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Quality parameters of different oils and fried foods after repeated deep-fat frying

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Abstract

The aim of present study was to investigate the quality, stability and suitability of different frying oils (coconut, palm, frying mix, rapeseed and sunflower oil), the quality and stability of breaded and fried foods (chicken nuggets) and the applicability and suitability of certain parameters (fat absorption, acid number, peroxide number and thiobarbituric acid (TBA) number, fatty acid composition and acrylamide content) as well as sensory attributes to control the repeated deep-(fat) frying process. Three repeated deep-frying processes affected the hydrolytic and oxidation stability (increase in the peroxide number and TBA number), the sensory properties (darkening of the oil colour, occurrence of odd smell and aroma as well as rancidity in oils) and the fatty acid composition of oil and fried chicken nuggets, and the acrylamide content in the nuggets (from the second deep-frying process onwards). All oils used in study were suitable for deep-frying; in terms of stability, coconut oil (followed by sunflower, palm, frying mix and rapeseed oil) was most suitable; in terms of fatty acid composition, the frying mix, rapeseed and sunflower oil were most suitable; and in terms of acrylamide formation and sensory quality, coconut and palm oil were most suitable.

Key words: oils, deep-frying, repeated deep-frying, breaded food, oil quality, oxidative stability of oil, sensory properties, fatty acid composition, acrylamide

Introduction

Deep-frying is one of the most common ways of preparing food, both in households and in industry. It can be defined as a preparation process in which food is immersed in deep-frying oil at a temperature between 150 and 200 °C, which is well above the boiling point of water (Choe and Min, 2007; Zeleňáková et al., 2019). Despite the frequent use of the deep-frying process, it is one of the most complex processes and is difficult to understand due to the large number of simultaneous reactions and the complexity of the resulting products. When deep-frying in heated oil, the water extracted from the food produces steam, which triggers the hydrolysis of the fat (Mir-Bel et al., 2012). During frying, the food absorbs a lot of oil (from 5 to 40 %) and releases some lipids to the frying fat (Moreira et al., 1997; Choe and Min, 2007; Kochhar, 2016). During the deep-frying of food the composition and stability of the fat changes constantly. The presence of food particles accelerates the darkening of the oil during

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the process; deep-frying fats react with food ingredients, proteins and carbohydrates, forming desirable and undesirable flavours (Mir-Bel et al., 2012). Extensive thermal-oxidative degradation of fats during long deep-frying not only reduces the sensory quality of the fried food, but can also reduce its nutritional value (Mba et al., 2017). Therefore, the deep-frying process must be carefully controlled, especially the oil temperature, the frying time, the creation of physical barriers on breaded foods, the control of the polarity of deep-frying fats with frequent oil changes (Choe and Min, 2007; O'Brien, 2009; Zeleňáková et al., 2019). It is necessary to change the deep-frying process by adjusting the temperature, frying time or method to reduce the fat absorption into the food, to develop the desired sensory properties of the fried food and to minimize the formation of thermal degradation products and interactions that cause unpleasant taste and potential safety problems (acrylamide) (Granda in Moreira, 2005; Gertz, 2014; Guerra-Hernandez, 2016).

For all these reasons the purpose of present research was to investigate quality parameters, the oxidation stability and suitability of various deep-frying oils and breaded foods, as well to evaluate the applicability and suitability of certain parameters for controlling the deep-frying process. The results of this study will contribute to the understanding of the thermostability of different oils and the interactions between food and oil during deep-frying. The study will also provide a realistic picture of food preparation in the household.

Material and methods

Five types of oils were used for deep-frying: 100 % edible refined sunflower oil under the sales designation CEKIN Sončnično olje, producer Tovarna olja Gea (S); 100 % edible refined rapeseed oil under the sales designation Mercator repično olje, producer Tovarna olja Gea (R); blended edible refined vegetable oil (50 % edible refined peanut oil, 50 % edible refined rapeseed oil), producer Tovarna olja Gea (hereinafter referred to as frying mix or M); 100 % refined organic coconut oil under the sales designation Bio Zone kokosovo olje, produced in the Philippines, bottled by Bufo Eko (C); 100 % edible refined palm oil, under the sales designation Zvijezda palm olein, produced in Indonesia for the company Zvijezda (P). Frozen breaded chicken nuggets, produced by Perutnina Ptuj under the trade name Chicken nuggets, were used for deep-frying. According to the manufacturer, chicken nuggets contain chicken meat (50.6 %), panada (38.1 %; wheat flour, modified wheat starch, gluten, water, table salt, yeast, spices), water, vegetable oil (sunflower), table salt. In the manufacturer's preparation instructions, it is recommended to deep-fry the chicken nuggets in a deep

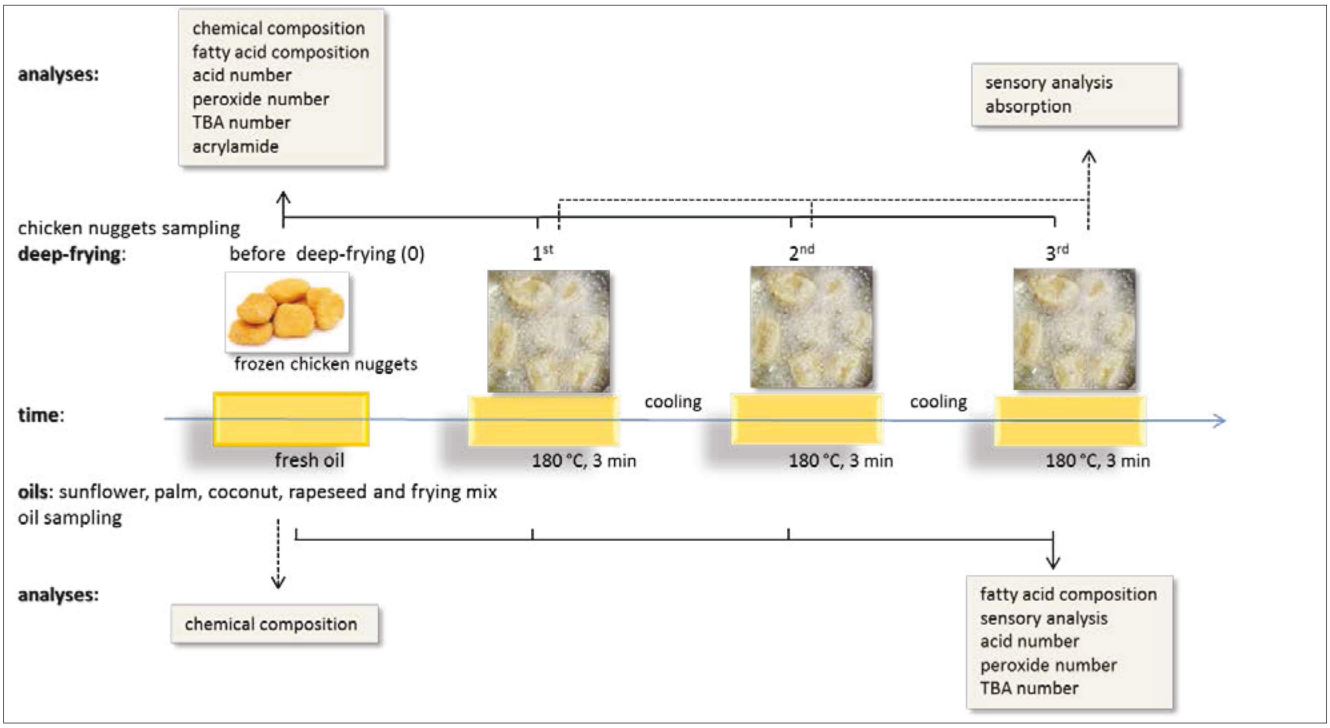

Fig. 1. Experimental design

fryer at 175 °C for approx. 3 minutes or reheating in the oven at 200 °C for approx. 10 minutes. A 3-litre deep fryer (model AGE F3, Elmont Bled) was used to deep-fry the chicken nuggets.

Chicken nuggets were deep-fried in five types of oil: sunflower oil, rapeseed oil, frying mix, coconut oil and palm oil. Frying was carried out in a deep fryer in which the oil was first heated to 180 °C and then the chicken nuggets were fried for 3 minutes according to the manufacturer's instructions. For each type of oil, three repeated deep-fryings of the chicken nuggets with intermediate cooling of the oil to room temperature (20 ±2 °C) were carried out, which lasted for about 2 hours. Ten chicken nuggets were deep-fried each time (Fig. 1). Oils and chicken nuggets were chemically analysed before deep-frying and after each frying. The oil absorption, the proximate nutrient composition (water, protein and fat), the fatty acid composition, the extent of lipid oxidation (acid number, thiobarbituric acid (TBA) number and peroxide number) and the acrylamide content were determined. The samples were also evaluated sensorially.

Methods

Instrumental methods: The moisture, protein and fat content in the samples of chicken nuggets were determined with the Food Scan™ Analyser with self-calibration (FOSS, Denmark).

Chemical analyses: The fatty acid composition of deep-frying oils and homogenised chicken nuggets (for 20 s with a Grindomix homogeniser GM 200 (Retch, Germany) at 5000-6000 rpm (ISO 3100-1, 1991)) was determined as described by Polak et al. (2008).

The extent of lipid oxidation of the chicken nuggets and deep-frying oils was monitored by measuring acid number, peroxide number and thiobarbituric acid (TBA) number. The acid number was determined by the method described in ISO standards (ISO 660:2009) and defined as the amount of number of milligrams of potassium hydroxide required to neutralize the free fatty acids present in 1 g of fat (mg/g). The peroxide number was determined by the method described as AOAC Official Method 965.33 and defined as the amount of peroxide oxygen (mmol)/kg of fat. The TBA number was determined using a modified extraction method (Witte et al., 1970). The procedure was precisely described in the study by Penko et al. (2015). The TBARs were measured at 532 nm with a spectrophotometer (Shimadzu, UV-160 A) and were calculated as mg malondialdehyde/kg product. The acrylamide content in chicken nuggets was determined by liquid chromatography with a mass spectrometer (LC - MS). Acrylamide extraction: 1 g of homogenized sample was weighed into a Falcon centrifuge tube, 100 µL of d3-acrylamide standard solution (72834, Merck) and 5 mL hexane (1.04371.2500, Merck) were added and shaken. This was followed by the addition of 10 mL distilled H_2O and 10 mL acetonitrile, 4 g $MgSO_4$ (1.05886.1000, Merck) and 0.5 g NaCl (1.06404.1000, Merck). The samples were shaken vigorously for 1 minute. After centrifugation (5 minutes) the upper hexane phase was removed and 1 mL of the intermediate phase (acetonitrile) was transferred to a 2 mL column (Bond Elut QuEChERS, Agilent) filled with 50 mg PSA (primary-secondary anion exchange) and 150 mg $MgSO_4$. Vortex shaking (1 minute) and centrifugation (5 minutes) followed. After centrifugation the supernatant was transferred into HPLC vials. LC-MS analysis followed. The acrylamide content of the samples was determined with an Agilent 1100 LC-MS system consisting of a binary pump model 1100 G1312A, a vacuum degasser G1379A and an autosampler model G1330B (Agilent Technologies, Germany). A Kinetex C18 reversed phase chromatography column (2.1 × 150 mm, 3 µm, Phenomenex, USA) was used. Isocratic chromatography was performed with a mixture of 2.5 % methanol (34860, Sigma-Aldrich)/ 97.5 %, 0.1 % formic acid (1.00263.1000, Merck) in water. 1 µL of a sample cooled to 8 °C was injected into the column. The column temperature was 30 °C, with a flow rate of 0.2 mL/min. The total chromatography time was 30 minutes. A mass-selective detector (Micromass Quattro micro API; Waters, USA) equipped with electrospray ionisation using a cone voltage of 20 V and a capillary voltage of 3.5 kV, was used for positive ionisation of the analytes (ESI+). Dry nitrogen was heated to 350 °C and the drying gas flow was 350 L/h. The cone gas (nitrogen) flow was 50 L/h at a cone temperature of 120 °C. The limit of detection (LOD) for the standard solution was in the range of 5 pg acrylamide injected on the column and LOD 3 µg/kg for the samples. The limit of quantification (LOQ) was 15 pg acrylamide injected on the column and 10 µg/kg for the samples (Fig. 2). All chemical parameters were performed in parallel.

Sensory analysis: A panel of five qualified and expe-

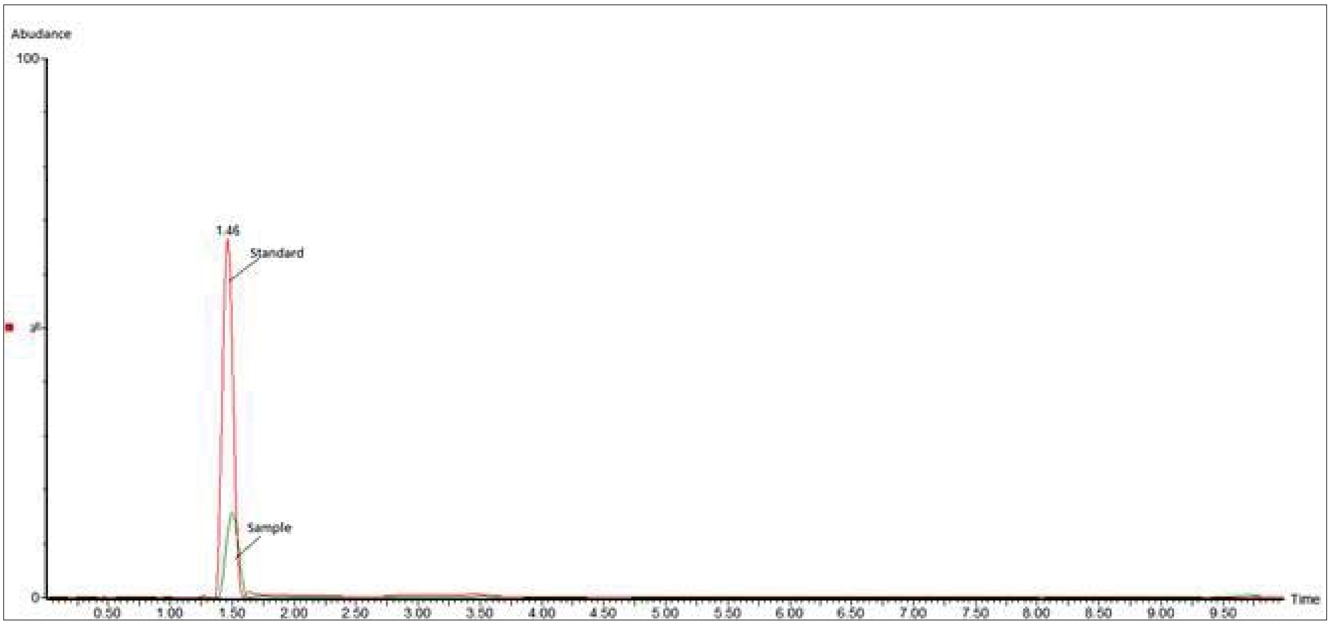

Fig. 2. Chromatogram of acrylamide standard and chicken nuggets sample

rienced panellists in the field of meat products and ready-to eat meals was used to assess the sensory qualities. The sensory evaluation of chicken nuggets and frying oils was performed according to international standards (ISO 8589:2007, ISO 8586:2012). The analytical-descriptive test (Golob et al., 2005) was carried out by scoring the sensory according to a non-structured scale from 1 to 7 points, whereby a higher score indicated a stronger expression of a particular quality. Exceptions were the characteristicality of surface colour/oil colour and the mouth feeling, which were evaluated by scoring on a structured scale from 1 to 4 to 7 (1-4-7). Here, a score of 4 points was considered optimal, with a score of 4.5 or higher indicating a stronger expression of a characteristic (too dark, too rough) and a score of 3.5 or lower indicating an insufficient expression of a characteristic (too light, too soft – not connected structure of product). The sensory profile of the chicken nuggets was evaluated using twelve descriptors grouped into four blocks: visual properties (characteristics and uniformity of the surface colour, adhesion of panada on cross-section), texture (crunchiness of panada, mouthfeel and greasiness), olfactory properties (characteristics of smell, oil smell, odd smell) and gustatory properties (aroma, used oil aroma, odd aroma and rancidity). For the sensory evaluation, a piece of chicken nuggets was offered, which were evaluated by the panellists. The sensory profile of the deep-frying oil was evaluated using twelve descriptors grouped into three blocks: visual properties (characteristics of colour and transparency), olfactory properties (smell, used food smell, odd smell) and gustatory properties (aroma, used food aroma, odd aroma and rancidity). For the sensory evaluation, a piece of chicken nuggets was offered to panellists. To neutralise the taste, the panel used the central dough of white bread.

Data analysis: The experimental data were evaluated statistically using the SAS/STAT programme (SAS Software, 1990). The data were analysed for normal distributions, the basic statistical parameters were calculated using the "means" procedure and then tested using a general linear model procedure. Data on lipid oxidation products, fatty acid composition, acrylamide content and sensory attributes of chicken nuggets and deep-frying oils were analysed using a statistical model for the effect of repeated deep-frying (RF; 0 – fresh, before first frying, 1 – first, 2 – second and 3 – third repeated deep-frying), type of frying oil (TO; C – coconut oil, M – frying mix, P – palm oil, R – rapeseed oil, S – sunflower oil). The following Model (1) was used:

$$y_{ijk} = \mu + RFi + TOj + e_{ijk} \qquad \text{(Model 1)}$$

where: y – the observed parameter; μ – the general mean; RF – effect of repeated deep-frying (i = 4); TO – type of used deep-frying oil (j = 5); k – parallel (1, 2); e – residual random term with variance δ_e^2. The $RF_\times TO_{ij}$ interaction (repeated deep-frying × type of oil) was excluded from the model because it was not significant. The means for the experimental groups were obtained, and Duncan's tests were used for comparisons at the 5% probability level. Pearson correlation coefficients between chicken nugget and oil parameters were calculated by the CORR procedure (SAS Software, 1990).

Results and discussion

Chicken nuggets

The analysed chicken nuggets contained 14.8 g protein, 6.3 g fat and 53.8 g water in 100 g before deep-frying. The protein and fat content of nuggets increases after repeated deep-frying and vice versa, and the water content decreases, which was expected, as water evaporates from the food (Vitrac et al., 2000), frying oil becomes part of the food and as a result the chemical composition of the food changes (Rossell, 1998). Chicken nuggets absorbed between 11 % and 31 % fat during deep-frying (Table 1), the statement is consistent with Kochhar (2016), who found that foods absorb 5-35 % oil during deep-frying. After the first and second frying, most of the fat was absorbed by chicken nuggets deep-fried in palm oil. After the third frying, most of the oil was absorbed by the chicken nuggets deep-fried in the frying mix and sunflower oil. The measurements were carried out in one parallel, so the results were not statistically analysed.

Table 1 Fat absorption (%) after repeated deep-frying (n = 15)

Frying oil	Fat absorption (%) according to repeated deep-frying 1	2	3
C	18	16	17
M	24	25	21
P	28	31	20
R	17	23	11
S	20	21	21

n, number of observations; C, coconut oil; M, frying mix; P, palm oil; R, rapeseed oil; S, sunflower oil.

Stability of chicken nuggets and oils

Three parameters were used to determine the stability of fats and chicken nuggets during repeated deep-frying, namely the acid number, peroxide number and TBA number. The acid number is a measure of the extent to which lipids are broken down by hydrolysis. A peroxide number measures the amount of hydroperoxides formed as primary oxidation products at the initial stages of lipid oxidation reactions (Chopra and Panesar, 2010). Peroxides are of transitory nature and are primary products, intermediate in the formation of hydroxyl and carbonyl compounds (Kanner, 1994). Malondialdehyde (MDA) is only one of the compounds that originate from the peroxide degradation. However, higher TBA number means a higher degree of oxidation, but not always a change in sensory properties (Penko et al., 2015).

It was found that deep-frying affects hydrolytic and oxidative stability, as the results of the analyses showed changes in both food and oil. However, larger changes occurred in oils; the changes in oils were transferred to the food to a lesser extent.

Chicken nugget acid numbers were significantly lower after repeated deep-frying in coconut oil and in frying mix than before deep-frying (Table 2). Opposite, chicken nugget TBA numbers after repeated deep-frying showed significantly higher values in all oils investigated than before deep-frying. It can be said that after the second (sometimes after the first) repeated deep-frying significantly increased chicken nugget TBA numbers than before frying, regardless of the oil type. The peroxide number of chicken nuggets after repeated deep-frying is below the detection limit, irrespective of frying repetition and the type of fat used.

Repeated deep-frying of chicken nuggets affected the acid number of coconut oil, deep-frying mix and palm oil, but not on the acid number of rapeseed and sunflower oil. The acid number of the oils before deep-frying was in range 0.05-0.16 mg KOH/g, after the first frying increased in coconut and palm oil (0.14-0.15 mg KOH/g) and then fell below the detection limit after subsequent repetitions, while in the case of the frying mix the acid number fell during the second deep-frying repetition. The peroxide number and TBA number were significantly higher for all oil types after repeated deep-frying of the chicken nuggets than before deep-frying. The peroxide number in recently refined oils should be too close or equal to zero and should not exceed 0.2 mmol O_2/kg (Rossell, 1998; Farhoosh et al., 2009). From the results, it can be concluded that the oils (except coconut oil) had already a higher peroxide number before deep-frying (1.72-3.93 mmol O_2/kg), and after three repeated deep-frying, all oils exceeded the proposed value (5.34-10.87 mmol O_2/kg). The Rules on the Quality of Edible Vegetable Oils, Edible Vegetable Fats and Mayonnaise (2009) state that refined vegetable edible oils should have a peroxide value not exceeding 7 mmol O_2/kg oil. Before deep-frying, all oils met this criterion, whereas after three repeated deep-frying, the oils (except coconut oil) exceeded this value. An adequate TBA number is up to 0.70 mg MDA/kg; values above 1 mg MDA/kg predict sensory perceived rancidity (Penko et al., 2015). In this study, TBA numbers for some oils were close to or above 1 mg MDA/kg and panellists in these cases perceived the rancidity. However, repeated deep-frying and the type of used oil affected the oil TBA numbers (Table 2). It can be said that the TBA numbers of the oil increased significantly after each frying, regardless of the type of oil. According to the TBA number, after three repeated deep-frying, coconut, sunflower, palm, frying mix and rapeseed oil follow from the most to the least heat-stable oil.

Table 2 Lipid oxidation parameters of chicken nuggets and oils during repeated deep-frying (n = 40)

Value of parameter according to repeated deep-frying											
		Chicken nuggets					Oil				
Parameter	Oil	0	1	2	3	P_{RF} (SE)	0	1	2	3	P_{RF} (SE)
Acid number (mg KOH/g)	C	1.16^{a}	1.00^{bCB}	1.01^{bC}	1.03^{b}	** (0.03)	0.08^{c}	0.14^{aA}	0.10^{bA}	0.00^{d}	*** (0.01)
	M	1.16^{b}	1.75^{aA}	1.78^{aA}	1.10^{b}	** (0.08)	0.16^{a}	0.14^{aA}	0.04^{bB}	0.03^{b}	* (0.03)
	P	1.16^{a}	0.92^{bC}	0.98b^{C}	1.10^{a}	** (0.04)	0.09b^{a}	0.15^{aA}	0.00^{bB}	0.00^{b}	* (0.03)
	R	1.16	1.04^{CB}	1.04^{C}	0.98	Ns (0.06)	0.11	0.10^{BA}	0.10^{A}	0.02	Ns (0.04)
	S	1.16	1.18^{B}	1.33^{B}	1.26^{a}	Ns (0.17)	0.05	0.05^{B}	0.12^{A}	0.05	Ns (0.02)
	P_{TO} (SE)	Ns (0.02)	*** (0.09)	*** (0.07)	Ns (0.14)		Ns (0.04)	*** (0.40)	*** (0.01)	Ns (0.03)	
Peroxide number (mmol O_2/kg)	C	Nd	Nd	Nd	Nd		0.00^{cD}	0.50^{cD}	3.22^{bC}	5.34^{aB}	** (0.70)
	M	Nd	Nd	Nd	Nd		1.72^{dC}	4.16^{cC}	7.62^{bB}	10.78^{aA}	*** (0.34)
	P	Nd	Nd	Nd	Nd		3.93^{bA}	4.91^{bCB}	10.75^{aA}	10.35^{aA}	*** (0.61)
	R	Nd	Nd	Nd	Nd		2.00^{cBC}	7.16^{bA}	0.93^{dD}	10.41^{aA}	*** (0.26)
	S	Nd	Nd	Nd	Nd		2.98^{dBA}	5.51^{cB}	9.61^{bA}	10.87^{aA}	*** (0.28)
	P_{TO} (SE)						*** (0.5)	*** (0.01)	** (0.02)	*** (0.53)	
TBA number (mg MDA/kg)	C	0.21^{b}	0.24^{aB}	0.24^{aC}	0.24^{aC}	** (<0.01)	0.03^{cD}	0.03^{cE}	0.06^{bE}	0.08^{aE}	*** (<0.01)
	M	0.21^{c}	0.30^{bA}	0.36^{aB}	0.36^{aB}	*** (0.01)	0.22^{dA}	0.41^{cB}	0.79^{bB}	0.94^{aB}	*** (0.02)
	P	0.21^{d}	0.24^{cB}	0.25^{bC}	0.26^{aC}	*** (<0.01)	0.08^{dC}	0.20^{cC}	0.41^{bC}	0.45^{aC}	*** (0.01)
	R	0.21^{c}	0.31^{bA}	0.44^{aA}	0.41^{aA}	*** (0.02)	0.22^{dA}	0.85^{cA}	1.18^{bA}	1.36^{aA}	*** (0.01)
	S	0.21^{b}	0.22^{bC}	0.24^{aC}	0.24^{aC}	** (<0.01)	0.13^{dB}	0.18^{cD}	0.27^{bD}	0.35^{aD}	*** (0.01)
	P_{TO} (SE)	Ns (0)	*** (0.01)	*** (0.02)	*** (0.01)		*** (0.01)	*** (0.02)	*** (0.47)	*** (0.02)	

*n, number of observations. C, coconut oil; M, frying mix; P, palm oil; R, rapeseed oil; S, sunflower oil. P_{RF}, statistical probability of repeated deep-frying, P_{TO}, statistical probability of type of oil: *** $P \leq 0.001$, statistically very highly significant; ** $P \leq 0.01$, statistically highly significant; * $P \leq 0.05$, statistically significant; Ns, $P > 0.05$, statistically not significant. SE, standard error of mean. Data with different superscript letters for individual parameter within a row and separately for chicken nuggets and oils differ significantly ($P < 0.05$, a-c differences between fryings). Data with different superscript letters for individual parameter and within a column differ significantly ($P < 0.05$, A-E differences between type of oils). Nd, not detected.*

Change in fatty acid composition of chicken nuggets and oils during repeated deep-frying

The proportions of SFA, MUFA and PUFA in chicken nuggets varied after successive frying depending on type of oil (Table 3). After three repeated deep-frying, the proportion of SFA in chicken nuggets fried in coconut and palm oil increased significantly, due to the high proportion of lauric acid (C12:0; coconut oil) or palmitic acid (C16:0; palm oil). After three repeated deep-frying, the proportion of SFA in chicken nuggets fried in the frying mix and in rapeseed oil decreased significantly, whereas it did not change significantly in sunflower oil. In chicken nuggets fried in coconut oil, a much lower proportion of MUFA were determined (13.72 % (m/m)) compared to pre-fried nuggets (35.48 % (m/m)). Compared to pre-fried chicken nuggets (35.48 % (m/m)), the content of MUFA in the frying mix, palm and rapeseed oil increased significantly after the first frying (60.53 % (m/m), 41.56 % (m/m), 55.93 %

(m/m)), but after frying in sunflower oil the content in chicken nuggets did not change (35.37 % (m/m)). After three repeated deep-frying, the proportion of PUFA in chicken nuggets fried in coconut, palm, rapeseed oil and frying mix decreased significantly after the first frying compared to the nuggets before frying (51.49 % (m/m) vs. 12.89 % (m/m), 20.69 % (m/m), 34.99 % (m/m), 28.72 % (m/m)). Foods with a high PUFA content, as the chicken nuggets used in our experiment, are very susceptible to oxidation processes (Morrissey et al., 1998; Betti et al., 2009), and accordingly we expected an increased oxidation rate when using more unsaturated fats for deep-frying compared to more saturated fats such as coconut and palm oil.

From a nutritional point of view, the fat quality indices, the n-6/n-3 PUFA ratio and the proportion of trans FA are important.

According to Enser et al. (2001), the recommended ratio of n-6/n-3 PUFA is narrower than 4:1, as decreased risk of developing various degenerative diseases. The number of repeated deep-frying also affected the proportions of n-3 and n-6 FA in chicken nuggets, which were 0.99 % (m/m) or 50.29 % (m/m) before frying and varied after repeated deep-frying depending on the oil used. The more favourable types of oil after third repeated deep-frying of chicken nuggets are rapeseed oil (n-6/n-3, 6.23), frying mix (8.32), followed by coconut (14.82) and palm oil (23.36), and sunflower oil (78.66).

Trans FA in chicken nuggets must not exceed the maximum allowable content (2 % trans FA/100 g total fat) established by Slovenian Regulation on the maximum allowable trans fatty acids content in foodstuffs (2018). The proportion of trans FA in chicken nuggets after deep-frying is low, with repeated deep-frying varied slightly, but remained very low at 0.34 to 0.67 % (m/m) after the third frying. The proportion of trans FA in different types of frying oils ranged from 0.10% (m/m) to 0.43 % (m/m), as follows coconut oil < sunflower < frying mix < rapeseed = palm oil. Despite the fact that there were differences in the content of trans FA between the different oils used, it was necessary to emphasized that the proportion of trans FA in all used oils has not changed significantly with repeated deep-frying (not shown in tables).

Data from the literature indicate that a P/S ratio above 0.4 is recommended (Wood et al., 2003). The chicken nuggets presented a favourable P/S ratio before frying. Repeated deep-frying in different types of oils affected the fatty acid composition of the chicken nuggets, since the proportions of the individual fatty acids changed due to the absorption of the oil into the food. The previously favourable P/S ratio in chicken nuggets (3.95) after repeated deep-frying in coconut oil decreased below 0.4 (0.17-0.20) due to the low P/S ratio in the oil used (0.03). Interestingly, the P/S ratio of chicken nuggets repeated deep-fried in palm oil does not fall below 0.4 (0.53-0.55), although palm oil presented a narrow P/S ratio (0.27). Other oils (frying mix, rapeseed and sunflower oil) presented a favourable P/S ratio.

The recommended IA values are as low as possible (Semwogerere et al., 2019). In our study, a low IA for frying mix, rapeseed, sunflower and palm oil were presented; meanwhile, coconut oil a high IA (14.72). Chicken nuggets presented a low IA (0.11) before frying, and after deep-frying the oil's properties were transferred to the food. The IA values of chicken nuggets increased during repeated deep-frying in coconut and palm oil. The values obtained were expected as palm and coconut oil contain a high proportion of SFA, in particular myristic acid (C14:0), which is considered four times when calculating the IA index. IA in chicken nuggets deep-fried in other oils, frying mix, rapeseed and soybean oil, decreased slightly with repeated deep-frying. IA assessment data are deficient. Ulbricht and Southgate (1991) reported a value of 0.72 for ground beef, Žlender et al. (2001) 0.49 to 0.51 for muscles semitendinosus and triceps brachii of Simmental and brown bulls, and Polak et al. (2008) values of 0.36 and 0.72 for game meat. In this study the IA values for heat treated and frozen chicken nuggets before repeated deep-frying were 0.11.

Acrylamide in chicken nuggets

Before deep-frying and after the first frying, the acrylamide content in chicken nuggets was not detected, after the second and third repeated deep-frying, the acrylamide content increased significantly regardless of the type of frying oil used (Table 4).

Acceptable acrylamide level in fried foods (fried at a temperature of 170 °C) is about 0.150-0.200 mg/kg (Guerra-Hernandez, 2016). After the second repeated deep-frying, the limit is exceeded by chicken nuggets fried in a frying mix and rapeseed oil, and after the third repeated deep-frying in sunflower oil. The acrylamide levels in chicken nuggets fried in coconut and palm oil remain below 0.200 mg/kg

Table 3 Lipid oxidation parameters of chicken nuggets and oils during repeated deep-frying (n = 40)

Value of parameter according to repeated deep-frying										
	Chicken nuggets (n = 40)					Frying oil (n = 40)				
Deep-fried in	0	1	2	3	P_{RF} (SE)	0	1	2	3	P_{RF} (SE)
Coconut oil										
SFAs	13.04^{d}	73.39^{b}	73.98^{a}	71.01^{c}	*** (0.14)	89.57^{a}	89.10^{b}	88.53^{c}	88.04^{d}	** (0.11)
MUFAs	35.48^{a}	13.72^{c}	13.31^{d}	15.06^{b}	*** (0.10)	8.24^{c}	8.35^{c}	8.60^{b}	8.91^{a}	** (0.07)
PUFAs	51.49^{a}	12.89^{c}	12.71^{c}	13.93^{b}	*** (0.20)	2.19^{b}	2.54^{ba}	2.87^{a}	3.05^{a}	* (0.16)
trans	0.39^{b}	0.27^{b}	1.16^{a}	0.34^{b}	** (0.07)	0.10	0.09	0.10	0.24	Ns (0.09)
AI	0.11^{d}	4.58^{b}	4.92^{a}	4.03^{c}	*** (0.02)	14.72^{a}	14.01^{a}	13.22^{b}	12.81^{b}	* (0.24)
P/S	3.95^{a}	0.18^{b}	0.17^{b}	0.20^{b}	*** (0.03)	0.02^{c}	0.03^{bc}	0.03^{ba}	0.03^{a}	* < (0.01)
n-3	0.99^{a}	0.75^{c}	0.80^{cb}	0.88^{b}	* (0.03)	< 0.01	0.02	0.03	0.02	Ns (0.01)
n-6	50.29^{a}	12.12^{c}	11.90^{c}	13.04^{b}	*** (0.16)	2.19^{c}	2.53^{bc}	2.85^{ba}	3.02^{a}	* (0.15)
Frying mix										
SFAs	13.04^{a}	10.74^{b}	10.59^{cb}	10.43^{c}	*** (0.06)	9.55^{b}	8.99^{c}	9.91^{a}	10.03^{a}	*** (0.11)
MUFAs	35.48^{b}	60.53^{a}	60.76^{a}	61.16^{a}	*** (0.20	67.6^{2}	68.28	68.69	68.53	Ns (0.22)
PUFAs	51.49^{a}	28.72^{b}	28.66^{b}	28.41^{b}	*** (0.19)	22.83^{a}	22.73^{a}	21.40^{b}	21.44^{b}	*** (0.12)
trans	0.39^{b}	0.61^{a}	0.52^{a}	0.62^{a}	* (0.04)	0.29	0.33	0.34	0.26	Ns (0.08)
AI	0.11^{a}	0.10^{b}	0.10^{c}	0.10^{c}	*** (< 0.01)	0.07	0.07	0.07	0.07	Ns (< 0.01)
P/S	3.95^{a}	2.67^{b}	2.71^{b}	2.72^{b}	*** (0.02)	2.39^{b}	2.53^{a}	2.16^{c}	2.14^{c}	*** (0.02)
n-3	0.99^{c}	3.13^{a}	3.09^{ba}	3.04^{b}	*** (0.02)	3.17^{a}	3.14^{ba}	3.17^{a}	3.10^{b}	* (0.01)
n-6	50.29^{a}	25.51^{b}	25.50^{b}	25.29^{b}	*** (0.16)	19.56^{a}	19.49^{a}	18.13^{b}	18.26^{b}	** (0.13)
Palm oil										
SFAs	13.04^{c}	37.75^{b}	38.05^{a}	37.77^{b}	*** (0.06)	43.74	43.81	43.71	43.60	Ns (0.09)
MUFAs	35.48^{c}	41.56^{b}	41.91^{a}	41.69^{ba}	*** (0.11)	44.44	44.33	44.35	44.49	Ns (0.08)
PUFAs	51.49^{a}	20.69^{b}	20.04^{c}	20.54^{b}	*** (0.10)	11.82	11.86	11.94	11.91	Ns (0.17)
trans	0.39	0.34	0.62	0.57	Ns (0.08)	0.43	0.37	0.35	0.42	Ns (0.06)
AI	0.11^{c}	0.59^{b}	0.60^{a}	0.59^{b}	*** (< 0.01)	0.77	0.76	0.76	0.76	Ns (<0.01)
P/S	3.95^{a}	0.55^{b}	0.53^{b}	0.54^{b}	*** (0.02)	0.27	0.27	0.27	0.27	Ns (< 0.01)
n-3	0.99^{a}	0.76^{c}	0.78^{cb}	0.84^{b}	** (0.02)	0.24	0.19	0.18	0.19	Ns (0.02)
n-6	50.29^{a}	19.85^{b}	19.18^{c}	19.62^{b}	*** (0.09)	11.50	11.56	11.61	11.64	Ns (0.14)
Rapeseed oil										
SFAs	13.04^{a}	9.08^{b}	9.16^{b}	9.66^{b}	*** (0.20)	7.31	7.46	7.48	7.55	Ns (0.19)
MUFAs	35.48^{c}	55.93^{a}	55.48^{a}	54.60^{b}	*** (0.26)	60.65	61.62	61.62	61.17	Ns (0.65)
PUFAs	51.49^{a}	34.99^{d}	35.36^{c}	35.74^{b}	*** (0.11)	32.04	30.91	30.90	31.28	Ns (0.47)
trans	0.39^{c}	0.50^{b}	0.52^{b}	0.67a	* (0.03)	0.39	0.47	0.44	0.46	Ns (0.02)
AI	0.11^{a}	0.08^{c}	0.08cb	0.09^{b}	** (< 0.01)	0.06	0.06	0.06	0.06	Ns (< 0.01)
P/S	3.95	3.85	3.86	3.70	Ns (0.08)	4.39^{a}	4.14^{b}	4.13^{b}	4.15^{b}	* (0.06)
n-3	0.99^{c}	5.27^{a}	5.13^{a}	4.93^{b}	*** (0.05)	6.27^{a}	5.89^{b}	5.79^{b}	5.76^{b}	* (0.09)
n-6	50.29^{a}	29.67^{d}	30.18^{c}	30.71^{b}	*** (0.10)	25.72	24.98	25.03	25.44	Ns (0.38)
Sunflower oil										
SFAs	13.04	11.47	11.05	12.44	Ns (0.45)	10.24	10.28	10.27	10.35	Ns (0.07)
MUFAs	35.48	36.06	36.37	35.71	Ns (0.20)	36.86	37.03	37.04	37.11	Ns (0.13)
PUFAs	51.49	52.47	52.58	51.85	Ns (0.27)	52.90	52.69	52.69	52.54	Ns (0.20)
trans	0.39	0.30	0.34	0.44	Ns (0.04)	0.17	0.16	0.18	0.18	Ns (0.02)
AI	0.11^{a}	0.09^{b}	0.09^{b}	0.10^{a}	* (< 0.01)	0.07	0.07	0.07	0.07	Ns (< 0.01)
P/S	3.95	4.58	4.76	4.17	Ns (0.19)	5.17	5.13	5.13	5.07	Ns (0.05)
n-3	0.99	0.65	0.54	0.65	Ns (0.15)	0.09	0.10	0.10	0.10	Ns < (0.01)
n-6	50.29	51.70	51.88	51.13	Ns (0.41)	52.70	52.46	52.44	52.30	Ns (0.17)

*n, number of observations. C, coconut oil; M, frying mix; P, palm oil; R, rapeseed oil; S, sunflower oil. PRF, statistical probability of repeated deep-frying, PTO, statistical probability of type of oil: *** P≤0.001, statistically very highly significant; ** P ≤ 0.01, statistically highly significant; * P ≤ 0.05, statistically significant; Ns, P > 0.05, statistically not significant. SE, standard error of mean. Data with different superscript letters for individual parameter within a row and separately for chicken nuggets and oils differ significantly (P < 0.05, a-c differences between repeated deep-frying). SFAs, saturated fatty acids: C12:0 + C13:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0 + C22:0 + C23:0 + C24:0. MUFAs, monounsaturated fatty acids: C12:1cis-11 + C13:1cis-12 + C14:1trans-9 + C14:1cis7 + C14:1cis-9 + C15:1trans-10 + C15:1cis-10 + C16:1trans-9 + C16:1cis-7 + C16:1cis-9 + C17:1trans-10 + C17:1cis-10 + C18:1trans + C18:1cis + C19:1trans-10 + C19:1cis-10 + C20:1cis-5 + C20:1trans-11 + C20:1cis-8 + C20:1cis-11 + C21:0 + C22:1trans + C22:1cis + C24:1. PUFAs, polyunsaturated fatty acids: C18:2trans-9,12 + C18:2cis-9, trans-12 + C18:2cis-9,12 + C18:3cis-6,9,12 (n-6) + C18:3cis-9,12,15 (ALA) (n-3) + C20:2cis-11,14(n-6) + C20:3cis-8,11,14 (n-6) + C20:4cis-5,8,11,14 (n-6) + C20:3cis-11,14,17 (n-3) + C20:5cis-6,9,11,14,17 (n-3) (EPA) + C22:2cis-13,16 (n-6) + C22:3cis-13,16,19 (n-3) + C22:4cis-7,10,13,16 (n-6) + C22:5cis-7,10,13,16,19 (n-3) (DPA) + C22:6cis-4,7,10,13,16,19 (n-3) (DHA). trans: C14:1trans-9 + C15:1trans-10 + C16:1trans-9 + C17:1trans-10 + C18:1trans + C18:2trans-9,12 + C19:1trans-10 + C20:1trans-11 + C22:1trans. IA, index of atherogenicity: (C12:0 + 4 xC14:0 + C16:0 + Σ (trans))/(Σ (n-6) + Σ (n-3) + C18:1cis-9 + MUFA) (Ulbricht in Southgate, 1991). P/S – PUFAs/SFAs ratio.*

after all three repeated deep-frying. According to Guerra-Hernandez (2016), frying breaded foods in palm oil produces more acrylamide due to the presence of monoglycerides and diglycerides, which have emulsifying properties and produce acrolein. In our results, no higher acrylamide content was found in chicken nuggets fried in palm oil; on the contrary, the results show less acrylamide compared to other oils (except coconut oil). Chicken nuggets fried in rapeseed oil have the highest acrylamide content (2.915 mg/kg).

Table 4 Content of acrylamide (mg/kg) in chicken nuggets after repeated deep-frying (n = 40)

		Value of parameter according to repeated deep-frying				
Parameter	**oil**	**0**	**1**	**2**	**3**	**P_{RF} (SE)**
Acrylamide (mg/kg)	C	Nd	Nd	0.016[bD]	0.093[aD]	*** (0.005)
	M	Nd	Nd	0.205[bB]	1.249[aC]	*** (0.004)
	P	Nd	Nd	0.014[bD]	0.116[aD]	*** (0.003)
	R	Nd	Nd	0.361[bA]	2.915[aA]	*** (0.036)
	S	Nd	Nd	0.122[bC]	1.448[aB]	*** (0.016)
	P_{TO} (SE)	-	-	*** (0.020)	*** (0.025)	

*n, number of observations. C, coconut oil; M, frying mix; P, palm oil; R, rapeseed oil; S, sunflower oil. PRF, statistical probability of repeated deep-frying, PTO, statistical probability of type of oil: *** P ≤0.001, statistically very highly significant; ** P ≤ 0.01, statistically highly significant; * P ≤ 0.05, statistically significant; Ns, P > 0.05, statistically not significant. SE, standard error of mean. Data with different superscript letters for individual parameter within a row and separately for chicken nuggets and oils differ significantly (P < 0.05, a-b differences between repeated deep-frying). Data with different superscript letters for individual parameter and within a column differ significantly (P <0.05, A-D differences between type of oils). Nd, not detected.*

Sensory quality of chicken nuggets and frying oils

The number of repeated deep-frying in different oils affected the sensory properties of the chicken nuggets, with a few exceptions where the sensory properties deteriorated (Table 5). For example, the sensory evaluation panel found deterioration in the colour uniformity of chicken nuggets fried in the frying mix, a darker colour in nuggets fried in coconut oil, a worse smell and a more distinct greasiness in nuggets fried in sunflower oil and a worse aroma in nuggets fried in palm oil. The number of repeated deep-frying also significantly worsened the final overall impression of chicken nuggets fried in a frying mix and fried in sunflower oil. The overall impression as sensory overall acceptance of the fried chicken nuggets was very good as all samples were rated high above the acceptance limit (value above 4). The panellists also assessed the mouthfeel of chicken nuggets, but this property was evaluated as optimal in all samples (not shown in the tables).

Contrary to the sensory quality of the fried food/nuggets, the number of repeated deep-frying significantly deteriorated the properties of the oils used, with the exception of the smell of the food, the aroma of the food and the transparency of the oils. The significant deterioration of the properties of the oils is also confirmed by the chemical analysis, which is presented below. Experts recommended that frying oils should not have an intense taste or colour; they should retain a light colour (Kochhar, 2016). All five oils in this study showed a neutral taste and colour before and after repeated deep-frying, but repeated deep-frying caused in all used frying oils a darker colour (by values from 0.5 to 0.7). The colour of the oils became even darker during the following deep-frying repetitions, after third repeated deep-frying the colour of the oils worsen by values between 1.1 and 1.3. The panellists also assessed the transparency of the oils, but this property did not change with repeated deep-frying and between the types of frying oils used (not shown in the tables).
Already after the first deep-frying of chicken nuggets, the smell and aroma (by value about 1) of all used oils significantly worsen, as certain odd smells and aromas occur (exception: sunflower oil). In the case of coconut oil, frying mix and palm oil, panellists detected rancidity (values from 1.5 to 1.7) after the first deep-frying, but not the smell and aroma of the food. A further deterioration of the smell by about 0.5 points for the second and third repeated deep-frying, for all oils except the frying mix was found; the deterioration is the result of more intensive rancidity (values from 1.9 to 2.6), for coconut oil and sunflower oil also increasingly pronounced odd smells (values from 1.6 to 1.9). The aroma of frying oils also contin-

ued to deteriorate between the second and third repeated deep-frying (by values from 0.7 to 1.0), in this step the frying mix was no exception, but the deterioration was less pronounced than for other oils (the aroma was rated the highest value, 5.7). Panellists evaluated both, the worse aroma and the smell due to a more pronounced rancidity and not more pronounced odd smells - these remain at the same level of expression (between 1.3 and 1.9). Of three repeated deep-frying, the smell and aroma worsen least in the frying mix (5.9 and 5.7 respectively) and most in sunflower oil (5.1). In the case of sunflower oil, the investigators found the most marked differences in odd smell and rancidity, but the differences were not significantly greater than in the other oils used.

Table 5 Sensory attribute of chicken nuggets and frying oils during repeated deep-frying

		Value of parameter according to repeated deep-frying								
		Chicken nuggets (n = 75)				Frying oil (n = 100)				
Attribute	Oil	1	2	3	P_{RF} (SE)	0	1	2	3	P_{RF} (SE)
Uniformity of colour (1-7)	C	5.9^{C}	6.0	6.0^{A}	Ns (0.1)					
	M	6.2^{BAa}	6.0^{ba}	5.8^{Ab}	* (0.2)					
	P	6.3^{A}	6.1	6.0^{A}	Ns (0.2)					
	R	6.0^{BC}	6.0	5.9^{A}	Ns (0.1)					
	S	6.0^{BC}	6.2	6.0^{A}	Ns (0.1)					
	PTO (SE)	* (0.2)	Ns (0.1)	Ns (0.2)						
Characteristicality of colour (1-7)	C	4.0^{b}	4.5^{a}	4.5^{Aa}	*** (0.0)	4.0^{c}	4.5^{b}	4.7^{bB}	5.3^{a}	*** (0.2)
	M	4.0	4.1	4.1^{B}	Ns (0.2)	4.0^{c}	4.6^{b}	5.0^{aA}	5.1^{a}	*** (0.2)
	P	4.0	4.3	4.1^{B}	Ns (0.2)	4.0^{c}	4.6^{b}	4.8^{bBA}	5.3^{a}	*** (0.2)
	R	4.1	4.1	4.1^{B}	Ns (0.2)	4.0^{d}	4.7^{c}	5.0^{bA}	5.3^{a}	*** (0.2)
	S	4.0	4.1	4.3^{BA}	Ns (0.2)	4.0^{d}	4.5^{c}	5.0^{bA}	5.2^{a}	*** (0.1)
	PTO (SE)	Ns (0.1)	Ns (0.2)	* (0.2)		- (< 0.1)	Ns (0.2)	** (0.2)	Ns (0.2)	
Adhesion of panada (1-7)	C	6.3^{A}	6.2^{A}	6.2^{A}	Ns (0.3)					
	M	6.3^{A}	6^{A}	5.9^{A}	Ns (0.5)					
	P	6.2^{A}	6.2^{A}	6^{A}	Ns (0.2)					
	R	6.1^{A}	6.1^{A}	5.9^{A}	Ns (0.3)					
	S	6.1^{A}	6.1^{A}	5.8^{A}	Ns (0.3)					
	PTO (SE)	Ns (0.3)	Ns (0.3)	Ns (0.4)						
Greasiness (1-7)	C	1.0	1.1	1.1	Ns (0.2)					
	M	1.1	1.6	1.6	Ns (0.4)					
	P	1.3	1.4	1.5	Ns (0.2)					
	R	1.1	1.5	1.4	Ns (0.3)					
	S	1.0^{b}	1.6^{a}	1.6^{a}	* (0.3)					
	PTO (SE)	Ns (0.2)	Ns (0.3)	Ns (0.3)						
Crunchiness of panada (1-7)	C	6.3	6.3	6.3	Ns (0.2)					
	M	6.1	6.2	6.1	Ns (0.4)					
	P	6.2	6.2	6.2	Ns (0.1)					
	R	6.1	6.0	6.1	Ns (0.3)					
	S	6.1	6.0	6.0	Ns (0.2)					
	PTO (SE)	Ns (0.2)	Ns (0.2)	Ns (0.4)						
Smell (1-7)	C	6.4^{A}	6.4^{A}	6.3^{A}	Ns (0.2)	7.0^{a}	6.0^{bA}	5.5^{cB}	5.4^{cB}	*** (0.2)
	M	6.2^{BA}	6.0^{B}	6.0^{B}	Ns (0.1)	7.0^{a}	6.0^{bA}	6.0^{bA}	5.9^{bA}	*** (0.2)
	P	6.1^{B}	5.7^{C}	5.9^{B}	Ns (0.3)	7.0^{a}	6.4^{bB}	6.0^{cA}	5.6^{dB}	*** (0.2)
	R	6.0^{B}	6.0^{B}	6.0^{B}	- (< 0.1)	7.0^{a}	5.9^{bA}	5.6^{cB}	5.5^{cB}	*** (0.2)
	S	6.0^{Ba}	5.6^{Cb}	5.4^{Cb}	*** (0.2)	7.0^{a}	6.0^{bA}	5.5^{cB}	5.1^{dC}	*** (0.1)
	PTO (SE)	* (0.2)	*** (0.2)	*** (0.2)		-	*** (0.2)	*** (0.2)	*** (0.2)	

Table 5 Sensory attribute of chicken nuggets and frying oils during repeated deep-frying

Value of parameter according to repeated deep-frying										
		Chicken nuggets (n = 75)				Frying oil (n = 100)				
Attribute	Oil	1	2	3	P_{RF} (SE)	0	1	2	3	P_{RF} (SE)
Used oil/food smell (1-7)	C	1.1	1.1^{B}	1.1	Ns (0.2)	1.0^{a}	1.0	1.1	1.1	Ns (0.2)
	M	1.0	1.0^{B}	1.1	Ns (0.1)	1.0^{a}	1.1	1.0	1.0	Ns (0.1)
	P	1.1	1.4^{A}	1.1	Ns (0.2)	1.0^{a}	1.0	1.0	1.0	- < (0.1)
	R	1.2	1.0^{B}	1.0	Ns (0.1)	1.0^{a}	1.0	1.0	1.0	- (0.0)
	S	1.0	1.0	1.0	- (< 0.1)	1.0^{a}	1.0	1.1	1.2	Ns (0.2)
	PTO (SE)	Ns (0.2)	*** (0.1)	Ns (0.2)		-(< 0.1)	Ns (0.1)	Ns (0.1)	Ns (0.2)	
Odd smell (1-7)	C	1.0	1.0^{B}	1.0^{B}	- (< 0.1)	1.0^{c}	1.4^{bB}	1.6^{baB}	1.8^{aA}	*** (0.3)
	M	1.0	1.0^{B}	1.0^{B}	- (< 0.1)	1.0^{b}	1.5^{aBA}	1.2^{bB}	1.2^{bB}	** (0.2)
	P	1.0	1.0^{B}	1.0^{B}	- (< 0.1)	1.0^{b}	1.4^{aB}	1.4^{aB}	1.4^{aB}	** (0.2)
	R	1.0	1.0^{B}	1.0^{B}	- (< 0.1)	1.0^{b}	1.7^{aA}	2.1^{aA}	2.0^{aA}	*** (0.3)
	S	1.0	1.4^{A}	1.5^{A}	Ns (0.3)	1.0^{c}	1.0^{cC}	1.5^{bB}	1.9^{aA}	*** (0.1)
	PTO (SE)	- (< 0.1)	***(0.1)	** (0.2)		- (< 0.1)	*** (0.2)	*** (0.3)	*** (0.3)	
Aroma (1-7)	C	6.4	6.4^{A}	6.4^{A}	Ns (0.2)	7.0	6.0^{b}	5.7^{cA}	5.3^{dB}	*** (0.2)
	M	6.3	6.3^{BA}	5.9^{B}	Ns (0.3)	7.0^{a}	6.0^{b}	5.3^{cBC}	5.7^{bA}	*** (0.3)
	P	6.3^{a}	6.0^{Bb}	6.0^{BAb}	* (0.2)	7.0^{a}	6.0^{b}	5.6^{cBA}	5.1^{dB}	*** (0.2)
	R	6.0	6.1^{BA}	5.9^{B}	Ns (0.4)	7.0^{a}	5.8^{b}	5.0^{cC}	5.1^{cB}	*** (0.3)
	S	6.0	5.6^{C}	5.6^{B}	Ns (0.3)	7.0^{a}	6.0^{b}	5.5^{cBA}	5.0^{dB}	*** < (0.1)
	PTO (SE)	Ns (0.3)	*** (0.3)	*** (0.3)		- (< 0.1)	Ns (0.2)	*** (0.2)	*** (0.2)	
Used oil/food aroma (1-7)	C	1.0^{B}	1.0	1.0	- (< 0.1)	1.0	1.0	1.1^{B}	1.1	Ns (0.2)
	M	1.0^{B}	1.0	1.1	Ns (0.1)	1.0	1.1	1.3^{BA}	1.2	Ns (0.3)
	P	1.0^{B}	1.1	1.1	Ns (0.2)	1.0	1.0	1.0^{B}	1.0	- < (0.1)
	R	1.2^{A}	1.1	1.1	Ns (0.2)	1.0	1.0	1.0^{B}	1.0	- < (0.1)
	S	1.0	1.0	1.0	- (< 0.1)	1.0	1.2	1.7^{A}	1.5	Ns (0.4)
	PTO (SE)	* (0.1)	Ns (0.1)	Ns (0.2)		- (< 0.1)	Ns (0.2)	** (0.3)	Ns (0.3)	
Odd aroma (1-7)	C	1.0	1.0	1.0	- (< 0.1)	1.0^{b}	1.4^{aB}	1.6^{aBA}	1.7^{a}	*** (0.2)
	M	1.0	1.0	1.3	Ns (0.3)	1.0^{b}	1.5^{aBA}	1.5^{aB}	1.4^{a}	** (0.2)
	P	1.0	1.0	1.0	- (< 0.1)	1.0^{b}	1.5^{aBA}	1.6^{aBA}	1.3^{ba}	* (0.3)
	R	1.0	1.3	1.3	Ns (0.4)	1.0^{b}	1.7^{aA}	2.0^{aA}	1.9^{a}	*** (0.3)
	S	1.0	1.4	1.2	Ns (0.3)	1.0^{b}	1.0^{bC}	1.2^{bB}	1.7^{a}	** (0.3)
	PTO (SE)	(< 0.1)	Ns (0.2)	Ns (0.4)		(< 0.1)	*** (0.2)	* (0.3)	Ns (0.4)	
Rancidity (1-7)	C	1.0	1.0	1.0	-	1.0^{d}	1.5^{cA}	1.9^{bB}	2.2^{a}	*** (0.2)
	M	1.0	1.0	1.0	-	1.0^{c}	1.7^{bA}	2.4^{aA}	2.0^{ba}	*** (0.3)
	P	1.0	1.0	1.0	-	1.0^{d}	1.6^{cA}	2.0^{bB}	2.5^{a}	*** (0.1)
	R	1.0	1.0	1.0	-	1.0^{b}	1.2^{bB}	2.4^{aA}	2.2^{a}	*** (0.3)
	S	1.0	1.0	1.0	-	1.0^{c}	1.0^{cB}	2.0^{bB}	2.6^{a}	*** (0.2)
	PTO (SE)	-	-	-		- (< 0.1)	*** (0.2)	* (0.3)	Ns (0.3)	

*n, number of observations. C, coconut oil; M, frying mix; P, palm oil; R, rapeseed oil; S, sunflower oil. PRF, statistical probability of repeated deep-frying, PTO, statistical probability of type of oil: *** P ≤ 0.001, statistically very highly significant; ** P ≤ 0.01, statistically highly significant; * P ≤ 0.05, statistically significant; Ns, P > 0.05, statistically not significant. SE, standard error of mean. Data with different superscript letters for individual parameter within a row and separately for chicken nuggets and oils differ significantly (P < 0.05, a-d differences between repeated deep-frying). Data with different superscript letters for individual parameter and within a column differ significantly (P < 0.05, A-C differences between types of oils).*

The data on the stability of chicken nuggets and the used frying oils were compared with the results of the sensory analysis. Sensory properties were loosely and in some properties even contradictory associated with the vaiations in acid number. The TBA number of chicken nuggets was significantly and negatively associated with the colour intensity (r = -0.381, P ≤ 0.05, number of comparisons (n) = 80) and the panada adhesion (r = -0.472, P ≤ 0.01), and significantly, positively, medium-strongly associated with the estimate for the intensity of odd aroma (r = 0.458, P ≤ 0.05). The smell and aroma of the oils in which the chicken nuggets were fried were significantly and negatively associated with the peroxide numbers (r, -0.564, -0.589) and TBA (r, -0.393, -0.552) numbers, as the odd smell, odd aroma and rancidity positively with the peroxide numbers (r, 0.254, 0.284, 0.538) and TBA (r, 0.473, 0.545, 0.440) numbers. Higher peroxide number and TBA number in oils also mean that oils have a less characteristic (darker) colour (r, 0.681, 0.501).

Conclusion

Oils should have a high proportion of monounsaturated fatty acids (C18:1 > 75 %), a low proportion of saturated fatty acids (C16:0, C14:0, C12:0) and polyunsaturated fatty acids (< 15 %), very little linolenic acid, C18:3 (< 1.5 %) and almost no trans FA. Oils containing a high PUFA proportion are more susceptible to oxidation and thermal decomposition, in this study sunflower oil contained the highest PUFA proportion. The results of the sensory analysis confirm that the oxidation and thermal degradation of sunflower oil took place to the most pronounced, as the panel rated sunflower oil worst after repeated deep-frying.

As can be seen from the results, no used oil in the study meets all the requirements. However, since we consume fried foods and not frying oil, coconut oil is the most suitable from the point of view of lipid oxidation, a frying mix, rapeseed and sunflower oil from the point of the fatty acid composition, and as for the sensory quality and acrylamide level coconut and palm oil.

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Parametri kvalitete različitih ulja i pržene hrane nakon ponovnog prženja u dubokom ulju

Sažetak

Cilj ovog rada bio je istražiti kvalitetu, stabilnost i prikladnost različitih ulja za prženje (kokosovog i palminog ulja, smjese za prženje, uljane repice i suncokretovog ulja), kakvoću i stabilnost pohane i pržene hrane (pileći medaljoni) te primjenjivost i prikladnost određenih parametara (apsorpcija masti, kiselinski broj, peroksidni broj i vrijednost tiobarbiturne kiseline (TBA), sastav masnih kiselina i sadržaj akrilamida) kao i senzortičkih svojstava u svrhu kontrole ponovljenog postupka prženja u dubokoj masnoći. Tri ponovljena postupka dubokog prženja utjecala su na hidrolitičku i oksidacijsku stabilnost (porast peroksidnog broja i TBA vrijednosti), osjetilna svojstva (pojava tamne boje ulja, neobičnog mirisa i arome kao i užeglost), sastav masnih kiselina ulja i prženih pilećih medaljona te na sadržaj akrilamida u medaljonima (od drugog postupka dubokog prženja pa nadalje). Sva ulja korištena u istraživanju bila su pogodna za duboko prženje. U pogledu stabilnosti, kokosovo ulje (nakon kojeg slijede suncokretovo, palmino, smjesa za prženje i ulje repice) bilo je najprikladnije. Što se tiče sastava masnih kiselina, smjesa za prženje, ulje repice i suncokretovo ulje bili su najprikladniji, dok su u pogledu stvaranja akrilamida i senzoričke kakvoće, najprikladnija bila ulja kokosa i palme.

Ključne riječi: ulja, duboko prženje, ponovno duboko prženje, pohana hrana, kakvoća ulja, oksidacijska stabilnost ulja, senzorička svojstva, sastav masnih kiselina, akrilamid

Qualitätsparameter verschiedener Öle und frittierter Lebensmittel nach dem erneuten Braten in tiefem Öl

Zusammenfassung

Ziel dieser Studie war es, die Qualität, Stabilität und Eignung verschiedener Frittieröle (Kokos- und Palmöl, Frittiermischungen, Raps- und Sonnenblumenöl), die Qualität und Stabilität von panierten und frittierten Lebensmitteln (Hühnermedaillons) sowie die Anwendbarkeit und Eignung bestimmter Parameter (Fettabsorption, Säurezahl, Peroxidzahl und Wert der Thiobarbitursäure (TBA), Fettsäurezusammensetzung und Acrylamidgehalt) und die sensorischen Eigenschaften zur Kontrolle des wiederholten Frittierprozesses in tiefem Öl zu untersuchen. Drei wiederholte Frittiervorgänge beeinflussten die hydrolytische und oxidative Stabilität (Erhöhung des Peroxidwerts und des TBA-Werts), die sensorischen Eigenschaften (Auftreten einer dunklen Ölfarbe, ungewöhnlicher Geruch und Aroma sowie Ranzigkeit), die Fettsäurezusammensetzung von Öl- und Brathähnchenmedaillons sowie den Acrylamidgehalt in Medaillons (ab dem zweiten Frittiervorgang). Alle in der Studie verwendeten Öle waren zum Frittieren geeignet. In Bezug auf die Stabilität war Kokosöl (gefolgt von Sonnenblumenöl, Palmöl, Frittiermischungen und Rapsöl) am besten geeignet. In Bezug auf die Fettsäurezusammensetzung waren Frittiermischungen, Rapsöl und Sonnenblumenöl am besten geeignet, während in Bezug auf die Acrylamidbildung und sensorische Qualität Kokos- und Palmöle am besten abgeschnitten haben.

Schlüsselwörter: Öle, Frittieren, erneutes Frittieren in tiefem Öl, frittiertes Essen, Ölqualität, Oxidationsstabilität von Ölen, sensorische Eigenschaften, Fettsäurezusammensetzung, Acrylamid

Parámetros de calidad de diferentes aceites y alimentos fritos después de freírlos en aceite profundo

Resumen

El objetivo de este estudio fue investigar la calidad, la estabilidad y la idoneidad de diferentes aceites de fritura (aceite de coco y palma, mezclas para freír, el aceite de colza y de girasol), la calidad y la estabilidad de los alimentos empanizados y fritos (los medallones de pollo) y la aplicabilidad y la idoneidad de los parámetros determinados (la absorción de grasas, el índice de acidez, el índice de peróxido y el índice de ácido tiobarbitúrico (TBA), la composición de ácidos grasos y el contenido del acrilamida), así como las propiedades sensoriales con el fin de controlar el proceso repetido de fritura profunda. Tres repetidos procesos de fritura profunda afectaron la estabilidad hidrolítica y la estabilidad oxidativa (el aumento del índice de peróxido y el valor de TBA), las propiedades sensoriales (la apariencia de color oscuro del aceite, el olor y el aroma inusuales, así como la rancidez), la composición de ácidos grasos del aceite y de los medallones de pollo frito y el contenido del acrilamida en los medallones (a partir del segundo proceso de fritura). Todos los aceites utilizados en el estudio fueron adecuados para freír. En términos de estabilidad, el aceite de coco (seguido del aceite de girasol, de palma, la mezcla para freír y del aceite de canola) fue el más adecuado. En términos de composición de los ácidos grasos, las mezclas para freír, el aceite de colza y el aceite de girasol fueron los más adecuados, mientras que en términos de formación de acrilamida y calidad sensorial, los aceites de coco y de palma fueron los más adecuados.

Palabras claves: aceites, fritura profunda, fritura profunda repetida, comida empanizada, calidad del aceite, estabilidad oxidativa del aceite, propiedades sensoriales, composición de ácidos grasos, acrilamida

Parametri di qualità di differenti tipi d’olio e del cibo fritto dopo una frittura profonda ripetuta

Riassunto

Questo studio è stato condotto al fine di esaminare la qualità, la stabilità e l’idoneità di differenti tipi d’olio per frittura (olio di cocco e olio di palma, miscele per friggere, olio di colza e olio di semi di girasole), la qualità e la stabilità del cibo impanato e fritto (medaglioni di pollo) e l’applicabilità e l’idoneità di determinati parametri (l’assorbimento dei grassi, il numero di acidi, il numero di perossidi e il numero di acido tiobarbiturico o numero TBA, la composizione degli acidi grassi e il contenuto di acrilamide), oltre che le proprietà sensoriali ai fini del controllo di una frittura profonda (in immersione) ripetuta. Il processo di frittura profonda, ripetuto tre volte, ha inciso sulla stabilità idrolitica e ossidativa (con la crescita del numero di perossidi e del numero TBA), sulle proprietà sensoriali (olio scuro e di odore e aroma insoliti, come di stantio), sulla composizione degli acidi grassi dell’olio e dei medaglioni di pollo e sul contenuto di acrilamide nei medaglioni (dal secondo processo di frittura profonda in poi). Tutti gli oli utilizzati per lo studio erano adatti alla frittura profonda. Dal punto di vista della stabilità, l’olio di cocco (seguito dall’olio di semi di girasole, dall’olio di palma, dalla miscela per frittura e dall’olio di colza) s’è dimostrato il più idoneo. Per quel che riguarda la composizione degli acidi grassi, la miscela per friggere, l’olio di colza e l’olio di semi di girasole hanno evidenziato una maggiore idoneità rispetto agli altri mentre, per quanto riguarda la formazione di acrilamide e per quanto riguarda le proprietà sensoriali, gli oli più adatti si sono dimostrati quelli di cocco e di palma.

Parole chiave: oli, frittura profonda, frittura profonda ripetuta, cibi impanati, qualità dell’olio, stabilità ossidativa dell’olio, proprietà sensoriali, composizione degli acidi grassi, acrilamide