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INFLUENCE OF FRYING CONDITIONS ON ACRYLAMIDE CONTENT AND FATTY ACID COMPOSITION IN FRENCH FRIES

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Abstract

The influence of different frying conditions (150, 170, 190°C/6, 8, 11 min) on the moisture, fat, acrylamide content, fatty acid composition, and colour parameters of French fries deep-fried in palm oil was investigated. Correlations between these parameters were established. Frying conditions significantly influenced the acrylamide content, which ranged from 118.47 to 232.05 µg/kg at 150°C, 188.38 to 684.37 µg/kg at 170°C, and 192.36 to 1141.41 µg/kg at 190°C, respectively. The acrylamide content in potatoes fried for 11 min at 170°C and 190°C exceeded the benchmark level established by the European Commission. Negative correlations were determined between the acrylamide content and moisture content (r= -0.943÷-0.989) and the colour parameter L^* (r= -0.820 ÷ -0.999). In contrast, positive correlations were obtained with fat content (r= 0.922-0.990), fatty acids (r= 0.917-0.993) and the colour parameters a^* (r= 0.966-1.000) and b^* (r= 0.637-0.999). French fries are considered one of the main sources of acrylamide intake for humans, so it is recommended to fry potatoes at lower temperatures (150, 170°C) for shorter durations (6, 8 min), until a golden yellow colour is obtained.

Keywords: French fries, acrylamide, frying conditions, colour parameters, fatty acids, potatoes

Introduction

Acrylamide is a chemical process contaminant formed when the Maillard reaction occurs. This compound is formed when asparagine and reducing saccharides react, being found in starchy foods subjected to temperatures above 120°C and low moisture conditions (EFSA, 2015). Additionally, besides the starchy foods, acrylamide can also form in oily matrices as a result of glycerol degradation into acrolein, which then converts to acrylic acid when oils are heated to a temperature

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higher than their smoking point (Maan et al., 2020). The reaction between acrylic acid and asparagine leads to acrylamide formation.

Considering that acrylamide is classified as a probable human carcinogen (group 2A) (IARC, 1994), has genotoxic effects and is a public health concern, Regulation 2017/2158 was implemented by the European Commission to establish some mitigation measures for reducing the acrylamide content in food products and additionally to set the benchmark levels. Currently, this regulation is under consideration to adjust the benchmark levels and also to establish maximum levels for other food products (European Commission, 2023).

One of the main sources of acrylamide in foods is represented by French fries, which are one of the most consumed potato-based products, being a popular snack option. Potatoes have a high content of asparagine and reducing saccharides. For frying potatoes, deep-frying is one of the most used techniques, both in domestic and industrial practices. During this process, the non-enzymatic browning reaction occurs, contributing to the development of colour and aroma and also leading to acrylamide formation.

The acrylamide content of French fries is influenced by several factors, including the variety of potatoes used (Tepe and Kadakal, 2019; Yang et al., 2016), moisture content (Mesías et al., 2019), the size of potato slice (Tepe and Kadakal, 2019), the frying process (Adascălului et al., 2021; Ahmed et al., 2023; Teruel et al., 2015), the frying parameters and conditions (Negoiță et al., 2022), and the type of frying oil used (Horneț et al., 2021; Kuek et al., 2020; Lim et al., 2014).

The parameters used during frying play a significant role in the formation of acrylamide. Studies conducted by Lu et al. (2015) and Yang et al. (2016) indicate that the level of acrylamide in potatoes increases with higher frying temperatures. Tepe and Kadakal (2019) showed that regardless of potato size (3, 6, 9 mm) or variety (Ranger Russet and Van Gogh), the acrylamide content increased with the increment of frying conditions (150, 170, 190°C/10, 20, 30 min).

The choice of frying oils plays a crucial role in acrylamide formation in French fries. Sunflower and palm oils are the most commonly used oils for frying potatoes. The level of unsaturation in these oils affects the acrylamide content of the fries; specifically, the higher the degree of unsaturation, the faster thermal degradation occurs (Yu et al., 2018). Based on this consideration, vegetable oil with a high content of saturated fatty acids, such as palm and coconut oils, is recommended for frying potatoes. Palm olein and palm oil are usually used in the deep-frying process due to their costs, high thermal stability, and sensory characteristics. Lim et al. (2014) showed that the acrylamide content formed in potato chips fried in coconut oil was not dependent on the unsaturation degree of this oil, which presented an 86.1% SFA content. Instead, it may have been influenced by the higher levels of free fatty acids present in this oil. Additionally, in the study realized by Pantalone et al. (2023), it was determined that free fatty acids present in the frying oil influence the acrylamide content as these acids are prone to be more susceptible to degradation during frying compared to triglycerides.

The purpose of this study was to investigate the influence of different frying temperatures and time combinations of potatoes on the moisture, fat, acrylamide content, colour parameters, and fatty acid composition of French fries deep-fried in palm oil. Moreover, the relationship between the acrylamide content and the investigated parameters was evaluated.

Materials and methods

Chemicals and reagents

Standards of acrylamide (+100 ppm hydroquinone) unlabelled 1 mg/mL in methanol (≥ 98%) and of labelled acrylamide (1,2,3-13C) (purity ≥ 99%) were purchased from Cambridge Isotope Laboratories (Andover, MA, USA). Isolute Multimode (1000 mg, 6 mL) and Isolute ENV^{+} (500 mg, 6 mL) cartridges, both supplied from Biotage (Uppsala, Sweden) were used for purification.

For fatty acid determination, F.A.M.E. Mix, C4-C24 (mixture of 37 fatty acid methyl esters (FAME), Bellefonte, PA, USA), and SRM®2377 (mixture of 26 FAME, NIST certified, Gaithersburg, MD, USA) standards were used.

All chemicals, solvents (n-hexane, ethyl acetate, methanol, 2,2,4-trimethylpentane, etc.) and reagents used were of chromatographic purity.

Materials

White potato tubers (*Solanum tuberosum* L., Queen Anne variety), with the label “special for frying” and refined non-hydrogenated palm oil, purchased from a local supermarket in Bucharest, Romania, were used. Before the analyses, potatoes were kept in a cold storage room.

Frying conditions

To investigate the influence of frying conditions on acrylamide content and fatty acid composition, potatoes were brought to room temperature, washed, peeled and cut into strips with a manual potato slicer (Zhejiang Yingxiao Industry and Trade Co, Jinhua, China). The potatoes size was 9 x 9 mm, with a length of 50 - 70 mm. After slicing, potatoes were washed in cold tap water for 30 min to remove the starch adhering to the surface, and then were drained and dried on a paper towel.

Potato strips were fried in an electric fryer (Hendi Blue Line, Rhenen, The Netherlands) with 2 detachable frying pans, a capacity of 4 L and a thermostat to prevent overheating.

The potato-to-oil ratio used in this study was 1:4 (w/w). Potatoes were deep fried at different temperatures (150, 170 and 190°C) and time combinations (6, 8 and 11 min). After frying, potatoes were let to cool at room temperature, and then they were ground and homogenized in a Büchi mixer (BÜCHI Labortechnik AG, Switzerland). and were kept in centrifuge tubes at -20°C before analyses.

Moisture content

For row potatoes and French fries’ moisture content determination, the AOAC method (AOAC, 1995) was used.

Fat content

Fat extraction with petroleum ether (40-60°C) using the Soxhlet Standard procedure with the Büchi B-811 system (BÜCHI Labortechnik AG, Switzerland) was realized for French fries. Prior to fatty acids determination, fat was stored at 4°C.

Acrylamide determination

For the acrylamide determination, the method described by Negoiță *et al*. (2021) was used. The workflow for the sample preparation steps for acrylamide determination is presented in Figure 1.

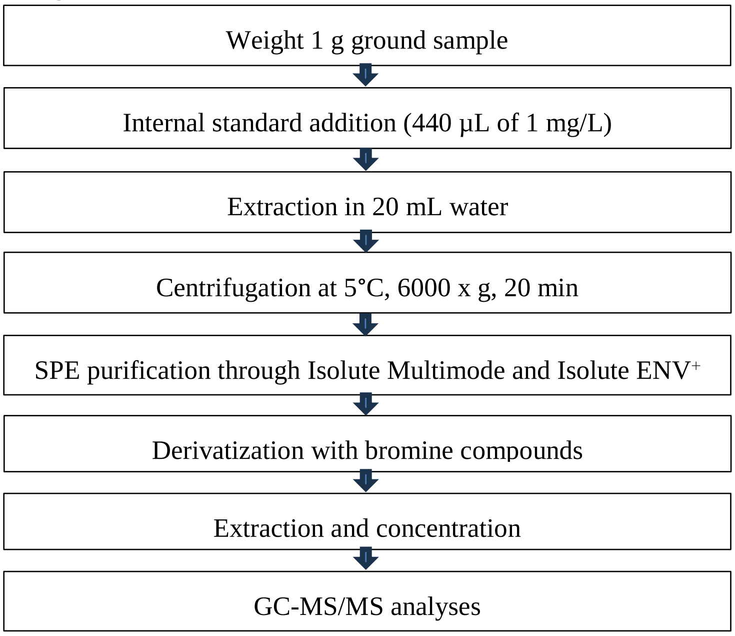

Figure 1. Workflow for sample preparation for acrylamide determination.

For acrylamide analyses, a GC-MS/MS system from Thermo Fisher Scientific (San Jose, CA, USA) was used. As a stationary phase, a TraceGOLDTM TG-WaxMS capillary column (30 m x 0.25 mm x 0.25 µm) acquired from Thermo Fisher Scientific (Waltham, MA, USA) was used, while the carrier gas was He (min. 99.9995% (5.0) purity) and argon was the collision gas (min. 99.9995% purity). The recording time of the chromatogram is 30 min.

For acrylamide quantification, the internal standard method was used, and two calibration curves prepared with standard solutions in the range of 0.05- 3 mg/L were drawn. For both curves, the correlation coefficients were higher than 0.999. The limit of detection (LOD) was set to 10.29 µg/kg, while the limit of quantification (LOQ) was 30.87 µg/kg, respectively. The method's recovery varied between 89.92-109.22%. The method's accuracy was expressed as relative standard deviation under repeatability (1.13- 4.26%), reproducibility (1.81- 7.21%), and intermediary precision (1.19- 8.84%). The results obtained for the validation parameters fulfilled the criteria specified by the European Commission (2017). The calculated uncertainty of the method was 17.5% of the concentration. To demonstrate the method's accuracy and precision we participated in proficiency tests organized by the Food Analysis Performance Assessment Scheme (FAPAS) (Sand Hutton, UK), yielding z-scores of -0.8 and 0 for French fries (pre-cooked) (3095/2019) and potato crisp (test 3099/2020) test materials, respectively.

Fatty acid composition

To determine the fatty acid profile of palm oil and French fries, fatty acids were converted to FAME by transesterification of the extracted fat. The FAME composition was determined using the transmethylation procedure with a boron trifluoride (BF3) catalyst as described by Mihai *et al*. (2019). The fatty acid composition was determined with the GC-MS/MS described before by using a high-polarity capillary column, TR-FAME (60 m × 25 mm × 0.25 µm) purchased from Thermo Fisher Scientific (USA) as stationary phase and He (99.9995% purity, 5.0) as mobile phase with a constant flow of 1 mL/min. The positive electronic ionization mode (EI+) and the "Selected Ion Monitoring-SIM" mode were used. The recording time of the chromatogram was 85.20 min.

The comparison with the retention times and with the *m/z* ratios specific for each FAME compound was used for FAME identification. Fatty acids were expressed as relative concentration (mass %) by using experimentally established correction factors determined for the two reference standards used. Mass percentages of each FAME individually determined were expressed per 100 g fat. Additionally, the saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA) content were calculated.

For both acrylamide and fatty acid composition, the Xcalibur Program was used for instrument control, data acquisition, and processing.

Colour determination

To determine the CIELAB'76 colour parameters (L*, a*, and b*) of grounded French fries, a Konica Minolta spectrophotometer (Universal Software V4.01 Miniscan XE Plus) with an illuminate D65 with an angle of view of 10° was used. Before analysis, the spectrophotometer was calibrated with white and black plates provided by the manufacturer. For each sample, 10 measurements of the colour parameters L* (lightness: black (0) to white (100)), a* (greenness (-) to redness (+)), and b* (blueness (-) to yellowness (+)) were performed on different points of the grounded French fries' samples.

Statistical analysis

All analysis were performed in duplicate, and results were expressed as mean ± standard deviation (SD). For statistical analysis, the Minitab statistical software version 20 was used. Initially, the normality condition was assessed and then one-way analysis of variance (ANOVA test), followed by Tukey's test, when $p < 0.05$, was used to evaluate the statistical significance between results. For fatty acids analysis, a heat map was assessed to check the variation of fatty acid composition in palm oil and French fries' samples.

To determine the relationship between the acrylamide content and the other investigated parameters (moisture, fat, fatty acids, colour parameters) of French fries, Pearson's correlation analysis was performed.

Results and discussion

Moisture and fat content of French fries' samples

The moisture content of French fries is an important factor which has a significant impact on the acrylamide formation, being influenced by the frying parameters. During deep frying, the heat transfers from the oil to the surface of the potatoes, thus the moisture content is reduced and the oil is absorbed into the French fries (Ahmed *et al*., 2023). In this process, the heat and mass transfer between the potatoes and oil is realized, and vapours are removed from the dry crust and the moist core (Rani *et al*., 2023).

The moisture content of potatoes before frying was 84.97%. As can be noticed from Table 1, regardless of the frying temperature, by increasing the frying time, the moisture content of all samples decreased significantly. Also, in the study conducted by *Romani et al.* (2009), the moisture content of French fries prepared in a similar fryer at 180°C, with a potato-to-oil ratio of 1:4 (w/v), decreased from 44.48% to 32.08% and 21.83% when potatoes were fried for 7, 10, and 13 min.

Similarly, Ahmed *et al.* (2023) showed that by deep frying potatoes at 160°C, when the frying time was increased from 3 to 7 min, the moisture content of French fries was reduced significantly from 46.19% to 40.54%. In our study, the highest moisture content was registered for samples fried at 150°C compared to the samples fried at the same time.

Table 1. Moisture, fat and acrylamide content of French fries' samples

Frying temperature, °C	Frying time, min	Moisture content, %	Fat content, %	Acrylamide, µg/kg
150	6	48.29 ± 0.45^{aA}	7.97 ± 0.07^{cG}	118.47 ± 1.82^{cG}
	8	41.08 ± 1.36^{bB}	10.10 ± 0.11^{bD}	199.87 ± 5.20^{bF}
	11	35.80 ± 0.28^{cC}	11.52 ± 0.11^{aB}	232.05 ± 5.35^{aE}
170	6	46.62 ± 0.39^{aA}	7.76 ± 0.15^{cG}	188.38 ± 2.39^{cF}
	8	38.70 ± 0.37^{bBC}	9.26 ± 0.11^{bE}	271.32 ± 5.22^{bD}
	11	29.45 ± 1.93^{cD}	10.66 ± 0.09^{aC}	684.37 ± 2.34^{aB}
190	6	41.01 ± 0.64^{aB}	8.80 ± 0.09^{cF}	192.36 ± 2.44^{cF}
	8	35.45 ± 0.30^{bC}	9.28 ± 0.11^{bE}	416.23 ± 1.14^{bC}
	11	25.93 ± 0.55^{cE}	13.32 ± 0.10^{aA}	1114.41 ± 12.69^{aA}

Values followed by different small letters in the same column for each temperature are significantly different ($p < 0.05$). Values followed by different capital letters in the same column for all temperatures and times are significantly different ($p < 0.05$).

By prolonging the frying time and temperature, the fat content of French fries significantly increased (Table 1).

When potatoes were fried for 6, 8 and 11 min, the fat content varied between 7.97- 11.52% for 150°C, 7.76- 10.66% for 170°C, and 8.80- 13.32% for 190°C. By keeping potatoes for a longer time (11 min) and at a higher temperature (190°C), the highest fat content was determined. In the study realized by Kammoun *et al.* (2022), potatoes fried for 5 and 7 min at 180°C, the oil uptake in French fries ranged from 12 to 15%.

A longer frying time results in the removal of a greater amount of water, the moisture content decreases, with the absorption of a larger amount of oil, thus increasing the fat content, compared to a shorter frying time.

Similarly, Ahmed *et al*. (2023) determined a higher oil content in potatoes deep fried for a longer immersion time, concluding that oil has more time to be absorbed in French fries.

Acrylamide content in French fries' samples

The acrylamide content of French fries is a public health concern as this compound has a carcinogenic potential and this kind of product is consumed frequently. The acrylamide content is influenced by the nitrogen source of acrylamide precursors, asparagine being the main amino acid responsible for acrylamide formation when palm oil is used as frying oil (Daniali *et al*., 2018).

The acrylamide content of French fries prepared under different frying temperatures (150, 170 and 190°C) and times (6, 8, and 11 min) is presented in Table 1. The frying parameters had a significant impact on the acrylamide content of the end products, the content increasing as a consequence of the increase in the speed of the Maillard reaction (Sharafi *et al.*, 2024). The acrylamide content of French fries prepared in our study varied between 118.47- 1114.41 µg/kg, the content being lower than the one reported by Oroian *et al.* (2015) who analyzed the level of this contaminant in French fries commercialized in fast foods from Romania and determined a content ranging between 210- 2680 µg/kg.

Regardless of frying temperature, the lowest acrylamide content was determined for potatoes fried for 6 min (118.47, 188.38, and 192.36 µg/kg). By increasing the frying temperature and frying time, the acrylamide content of French fries significantly increased ($p < 0.05$).

By increasing the frying time from 6 to 8 min, the acrylamide content increased significantly, being 1.69, 1.44 and 2.16-fold higher for 150, 170 and 190°C temperatures. When the frying time was prolonged from 6 to 11 min, the acrylamide content was 1.96, 3.63, and 5.79-fold higher for the same frying temperatures.

When frying temperature increased from 150°C to 170°C, the acrylamide content increased significantly, being 1.59, 1.36, and 2.95-fold higher for 6, 8 and 11 min of frying. By increasing the frying temperature from 150°C to 190°C, the acrylamide content was 1.62, 2.08, and 4.80-fold higher for the same frying times.

The frying time has a greater effect on the acrylamide content than the frying temperature.

Kuek *et al.* (2020) determined for potatoes fried in palm olein and red palm olein at 180°C for 3.5 min an acrylamide content of 447 and 678 µg/kg, higher than the content determined in our study when potatoes were fried for a higher temperature (190°C) and longer time (6 min).

In the case of potatoes fried for 11 min at 170°C and 190°C, respectively, the acrylamide content of French fries exceeded the benchmark level (500 µg/kg) established by the European Commission (2017). The effect of acrylamide intake on human health has not been fully understood. However, consumption of food products contaminated with acrylamide can result in neurotoxic, genotoxic, carcinogenic, reproductive, and hepatotoxic effects on human health (Zahir *et al*., 2025). Exposure to acrylamide of the general adult population could also be related to depression symptoms, determined by oxidative stress, inflammation and alkaline phosphatase (Wan *et al*., 2024).

To eliminate the effect of changes in the water content of French fries, the variations of acrylamide content depending on the temperature variation, and time duration of frying, respectively, were also calculated based on the dry matter content of the end product, results being expressed in µg/100 g d.m..

By increasing the frying time from 6 to 8 min, the acrylamide content of French fries (% d.m.) was 1.48, 1.25, and 1.98-fold higher for the frying temperatures of 150, 170 and 190°C, respectively. When increasing the frying time from 6 to 11 min, the acrylamide content was 1.58, 2.75, and 4.61-fold higher for the same frying temperatures.

Daniali *et al.* (2018) showed that the acrylamide content is influenced more by the frying temperature than by the frying time when a modelling system with asparagine, and glutamine in palm olein and soybean oil was used.

Fatty acid composition of French fries

The fatty acids composition of palm oil used for frying and of French fries was determined by GC-MS, and results are presented in a heatmap as presented in Figure 2. The fatty acid profile of French fries changes during frying due to the oil degradation that occurs.

Compared to palm oil, when frying potatoes, the content of PUFA decreases, while the content of the SFA increases (Aniołowska and Kita, 2015; Kuek *et al*., 2022). During potato frying, some PUFA and MUFA in the composition of palm oil, more sensitive to oxidation, transform into SFA, increasing the percentage of these acids.

The SFA content of French fries varied between 43.62% and 45.81%, higher than the content of palm oil used for frying (39.73%). Among the SFA that showed an increase during frying, compared to the SFA content in palm oil, palmitic (C16:0) and stearic (C18:0) acids were identified. Compared to the palmitic acid content of palm oil, the content of this acid in all the French fries samples obtained was significantly higher. Also, in the case of stearic acid, except for potatoes fried at 190°C for 11 min, the content was higher compared to the one of palm oil. The increase in the content of these fatty acids could be the result of the oxidation of linoleic acid (C18:2n6), the content of this acid decreasing while frying the potatoes (Kuek *et al*., 2022; Li *et al*., 2017). The content of the other SFA was low, both in palm oil and in French fries.

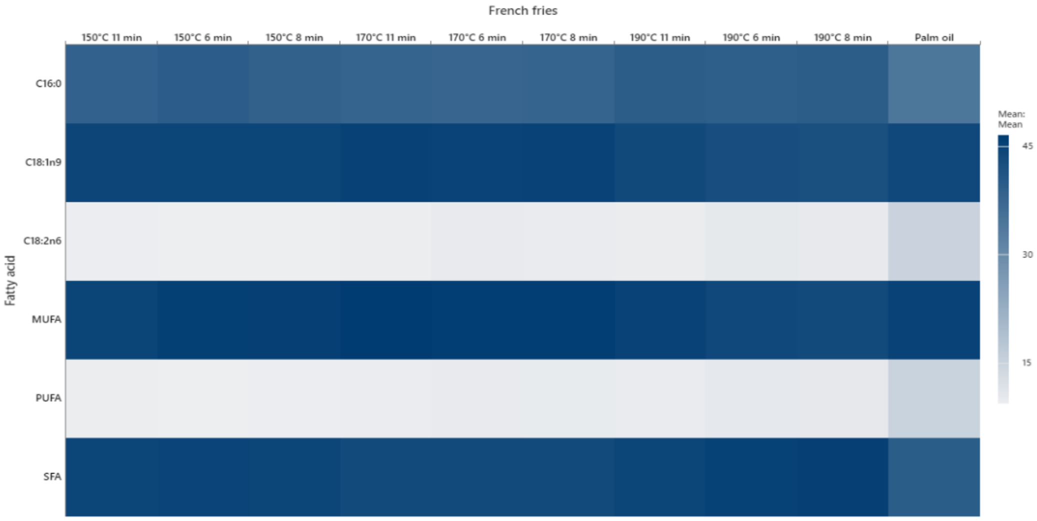

Figure 2. Heatmap plotting of the fatty acid compositions of palm oil and French fries prepared at different frying conditions. The values are from mean ± sd (n=2)

The MUFA content in fried potatoes ranged between 43.64% and 46.54%. In the case of palm oil, the content was 45.27%. All samples had a high content of oleic acid, ranging between 42.43% and 45.51%. It is known that oleic acid is more stable to oxidation, a higher intake of this acid and a limited ingestion of SFA leads to beneficial effects on the protection against cardiovascular disease (Hernandez, 2016).

In the case of PUFA, the content in French fries varied between 9.45 and 10.67%. The PUFA content of French fries was lower than that of palm oil (15.01%). In the study conducted by Kamarudin *et al.* (2018) it was shown that after deep-frying red and yellow palm oils, the PUFA content decreased with the increase of the frying cycle.

Colour determination

The visual appearance of French fries prepared in this study under the experimental variants is presented in Figure 3. In the case of French fries, colour is an important factor in choosing the frying end-point and purchase decision. The visual aspect and the colour of the French fries are the decisive parameters for consumers' perception and preferences. During frying, the non-enzymatic reaction takes place and potatoes develop a specific colour and aroma, these attributes being dependent on frying conditions. Regulation 2017/2158 recommends frying potatoes until a golden yellow colour is obtained. To predict the acrylamide content of French fries, the *a** parameter is the most important colour parameter, being directly correlated with the acrylamide content (Mesias *et al*., 2021). Consumer preference regarding the colour of French fries influences the risk of acrylamide intake. Mesias *et al.* (2018) conducted a pilot study to investigate the effect of consumer practices on the acrylamide formation when making French fries. From the 73 consumers who participated in the study, 91.8% prefer a golden yellow colour, 6.8% a light colour, while 1.4% prefer a toasted colour.

The colour parameters of the French fries prepared in this study are presented in Table 2.

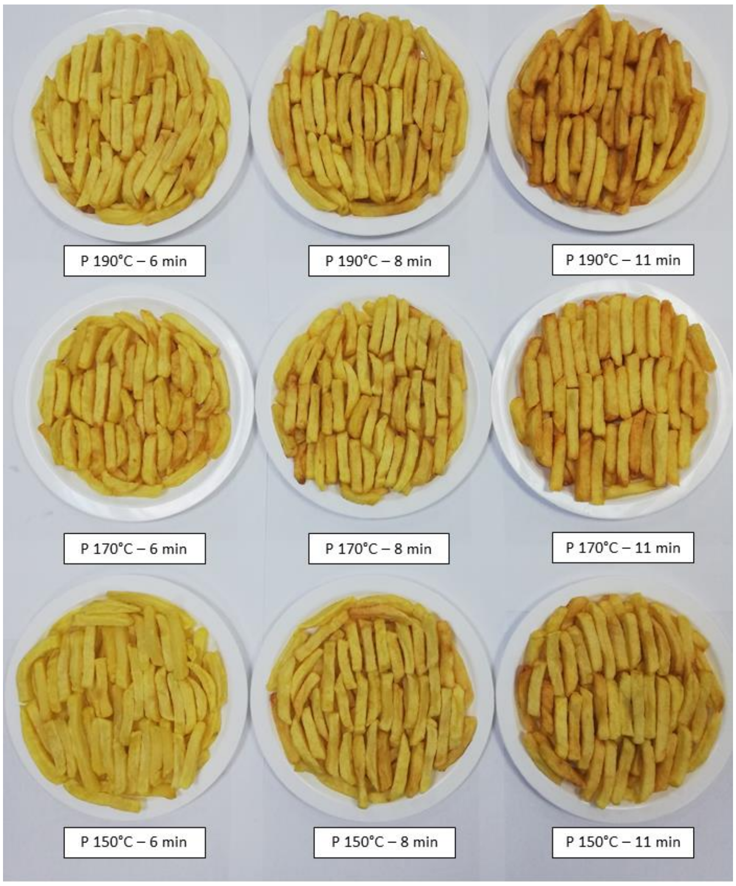

Figure 3. French fries prepared in a fryer under different frying conditions

The lightest colour parameters were determined for potatoes fried for 6 min. By increasing the frying time and keeping the same frying temperature, the values of the L^* parameter decreased, and French fries became darker, while the values of the a^* and b^* parameters increased, products became redder and yellower, practically having the golden yellow colour. Similarly, Teruel *et al.* (2015) reported a decrease in the L^* parameter and an increase in the a^* and b^* parameters of French fries as a consequence of increasing the frying time. In the study realized by Othman and Jamil (2021) potatoes of 10 mm thickness fried for 20 min at the same frying temperatures as the one from our study presented a decrease in the lightness of French fries with the increase of the frying temperature, whereas the values of *b** parameter increased with frying temperature of oil and time. Also, Kammoun *et al.* (2022) studied the influence of frying conditions (170, 180, 190°C/5, 7, 10 min) on the colour parameters of fried potatoes and showed that by applying a more intense frying process, the values of *L** parameter decreased, while the values of *a** and *b** parameters increased.

Additionally, when increasing the frying temperature and maintaining the frying time, French fries became darker, and the *L** parameter decreased.

Othman and Jamil (2021) showed that besides frying temperature and potato thickness, moisture content is an important factor in the colour development of French fries.

Table 2. Variation of colour parameters obtained in the experimental variants

Frying temperature, °C	**Frying time, min**	**Colour parameters**		
		*L**	*a**	*b**
150	6	74.22 ± 0.01^{aA}	1.11 ± 0.01^{cI}	30.78 ± 0.04^{bF}
	8	73.54 ± 0.03^{bB}	2.33 ± 0.01^{bH}	30.49 ± 0.06^{cG}
	11	70.20 ± 0.02^{cG}	3.62 ± 0.02^{aC}	32.89 ± 0.05^{aC}
170	6	72.89 ± 0.02^{aC}	2.64 ± 0.02^{cF}	29.93 ± 0.05^{cH}
	8	71.56 ± 0.02^{bE}	3.21 ± 0.02^{bE}	32.31 ± 0.02^{bE}
	11	67.86 ± 0.06^{cH}	5.18 ± 0.06^{aB}	32.69 ± 0.05^{aD}
190	6	72.84 ± 0.03^{aD}	2.47 ± 0.02^{cG}	32.30 ± 0.02^{cE}
	8	70.97 ± 0.02^{bF}	3.58 ± 0.02^{bD}	33.50 ± 0.04^{bB}
	11	63.56 ± 0.05^{cI}	6.88 ± 0.06^{aA}	35.86 ± 0.08^{aA}

Values followed by different small letters in the same column for each temperature are significantly different ($p < 0.05$). Values followed by different capital letters in the same column for all temperatures and times are significantly different ($p < 0.05$).

Correlations between the acrylamide content of French fries and investigated parameters

The relationship between the acrylamide content and the moisture, fat content, fatty acids composition, and colour parameters of French fries fried under different conditions were determined by using Pearson correlation and results are presented in Table 3.

Both moisture and fat content were influenced by the intensity of frying parameters. Between the acrylamide content and moisture content of French fries fried at 150, 170 and 190°C for 6, 8, and 11 min, negative, very high, and significant correlations (r= -0.943 ÷ -0.989) were determined.

In the case of fat content, positive, very high, and significant correlations (r=0.922-0.990) were determined between this parameter and the acrylamide content.

The correlations indicate the relationship between the physical-chemical composition of French fries and the acrylamide content. The correlation between the moisture and fat content of French fries prepared under the conditions presented was determined and results showed that there is a very high negative and significant correlation (-0.959 ÷ -0.995) between these parameters (Table 4). In the study realized by Ngobese and Wrokneh (2018), it was shown that during the frying process, oil replaces the water from the potato structure and these parameters are negatively correlated.

Pearson correlation showed a very high positive relationship between the acrylamide content and SFA, MUFA and PUFA content expressed as % of French fries.

Table 3. Pearson correlation between acrylamide content of French fries fried under different conditions and investigated parameters

Parameter	Acrylamide, µg/kg					
	150°C/6, 8, 11 min		170°C/6, 8, 11 min		190°C/6, 8, 11 min	
	r	*p-value*	*r*	*p-value*	*r*	*p-value*
Moisture, %	-0.974	0.001	-0.943	0.005	-0.989	0.000
Fat, %	0.985	0.000	0.922	0.009	0.990	0.000
SFA, % product	0.990	0.088	0.927	0.245	0.972	0.000
MUFA, % product	0.993	0.075	0.927	0.244	0.987	0.102
PUFA, % product	0.989	0.095	0.917	0.262	0.990	0.092
L*	-0.820	0.388	-0.995	0.064	-0.999	0.028
a*	0.966	0.166	0.998	0.037	1.000	0.006
b*	0.637	0.560	0.723	0.486	0.995	0.065

r- correlation coefficient. Significant differences are expressed at $p < 0.05$

Table 4. Pearson correlation between acrylamide content and moisture and fat content of French fries

Correlations (r)	Moisture/fat content	
	r	*p-value*
150°C/6, 8, 11 min	-0.995	0.000
170°C/6, 8, 11 min	-0.983	0.000
190°C/6, 8, 11 min	-0.959	0.002

r- correlation coefficient. Significant differences are expressed at $p < 0.05$

The correlation between the acrylamide content and colour parameters of French fries prepared in this study under different frying conditions is presented in Table 3.

Linear negative correlations were found between the acrylamide content of French fries and the lightness parameter *L** (r= -0.820 ÷ -0.999), while positive correlations were found with *a** (r= 0.966- 1.000) and *b** (r= 0.637-0.995) parameters. Similarly, Yang *et al.* (2016) determined a significant negative correlation between the acrylamide content and the *L** parameter of French fries (r= -0.586), and a positive correlation with the *b** parameter (r= 0.420).

The highest correlations for all the investigated parameters were determined mostly between the acrylamide content of potatoes fried at 190°C for the three-time durations compared to the other temperatures.

Conclusions

The results of this study indicate that the acrylamide content of French fries is directly affected by the frying conditions, by increasing the frying temperature and time, the acrylamide content is higher. Frying duration influences the acrylamide content more than the frying temperature. By frying potatoes at a lower temperature (150, 170°C) for a shorter time (6, 8 min), the safety and sensory attributes of French fries are maintained, thereby ensuring that the products are accepted by consumers. Potatoes fried at 170°C and 190°C, for 11 min exceeded the benchmark level set for acrylamide by the European Commission (2017).

The acrylamide content of French fries was significantly negatively correlated with the moisture content and significantly positively correlated with the fat content. The more intense the frying process was, the more water evaporated and more fat was absorbed in French fries.

When it comes to the colour of the French fries, the acrylamide content was negatively correlated with the colour parameter *L** and positively correlated with the colour parameters *a** and *b**.

During the thermal treatment, some PUFA of palm oil were transformed into SFA as a consequence of oil oxidation, and the content of SFA increased. The acrylamide content of French fries was positively correlated with the fatty acid composition.

The acrylamide content of French fries is important in all sectors concerned with food safety, health, regulatory agencies, and for consumers. Manufacturers and those responsible for the production of French fries should focus on balancing acrylamide content and colour parameters to meet consumer preferences while considering health concerns.

A limitation of the study is that the acrylamide precursors were not determined, and the alteration of cooking oil during frying was not investigated. Future research should explore the selection of other potato varieties, the determination of acrylamide precursors content, total polar compounds, and the investigation of other frying conditions.

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