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Deep-fried French fries in Slovak catering: A comprehensive evaluation of nutritional benefits, health risks, and sensory-textural properties

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Abstract:
This study aimed to evaluate the oxidative stability of rapeseed oil, changes in the fatty acid profile, and acrylamide formation in French fries during their deep-frying in Slovak catering establishments. Their nutritional benefits and potential health risks were assessed by chemical, textural, and sensory analyses.

The primary materials for all analyses were raw potato fries and frozen pre-fried French fries. Chemical and physical degradation of the frying oil was monitored using total polar compounds measured with a Testo 270 tester and the peroxide value determination, while the acid value was determined via titration with potassium hydroxide. Textural analysis of the potato fries was performed using a TA.XT plus texture analyzer to quantify parameters like hardness and crispness, followed by a sensory evaluation conducted by a panel using a 9-point hedonic scale.

Frozen pre-fried French fries were deep-fried in rapeseed oil at 175°C/4 min and 200°C/3 min until total polar compounds reached 24%. Textural properties were assessed before and after deep-frying of raw and frozen pre-fried French fries, while their sensory evaluation followed the first deep-frying. Rapeseed oil remained stable longer at 175°C/4 min (22.5 h) than at 200°C/3 min (20.5 h). Peroxide values increased by 66% at 175°C and by 33% at 200°C. Acid values increased by 50% at 175°C and by 33% at 200°C. The content of polyunsaturated fatty acids decreased, while that of monounsaturated fatty acids increased ($p \leq 0.05$). Acrylamide levels were within legal limits (< 500 µg/kg). Higher frying temperatures (200°C) increased crispness but reduced breaking force and hardness. Raw fries had higher strength and crispness at pre-frying, while frozen pre-fried fries exhibited lower crispness. Sensory evaluation favored semi-finished products over raw potato fries, with better ratings for color, aroma, and taste. Shorter, high-temperature frying significantly affected the textural changes ($p \leq 0.05$), while lower temperatures (175°C) had a greater effect on hardness than breaking force. Overall, deep-fried pre-fried French fries were preferred in the sensory tests.

Our findings provide scientifically based information for optimizing frying processes to improve the quality of French fries and support the development of innovative recipes in catering establishments.

Keywords: Frying, potato, rapeseed oil, catering, acrylamide formation, oxidation, food safety

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INTRODUCTION

Deep-frying is the heat treatment of foods immersed in fat at temperatures between 150 and 200°C. Hot fat surrounds food mostly from all sides, so the heat is transferred quickly. Frying oil should be selected by its properties during the frying process. Currently, thermal-oxidative stability, availability and price, as well as nutritional and physiological functions are important decision-making factors. However, there is no oil that is ideal for all types of frying and deep-frying [1–3]. During the frying process, many reactions occur that lead to the formation of new substances due to high temperatures,

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interaction between the food and the frying medium, as well as the water and air contact. Chemical reactions associated with deep-frying change the composition of fatty acids in oil. They include oxidation, hydrolysis, polymerization, and isomerization. The frying process causes the formation of free fatty acids, alcohols, aldehydes, ketones, diglycerides, monoglycerides, peroxides, acrylamides, hydrocarbons, and cyclic compounds [4–9]. As a result, degraded oil can endanger human health. Total polar compounds include oligomeric and dimeric triacyclglycerols, oxidized triacylglycerols, diacylglycerols, and free fatty acids [10, 11]. Widely accepted and recommended values are 24% for total polar compounds and 12% for polymerized triglycerides. The peroxide value and the acid value are applied as the indicators of oxidation degree in edible oils [12, 13]. However, during the next heating period, the peroxide value decreases since hydroperoxides are decomposed rapidly and other degradation substances are produced. This change in the peroxide value is observed at the time when the oil cools down. This indicator is therefore more suitable for the quality of fresh oil rather than the quality of oil during deep-frying [14].

Polyunsaturated fatty acids are more susceptible to oxidation because of their higher degree of unsaturation [15, 16]. In general, oils with a high content of polyunsaturated fatty acids are used for cold cuisine and short-term heat treatment [17]. Oils that are low in linoleic acid and high in oleic acid are more stable during the deep-frying process [18]. This fact was observed by Zárate *et al*. [19], Rotondo *et al*. [20], and den Hartigh [21], who stated that higher contents of oleic acid caused better resistance to degradation at processing with dry heat methods.

Acrylamide is a toxic and carcinogenic compound that is produced in foodstuffs during high-temperature processing [22]. Products based on potatoes can contain significant amounts of acrylamide [23]. According to the EU Regulation No. 2017/2158, acrylamide should not exceed 500 µg/kg in French fries ready for direct consumption [24].

Food control is very important to take corrective actions, if necessary. Several studies have monitored changes in various quality parameters of edible oils and French fries during frying [25–28].

The texture of French fries is one of their key quality indicators. It is based on their mechanical, geometrical, and sensory properties, such as oil content, moisture, color, and taste. Texture has long been defined as a sensory-perceptual property of a product that is perceived through vision, hearing, and touch. Texture evaluation is performed by both sensory (subjective) and instrumental (objective) methods [29].

Although sensory analysis is the standard for evaluating food texture, its implementation is time-consuming and costly, requiring calibration using reference standards [30]. Therefore, significant attention has been given to the development of instrumental methods that allow the creation of predictive models linking sensory attributes with physical parameters [31]. For instance, Li *et al*. [32] analyzed the relationship between various texture analysis methods in the evaluation of ten types of French fries. Several studies have focused on assessing French fries texture using instrumental tests, such as the puncture test [33], compression test [34], three-point bending test [35], and shear test [36].

In this study, we aimed to assess the effect of deep-frying conditions on the oxidative stability of rapeseed oil and the variability of fatty acids and acrylamide content in French fries. We also evaluated their quality and safety employing comprehensive textural and sensory analyses.

STUDY OBJECTS AND METHODS

Experimental material. The primary materials for all analyses were raw potato fries (RPFs) and frozen pre-fried French fries (FPFFs). Potato fries were cut from fresh Agria potatoes, with a 9 × 9 mm cut size. Potatoes of the Agria variety (cooking type B) are one the most commonly cultivated and consumed cultivars in Slovakia. They are characterized by large, oval-shaped tubers with dark yellow flesh and high yield potential. Due to their textural and compositional properties, they are suitable for direct consumption (cooking and baking), as a side dish, or for the preparation of French fries and chips. Frozen pre-fried French fries intended for catering were obtained from Lamb Weston Holdings, Inc. (Eagle, Idaho, USA). Their composition included potatoes (86%); modified starch, rice flour, starch, salt, additives E450, E500, and E415 (7%); as well as pepper, turmeric, paprika, and dextrose.

Rapeseed oil was purchased in 5-L packages from PALMA a.s. (Bratislava, Slovakia). It contained 91.5 g of fat (of which 8.6 g were saturated fatty acids) and 0 g of carbohydrates per 100 g of the product. Although not indicated on the label, 8.5 g of non-lipid components in 100 g of rapeseed oil primarily consist of bioactive substances such as sterols, vitamins, and pigments, as well as phospholipids, waxes, and other minor constituents. The rapeseed oil utilized in this study is one of the most widely consumed vegetable oils in Slovakia. It is refined, deodorized, and has a neutral flavor, which makes it suitable for culinary applications such as cooking and frying in both domestic and public catering establishments.

Design of the experiment. Experimental variants are presented in Table 1.

For the chemical analyses, frozen pre-fried French fries were deep-fried in oil at two different combinations of temperature and time (175°C/4 min and 200°C/3 min) until the content of total polar compounds (TPCs) reached 24%. Deep-frying was performed continuously in two fryers (Bartscher SNACK III A162810E, Salzkotten, Germany), with a sensitive thermostat with a capacity of 8 L. The oils were loaded separately, then heated to 175 and 200°C. One deep-frying cycle consisted of 100 g of French fries. The French fries were placed in a plate and extra oil was absorbed with tissue paper. The frying pro-

Table 1 Characterization of all experimental variants

Labelling	Material	Temperature, °C	Length of deep-frying, min	Sampling
RPFs	Raw potatoes	4	–	Raw potato fries
FPFFs	Semi-finished French fries	–18	–	Frozen pre-fried French fries (original packaging)
A	French fries deep-fried in rapeseed oil	175	4	Immediately after the first deep-frying
B	French fries deep-fried in rapeseed oil	200	3	Immediately after the first deep-frying
C	French fries deep-fried in rapeseed oil	175	4	Sampling after exceeding 24% total polar compounds
D	French fries deep-fried in rapeseed oil	200	3	Sampling after exceeding 24% total polar compounds

RPFs – raw potato fries; FPFFs – frozen pre-fried French fries

cedure was performed for several days (6 h/day to 24% TPCs). At the end of each day, the oil was cooled down. All the experiments were carried out at least in triplicate.

Raw potato fries and frozen pre-fried French fries were analyzed texturometrically before and after the first deep-frying while sensorially only after the first deep-frying under the above-mentioned conditions (175°C/4 min and 200°C/3 min).

Chemical analyses. ***Total polar compounds determination.*** The content of total polar compounds (TPCs) was determined by using a Testo 270 oil tester (Hanon Advanced Technology Group Co., Ltd, Jinan, China). This indicator is based on dielectric constant changes measured in hot oil and shows the degree of its deterioration.

The TPCs content was determined in fresh oil and then every 30 min at 130°C throughout the deep-frying period. The analyses were terminated when TPCs reached ≥ 24%, indicating oil deterioration.

Peroxide value determination. The peroxide value was monitored in fresh oil and then hourly during the deep-frying period. The measurements were completed when TPCs reached ≥ 24%.

Following ISO standard 3960:2017 (EN), the oils were dissolved in isooctane and glacial acetic acid and then mixed with potassium iodide. The iodine liberated by the peroxides was determined iodometrically (visually) using starch as an indicator and a sodium thiosulfate standard solution. The peroxide value (PV) was expressed in mEq O_2/kg and calculated as follows (Eq. (1)):

$$\mathrm{PV} = \frac{\left(V - V_0\right) \times C_{thio} \times C_{stand} \times 1000}{\mathrm{m}} \qquad (1)$$

where V is the volume of the $Na_2S_2O_3$ standard solution (C = 0.01 mol/L) used for the sample titration, mL; V_0 is the volume of the $Na_2S_2O_3$ standard solution (C = 0.01 mol/L) used for the blank titration, mL; C_{stand} is the exact concentration of the $Na_2S_2O_3$ standard solution (C = 0.01 mol/L); C_{thio} is the approximate concentration of the $Na_2S_2O_3$ standard solution, C = approx. 0.01 mol/L; and m is the mass of the sample, g.

Acid value determination. The acid value (AV) was determined in fresh oil and then hourly during the deep-frying period. The measurements were completed when TPCs reached ≥ 24%.

Following ISO standard 660:2020 (EN), the obtained fat was heated and dissolved in the ethanol-diethyl ether (1:1) extract (25.0 mL). Then alkalimetric titration against phenolphthalein was performed with the potassium hydroxide solution. The AV was expressed as mg KOH/g, indicating the amount, mg, of potassium hydroxide needed for neutralizing free fatty acids in one gram of fat (Eq. (2)):

$$\mathrm{AV} = \frac{56.1 \times V \times C}{\mathrm{m}} \qquad (2)$$

where V is volume of the potassium hydroxide standard solution, mL; C is the concentration of the potassium hydroxide standard solution, mol/L; and m is the mass of the sample, g.

Fatty acids determination. The content of fatty acids in the French fries was analyzed immediately after their removal from the package, after the first deep-frying, and after obtaining ≥ 24% TPCs. For this, 150 g of each sample was frozen until the time of analysis.

Gas chromatography was performed according to ISO 12966-1:2014. Briefly, 0.1 g of oil was dissolved in 5 mL of hexane and 1 mL of KOH (2 mol/L in methanol). The tubes were stirred for 30 min to separate two phases. The upper phase was used for gas chromatography performed on a 6890 GC Chromatograph (Agilent Technologies, Palo Alto, CA) with a multi-mode injector, a 7683 B automatic liquid sampler, and flame ionization detection. Separation was done with an Agilent 6890 GC column (Agilent Technologies, Inc. Headquarters, Santa Clara, United States) (60 m × 0.25 mm i.d. × 0.15 µm DB-23). The temperature program was set up as follows: the initial column temperature of 50°C was maintained for 1 min, then increased to 175°C at 25°C/min, further increased to 230°C at 2°C/min, maintained for 5 min, and increased again to 245°C at 120°C/min for 8 min. The injector temperature was 250°C. H_2 was used as a carrier gas, with a flow rate of 2.225 mL/min and a pres-

sure of 238.96 kPa. Fatty acids were determined by injecting 1 µL of a sample at a split ratio of 1:10, with a constant flow mode at 20.4 cm/s. The flame ionization detector was set up at 280°C with a flow rate of hydrogen at 35 mL/min and air at 350 mL/min. Nitrogen was used as a make-up gas with a flow rate of 30 mL/min. The total time for a single sample run was 32 min. Fatty acid methyl esters (FAME) were identified by comparison with the FAME standard mixture retention times and mass spectra.

Acrylamide determination. The content of acrylamide in the French fries was analyzed after its removal from the package, after the first deep-frying, and after the TPCs reached ≥ 24%. For this, 50 g of each sample was mixed and then frozen until the time of analysis.

Acrylamide was determined as described by Ciesarova *et al*. [37]: the samples were extracted with an acetic acid (0.2 mM) water solution and pre-extracted to ethyl acetate. The results were obtained by using the software MassHunter Workstation version B.04.00 and Agilent MassHunter Worstation version B.04.01. At the acrylamide content of < 500 µg/kg (lower than the reference level), Y was equal to 0 (Y = 0). The results were expressed as odds ratios and 95% confidence intervals (95% CI). The receiver operating characteristic curve was calculated. Performance parameters were quantified by calculating the area under the curve. The Youden index identified the conditions under which sensitivity and specificity were maximized. Statistical results were evaluated at a significance level of $p \leq 0.05$, with the use of SPSS version 25.0 (SPSS Inc., Chicago, IL).



Figure 1 Texture analysis of hardness of potato fries

Textural and sensory analyses. ***Textural analyses.*** The primary samples for all analyses were RPFs and FPFFs. These were analyzed in their raw state at 4°C and after frying under two different temperature-time combinations (175°C/4 min and 200°C/3 min). To ensure objectivity of the measurements, the potato fries were of uniform length and thickness, and all determinations were performed under identical laboratory conditions. Each parameter was assessed in 10 replicate measurements per sample.

Textural properties were assessed using a TA.XT Plus texture analyzer (Stable Micro Systems, UK), focusing on the following parameters (Table 2):

– hardness, g; breaking force, mm – spherical probe (Fig. 1);

– strength, N/mm; cutting work/crispness, N/mm/s – Warner-Bratzler shear blade.

The measured data from the texturometric analysis were statistically evaluated for each indicator using basic descriptive statistical methods, including the arithmetic mean ($\bar{x}$), standard deviation (SD), and coefficient of variation (v). Statistical analysis was performed using Excel (Microsoft Office 365, Washington, USA) and the statistical software XLSTAT (version 2021.1.1). A paired *t*-test was used to process the results at a significance level of 0.05.

Sensory analyses. Raw potato fries and frozen pre-fried French fries were analyzed sensorially only after the first deep-frying under two temperature-time conditions (175°C/4 min and 200°C/3 min). The evaluation was performed by a panel consisting of employees from foodservice establishments and consumers. The panel comprised 15 evaluators aged between 18 and 65 years, who were trained according to the ISO 8586-1 standard (International Organization for Standardization, ISO, 1993). The panel was gender-balanced, including both male and female evaluators.

Table 2 TA.XT Plus settings for measuring textural properties of potato fries (raw, pre-fried, deep-fried)

Instrument settings	Measurement parameter	
	Strength and cutting work/crispness	Hardness and breaking force
Test mode	Compression force measurement	
Selection	Return to start	
Probe pre-test speed	1.50 mm/s	
Probe test speed	1.50 mm/s	
Probe post-test speed	10.00 mm/s	
Probe penetration depth	20 mm	30 mm
Trigger type	Auto – 40 g	
Zero mode	Auto	
Data acquisition rate	200 pps	
Accessories (5 kg load cell)	Warner – Bratzler shear blade	Spherical probe

A pre-prepared questionnaire was used, which was designed to be simple and intuitive for all participants. The evaluators filled out the questionnaire independently, based on their subjective judgment.

The sensory evaluation analyzed the following attributes: color, aftertaste, aroma, crunchiness, chewiness, oil content, and overall impression. A consumer hedonic preference test was used for the evaluation, based on a 9-point scale. This approach is standard in sensory analysis and is irreplaceable by other instrumental methods. Score 1 on the scale indicated the lowest quality of the product evaluated, while score 9 represented the highest quality.

The sensory evaluation took place in a controlled sensory laboratory environment at 20°C and a relative humidity of 45%, ensuring optimal conditions for conducting the analysis.

Statistical analysis. Statistical analysis was performed with Microsoft Office Excel and its additional analytical tools, as well as the SAS Enterprise Guide version 1.5. The data was analyzed by using ANOVA in general linear models (GLM), Scheffe's test, Tukey's honestly significant difference test, and *t*-test at the significance level $\alpha = 0.05$ and 0.001.

RESULTS AND DISCUSSION

Deep-fried foods are very popular among consumers. Their sensory properties cannot be imitated by any other technological treatments. Our experiment was based on the requirements of Slovak legislation (Decree of Ministry of Health of the Slovak Republic no. 533/2007 Coll.), according to which only fats intended for heat preparation and given purpose can be used for continuous frying and deep-frying. They can be used for a maximum of 24 h at a maximum temperature of 180°C, unless the manufacturer states otherwise. Gastronomic establishments, however, do not comply with these requirements for economic, time, and personnel reasons and deep-fry for a significantly longer time, often in low-quality oil and at a higher temperature. Due to the degradation of frying oil, the frying conditions should be carefully monitored.

Total polar compounds in deep-frying oils. Total polar compounds (TPCs) are a decisive parameter for investigating the thermal-oxidative properties of oils, as well as determining the content of fatty acids and acrylamide in French fries. The French fries, which were primarily intended for catering establishments, were fried in rapeseed oil at two conditions (175°C/4 min and 200°C/3 min) until the TPCs content of 24% was obtained.

Rapeseed oil was more stable at 175°C/4 min during the entire frying process. The TPCs measured at 4% in fresh rapeseed oil increased during continuous deep-frying under the above conditions. Oil deterioration (≥ 24%) occurred after 20½ (variants B–D) and 22½ (variants A–C) h of continuous deep-frying (Table 3).

TPCs increased throughout the frying process in both oils. The progress of each linear function was described by the regression equation and the reliability of all determinations was expressed by determination coefficients (R^2). As can be seen in Fig. 2, the level of detection reliability was comparable in both combinations of deep-frying ($R^2 = 97.01\%$ at 175°C/4 min and $R^2 = 98.44\%$ at 200°C/3 min). A very high positive linear correlation and very high tightness were found between the time of frying and the value of TPCs.

As stated by Yin & Fan [38], the degree of dependence between the variables is characterized by different measures of tightness of statistical dependence. The coefficient of determination R^2 is very important for evaluating the degree of dependence between two variables. The theoretical values are estimated based on the regression line.

In our study, these principles were also applied to evaluate the acid and peroxide values.

Zeleňáková *et al.* [39] reported higher stability of the oil containing higher contents of oleic acid during a week of continuous measurement of TPCs. Thermodegradation changes in the oil were also monitored by Zeleňáková *et al.* [27]. In this study, lower TPCs were found to be in rapeseed oil (3.3%) and the threshold (24%) was obtained on the fourth day. The deep-frying rapeseed oil deteriorated after 23½ h. Fresh sunflower oil contained 5.5% of TPCs on the first day and the limit of 24% was obtained on the third day. The deep-frying sunflower oil deteriorated after 17½ h. Significant differences ($p \leq 0.05$) in the TPCs contents were observed between rapeseed and sunflower oils during deep-frying.

Several indicators are checked in edible oils during frying, including TPCs, oxidized triglyceride oligomer and dimer (TGO + TGD), acid value, smoke point, and

Table 3 Total polar compounds during the deep-frying process

Deep-fat fryers	Deep-frying conditions	Oil deterioration, h	Number of cycles
1	175°C/4 min	22.5	45
2	200°C/3 min	20.5	41

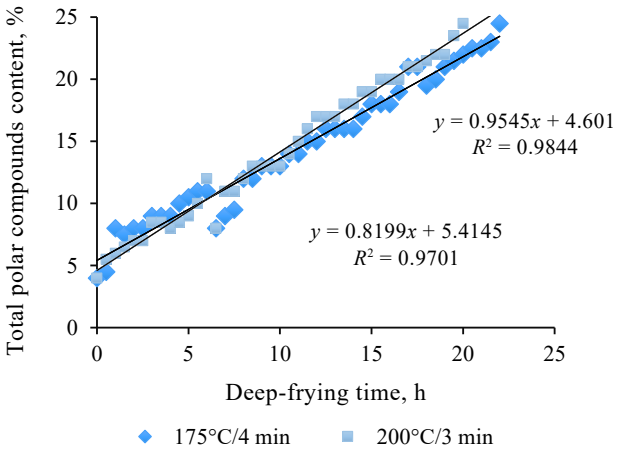


Figure 2 Total polar compounds in rapeseed oils depending on the French fries deep-frying conditions

frying temperature. TPCs are the most important indicator set as a requirement in many countries [40]. Their maximum content in frying oil ranges from 24 to 27 g/100 g worldwide [41]. Chen *et al.* [42] reported that TPCs in soybean and palm oils exceed the limit of 25% (in Taiwan) after 48 h of use.

Li *et al.* [43] monitored the validity of TPCs and their three components in the evolution of epoxy fatty acids in frying oil in the fast-food restaurants. The content of epoxy fatty acids can be predicted using TPCs rather than oxidized triglyceride monomer. In their study, with the TPCs reaching 24, 25, and 27 g/100 g, the contents of epoxy fatty acids were 1.47–3.63, 1.58–4.06, and 1.83–5.08 mg/g, respectively.

Acid and peroxide values in deep-frying oils. The oxidation level can be evaluated by a few chemical analyses, including peroxide value, TPCs, and acid value [44]. Among these, TPCs are one of the most important indicators used to evaluate the quality of frying oils.

The acid value is an indicator of the content of free fatty acids. Cooking oil has an acid value of 0.00–3.00 mg KOH/g. The lower this value, the higher the oil's quality [45].

After the first cycle of frying the acid value at 175°C/4 min reached 0.224 mg KOH/g and after the last frying – 0.448 mg KOH/g. At 200°C/3 min, the acid values were 0.224 and 0.673 mg KOH/g after the first and last cycles, respectively. As indicated in Fig. 3, a linear increase in the acid value was observed in both combinations. However, at 175°C/4 min, the determination coefficient was only 22.82%, indicating a slight tightness ($10\% \leq R^2 < 25\%$) in assessing the degree of dependence between the variables. Conversely, a slightly higher value (R^2 = 78.97%) was found at 200°C/3 min, indicating a high tightness between the two variables ($50\% \leq R^2 < 25\%$).

The increase in acidity can be attributed partially to hydrolysis and partially to carboxyl groups, which accelerate the degradation of hydroperoxides during deep-frying [46].

The peroxide value is used to assess the products of primary oxidation of fatty acids [4]. Its increase during deep-frying is caused by the attack of free radicals on unsaturated fatty acids, resulting in products of primary oxidation in oil [18].

In our study, at the first measurement the peroxide value reached 2.8 mEq O_2/kg at 175°C/4 min and at the end – 4.2 mEq O_2/kg. At 200°C/3 min, the values were 0.8 and 2.4 mEq O_2/kg at the first and last measurements, respectively. A regression linear line was created from the measured values, showing differences between the two deep-frying combinations. A very low tightness $R^2 < 10\%$ was found at 175°C/4 min (9.19%), meaning that this model does not provide any significant information for understanding the dependent variable and is therefore useless. The prediction of values was very low.

Notably, the acid and peroxide values varied during the entire deep-frying period, with many of them exceeding the values established by Slovak Decree No. 424/2012 (peroxide value: max 10 mEq O_2/kg, acid value: max 0.6 mg KOH/g).

Deep-frying causes rapid oxidation and an increase in the peroxide value. At further heating, however, the peroxide value decreases because hydroperoxides are decomposed more rapidly, and other secondary degradation products are formed. Therefore, the rise of the peroxide value occurs at a time when the oil cools down. From this we can conclude that this indicator is better suited for evaluating the quality of fresh oil rather than the oil during frying or deep-frying [14, 27].

The acid, peroxide, and total oxidation values in our study were higher than those established by the Codex Alimentarius Commission standards. In particular, the peroxide values deviated from their standard of 10 mEq O_2/kg, while the acid values (0.56–4.315 ± 0.605 mg KOH/g) were significantly higher than the standard values. According to Pardeshi [10], the water contents and acid values were higher in waste frying oils used by fast food establishments, compared to other sectors.

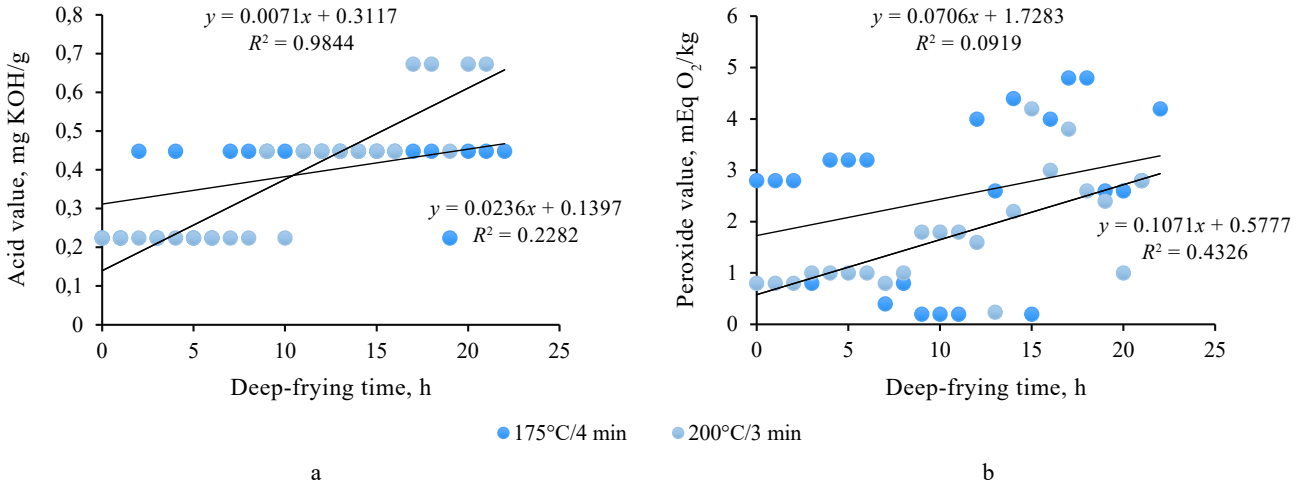


Figure 3 Acid (a) and peroxide (b) values in rapeseed oils depending on the French fries deep-frying conditions

Vegetable oils rich in linoleic acid contribute to the distinct aroma and flavor of fried food but exhibit lower oxidative stability compared to those abundant in saturated and monounsaturated fatty acids.

Fatty acids in French fries and oil. A total of 43 types of fatty acids were analyzed in individual samples of French fries. The presence of 11 fatty acids was recorded in all the samples during each analysis, while the content of erucic acid was detected only in the fries that underwent the initial frying. This acid was not detected in the primary semi-finished product. As shown in Table 4, the French fries predominantly consisted of linoleic and palmitic acids, with the content of other acids being less than 5%.

The French fries removed from the package consisted of 51.59% linoleic, 35.53% oleic, 6.44% palmitic, and 3.56% stearic acids. However, the profile of fatty acids varied depending on the frying conditions, with some acids showing a decrease while others exhibited an increase (palmitoleic, oleic, α-linolenic, arachidonic, eicosapentaenoic, and docosahexaenoic acids).

Linoleic acid, which belongs to ω-6 fatty acids, was found in fresh fries at 51.59%. After the first frying at 175°C/4 min, its content decreased to 21.69% ($p \leq 0.05$), and after 22½ h, it decreased further to 20.40% ($p \leq 0.05$). A slightly higher amount of this fatty acid (22.07%) was found in the fries at 200°C/3 min, and a decreasing trend was observed at the end of deep-frying (21.52%).

On the contrary, the content of oleic acid in the French fries increased from 35.53 to 60.17% at 175°C/4 min (variant A), and after TPCs reached the threshold, it further increased to 61.73% (variant C). This trend was also observed at higher frying temperatures. All the results were statistically significant ($p \leq 0.05$). The largest group of fatty acids in the French fries consisted of polyunsaturated fatty acids (PUFAs), which are the most susceptible to oxidation and oil deterioration.

By comparing the contents of PUFAs, monounsaturated fatty acids (MUFAs), and saturated fatty acids (SFAs), we found that the content of PUFAs decreased due to the frying process (from 51.85 to 27.89–25.59% in variants A–C and to 28.16–26.27% in variants B–D). The trend for MUFAs was quite the opposite ($p \leq 0.05$).

The content of SFAs in the French fries was initially 11.45%, decreasing to 7.79% after the first frying at 175°C/4 min and increasing to 8.25% at the end of the process. No statistically significant difference was observed between the samples fried at 175°C/4 min and 200°C/3 min ($p > 0.05$).

The statistical analysis using the *t*-test showed some interesting results (Table 5). While the contents of PUFAs and SFAs were slightly higher in the French fries either in the primary state or after deep-frying, the trend was opposite for MUFAs. The statistical differences in the contents of these fatty acids were significant between the fries and the oils ($p \leq 0.05$).

Zeleňáková *et al*. [47] determined the fatty acid profile in rapeseed oil (43 types of fatty acids). The presence of 8 fatty acids was recorded in all the samples during each analysis, while the content of 6 fatty acids was detected only in some samples, or none was found in the first days of frying. Oleic acid predominated (60.5%), followed by linoleic acid (18.9%), while other acids showed less than 10% content, such as linolenic acid (6.4%), palmitic acid (5.1%), stearic acid (1.7%), and eicosanoid acid (1.2%).

Zhang *et al*. [3] monitored changes in the composition of fatty acids in potato products depending on different frying times. They found that frying for 10 h increased the contents of palmitic, oleic, and arachidonic acids and decreased the contents of stearic and linolenic acids.

Rapeseed oil consists of oleic (52–67%), linoleic (16–25%), and linolenic (6–14%) acids. Due to the higher expression of linoleic acid, the content of polyunsaturated fatty acids may increase. The best source of monounsaturated fatty acids in the Mediterranean countries is olive oil (74 g/100 g), with rapeseed oil (59 g/100 g) among other sources [48].

Acrylamide determination in French fries. Acrylamide in food is dangerous and carcinogenic. It is produced during processing of food from starchy raw material. Efforts by all stakeholders to reduce acrylamide formation have been evident, in particular via optimization of the production process and guidelines for manufacturers [49].

The EU Commission Regulation No. 2017/2158 establishes measures to reduce acrylamide levels for food establishments that manufacture and market French fries (max 500 µg/kg), chips, roasted potatoes, bread and common bakery products, breakfast cereals, long-life bakery products (cookies, biscuits, crackers, bars, crisps), grilled vegetables, coffee, and coffee substitutes. These foods can be produced industrially or prepared at home or in public catering facilities.

As can be seen in Table 6, the contents of acrylamide varied significantly depending on the deep-frying conditions. None of the examined samples exceeded the reference value of 500 µg/kg. There was a clear trend showing that higher deep-frying temperature and time generally resulted in higher acrylamide contents in the French fries. For example, the samples fried at 200°C/3 min (B and D) exhibited higher average acrylamide contents compared to those deep-fried at 175°C/4 min (A and C). Each variant (A, B, C, D) had a unique acrylamide content, with sample B having the highest level (106.81 µg/kg) and variant C having the lowest level (3.51 µg/kg). These differences may be attributed to variations in the frying conditions and oil quality. Variants B and D had relatively low variation values, indicating less variability in acrylamide levels compared to variants A and C. The standard deviation (SD) provides a measure of the dispersion or variability of acrylamide content within each sample (Fig. 4). The letters ($^{a, b, d, e}$) next to the average values (Table 6) denote statistically significant differences between the samples based on the Tukey test or similar post-hoc

Table 4 Contents of fatty acids, wt.%, in French fries deep-fried in edible rapeseed oil under different experimental conditions

Experimental variants	Palmitic	Palmitooleic	Stearic	Oleic	Linoleic	α-Linolenic	Arachidic	EPA
FPFFs	$6.44^{a, b, c, d} \pm 0.00$	$0.11^{a, b, c, d} \pm 0.00$	$3.56^{a, b, c, d} \pm 0.00$	$35.53^{a, b, c, d} \pm 0.01$	$51.59^{a, b, c, d} \pm 0.01$	$0.23^{a, b, c, d} \pm 0.00$	$0.26^{a, b, c, d} \pm 0.01$	$0.17^{a, b, c, d} \pm 0.01$
175°C/4 min (A)	$4.82^{k, d, c} \pm 0.00$	$0.20^{k} \pm 0.00$	$1.96^{k, d, c} \pm 0.00$	$60.17^{k, b, c, d} \pm 0.01$	$21.69^{k, b, c, d} \pm 0.01$	$6.05^{k, b, c, d} \pm 0.01$	$0.52^{k, c} \pm 0.00$	$1.01^{k, c, d} \pm 0.00$
200°C/3 min (B)	$4.84^{k, d, c} \pm 0.01$	$0.20^{b} \pm 0.01$	$2.00^{k, d, c} \pm 0.00$	$59.87^{k, a, c, d} \pm 0.01$	$2207^{k, a, c, d} \pm 0.01$	$5.94^{k, a, c, d} \pm 0.01$	$0.52^{k, c} \pm 0.00$	$0.99^{k, c} \pm 0.00$
175°C/4 min (C)	$5.10^{k, b, a} \pm 0.06$	$0.21^{k} \pm 0.01$	$2.08^{k, a, b, d} \pm 0.02$	$61.73^{k, a, b, d} \pm 0.03$	$20.40^{k, a, b, d} \pm 0.04$	$4.90^{k, a, b, d} \pm 0.04$	$0.5^{k, a, b, d} \pm 0.01$	$1.04^{k, a, b, d} \pm 0.00$
200°C/3 min (D)	$5.18^{k, b, a} \pm 0.02$	$0.20^{k} \pm 0.00$	$2.19^{k, a, b, c} \pm 0.01$	$60.89^{k, a, b, c} \pm 0.10$	$21.52^{k, a, b, c} \pm 0.01$	$4.45^{k, a, b, c} \pm 0.04$	$0.53^{k, c} \pm 0.00$	$0.98^{k, a, c} \pm 0.01$
	Behenic	Erucic	Lignoceric	DHA	PUFAs	MUFAs	SFAs	
FPFFs	$0.74^{a, b, c, d} \pm 0.00$	n.d.	$0.26^{a, b, c, d} \pm 0.00$	$0^{a, b, c, d} \pm 0.00$	$51.82^{a, b, c, d} \pm 0.01$	$35.81^{a, b, c, d} \pm 0.01$	$11.45^{a, b, c, d} \pm 0.01$	
175°C/4 min (A)	$0.35^{k, b, c, d} \pm 0.00$	0.10 ± 0.00	$0.15^{k, c} \pm 0.01$	$0.15^{k, c, d} \pm 0.01$	$27.89^{k, b, c, d} \pm 0.01$	$61.47^{k, b, c, d} \pm 0.01$	$7.79^{k, c, d} \pm 0.01$	
200°C/3 min (B)	$0.36^{k, a, c, d} \pm 0.00$	0.10 ± 0.01	$0.15^{k, c} \pm 0.00$	$0.14^{k, c, d} \pm 0.00$	$28.16^{k, a, c, d} \pm 0.01$	$61.16^{k, a, c, d} \pm 0.01$	$7.88^{k, c, d} \pm 0.01$	
175°C/4 min (C)	$0.37^{k, a, b, d} \pm 0.00$	0.10 ± 0.01	$0.14^{k, a, b, d} \pm 0.00$	$0.28^{k, a, b} \pm 0.01$	$25.59^{k, a, b} \pm 0.08$	$63.17^{k, a, b, d} \pm 0.02$	$8.25^{k, a, b, d} \pm 0.08$	
200°C/3 min (D)	$0.39^{k, a, b, c} \pm 0.00$	0.09 ± 0.00	$0.15^{k, c} \pm 0.00$	$0.30^{k, a, b} \pm 0.00$	$26.27^{k, a, b, c} \pm 0.05$	$62.25^{k, a, b, c} \pm 0.04$	$8.43^{k, a, b, c} \pm 0.02$	

FPFFs – frozen pre-fried French fries; EPA– cis-5,8,11,14,17-eicosapentaenoic acid; DHA – cis-4,7,10,13,16,19-docosahexaenoic acid; PUFAs – polyunsaturated fatty acids; MUFAs – monounsaturated fatty acids; SFAs – saturated fatty acids; n.d. – not detected

The data is expressed as mean ($\bar{x}$) ± standard deviation. The results of statistical evaluation (Scheffe's test, $p \leq 0.05$) of experimental variants are expressed with the use of superscript letters within a column for individual fatty acids (letters within the column mean 'significant difference' between the groups, no letter means 'insignificant difference')

Table 5 Statistical evaluation of SFAs, MUFAs, and PUFAs in French fries and edible rapeseed oil deep-fried in different experimental variants

Groups of fatty acids	Experimental variants, wt.%							
	175°C/4 min (A)		200°C/3 min (B)		175°C/4 min (C)		200°C/3 min (D)	
	French fries	Oil	French fries	Oil	French fries	Oil	French fries	Oil
Polyunsaturated fatty acids (PUFAs)	27.89 ± 0.01	25.91 ± 0.06	28.16 ± 0.01	25.85 ± 0.03	25.59 ± 0.08	23.98 ± 0.02	26.27 ± 0.05	23.41 ± 0.01
Monounsaturated fatty acids (MUFAs)	61.47 ± 0.01	63.75 ± 0.04	61.16 ± 0.01	63.78 ± 0.01	63.17 ± 0.02	65.22 ± 0.01	62.25 ± 0.04	65.56 ± 0.01
Saturated fatty acids (SFAs)	7.79 ± 0.01	7.21 ± 0.02	7.88 ± 0.01	7.23 ± 0.01	8.25 ± 0.08	7.64 ± 0.01	8.43 ± 0.02	7.70 ± 0.01

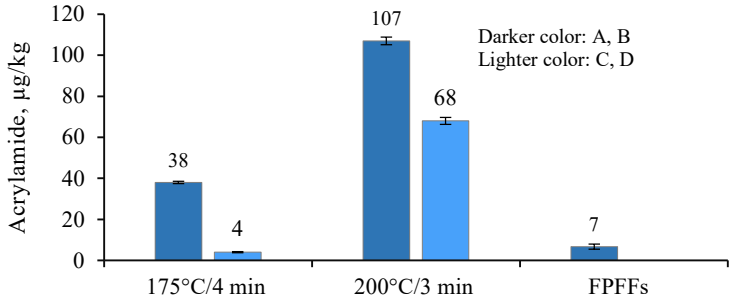
The results are expressed as a mean value of individual fatty acid ± standard deviation. Statistically significant difference between the groups by *t*-test ($p < 0.001$)

Table 6 Acrylamide contents in French fries deep-fried in edible rapeseed oil, μg/kg, under different experimental conditions

Sample	Parameter				
	$\bar{x}$	X_{min}	X_{max}	SD	v, %
FPFFs	6.60^{g}	5.00	8.00	1.247	18.9
175°C/4 min (A)	37.82^{d}	37.09	38.32	0.566	1.5
200°C/3 min (B)	106.81^{a}	104.48	109.01	1.859	1.7
175°C/4 min (C)	3.51^{e}	3.15	3.77	0.279	7.9
200°C/3 min (D)	67.40^{b}	65.20	69.16	1.697	2.5

FPFFs – frozen pre-fried French fries; $\bar{x}$ – mean value; SD – the standard deviation; and v – coefficient of variation

The different letters $^{a, b, c, d, e, f, g}$ next to the mean values in the columns represent statistically significant differences between the experimental groups ($p < 0.005$)



FPFFs – frozen pre-fried French fries

The data is expressed as mean ± standard deviation

Figure 4 Acrylamide contents in French fries

Table 7 Texture analysis of crispness and strength of potato fries before and after deep-frying

Sample	Cutting work/crispness, N/mm/s			Strength, N/mm		
	$\bar{x}$	SD	v, %	$\bar{x}$	SD	v, %
Potato fries before deep-frying Hranolka surová						
RPFs	1.44	0.34	23.29	0.22	0.03	12.8
FPFFs	0.13	0.03	19.17	0.03	0.00	13.89
Potato fries after deep-frying at 175°C/4 min						
RPFs-A	0.18	0.05	29.21	0.03	0.01	32.66
FPFFs-A	0.39	0.11	29.23	0.08	0.02	22.72
Potato fries after deep-frying at 200°C/3 min						
RPFs-B	0.19	0.03	13.40	0.03	0.01	25.79
FPFFs-B	0.36	0.03	8.35	0.08	0.01	10.92

RPFs – raw potato fries; FPFFs – frozen pre-fried French fries; RPFs-A – raw potato fries (variant A); FPFFs-A – frozen pre-fried French fries (variant A); RPFs-B – raw potato fries (variant B); FPFFs-B – frozen pre-fried French fries (variant B)

$\bar{x}$ – mean value; SD – the standard deviation ($p \leq 0.05$); and v – coefficient of variation

analyses. For example, variant B (fried at 200°C/3 min) has a significantly higher acrylamide content compared to variant A or C.

We had predicted that after the first frying of French fries, the acrylamide content would be lower than after obtaining TPCs due to oil deterioration, but the opposite trend was observed. These findings are consistent with other studies. For example, Skinner *et al.* [50] reported that the acrylamide formation rate increased at the early stage of frying and then decreased.

Sanny *et al.* [51] investigated the effect of frying instructions on the food handlers' control decisions in the restaurants and the effect of their decisions on the acrylamide content in French fries. They found that when the food handlers strictly followed the given instructions, the acrylamide content significantly decreased (169 µg/kg), compared to its level before following the instructions (1517 µg/kg).

Oxidation products and acrylamide levels are determined by both the temperature and the time of frying. They start to rise at temperatures above 120°C, reaching their maximum at over 170–180°C. An increase in acrylamide may be caused by the Maillard reaction [52]. Acrylamide content depends on several factors such as temperature (> 120°C), carbohydrates, low proteins, free asparagine, reducing sugars, pH, water content, and a high content of amino acids. It can be reduced by using raw materials and by certain food processing procedures. However, just as important are sensory and textural properties, nutritional value, as well as thermodegradative properties [53]. Because of the high content of precursors in the tuber and the heat treatment, French fries are susceptible to the formation of acrylamide. Potato composition varies by variety, place of cultivation, agricultural practices, maturity, and storage, among others [54].

Textural analyses of French fries. Tables 7 and 8 present average measured values for each sample, along with the corresponding standard deviation and coefficient of variation. Based on the paired *t*-test evaluation, a statistically significant difference was found between the raw potato fries (RPFs) and the frozen pre-fried French fries (FPFFs) in terms of cutting work/crispness and strength before and after frying (Table 7, Fig. 5). Before deep-frying, the RPFs showed higher strength (0.22 N/mm) and crispness (1.44 N/mm/s) compared to the FPFFs. However, the difference was relatively small, although statistically significant ($p \leq 0.05$). After deep-frying at 175°C/4 min, the RPFs-A sample demonstrated lower strength and crispness compared to the FPFFs-A sample. Although both values were lower than before deep-frying, the difference between the samples

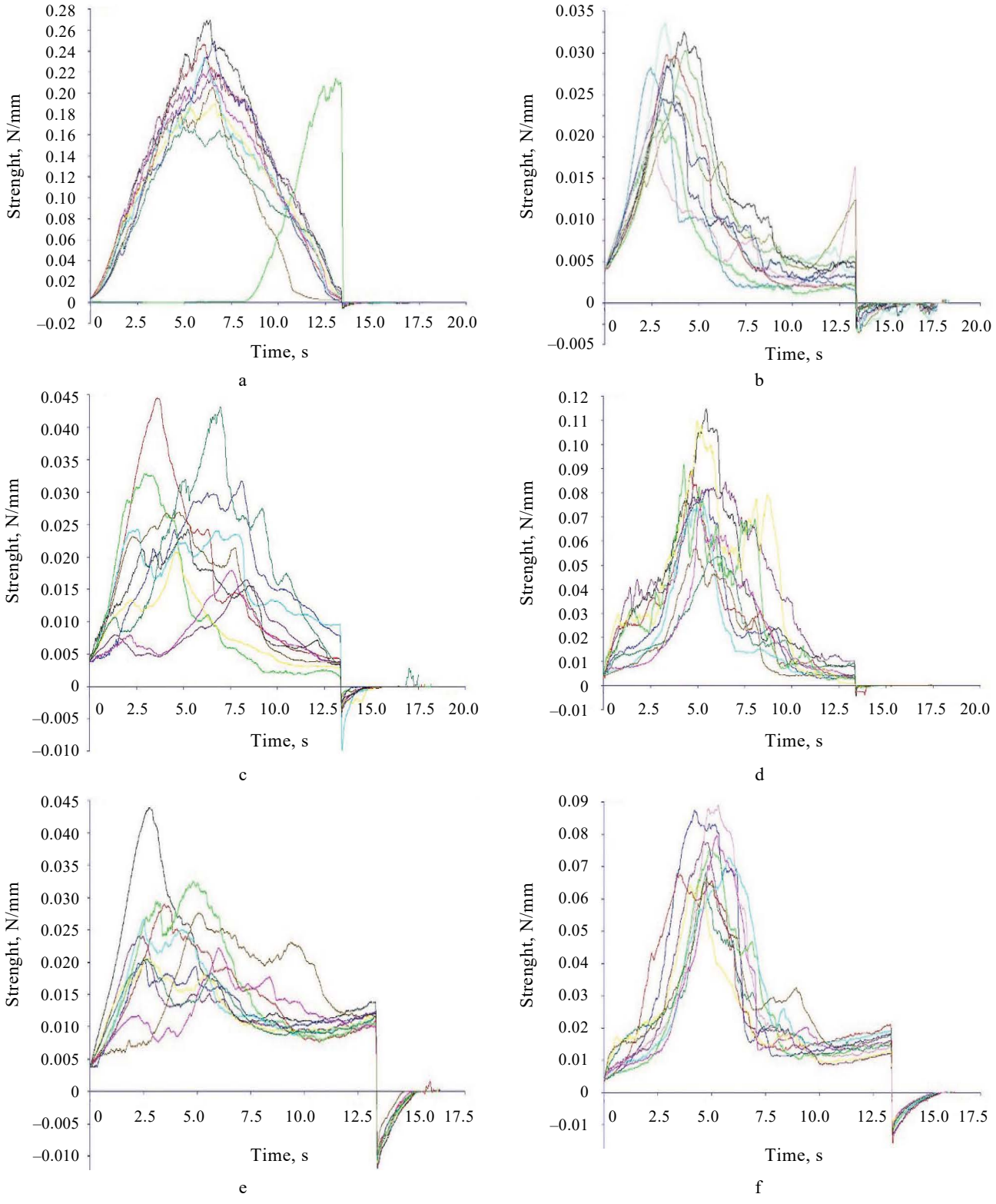


Figure 7 Sensory analysis of French fries deep-fried at 200°C/3 min

remained statistically significant. After deep-frying at 200°C/3 min, the RPFs-B sample exhibited lower strength and crispness compared to the FPFFs-B sample, too.

After deep-frying at higher temperatures and shorter times, both samples showed an increase in crispness. In general, higher temperatures and shorter frying times (200°C/3 min) may provide better conditions for achieving optimal crispness and strength in potato fries.

Table 8 shows that deep-frying affects the hardness and breaking force of potato fries, with significant differences between the samples and deep-frying conditions in some cases. Before deep-frying, the breaking force and hardness of both samples were very similar, with non-significant differences ($p > 0.05$). After deep-frying at 175°C/4 min, the RPFs-A sample exhibited lower breaking force (3.17 mm) and hardness (266.56 g) com-

Table 8 Texture analysis of hardness and breaking force of potato fries before and after deep-frying

Sample	Hardness, g			Breaking force, mm		
	$\bar{x}$	SD	v, %	$\bar{x}$	SD	v, %
Potato fries before deep-frying						
RPFs	446.86	89.22	19.97	4.66	0.53	11.42
FPFFs	429.26	100.86	23.49	4.65	0.50	10.78
Potato fries after deep-frying at 175°C/4 min						
RPFs-A	266.56	78.88	29.59	3.17	1.32	41.62
FPFFs-A	421.91	146.84	34.80	3.55	0.89	25.02
Potato fries after deep-frying at 200°C/3 min						
RPFs-B	272.06	84.35	31.00	3.82	2.75	71.92
FPFFs-B	404.11	144.81	35.83	3.11	0.51	16.29

RPFs – raw potato fries; FPFFs – frozen pre-fried French fries; RPFs-A – raw potato fries (variant A); FPFFs-A – frozen pre-fried French fries (variant A); RPFs-B – raw potato fries (variant B); FPFFs-B – frozen pre-fried French fries (variant B)

$\bar{x}$ – mean value; SD – the standard deviation ($p \leq 0.05$); and v – coefficient of variation

pared to the FPFFs-A sample (3.55 mm and 421.91 g, respectively), with these differences being statistically significant ($p \leq 0.05$). After deep-frying at 200°C/3 min, the breaking force of the FPFFs-B sample (3.11 mm) decreased, while its hardness increased (404.11 g), with these changes being statistically significant for hardness ($p \leq 0.05$). The RPFs-B sample still showed lower hardness (272.06 g) and higher breaking force (3.82 mm) after deep-frying, but the difference in this parameter was not statistically significant ($p > 0.05$).

Deep-frying reduced the breaking force and hardness in both samples, with a larger difference between the samples at lower temperatures (175°C). Higher temperature (200°C) and shorter frying times had a more significant effect on hardness than on the breaking force, with the frozen pre-fried French fries showing higher hardness after deep-frying.

The hardness values in our samples ranged from 266.56 to 446.86 g. They were lower than those reported by Dong *et al.* [55]. This difference can be attributed to variations in the frying method (oil deep-frying in our study and air frying in [55]). The cutting work/crispness values in our samples ranged from 0.13 to 1.44 N/mm/s. They were lower than those reported by Li *et al.* [32], who analyzed the texture of French fries from fast-food restaurants.

In the breaking force test, the values ranged from 3.11 to 4.66 mm. They were comparable to the values typically reported for French fries deep-fried for 3–5 min [56].

The Warner-Bratzler shear force values in our experiment ranged from 0.03 to 0.22 N/mm. They were lower than those reported by Quan *et al.* [35]. This discrepancy may be due to differences in the frying method since their study used an air fryer, whereas our samples were deep-fried in oil.

Sensory analyses of French fries. Fried products generally attract consumers due to their enhanced taste, sweetness, and appearance. The sensory properties of potato fries primarily include their consumer characteristics and processing method. The evaluation focuses on both the external and internal processing structure, as well as the size, thickness, and mechanical damage. The internal structure of the fries is mainly determined by their taste and aroma. Improper cooling and incorrect storage negatively affect the internal structure. The sensory properties are a significant factor in assessing the quality of potato fries and represent a potential source of customers and, consequently, financial income for restaurant owners [29].

In our study, 15 panelists evaluated the sensory qualities of the potato fries fried under pre-determined conditions. They focused on their color, aroma, oil content, crispiness, chewiness, taste, and overall acceptability (Fig. 6 and 7).

According to the sensory evaluation results, the FPFFs deep-fried at 175 and 200°C achieved a higher level of acceptance among the panelists compared to the fries prepared from RPFs. Overall sensory parameters such as color, aroma, and taste were rated significantly more favorably for the pre-fried samples. The results suggest that the pre-frying process significantly influenced the color characteristics of the fries after subsequent frying. The consumers preferred the golden color of the pre-fried fries compared to the darker, brownish hue of the fries from raw potatoes, highlighting the positive impact of pre-frying on the product's visual acceptability.

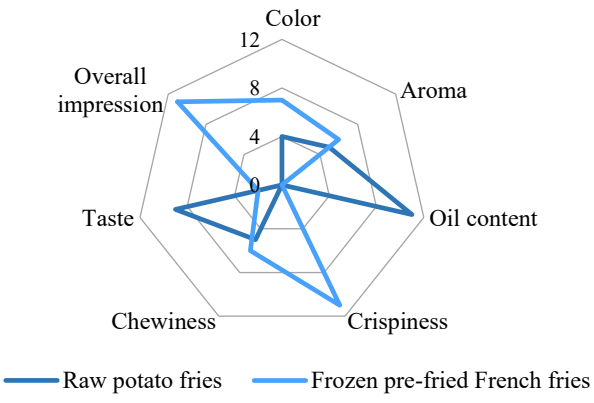


Figure 6 Sensory analysis of French fries deep-fried at 175°C/4 min

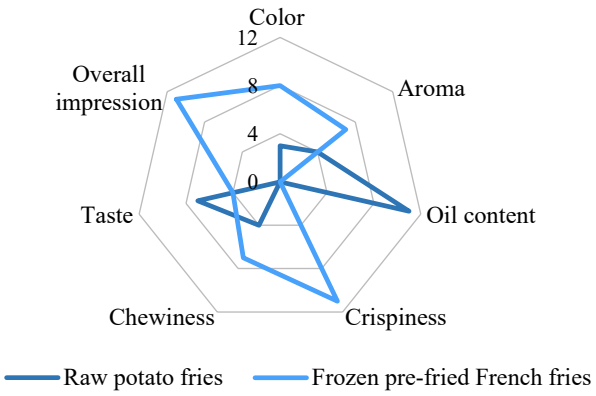


Figure 7 Sensory analysis of French fries deep-fried at 200°C/3 min

Furthermore, the pre-fried potato fries exhibited higher values for crispiness and oil content after the first frying, compared to the fries prepared from raw potatoes. Frying at 200°C/3 min significantly improved the sensory attributes such as color, aroma, and taste, leading to a more intense perception of positive sensory attributes.

Higher oil absorption was observed at the lower temperature (175°C) and longer duration due to the extended contact time with the oil and the slower formation of a protective crust on the product's surface. Conversely, at the higher frying temperature (200°C), the surface crust formed more quickly, limiting further oil penetration into the internal structure of the fries, thereby reducing the overall oil absorption. From a textural perspective, higher frying temperature promotes the development of a crispier surface due to the faster dehydration of the outer layers of the fries and the subsequent caramelization of surface carbohydrates. Pre-frying also improves moisture distribution within the product's structure, contributing to a more uniform texture and crispiness after the final deep-frying.

Botero-Uribe *et al.* [57] reported that high-quality potato fries should have a thickness of 1–2 mm. They also found that the fries with a modified surface and greater thickness tend to have lower crispiness. Finally, potato fries must be served immediately after the heat treatment.

The crispiness of the potato crust can also be influenced by starch gelatinization and sugar caramelization during frying. Golden appearance is more attractive to the consumers, with the color differences gradually decreasing at longer frying times [58].

Li *et al.* [59] studied 10 types of French fries from different restaurants evaluated by eight trained panelists. The ANOVA test was used to assess eight attributes: oiliness, chewiness, roughness, hardness, smoothness, adhesiveness, cohesiveness, and crispiness. The results were statistically significant ($p \leq 0.05$), which was explained by individual physiological differences among the panelists. Navas *et al.* [60] evaluated the sensory properties of French fries deep-fried in different types of oils. They used corn oil, both unseasoned and seasoned with garlic, coriander, and chili. Their results revealed differences in taste perception between the fries fried in seasoned oil and those prepared in unseasoned oil. The most relevant sensory attributes were sharp taste, spiciness, and fry color. Taste and aroma can also be affected by thermal effects.

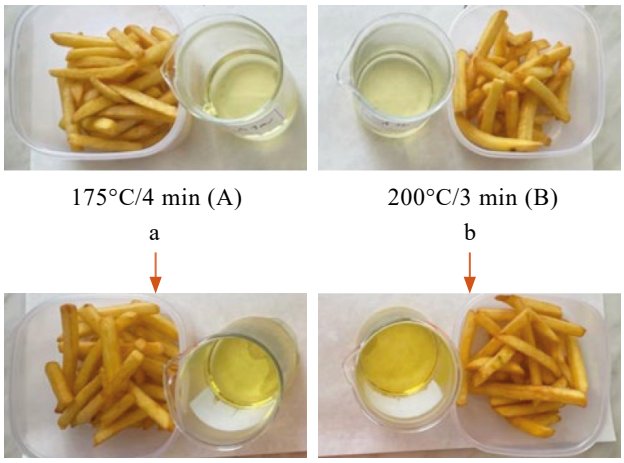


Figure 8 French fries (frozen pre-fried) deep-fried in rapeseed oil: a – 175°C/4 min (A); b – 200°C/3 min (B); c – 175°C/4 min, ≥ 24% total polar compounds (C); and d – 200°C/3 min, ≥ 24% total polar compounds (D)



Figure 9 French fries (from raw potatoes) deep-fried in rapeseed oil

In our study, the samples fried at 200°C/3 min were rated better in several parameters compared to those fried at 175°C/4 min (Fig. 8 and 9).

CONCLUSION

Examining the processes of deep-frying French fries is essential to protect consumer health, maintain product quality, optimize the use of food resources, and ensure regulatory compliance.

Our results, supported by previous studies, provide scientifically validated insights into the effect of deep-frying conditions on the quality of French fries.

Our study aimed to evaluate the oxidative stability of rapeseed oil, changes in the fatty acid profile, and acrylamide formation in French fries during deep-frying in Slovak catering establishments. By integrating chemical, textural, and sensory analyses, we offer a comprehensive assessment of both the nutritional benefits and the potential health risks associated with these culinary practices. Rapeseed oil selected for this study is one of the most commonly used vegetable oils in Slovakia, both in households and public catering establishments.

The study's design and experimental implementation adhered to Slovak legislation (Decree No. 125/2017), according to which frying fats should not be heated above 180°C or used for more than 24 continuous h. The law explicitly prohibits frying in the equipment without temperature control. However, in practice, non-compliance is frequently observed as many fast-food operators reuse frying oils for several days.

Our findings are based on systematic experimentation, analysis, and validation in accordance with the legislative guidelines. They cover the following parameters:
– oxidative stability: rapeseed oil maintained greater stability at 175°C/4 min, degrading after 22.5 h of deep-frying, while at 200°C/3 min, degradation occurred after 20.5 h;
– fatty acid dynamics: deep-frying reduced polyunsaturated fatty acids and increased monounsaturated fatty acids, with significant differences between the oil and the fries ($p \leq 0.05$);
– acrylamide formation: acrylamide contents varied significantly with frying conditions but remained within the regulatory limit (max 500 µg/kg);
– textural properties: higher temperature (200°C/3 min) enhanced crispness but reduced the breaking force and hardness, affecting the sensory perception; and
– sensory preference: the commercial frozen pre-fried French fries achieved greater acceptance in terms of color, aroma, and taste, compared to the raw potato fries.

Our study provides actionable insights into real-world catering practices, highlighting non-compliance with legislation and offering data-driven recommendations for safer and more sustainable frying methods. Our findings serve as a valuable resource for food processors and catering operators, contributing to the optimization of frying processes while balancing sensory qualities, safety, and nutritional value.

CONTRIBUTION

All the authors were equally involved in writing the manuscript and are equally responsible for any potential plagiarism.

CONFLICT OF INTEREST

The authors declared no potential conflict of interest regarding the research, authorship, and/or publication of this article.

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