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Effects of frying oil type on its stability and composition of fried food

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Abstract: The stability of three frying oils (rapeseed, sunflower, and rice) and their effect on the nutritional value of deep-fried fish fingers (FF) and potato croquettes (PC) was evaluated, considering the nutritional importance of reducing the amount of oil absorbed by fried foods. Ten frying cycles were performed for each food to mimic the repeated frying conditions. Dry matter content of fried foods was determined gravimetrically; fat extraction was performed using a Soxhlet apparatus. Oil stability changes were evaluated using the Schaal test; colour changes were monitored spectrophotometrically. Repeated frying had no significant effect ($P > 0.05$) on the fat content of the tested foods but influenced the dry matter content of PC. The highest and lowest oxidative stabilities during repeated frying were observed for rice and sunflower oil, respectively. During the frying of FF, all oils tended to darken after each frying, which was not observed for PC. The intake of fat owing to the consumption of one portion of the fried FF (150 g) or PC (200 g) approximately equals 9 g and 5 g, respectively. This demonstrates that fried foods themselves (not only the oil soaked) could be a considerable source of fat.

Keywords: fish fingers; potato croquettes; fat absorption; oil oxidation; oil colour

Fried foods are widely popular because of their crunchy crust, characteristic smell and taste, and golden-brown colour resulting from the Maillard reaction (Bouchon 2009). Potato croquettes (PC) and fish fingers (FF) are some of the most popular foods prepared by deep frying, during which foods are immersed into a thick layer of oil pre-heated to 150–200 °C (Khaled et al. 2015).

When choosing frying oil, one should consider that its type affects the organoleptic properties and nutritional value of fried foods (Rossi et al. 2007). The main factors affecting the quality of frying oil are its fatty acid composition, presence of unsaponifiable accompanying compounds and antioxidants, age, fried food composition, and frying technology (Choe and Min 2007). During frying, oil gets absorbed by the prepared food and thus increases its energy value.

Vegetable oils rich in linoleic acid endow fried food with its characteristic aroma and taste but are less oxidatively stable than those rich in saturated and monounsaturated fatty acids. Sunflower oil is rich in polyunsaturated linoleic (40–74%) and oleic (13–40%) acids and is, therefore, less oxidatively stable than oils predominantly containing monounsaturated fatty acids. Rapeseed oil contains oleic (52–67%), linoleic (16–25%), and linolenic (6–14%) acids (Velíšek 2014). Rice oil is produced from sprouts or bran and contains oleic

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(42%), linoleic (39%), and palmitic (15%) acids as well as tocochromanols and γ-oryzanol, therefore having a high nutritional value (Nayik et al. 2015).

The excessive intake of fried foods adversely affects human health and promotes the development of conditions such as obesity, cardiovascular diseases, and cancer (Stott-Miller et al. 2013). Therefore, much attention is currently directed at reducing fat intake, e.g. by decreasing the amount of oil absorbed by food during frying (Ziaiifar et al. 2008).

Herein, we examined the effect of the frying oil type and repeated frying on the fat content of fried food, testing if deep frying affects the fat content of fried food; oil absorption is affected by the type of frying oil and fried food and oil stability during repeated frying is affected by the oil type.

MATERIAL AND METHODS

Sample preparation. Sunflower (Fabio Product, Holín, Czech Republic), rapeseed (Glencore Agriculture Czech, Ústí nad Labem, Czech Republic), and rice (Gaston, Prague, Czech Republic) oils were used as frying media for pre-fried FF and PC (Bidfood, Opava, Czech Republic). Frying was performed at the temperature recommended by the fryer manufacturer (Nova, Belgium), at 180 °C for 3 min for FF (one piece per frying, ~25 g) and at 170 °C for 5 min for PC (two pieces per frying, ~21.5 g). Ten batches of frying for each food type were prepared to mimic the repeated frying conditions of (fast food) restaurants. During frying, the oil was not refilled. The oil volume and drip-off time for each food equalled 2 L and 15 min, respectively.

After frying, the samples were frozen at −80 °C, lyophilised [cooling unit (CoolSafe 110-4; SCANVAC, Denmark) and rotary vane pump (FB65460; ILMAC, Germany)], and homogenised for 1–2 min using an IKA laboratory grinder (Yellowline A10; Ilabo, Czech Republic). In total, 66 samples were analysed: 10 batches of FF and 10 batches of PC per each oil type, non-fried FF (n = 3, control), and non-fried PC (n = 3, control).

Fried foods analyses. Dry matter was determined by drying at 103 ± 2 °C to constant weight (UFB 500 oven; Memmert GmbH + Co.KG, Germany). Fat content was determined using the Soxhlet method (SER 148; VELP Scientifica, Italy). A homogenised sample (2.5 g) was extracted with petroleum ether (70 mL; Lachner, Czech Republic) at 40–65 °C for 110 min.

Schaal test. After a certain number of frying cycles (1, 3, 5, 7, and 10), ~25 g of oil were weighed into a 100 mL beaker, placed into a thermostat (Binder 2.0; Binder, Germany) at 60 °C for 77 days, and weighed twice per week on analytical balances (KERN ABJ 120--4NM; KERN & Sohn, Germany). The observed weight changes indicated the amount of oxygen absorbed by the oil, i.e. the degree of oil oxidation. The relative change in weight was calculated as the difference between the weight of the sample on a given day and its weight on day zero divided by the weight on day zero.

Oil colour changes. The colour of the oil was determined by spectrophotometer Minolta Spectra Magic TM NX (Konica Minolta Sensing, Inc., Japan) after each frying cycle. The system of the CIELAB colour space ($L^*a^*b^*$) was used.

Statistical analysis. The data were evaluated by the Statistica 12 software (StatSoft, Inc., USA) using Student's t-test, analysis of variance (ANOVA), and Sheffe's post-hoc test at a probability level of 0.05.

RESULTS AND DISCCUSION

Dry matter and fat contents. Dry matter and fat contents were significantly affected (P < 0.0001) by the fried food type. Therefore, the effect of the frying medium was evaluated separately for each food type.

The oil type had no effect (P > 0.05) on the dry matter and fat contents of the fried FF (Table 1). The re-

Table 1. Average dry matter and fat contents of 10 batches of fish fingers (FF) fried in different oils (mean ± SD; n = 10 for oils and n = 3 for control)

Oil	Dry matter	Fat	
	[g (100 g sample)$^{-1}$]	[g (100 g sample)$^{-1}$]	[g (100 g dry matter)$^{-1}$]
Rapeseed	39.03 ± 1.18[a]	6.17 ± 0.29[a]	15.81 ± 0.72[a]
Sunflower	39.99 ± 1.79[a]	6.22 ± 0.29[a]	15.55 ± 0.40[a]
Rice	38.69 ± 0.77[a]	6.05 ± 0.21[a]	15.64 ± 0.41[a]
Control	38.57 ± 0.55[a]	6.10 ± 0.04[a]	15.82 ± 0.05[a]

[a]Different superscript letters indicate statistically significant differences between variables at P < 0.05 within the same column

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sults of dry matter and fat content did not show any tendency (1st–10th frying) when frying the same food in the same type of oil; therefore, Tables 1, 2 show the average results.

In the case of PC, a difference in the dry matter content was observed between the control sample and samples fried in all types of oils. There were also differences in the dry matter and fat in dry matter contents among the tested samples.

The dry matter content of our pre-fried PC was different from the value of 30.00% determined for pre-fried potatoes by Romero et al. (2007), which can be ascribed to the different samples used. After the 10th frying of PC in sunflower oil, their dry matter content reached 40.00%, which was smaller than the value of 64.30% determined by Romero et al. (2007) for potatoes after the 16th frying. Despite the above disagreement in the dry matter content owing to the different sample types and methodologies used, prior works indicate that repeated deep frying increases the dry matter content of potatoes (Schuten et al. 2004; Ziaiifar et al. 2008). However, in the case of our PC, frying had no significant effect on the dry matter content.

The water content of pre-fried FF did not significantly change after repeated frying. In contrast, Pérez-Camino et al. (1991) found that the moisture content of pre-fried cod in batter (58.20%) changed to 41.50% after the first deep frying in sunflower oil and stayed almost the same (42.00%) when deep frying was repeated in the already used sunflower oil. This difference can be ascribed to the fact that FF do not contain only fish meat, and the amount of water lost during frying is also affected by the crumb (coating) on the surface.

Chen et al. (2009) probed the effect of frying (180 °C in palm oil) on the content of fat in the crust of pre-fried fish pieces, revealing that it increased from 10.06% to 14.79% after frying. This higher (compared to our results) amount of absorbed fat is probably because the crust absorbs more fat than the whole sample (Ziaiifar et al. 2008) and unlike Chen et al. (2009), we allowed the fat to drip off the fried products for 15 min, which could have decreased the total fat content, as confirmed by Ziaiifar et al. (2008). Kita et al. (2005) reported that the fat content of pre-fried French fries increased by 6.00% after deep frying in rapeseed oil, while Kita et al. (2007) found that the amount of oil absorbed by potato chips during deep frying at 170 °C increased in the order of rapeseed < olive < sunflower oil. On the contrary, according to our results, PC absorbed the lowest amount of fat when fried in sunflower oil. The above discrepancies can be attributed to the different types of food samples used. In the case of FF, oil type had no statistically significant effect on the fat content calculated per 100 g of the sample or per 100 g of dry matter. On the other hand, the fat content per 100 g of dry matter of PC was affected by oil type (the smallest for sunflower oil). This is probably because most of the oil was absorbed by the crust, which accounts for a minor part of the total sample, as well as crust composition and surface morphology (Moreno and Bouchon 2013). Kita et al. (2005) wrote that fat absorption is higher when the amount of unsaturated fatty acid increases in oil. On the other hand, Vitrac et al. (2000) showed that oil uptake is weaker with an unsaturated oil such as cotton oil than with palm oil because of the former's weak viscosity during cooling and its ability to drain easily. These contradictions could be explained by the fact that oil viscosity is very influential in the oil absorption mechanism but is involved both in adhesion and draining dynamics. Fat content can be a sum of both, fat penetration into the crust and fat crystallisation on the surface (Ziaiifar et al. 2008). However, the differences in the fat content per dry matter were not very big in absolute terms. So, this conclusion would need to be examined more in the future.

Effect of frying on oil oxidative stability. The results of the Schaal test (Figures 1–3) revealed that the

Table 2. Average dry matter and fat contents of 10 batches of potato croquettes (PC) fried in different oils (mean ± SD; n = 10 for oils and n = 3 for control)

Oil	Dry matter	Fat	
	[g (100 g sample)$^{-1}$]	[g (100 g sample)$^{-1}$]	[g (100 g dry matter)$^{-1}$]
Rapeseed	47.84 ± 0.77^{a}	2.62 ± 0.04^{a}	5.48 ± 0.08^{b}
Sunflower	48.05 ± 1.51^{a}	2.58 ± 0.10^{a}	5.37 ± 0.15^{c}
Rice	48.18 ± 0.79^{a}	2.63 ± 0.04^{a}	5.46 ± 0.11^{b}
Control	46.22 ± 0.41^{b}	2.58 ± 0.01^{a}	5.59 ± 0.02^{a}

$^{a–c}$Different superscript letters indicate statistically significant differences between variables at P < 0.05 within the same column

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highest and lowest oxidative stabilities were observed for rice and sunflower oils, respectively. Figure 1 compares the stabilities of oils before frying, showing that, although a rapid and clear beginning of the propagation phase was observed for sunflower oil, no such sharp difference between the initiation and propagation phases was observed for rapeseed oil. The induction period (IP) was around 12 days for sunflower oil and 14 days for rapeseed oil. In the case of rice oil, the IP could not be determined, as a continuous increase in the sample weight due to oxidation was observed.

Figure 2 shows that the frying medium stability decreased after the first frying and demonstrates that the IPs of sunflower oil (11 days for FF and 10 days for PC) were close to those obtained for rapeseed oil (13 days for FF and 12 days for PC). For rice oil, no steep weight gain associated with the beginning of the propagation phase could be observed. The oil stability further decreased after the last (10^{th}) frying (Figure 3). In this case, the IPs of sunflower/rapeseed oil were 8 days/9 days for FF and 9 days/12 days for PC, respectively. It was again difficult to detect the beginning of propagation phase in rice oil, but some change in the curve can be seen around 24 days and 20 days for FF and PC, respectively.

The short IP for sunflower oil reflects its high content of polyenoic fatty acids. Rapeseed and rice oil are less unsaturated and therefore more stable to oxidation. Of course, other factors are also important, such as natural antioxidants, the method of processing, and storage. It is also visible that the relative weight gain decreased after about 60 days, probably because the primary products of oxidation (peroxides, respectively hydroperoxides) already started to decrease and change into secondary oxidation products. These secondary oxidation products can also be volatile under the conditions of the Schaal test, so the weight of the monitored sample can decrease over a longer period. Wroniak et al. (2015) showed that sunflower oil had lower oxidative stability than rapeseed oil, which is in line with our results. Maszewska et al. (2018a) found that rapeseed and rice oils had similar stabilities. In our study, rice oil showed significantly higher oxidation stability than rapeseed oil. Yang et al. (2016) identified rice oil as more stable than soybean and cottonseed oils, ascribing this increased stability to the natural antioxidant (γ-oryzanol) present in rice oil. In the study of Maszewska et al. (2018b), it was concluded that rapeseed oil was significantly less stable than palm oil, which is rich in saturated fatty acids.

Effect of frying on oil colour. In the statistical evaluation of all obtained data, no differences were found between the samples in terms of the colour parameters (L^*, a^*, and b^*) depending on the number of frying batches. On the contrary, differences were found between the samples depending on the type of oil and fried food. During the frying of FF, all the tested oils tended to get slightly darker after each frying batch (decrease in the L^* value) (Figure 4), but the same tendency was not observed for PC. Contrarily, during the frying of PC in rice oil (until the 5^{th} frying) and in sunflower oil (until the 7^{th} frying) the oil slightly brightened. During frying in rapeseed oil, the oil became brighter after the first frying; then, it darkened from the 3^{rd} to the 10^{th} frying. There was a difference between the L^* values of the rice and sunflower oils and those of the rapeseed and sunflower oils (sunflower oil was brighter).

Evaluating parameter a^* [from red (+) to green (–)], it can be seen from Figure 5 that when the FF were fried in rice and rapeseed oils, the a^* value shifted from green toward red. Samples of PC fried in rice and rapeseed oils were different from other samples. Regarding the effect of the frying medium, there was a difference between the a^* values of the rice and sunflower oils and those of the rapeseed and sunflower oils (sunflower oil was less green).

As can be seen in Figure 6, there were slight changes in parameter b^* [from yellow (+) to blue (–)] during frying in all samples. Sunflower oil exhibited lower

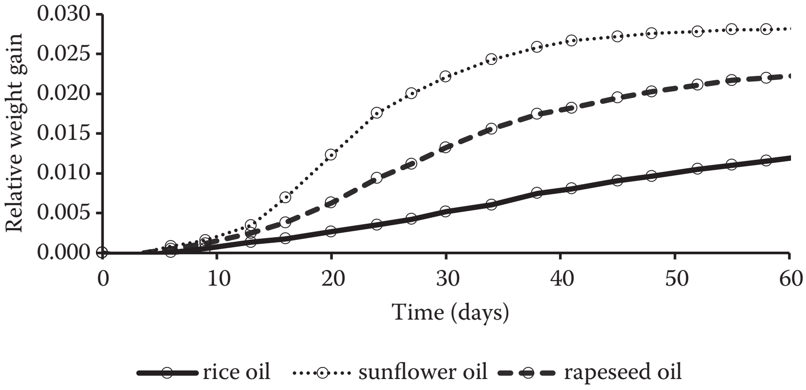

Figure 1. Oxidative stability of different oils before frying

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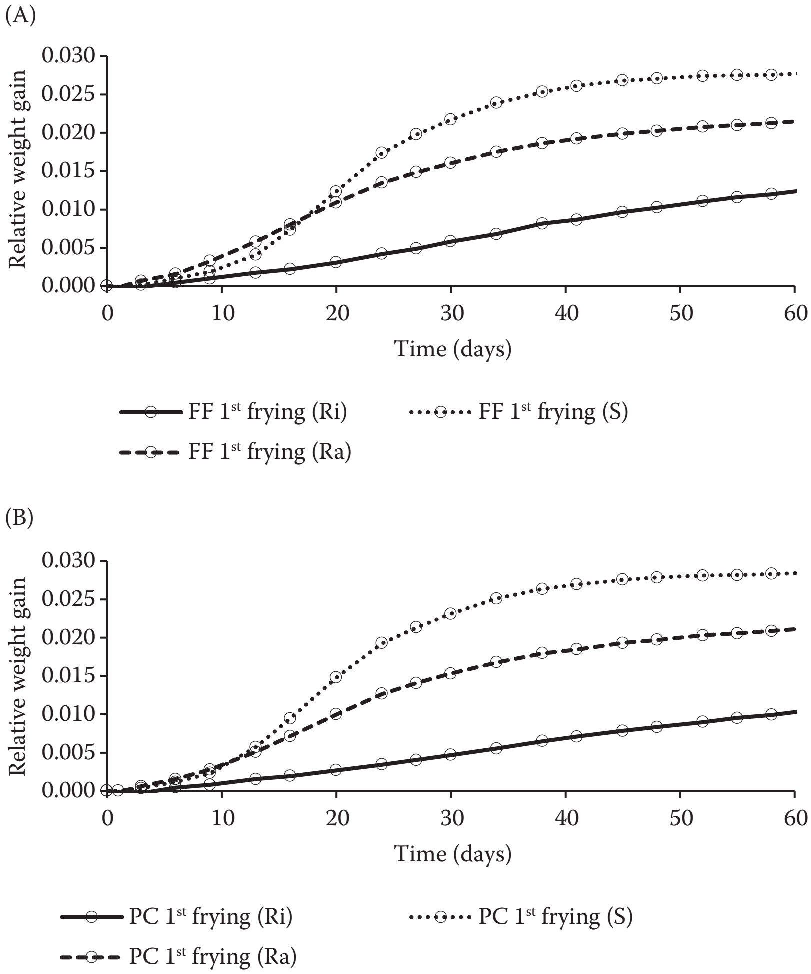

Figure 2. Oxidative stability of different oils after the first frying of (A) fish fingers (FF) and (B) potato croquettes (PC)

Ri – rice oil; Ra – rapeseed oil; S – sunflower oil

b^* values compared to other samples and was less yellow. There were differences between all oils.

Oils, in which FF were fried, darkened after every frying batch, probably because breadcrumb particles from the FF leaked into the oil. This trend was not observed for PC, potentially because their surface was far smoother; thus, not many particles could penetrate into the oil and contribute to colour formation. Although, there was no statistically significant difference. This is in line with the observations and theories of Lazarick (2012) and Bordin et al. (2013). Lazarick (2012) found that protein products caused faster darkening and thermo-oxidative deterioration of the frying oil. This breakdown was further supported by the addition of other food components, such as glucose, amino acids, and lipid hydroperoxides, in concentrations higher than 5% of the frying oil. Breadcrumbs contributed to oil colour formation owing to particles from the food crust disintegrating into the frying oil to further accelerate browning reactions. In the work of Srivastava and Semwal (2015), colour values showed a decrease in L^* and an increase in the a^* and b^* values after 8 h of continuous frying at 180 ± 5 °C in virgin coconut oil. A linear decrease in L^* with increasing frying days of soybean oil was also noted by Ma et al. (2016).

Unfortunately, there is a lack of data on colour changes of oils tested in our work, as many authors focus on the colour changes of fried food (not the oil) (Krokida et al. 2001; Salehi 2019). In these cases, the L^* value often decreases (products become darker), and that could affect the oil colour itself.

Nutritional evaluation. According to current recommendations, the total fat intake should not exceed 30% of total energy intake for a lightly working adult, which is ~70 g per day (WHO 2020). Our results showed that the intake of fat through one serving of fried FF (150 g) or PC (200 g) corresponds to approximately 9 g and 5 g, respectively. In contrast, according to data from the EuroFIR (2020) database, the total fat content of pre-fried FF in different oils is 12–16 g (100 g)$^{-1}$ [18–24 g (150 g)$^{-1}$], while that of pre-fried PC 13–18 g (100 g)$^{-1}$ [26–36 g (200 g)$^{-1}$]. This may be due to the high hydrophobicity of the ingredients of the tested foods and the variation in their

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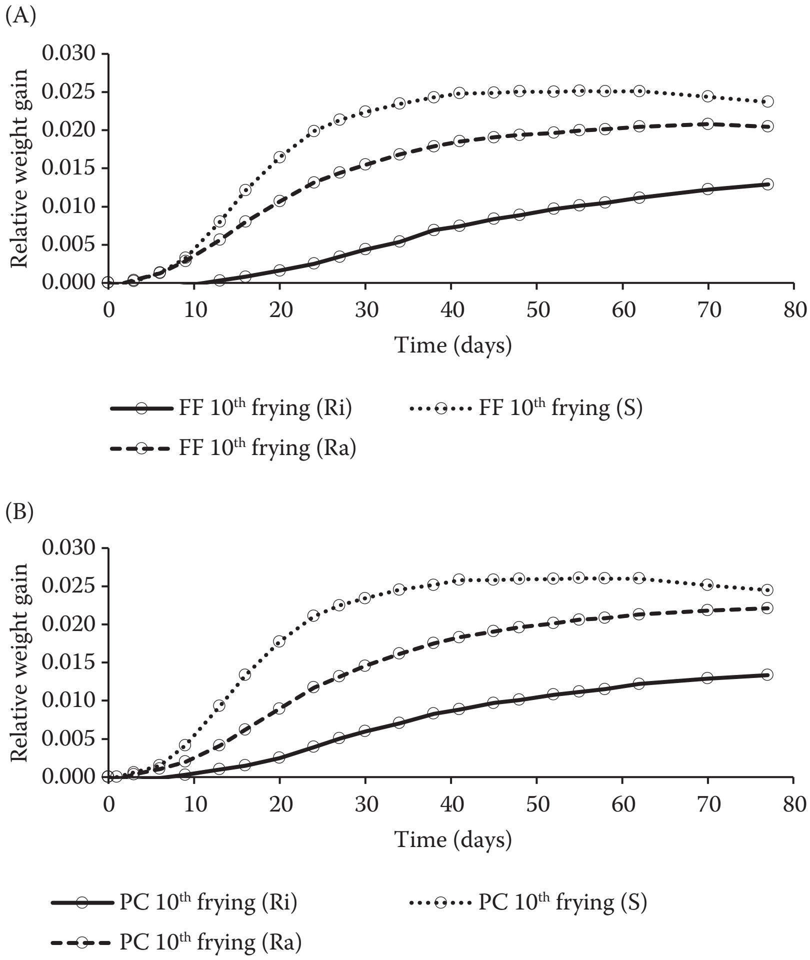

Figure 3. Oxidative stability of different oils after the 10th frying of (A) fish fingers (FF) and (B) potato croquettes (PC)

Ri – rice oil; Ra – rapeseed oil; S – sunflower oil

preparation styles (i.e. dripping fat before consumption of fried foods).

Our results show that rice oil is the most appropriate for frying FF, while sunflower oil is the best choice for PC. This difference may be owing to the different matrices (more protein in FF and more starches in PC) and/or structures (compact round PC *vs.* less compact rectangular FF with starch granules on the top and lean protein inside) of these foods. Despite its favourable fatty acid composition, rapeseed oil is unstable

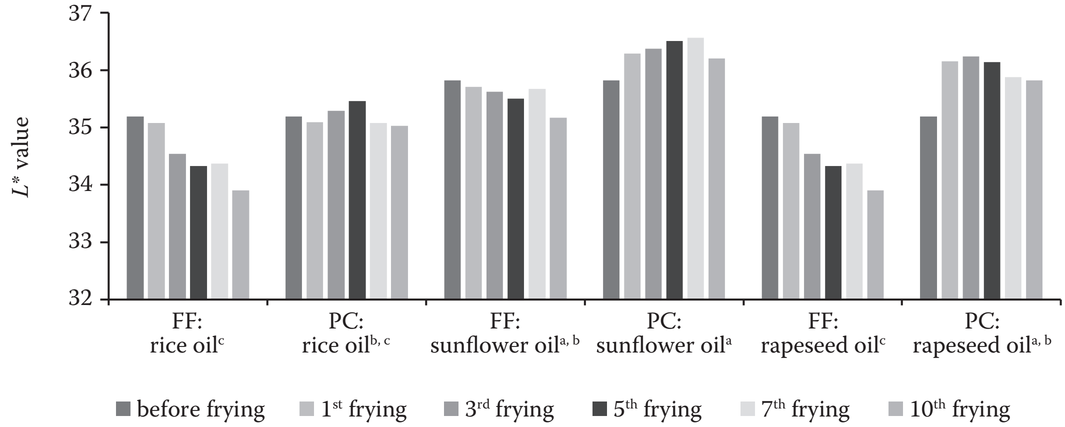

Figure 4. Perceptual lightness of each oil during frying – L^* value

$^{a–c}$Different letters indicate statistically significant differences between variables (type of oil and fried food) at $P < 0.05$; FF – fish fingers; PC – potato croquettes; L^* value – represents darkness to lightness with values ranging from 0 to 100

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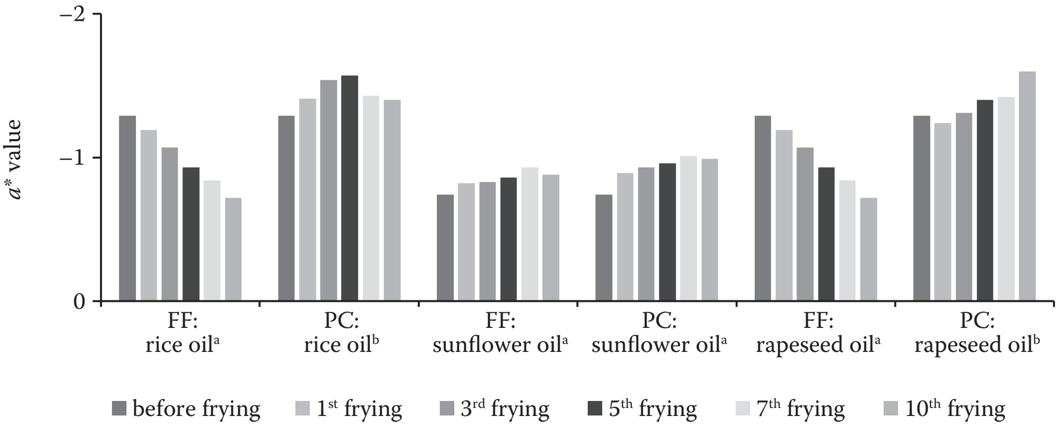

Figure 5. Redness (position between red and green) – *a** value

[a–b]Different letters in brackets indicate statistically significant differences between variables (type of oil and fried food) at $P < 0.05$; FF – fish fingers; PC – potato croquettes; *a** value – represents greeness to redness with values from −128 to +127

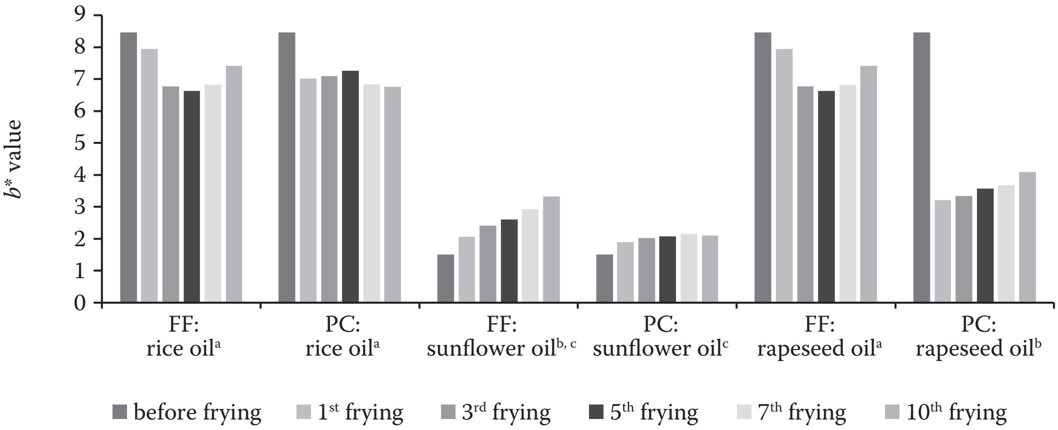

Figure 6. Yellowness (position between yellow and blue) – *b** value

[a–c]Different letters in brackets indicate statistically significant differences between variables (type of oil and fried food) at $P < 0.05$; FF – fish fingers; PC – potato croquettes; *b** value – represents blueness to yellowness with values from −128 to +127

during prolonged heating. In contrast, rice oil is stable during heating but contains more saturated fatty acids (Nayik et al. 2015). Thus, their intake may be increased by the consumption of foods fried in rice oil. On the other hand, for technological purposes, rice oil seems to be a great option (saturated fatty acids are more stable during heating). For deep frying, one is advised to use oils from specially bred varieties of sunflower or rapeseed with an increased oleic acid content, as these oils are more stable during heating and have a favourable fatty acid composition (Velíšek 2014).

CONCLUSION

Frying did not significantly affect the fat content of FF and PC. Moreover, no differences in the fat content were observed after the repeated frying of FF or PC in different oils. Frying influenced the dry matter content of PC but not in FF. Rice oil showed the highest oxidative stability during repeated frying and was therefore concluded to be the best frying medium among the tested oils, while the less saturated sunflower oil exhibited the lowest stability. The darkening of the monitored oils during repeated frying of FF was not significant.

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