo Fisher Scientific, Waltham, MA, USA) and two types of SPE columns as described before. The Isolute Multimode column was conditioned with MeOH (3 mL) and water (12 mL) and after this step the aqueous extract (10 mL) was loaded onto the column and the eluate obtained was collected. The Isolute ENV^+ column was conditioned with MeOH (5 mL) and water (5 mL) and the extract obtained from the first column was loaded and after it was rinsed with water (4 mL) and then the eluate and the rinsing solvent were discarded. On this column 5 mL of 60% MeOH in water was loaded and acrylamide was collected in the extract.

The acrylamide extract was derivatized with bromine compounds (KBr, HBr and bromine-water solution) and after the reaction took place, the dibromo derivative of acrylamide was extracted with 40 ml ethyl acetate and hexane (4:1, v/v). The acrylamide extract was concentrated using a vaccum evaporation system (Rotovapor R-210, BÜCHI Labortechnik, Flawil, Switzerland) and a nitrogen steam. The residue obtained was redissolved in 400 µL ethyl acetate and 40 µL triethylamine and injected to GC-MS/MS.

Acrylamide Analysis by GC-MS/MS and method validation parameters

For acrylamide quantification a gas chromatograph in tandem with mass spectrometer (GC-MS/MS) was used. A TraceGOLDTM TG-WAXMS column (30 m x 0.2 mm i.d. x 0.25 µm film thickness) was used. The chromatographic conditions are described in the study realized by Negoiță

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et al. (2022). The Selected Reaction Monitoring mode (SRM) and internal standard method were performed for acrylamide quantification.

The method was validated taking in consideration the following parameters: linearity, linearity range, limit of detection (LOD), limit of quantification (LOQ), selectivity, precision, accuracy, recovery and measurement uncertainty as described by Negoiță et al. (2020). Two calibration curves in the ranges of 0.05–0.5 mg/L and 0.4–3 mg/L, respectively, were used and correlation coefficients were higher than 0.998. LOD and LOQ were 10.29 and 30.87 µg/kg, respectively. The results obtained by participation in two proficiency tests launched by FAPAS on French fries precooked (test 3095/2019, z score= -0.8) and potato crisps (test 3099/2020, z score= 0) demonstrated a good precision and accuracy of the method. The recovery for potato-based products ranged between 85.64% and 109.22%. The method uncertainty was ± 17.5%.

Color determination

Konica Minolta spectrophotometer (Universal Software V4.01 Miniscan XE Plus) was used to determine the color parameters. The instrument was calibrated using white and black plates provided by the manufacturer. Color measurements of French fries were realized by using illuminate D65 with an angle of view of 10°. For each sample, 10 measurements of the color parameters L^* (lightness), a^* (greenness - redness), and b^* (blueness- yellowness) were performed on different points of the grounded samples.

Statistical analysis

All samples for acrylamide determination were analysed in duplicate and results are expressed as mean ± SD. For color measurements, 10 measurements were performed for each sample and results are expressed as mean ± SD. To evaluate the statistical difference between samples, one-way analysis of variance (one-way ANOVA) followed by Tukey's test were performed. The chosen level of significance was set at $p < 0.05$. Correlations between the acrylamide content and color parameters were determined.

3. RESULTS AND DISCUSSIONS

Acrylamide content of French fries

For this study, the influence of potato strips size (7, 9, and 11 mm) fried at different conditions (190°C/6, 8, and 11 min) on the acrylamide content of French fries obtained was evaluated.

The acrylamide content of French fries was influenced both by the potato strips size and the frying time and results are presented in figure 1.

A lower acrylamide content was obtained for potatoes fried for 6 min at 190°C, values ranging between 192.36 and 222.90 µg/kg. Similarly, in the study realized by Abd Razak et al. (2021), the acrylamide content of French fries fried at 180°C in palm olein for 3.5 min was around 200 µg/kg.

The lowest acrylamide content was determined for potato strips with the largest size of 11 mm fried at 190°C/6, 8 and 11 min (192.36– 906.7 µg/kg). The highest acrylamide content was determined for French fries sliced at the smallest size of 7 mm and fried at 190°C/6, 8, 11 min (222.90–2636.06 µg/kg).

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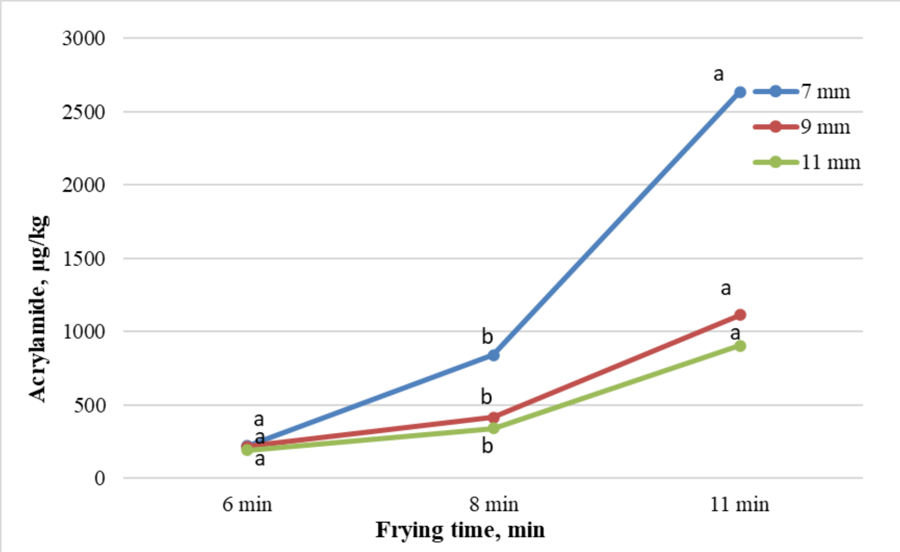

Figure 1. Influence of the potato strips size (7, 9, 11 mm) on the acrylamide content of French fries prepared in the fryer (190°C for 6, 8, 11 min)

Bullets followed by different letters for the same size are significantly different ($p < 0.05$)

From the results obtained it is observed that the acrylamide content decreased as the size of the potato strips increased, for all 3 durations (6, 8, 11 min), the same temperature of 190°C.

Increasing the potato strips size by 2 and 4 mm, respectively, from 7 to 9 mm or from 7 to 11 mm, determined reductions in acrylamide content between 2.38-13.70% at 6 min of frying, between 50.59 – 59.26% for 8 min of frying, and between 57.72 – 65.60% for 11 min of frying.

Similar with our results, in the study realized by Tepe and Kadakal (2019), 2 varieties of potatoes (Ranger Russte and Van Gogh) sizes 3, 6 and 9 mm were deep fried at 150, 170 and 190°C for 10, 20 and 30 min and results showed that the acrylamide content of French fries is influenced by the size of potato strips and also by the frying conditions. It was showed that by increasing the potato slice sizes, the acrylamide content of French fries decreased.

All samples fried for 11 min at 190°C exceeded the benchmark level of 500 µg/kg acrylamide established by Commission Regulation (EU) 2017/2158, and also the potato strips sliced at 7 mm and fried for 8 min at 190°C.

Color parameters of French fries

Color is an important parameter when frying potatoes, the final color of end-products being a decisive factor when choosing the frying end point of French fries. The color parameters of French fries were determined and results are presented in table 1.

Results shows that by increasing the potato strips size and by keeping the same frying conditions, the L^* parameter increased significantly, while a^* and b^* color parameters decreased significantly, French fries becoming lighter.

Also, by increasing the frying time, the L^* parameter decreased, French fries became darker while the a^* and b^* color parameters increased, potatoes becoming redder, and yellower.

Similar results were obtained by Tepe and Kadakal (2019) who showed that by increasing the frying time from 10 to 30 min and keeping the same temperature (190°C), the L^* parameter

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decreased, while *a** and *b** parameters increased. When the potato strips size increased from 3 mm to 9 mm, the *L** parameter increased, while *a** and *b** parameters decreased.

Table 1. Color parameters of French fried sliced at 7, 9 and 11 mm and fried at 190°C for 6, 8 and 11 min

Potato strips size, mm	**Frying conditions/ color parameters**		
	6 min, 190°C		
	L*	***a****	***b****
7	70.03 ± 0.03[c]	3.84 ± 0.02[a]	35.56 ± 0.07[a]
9	72.84 ± 0.03[b]	2.47 ± 0.02[b]	32.30 ± 0.02[b]
11	74.01 ± 0.04[a]	2.21 ± 0.03[c]	29.37 ± 0.03[c]
8 min, 190°C			
7	64.57 ± 0.13[c]	6.94 ± 0.06[a]	38.77 ± 0.10[a]
9	70.97 ± 0.02[b]	3.58 ± 0.02[b]	33.50 ± 0.04[b]
11	71.73 ± 0.03[a]	2.87 ± 0.03[c]	30.07 ± 0.08[c]
11 min, 190°C			
7	61.06 ± 0.02[c]	11.06 ± 0.03[a]	42.21 ± 0.04[a]
9	63.56 ± 0.05[b]	6.88 ± 0.06[b]	35.86 ± 0.08[b]
11	66.85 ± 0.05[a]	5.58 ± 0.02[c]	33.24 ± 0.07[c]

Values followed by different letters in the same column for each potato strips size and frying time are significantly different ($p < 0.05$).

The lowest values of the *L** parameter were found in the potato strips with the smallest size (7 mm), fried in different conditions (190°C/6, 8, 11 min).
The lowest values of the *a** and *b** parameters were found in the potato strips with the largest size (11 mm) fried in the experimental conditions.

Correlations between the acrylamide content and color parameters

The correlations between the acrylamide content and color parameters of French fries were determined and results are presented in table 2.

Table 2. Correlations between the acrylamide content of French fries and color parameters when varying the potato strips size (7, 9 and 11 mm)

Correlations (R^2)	**Frying parameters/190°C**		
	6 min	**8 min**	**11 min**
Acrylamide- *L**	-0.684	-0.998	-0.777
Acrylamide- *a**	0.543	0.999	0.986
Acrylamide- *b**	0.849	0.931	0969

Very strong correlations were found between the acrylamide content and the color parameters of French fries fried for 8 min.
When increasing the potato strips size (7, 9, 11 mm), linear negative correlations (R^2= 0.684–0.998) between the acrylamide content and the color parameter *L** were obtained.
When the size of potato strips increased (7, 9, 11 mm), linear positive correlations between the acrylamide content and *a** (R^2= 0.543– 0.999) and *b** color parameters (R^2= 0,849– 0,969) were found.

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4. CONCLUSIONS

Results of this study showed that the acrylamide content of French fries decreased as the size of the potato strips increased (7, 9, 11 mm), for all 3 durations of time (6, 8, 11 min), keeping the same frying temperature (190°C). In order to obtain French fries with a low acrylamide content, under the level set by the EC (2017), it is recommended to cut potatoes at a thicker size (11 mm) and to fry it for a short time (8 min).

When increasing the potato strips size, positive linear correlations were obtained between the acrylamide content and the *a** and *b** color parameters and negative linear correlations with the color parameter *L**.

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