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Nutritional quality of chicken nuggets and Tuscan-type sausage submitted to frying in different lipid sources

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Abstract

The nutritional compositions of chicken nuggets and Tuscan-type sausage were evaluated in this study after frying them at 120 °C by immersion, intermittently, in soybean, canola, sunflower, and coconut oils as well as in swine lard for 10 and 15 min, respectively, to reach 72 °C in the geodesic center of each product. Proximate analytical composition after frying revealed, in addition to the expected reduction in moisture content, also preservation of protein content and increase in those of lipids and ash. On the other hand, the lipid profile analysis revealed aggregation of fatty acids present in lipid sources with changes in their composition, especially in chicken nuggets fried in coconut and canola oils. These results suggest an interaction between the lipid source used in the frying process and the food matrices under investigation. This information is important for the food industry since it makes wide use of this cooking method in the manufacture of food intended for consumption.

Keywords: vegetable oils; swine lard; coconut oil; frying by immersion.

Practical Application: Polyunsaturated lipid sources applied in frying process can affect the fried foods positively.

1 Introduction

Currently, the food industry innovates and increases its production of fried and prefried products under the demand of the consumer market for low-cost food prepared quickly and easily (Monteiro et al., 2011; Honerlaw et al., 2020).

However, it is already known that this category of food undergoes changes in cooking that influence their nutritional value (Honerlaw et al., 2020; Alzaa et al., 2021). Lipid source changes are the result of distinct effects depending on the frying time, the contact area of the food surface, its moisture content, the type of oil used, and oil absorption in the product (Araújo, 2015). Oil and fatty acid contents can be increased before frying time in distinct formulations (Lacerda et al., 2022), which contributes to nutritional value.

Vegetable oil, which is liquid at room temperature, has the characteristic color, flavor, and odor of the original processed plant, such as soy, olive, peanut, corn, linseed, rice, or cotton, among others (Lima et al., 2022); however, to make it palatable and pleasant for human consumption, the food industry promotes its refinement (Pal et al., 2015). On the other hand, swine lard is a lipid source from pig adipose tissue, which has a white color and characteristic organoleptic properties (Bertol, 2019). Although solid at room temperature, it is liquid at the high temperatures used for the frying process.

Simple lipids in oil or fat are mainly composed of free fatty acids, classified according to the length (short, medium or long) carbon chain. Chemically, predominant fatty acids have a straight chain and can be saturated or contain carbon-carbon double bonds with an even number of carbon atoms. Those containing one or more double bonds in the chain are called monounsaturated or polyunsaturated fatty acids, respectively (Ratnayake & Galli, 2009).

There are few studies that deal with the effects of the frying process on lipid and fatty acid profiles (Multari et al., 2019; Pinzón-Martinez et al., 2022). Therefore, this study aimed to exploit the existing knowledge to unveil modifications that occur in the products after frying and their effects on consumer health.

2 Materials and methods

The project was developed in the Laboratories of Physicochemistry, Biotechnology, and Instrumentation of the *stricto sensu* Postgraduate Program of Food Technology at the Federal Institute of Education, Food Science and Technology of Mato Grasso (IFMT), Campus Cuiabá - Bela Vista, MT, Brazil. The products, i.e., Tuscan-type sausage and chicken nuggets, as well as lipid sources, namely, soybean, canola, sunflower, and coconut oils and swine lard, were purchased in supermarkets of Cuiabá, MT, Brazil. Both products were acquired in distinct lots considered repetitions. The study was performed with a completely randomized design (CRD) according to a 6x2 factorial scheme, including six treatments: uncooked, fried in soybean oil, fried in canola oil, fried in coconut oil, fried in sunflower oil, or fried in swine lard, and two products: chicken nuggets and Tuscan-type sausage.

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2.1 Frying process

The immersion frying process was performed in an industrial fryer with a thermostat and a capacity of 8 liters (Progás, PR 70E Model, Caxias do Sul, RS, Brazil). Each lot of product was immersed in each of the lipid sources at 120 °C until it reached the center temperature of 72 °C, corresponding to frying times of approximately 10 and 15 min for chicken nuggets and Tuscan-type sausage, respectively. After each frying, the lipid source was replaced, and the fryer was cleaned. After being fried, the products were crushed with a processor, homogenized, and then separated into samples for analysis.

2.2 Proximate composition

Proximate analyses of ash, moisture, and lipids were performed in duplicate according to the methodologies of the Association of Official Analytical Chemists (1995). The crude protein content was quantified by the micro-Kjeldahl method using a correlation factor of 6.25 to convert nitrogen into crude protein, as described in method 991.20 of Association of Official Analytical Chemists (1995).

2.3 Determination of the fatty acid profile by gas chromatography

For the analysis of the composition of fatty acids, the samples underwent extraction with 2:1 (v/v) chloroform/methanol as solvent, and esterification with methanol by the method 55/IV of the Instituto Adolfo Lutz (2008). To do so, we used a gas chromatograph (model GC-7890A/MSD-5975C) with an autosampler (GC sampler 120) coupled to a mass detector (model 5975C inert XL MSD) (Agilent Technologies, Palo Alto, CA, USA). The detector operating temperatures were 250, 230, and 150 °C for the transfer line, ionic source, and quadrupole, respectively. Detection was performed by scanning the mass/charge ratio range of 30-450 m/z and ionization by the impact of electrons at 75 eV. A 30 mm × 0.25 mm × 0.2 μm VF-WAXMS capillary column (Agilent Technologies) was used. The injector and column temperatures were 240 and 60 °C, respectively. The heating profile was as follows: maintenance of the initial temperature (60 °C) for 2 min; increase in temperature at a rate of 10 °C/min up to 200 °C (14 min) and then at 5 °C/min up to 220 °C (4 min); maintenance of this temperature until the end of the run (25 min). The other conditions were as follows: flowrate in the column of 1 mL/min at 12 psi; 1 μL of injected sample, split mode, in the ratio of 1:50. All solvents used were HPLC grade. For quantification of fatty acid methyl esters, a reference standard mixture was used containing 37 methyl esters, from C4 to C24 (Sigma-Aldrich, St. Louis, MO, USA). After converting the peak areas into percentages through Shimadzu CG 2010 software, according to Method 344/IV of the Instituto Adolfo Lutz (2008), the results were grouped into total (a) saturated fatty acids (SFAs), (b) monounsaturated fatty acids (MUFAs), (c) polyunsaturated fatty acids (PUFAs), d) unsaturated fatty acids, e) omega-6 fatty acids (ω6), f) omega-3 fatty acids (ω3), and g) ω6/ω3 ratio. The analysis was performed by comparing the retention time and the standard with fatty acids from C4:0 to C24:0.

From the results of the fatty acid profile, we calculated the atherogenic index (AI), the thrombogenic index (TI) according to Ulbricht & Southgate (1991) and the ratio of hypocholesterolemic/hypercholesterolemic fatty acids (h/H) according to Santos-Silva et al. (2002), as follows (Equations 1 to 3):

$$AI = \{[C12:0 + (4xC14:0) + (C16:0)] / (\Sigma MUFAs + \Sigma\omega6 + \Sigma\omega3)\} \quad (1)$$

$$TI = (C14:0 + C16:0 + C18:0) / [(0.5 \times \Sigma MUFAs) + (0.5 \times \Sigma\omega6 + (3X\Sigma\omega3) + (\Sigma\omega3 / \Sigma\omega6)] \quad (2)$$

$$h / H = (C18:1c9 + C18:2 + C20:4 + C18:3 + C20:5 + C22:5 + C22:6) / (C14:0 + C16:0) \quad (3)$$

where ΣMUFAs is the sum of monoinsaturated fatty acids, Σω6 is that of ω6 fatty acids and Σω3 is that of ω3 fatty acids.

2.4 Statistics

Statistical analysis was performed using the R Core Team (2016) software package version i386 4.0.0. The analysis of variance (ANOVA) was applied to the results, and when a significant difference was found, the Tukey test was applied for comparison at the 0.05 significance level ($p < 0.05$), i.e., a 5% probability of error.

3 Results and discussion

3.1 Proximate composition

The results of proximate analyses carried out for the chicken nuggets and Tuscan-type sausage, both uncooked and after frying in swine lard or in canola, coconut, sunflower or soybean oils, are listed in Tables 1 and 2, respectively.

These results respect the identity and quality standards in Brazil for both raw products (Brasil, 2000, 2001), i.e., maximum moisture content of 70%, maximum fat content of 30%, and minimum protein content of 12% for sausage and 10% for chicken nuggets.

It is possible to observe significant differences between the uncooked products and those after the different immersion frying treatments. In both fried products, the most significant differences were observed for moisture and lipid contents, since, regardless of the lipid source used, the main changes in their composition were loss of water contained inside the food and absorption of oil or fat used for frying. Comparing the lipid sources used, canola and soybean oils were the ones that were most incorporated by the Tuscan-type sausage and the chicken nuggets, respectively.

There was also a statistically significant increase in ash content in both products after frying, which was certainly due to the mineral concentration resulting from the decrease in moisture content. In contrast, there was no significant difference in protein content, since oils and fats do not have proteins in their composition (Universidade Estadual de Campinas, 2011; Universidade de São Paulo, 2020).

Table 1. Results of the proximate analysis performed on the chicken nuggets either raw or fried in swine fat or in canola, coconut, sunflower or soy oil.

Treatment	Ash	Moisture	Proteins	Lipids
Raw	2.10 ± 0.14^{c}	49.08 ± 6.63^{b}	13.86 ± 0.57	17.72 ± 1.02^{b}
Swine fat	2.46 ± 0.37^{a}	39.67 ± 3.40^{a}	13.39 ± 0.72	24.88 ± 2.37^{a}
Canola oil	2.39 ± 0.20^{bc}	38.38 ± 1.50^{a}	13.40 ± 1.02	24.75 ± 1.93^{a}
Coconut oil	2.41 ± 0.29^{ab}	36.78 ± 2.88^{a}	13.00 ± 0.57	27.09 ± 1.47^{a}
Sunflower oil	2.34 ± 0.10^{abc}	39.90 ± 1.51^{a}	14.03 ± 1.03	24.67 ± 2.06^{a}
Soybean oil	2.38 ± 0.39^{ab}	35.34 ± 2.52^{a}	14.82 ± 1.59	27.04 ± 2.59^{a}

The results are expressed as a percentage (%) and presented as the mean ± standard deviation. Values followed by different letters in the same column are significantly different. In these cases, the Tukey test was applied, with a significance level of 0.05 ($p < 0.05$).

Table 2. Results of the proximate analysis performed on the Tuscan-type sausage either raw or fried in swine fat or in canola, coconut, sunflower or soy oil.

Treatment	Ash	Moisture	Proteins	Lipids
Raw	2.98 ± 0.27^{c}	64.27 ± 6.81^{a}	13.14 ± 2.93	16.15 ± 4.64^{b}
Swine fat	3.60 ± 0.27^{a}	57.40 ± 1.05^{bc}	15.04 ± 3.02	19.05 ± 6.26^{ab}
Canola oil	3.17 ± 0.23^{bc}	54.33 ± 8.17^{c}	14.96 ± 2.32	21.13 ± 6.55^{a}
Coconut oil	3.42 ± 0.25^{ab}	58.11 ± 2.51^{bc}	14.85 ± 3.38	18.76 ± 3.34^{ab}
Sunflower oil	3.40 ± 0.20^{ab}	58.61 ± 1.32^{bc}	15.16 ± 1.90	17.49 ± 3.75^{ab}
Soybean oil	3.62 ± 0.37^{a}	59.45 ± 0.51^{b}	14.87 ± 2.87	18.53 ± 4.75^{ab}

The results are expressed as a percentage (%) and presented as the mean ± standard deviation. Values followed by different letters in the same column are significantly different. In these cases, the Tukey test was applied, with a significance level of 0.05 ($p < 0.05$).

3.2 Fatty acid profiles

The fatty acid profiles in chicken nuggets and Tuscan-type sausage, either raw or fried in coconut, soybean, sunflower or canola oil or in swine lard, are listed, together with the results of the statistical analyses, in Tables 3 and 4, respectively.

The saturated fatty acids (SFAs) C8:0 (octanoic acid), C10:0 (decanoic acid), and C12:0 (dodecanoic acid), present in coconut oil, were found in significant amounts both in breaded chicken (Table 3) and Tuscan-type sausage (Table 4) fried in this vegetable oil. However, C6:0 (hexanoic acid), also characteristic of coconut oil, was detected only in chicken nuggets fried in it, which can be explained by the ability of carbohydrates used for breading to absorb this medium-chain fatty acid.

Coconut oil is rich in short- and medium-chain fatty acids, which give it a liquid physical state, and differs from other vegetable oils due to the high level of SFAs in its composition. These fatty acid categories have beneficial effects on metabolism that appear to be linked to a decrease in cardiovascular disease risk factors (Eyres et al., 2016; Valerius et al., 2018). It is known, however, those SFAs are considered to have the greatest impact on the plasma level of LDL cholesterol, although this relationship may be linked to the type of fatty acid (Sheela et al., 2016; Khaw et al., 2018; Oliveira-de-Lira et al., 2018).

For long-chain SFAs, a significant increase in C14:0 (myristic acid) was observed in both Tuscan-type sausage (2.01%) and chicken nuggets (12.42%) fried in coconut oil due to the high content of this fatty acid (16.8%) in coconut oil (Universidade Federal de São Paulo, 2016). In Tuscan-style sausage fried in coconut oil, there was a less marked change compared to the uncooked product, probably due to the action of wrapping as a barrier, which was absent in chicken nuggets. The myristic acid content of breaded chicken fried in coconut oil increased significantly when compared to the uncooked product, whereas no significant changes were detected when the other lipid sources were used.

In contrast, the myristic acid content in Tuscan-type sausage fried in all the vegetable oils decreased in relation to the uncooked product, whereas there was no significant variation after frying in swine lard. Such small variations, although some of them are statistically significant, can be explained by the low content of myristic acid in these other lipid sources. These results corroborate the very close values reported in the online table TABNUT (Universidade Federal de São Paulo, 2016) for this fatty acid in uncooked sausage and breaded chicken.

C16:0 (palmitic acid) was found in considerable amounts in both raw and fried products. Frying chicken nuggets in coconut or canola oil led to a reduction in its content compared to the raw product, while no significant variations were observed using the other lipid sources. On the other hand, for the Tuscan-type sausage, a reduction in palmitic acid content was observed only when soybean or canola oils were used. These reductions, resulting from the lower content of this fatty acid in lipid sources than in the raw product, must be seen as beneficial from a nutritional point of view, since palmitic acid, being saturated, is considered cholesterolemic, although with a smaller effect than myristic acid (Agostoni et al., 2016; Aep & Segnp, 2017).

The contents of C18:0 (stearic acid) in uncooked breaded chicken and sausage were significantly higher than those in the same products fried in coconut or canola oil and in soybean or canola oil, respectively, probably due to the lower concentration

Table 3. Fatty acid profile of chicken nuggets either raw or fried in coconut, soybean, sunflower or canola oils or in swine fat.

Fatty acid	Raw	Fried in coconut oil	Fried in soybean oil	Fried in sunflower oil	Fried in canola oil	Fried in swine fat	*p* value
C6:0	-	0.37 ± 0.07			-	-	>0.05
C8:0		4.94 ± 0.38	0.01 ± 0.00		0.01 ± 0.00		>0.05
C10:0		3.96 ± 0.41	0.07 ± 0.01	0.04 ± 0.00	0.01 ± 0.00	0.07 ± 0.01	>0.05
C12:0		25.60 ± 1.20^{a}	0.07 ± 0.01^{b}	0.06 ± 0.01^{b}	0.05 ± 0.02^{b}	0.07 ± 0.02^{b}	<0.05
C14:0	1.02 ± 0.18^{b}	12.42 ± 0.64^{a}	1.20 ± 0.20^{b}	0.95 ± 0.14^{b}	0.29 ± 0.04^{c}	1.32 ± 0.22^{b}	<0.05
C16:0	23.85 ± 1.23^{a}	15.59 ± 0.46^{b}	23.46 ± 1.37^{a}	23.73 ± 0.96^{a}	15.45 ± 0.87^{b}	24.11 ± 1.12^{a}	<0.05
C16:1	2.68 ± 0.49^{a}	0.82 ± 0.23^{b}	2.41 ± 0.51^{ab}	2.87 ± 0.74^{a}	2.46 ± 0.20^{ab}	2.45 ± 0.45^{ab}	<0.05
C18:0	12.90 ± 2.07^{ab}	4.99 ± 0.53^{c}	13.89 ± 0.20^{ab}	11.62 ± 1.17^{b}	5.14 ± 0.58^{c}	14.43 ± 1.63^{a}	<0.05
C18:1	38.89 ± 3.45^{b}	17.21 ± 0.53^{c}	38.80 ± 0.73^{b}	39.24 ± 4.33^{b}	46.97 ± 1.60^{a}	38.44 ± 2.29^{b}	<0.05
C18:2	19.18 ± 2.91	13.72 ± 1.12	17.43 ± 1.40	19.62 ± 2.40	21.53 ± 1.98	16.43 ± 2.17	<0.05
C18:3	0.75 ± 0.21^{b}	0.54 ± 0.21^{b}	0.59 ± 0.16^{b}	0.81 ± 0.28^{b}	6.37 ± 0.53^{a}	0.65 ± 0.07^{b}	<0.05
C20:0		0.06 ± 0.01	0.15 ± 0.09	0.09 ± 0.01	0.48 ± 0.06		>0.05
C20:1	0.41 ± 0.20^{ab}	0.15 ± 0.02^{b}	0.54 ± 0.22^{ab}	0.46 ± 0.14^{ab}	0.79 ± 0.09^{a}	0.68 ± 0.14^{a}	<0.05
C20:2	0.53 ± 0.24^{a}	-	0.55 ± 0.09^{a}	0.39 ± 0.11^{b}	-	0.57 ± 0.16^{a}	<0.05
C20:4			0.48 ± 0.11	0.30 ± 0.62	0.14 ± 0.05	0.62 ± 0.23	>0.05

The results are expressed as a percentage (%) and presented as the mean ± standard deviation. Values followed by different letters on the same line are significantly different. In these cases, the Tukey test was applied, with a significance level of 0.05 ($p < 0.05$).

Table 4. Fatty acid profile of Tuscan-type sausage either raw or fried in coconut, soybean, sunflower or canola oils or in swine fat.

Fatty acid	Raw	Fried in coconut oil	Fried in soybean oil	Fried in sunflower oil	Fried in canola oil	Fried in swine fat	*p* value
C6:0	-				-	-	
C8:0	-	0.20 ± 0.10	0.01 ± 0.00	0.06 ± 0.04	0.01 ± 0.00	0.10 ± 0.06	>0.05
C10:0	0.08± 0.02	0.21 ± 0.10		0.05 ± 0.01		0.11 ± 0.05	>0.05
C12:0	0.09 ± 0.04	1.35 ± 1.03	0.02 ± 0.01	0.11 ± 0.08	0.02 ± 0.00	0.48 ± 0.43	>0.05
C14:0	1.56 ± 0.51^{b}	2.01 ± 0.40^{a}	0.28 ± 0.03^{c}	0.79 ± 0.33^{c}	0.26 ± 0.02^{c}	1.33 ± 0.23^{b}	<0.05
C16:0	24.02 ± 0.86^{a}	23.99 ± 0.47^{a}	17.50 ± 1.20^{b}	23.69 ± 2.71^{a}	18.87 ± 0.36^{b}	23.55 ± 1.09^{a}	<0.05
C16:1	2.64 ± 0.25^{ab}	2.74 ± 0.18^{ab}	2.38 ± 0.29^{ab}	2.94 ± 0.68^{a}	2.09 ± 0.12^{b}	2.28 ± 0.30^{ab}	<0.05
C17:0	0.39 ± 0.19	0.41 ± 0.07	0.06 ± 0.01	0.25 ± 0.15	-	0.33 ± 0.10	>0.05
C17:1	0.34 ± 0.11	0.35 ± 0.22	0.07 ± 0.01	0.14 ± 0.08	0.07 ± 0.01	0.19 ± 0.13	>0.05
C18:0	14.71 ± 0.92^{a}	14.17 ± 0.72^{a}	5.74 ± 0.56^{b}	8.11 ± 4.29^{b}	5.80 ± 0.33^{b}	13.84 ± 1.80^{a}	<0.05
C18:1	38.94 ± 2.33^{a}	34.87 ± 1.73^{b}	32.42 ± 1.26^{b}	26.52 ± 6.46^{c}	30.03 ± 0.40^{bc}	40.29 ± 2.83^{a}	<0.05
C18:2	14.79 ± 2.06^{d}	17.47 ± 6.69^{c}	39.08 ± 1.74^{a}	35.87 ± 2.18^{b}	37.27 ± 1.06^{ab}	15.93 ± 1.56^{cd}	<0.05
C18:3	0.51 ± 0.18^{b}	0.56 ± 0.26^{b}	2.08 ± 1.84^{a}	-	5.00 ± 0.22^{a}	0.42 ± 0.12^{b}	<0.05
C20:0	0.14 ± 0.09	0.14 ± 0.03	0.16 ± 0.02	0.31 ± 0.03	0.25 ± 0.03	0.16 ± 0.01	>0.05
C20:1	0.79 ± 0.30^{a}	0.74 ± 0.16^{a}	0.20 ± 0.04^{b}	0.41 ± 0.24^{ab}	0.21 ± 0.01^{b}	0.47 ± 0.24^{ab}	<0.05
C20:2	0.56 ± 0.23^{a}	0.59 ± 0.15^{a}	-	0.30 ± 0.17^{b}	0.10 ± 0.10^{c}	0.44 ± 0.22^{b}	<0.05
C20:4	0.53 ± 0.11	0.58 ± 0.30	0.17 ± 0.07	1.08 ± 0.10	0.15 ± 0.02	0.39 ± 0.14	>0.05

The results are expressed as a percentage (%) and presented as the mean ± standard deviation. Values followed by different letters on the same line are significantly different. In these cases, the Tukey test was applied, with a significance level of 0.05 ($p < 0.05$).

of this fatty acid in lipid sources than in the products. Stearic acid was found in small amounts in sunflower, soy, canola, and coconut oils, while in swine fat, it was more abundant. Even though it is a SFA, previous studies suggested that it is not hypercholesterolemic as expected from other fatty acids (Mensink, 2005). Compared to palmitic acid consumption, stearic acid consumption reduced both LDL and serum HDL cholesterol (van Rooijen et al., 2021).

For monounsaturated fatty acids (MUFAs), chicken nuggets suffered a reduction in the content of C16:1n-7 (palmitoleic acid) only when they were prepared in coconut oil. This did not occur with Tuscan-style sausage, possibly due to the role of the wrapper as a physical barrier as well as the small difference between its contents in the lipid sources and the product. This result is promising considering that MUFAs have beneficial effects on glucose uptake and absorption and on triglyceride metabolism in the body (Qian et al., 2016).

Among the MUFAs, C18:1 *cis*-9 (oleic acid), which is the most recurrent in foods and vegetable oils such as canola oil, olive oil and others that are not considered in this study, contains eighteen carbons and a double bond. Its percentage in breaded chicken was reduced when fried in coconut oil and increased when fried in canola oil compared to the raw product, whereas

it did not show any significant differences when using the other lipid sources. This behavior can be explained by the difference between the fatty acid profiles of the lipid sources used in the frying process, especially that of breaded chicken. On the other hand, frying Tuscan-style sausage led to a reduction in the content of this fatty acid when coconut, soybean, sunflower and canola oils were used as lipid sources, whereas an increase took place when using swine lard, since oleic acid is the major fatty acid in this lipid source (41%), while the total content of SFAs is approximately 40% (Silva et al., 2009). The variations in Tuscan-type sausage were less marked than those observed for chicken nuggets, mainly due to the high content of oleic acid in the canola oil and its low content in the coconut oil, which makes evident once again the effect of the wrapping as a physical barrier. Maintaining or increasing this fatty acid in food products is nutritionally important, as its abundant presence in the Mediterranean diet has been identified as one of the causes of the low incidence of heart disease (Albuquerque et al., 2016). In clinical trials where the effects of the Mediterranean diet on cardiovascular disease prevention were investigated, foods rich in unsaturated fatty acids, such as olive oil and nuts, were included in diets without restriction of caloric intake of healthy volunteers aged 55 to 80 years. This showed a substantial reduction in the risk of cardiovascular events among people with potentially heart disease (Estruch et al., 2013; Mayneris-Perxachs et al., 2014).

3.3 Essential fatty acids

The polyunsaturated fatty acids (PUFAs) ω3 and ω6 are recognized for their beneficial effects, such as lowering LDL and lipid levels, regulating blood pressure and stimulating the immune response as well as anti-inflammatory, anti-thrombus, and vasodilating properties (Moreira et al., 2020; Simopoulos, 2020; Mukhametov et al., 2022). In addition, high serum levels of ω3 are associated with a lower risk of premature death (Harris et al., 2021), and linolenic acids particularly effective in fighting cardiovascular diseases, improving glucose homeostasis and reducing hepatic steatosis (Moreira et al., 2020). These two physiologically and metabolically distinct fatty acid groups are considered essential, because they are not synthesized by the human body, requiring the intake of both through the diet (Simopoulos, 2020).

In chicken nuggets, the content of 18:2 (n-6) or 18:2 *cis*-9,12 (linoleic acid), a di-unsaturated fatty acid with 18 carbon atoms of the ω6 series was not significantly influenced by frying in sunflower and canola oils, while it was significantly reduced, when compared to the raw product, by frying in coconut and soybean oils and in swine fat. In contrast, significant increases in the content of this essential fatty acid were observed in Tuscan-type sausage when subjected to frying in soybean, sunflower, and canola oils, in addition to nonsignificant effects when it was fried in coconut oil and swine fat.

Both raw products had a low total content (0.5-0.7%) of C18:3 (linolenic acid), considered here as a mixture of tri-unsaturated fatty acids with 18 carbons, mainly belonging to the ω3 (α-linolenic acid) and ω6 (γ-linolenic acid) series. However, this content increased significantly after frying breaded chicken in canola oil and sausage in canola and soybean oils, as expected from the fact that these two vegetables are the main sources of ω3.

3.4 Other long-chain fatty acids

The C20:0 (arachidic acid) content was very low in both raw and fried products, regardless of oil type, and all variations were not statistically significant, suggesting that this SFA, like all those with an even number of carbons in small amounts, could act as an intermediary for metabolic pathways involving other stable fatty acids.

The C20:1 (gadoleic acid) content in raw breaded chicken did not differ significantly from the product fried in the different lipid sources studied. For the Tuscan-type sausage, reductions in the content of this MUFA were only observed concerning the raw product after frying in soybean and canola oils. Its content, however, was so low that it was not possible to attribute any nutritional significance to the detected variations.

The fatty acid C20:2 (n-6) (eicosadienoic acid), belonging to the ω6 series, was not detectable in breaded chicken fried in coconut oil; however, it had similar content products fried in soy oil or swine fat and low content in that fried in sunflower oil. In the raw Tuscan-style sausage (control), the content in of this di-unsaturated fatty acid was statistically coincident with that of the sample fried in coconut oil, while it was significantly reduced in those fried in the other lipid sources ($p<0.05$).

It is likely that C20:1 and C20:2, which were found at low levels, are intermediates in the synthesis pathway of C20:4 (n-6) (arachidonic acid), a polyunsaturated fatty acid detected in small amounts in some samples. It is well known that some of the fatty acids belonging to the ω6 series are essential; that is, they must be obtained through food as mammals do not produce them (Ratnayake & Galli, 2009). These fatty acids, depending on the position of the last double bond in the carbon chain in relation to the methyl terminus, act as precursors for the synthesis of polyunsaturated fatty acids, including arachidonic acid, C20:5 (n-3) (eicosapentaenoic acid, EPA) and C22:6 (n-3) (docosahexaenoic acid, DHA). Indeed, arachidonic acid was detected in all samples of raw or fried Tuscan-type sausage, although there was no significant difference among treatments. On the other hand, it was not detected in breaded chicken, either raw or fried in coconut oil, while no statistically significant difference was observed among samples fried in soybean, canola, and sunflower oils or in swine fat.

3.5 Comparison among different classes of fatty acids

As seen in Table 5, which gathers the sums of SFAs, MUFAs and PUFAs belonging to the ω3 and ω6 series in the products under study, the presence of fatty acids typical of the selected lipid sources (Universidade Estadual de Campinas, 2011; Universidade de São Paulo, 2020) led to statistically significant variations in some of their contents between raw and fried products, except of those prepared in swine fat.

In particular, the content of SFAs in breaded chicken fried in soybean and sunflower oils or swine fat did not show any statistically significant difference compared to the raw product

(p>0.05), whereas it increased significantly when frying in coconut oil (p<0.05) and decreased when frying in canola oil. On the other hand, in Tuscan-type sausage, this content was not significantly influenced by frying in coconut oil or fat, while it was reduced using soybean or sunflower oil as a lipid source.

Among these results, the variations provided by frying in coconut oil and canola oil stand out. Frying in coconut oil was the only treatment that led to a significant increase in SFA content in chicken nuggets. The same result did not occur with the Tuscan-type sausage, probably due to its wrapping, which may have reduced lipid exchange between the lipid source and the product. On the other hand, when samples were fried in canola oil, there was the greatest reduction in SFA content in both chicken nuggets and Tuscan-style sausage. This difference in behavior, which can be explained by the different SFA contents of coconut oil (86.5%) and canola oil (7.88%), must be taken into consideration from a nutritional viewpoint, as 25% of coconut oil fatty acids are myristic and palmitic acids, which are considered cholesterolemic (Ulbricht & Southgate, 1991).

The literature reveals that frying foods in oils or fats leads to changes in their composition that depend mainly on the treatment time and temperature, the oxidation and degradation of the lipid source, the type of oil or fat used, and the type of food since temperatures higher than 180 °C can reach the smoke point and cause loss of the desired oil characteristics (Liu et al., 2018; Multari et al., 2019). In the present study, a relatively low temperature (120 °C) was used to prevent the oxidation of unsaturated fatty acids present at high levels in the selected lipid sources.

3.6 Lipid quality indicators

Table 6 shows the lipid quality indicators for both products. The atherogenic (AI) and thrombogenic (TI) indices of breaded chicken fried in the different lipid sources were close to each other, with the lowest values of both parameters observed in both products fried in canola oil. The breaded chicken, when fried in coconut oil, exhibited the highest AI values, while the highest TI values were observed in breaded chicken either raw or fried in soybean and sunflower oils or in swine fat as well as in Tuscan-type sausage either raw or fried in coconut oil. This behavior can be explained by the highest contents of SFAs and lowest contents of MUFAs and Ω6 and Ω3 observed in the groups that showed the highest values of AI and TI. On the other hand, both products, when fried in canola oil, showed fatty acid profiles (low SFA content, high MUFA content, and good Ω6/Ω3 ratio) that ensured low AI and TI values. In a study in which the animal fat was replaced in Tuscan-type sausage with canola

Table 5. Average composition of saturated, monounsaturated and polyunsaturated fatty acids in breaded chicken (BC) and Tuscan-type sausage (TS), either raw or fried in coconut, soybean, sunflower and canola oils or in swine fat.

		Raw	Fried in coconut oil	Fried in soybean oil	Fried in sunflower oil	Fried in canola oil	Fried in swine fat
SFAs	BC	37.56 ±1.75^{b}	54.03 ± 1.96^{a}	30.42 ± 1.16^{b}	35.73 ± 2.65^{b}	20.59 ± 1.21^{c}	39.85 ± 1.64^{b}
	TS	40.30 ± 1.50^{a}	41.15 ± 2.52^{a}	27.23 ± 1.26^{b}	35.19 ± 6.50^{b}	24.68 ± 0.81^{c}	38.72 ± 2.06^{a}
MUFAs	BC	41.22 ± 1.64^{b}	21.16 ± 4.90^{c}	40.81 ± 4.44^{b}	41.41 ± 2.25^{b}	46.13 ± 1.51^{a}	40.89 ± 3.23^{b}
	TS	42.24 ± 5.23^{a}	40.60 ± 6.07^{a}	34.41 ± 3.81^{b}	31.03 ± 8.09^{b}	40.12 ± 0.89^{a}	42.56 ± 5.56^{a}
Ω3	BC	0.73 ± 0.18^{b}	0.54 ± 0.20^{b}	0.60 ± 0.16^{b}	0.77 ± 0.24^{b}	6.31 ± 0.48^{a}	0.65 ± 0.06^{b}
	TS	0.51 ± 0.18^{b}	0.55 ± 0.24^{b}	1.93 ± 1.60^{b}	-	5.00 ± 0.00^{a}	0.42 ± 0.12^{b}
Ω6	BC	19.53 ± 2.71^{b}	14.21 ± 1.18^{c}	28.17 ± 11.37^{a}	22.15 ± 1.79^{ab}	27.40 ± 8.17^{a}	17.24 ± 2.37^{b}
	TS	16.11 ± 2.16^{c}	17.59 ± 3.57^{c}	35.43 ± 6.57^{a}	32.28 ± 51.01^{a}	27.95 ± 9.80^{ab}	17.64 ± 2.22^{c}

The results are expressed as a percentage (%) and presented as the mean ± standard deviation. Values followed by different letters on the same line are significantly different. In these cases, the Tukey test was applied, with a significance level of 0.05 (p < 0.05). SFAs: saturated fatty acids; MUFAs: monounsaturated fatty acids; Ω3 = polyunsaturated fatty acids belonging to the omega-3 series; Ω6 = polyunsaturated fatty acids belonging to the omega-6 series.

Table 6. Atherogenic index (AI), thrombogenic index (TI), ratio between hypocholesterolemic and hypercholesterolemic fatty acids (h/H) and ratio between omega-6 and omega-3 fatty acids (Ω6/Ω3) of breaded chicken (BC) and Tuscan-type sausage (TS), either raw or fried in coconut, soybean, sunflower and canola oils or in swine fat.

		Raw	Fried in coconut oil	Fried in soybean oil	Fried in sunflower oil	Fried in canola oil	Fried in swine fat
AI	BC	0.455^{b}	0.903^{a}	0.474^{b}	0.443^{b}	0.213^{c}	0.502^{b}
	TS	0.521^{ab}	0.592^{a}	0.243^{d}	0.410^{c}	0.267^{d}	0.495^{b}
TI	BC	1.158^{a}	0.850^{b}	1.226^{a}	1.094^{a}	0.380^{c}	1.279^{a}
	TS	1.321^{a}	1.355^{a}	0.545^{c}	0.998^{b}	0.500^{c}	1.259^{a}
h/H	BC	2.371^{b}	2.020^{b}	2.321^{b}	2.434^{b}	4.799^{a}	2.218^{b}
	TS	2.151^{d}	2.047^{d}	4.148^{a}	2.646^{c}	3.606^{b}	2.303^{cd}
Ω6/Ω3	BC	26.75^{b}	26.31^{b}	45.12^{a}	28.76^{b}	4.34^{c}	26.56^{b}
	TS	31.58^{b}	31.98^{b}	18.35^{b}	*	5.59^{d}	42.00^{a}

Values followed by different letters on the same line are significantly different by the Tukey test, with a significance level of 0.05 (p < 0.05). *Ω3 not detected in samples of this group.

oil, there was a similar reduction in AI and TI after cooking (Monteiro et al., 2017).

The ratio between hypocholesterolemic and hypercholesterolemic fatty acids (h/H) both in breaded chicken and in Tuscan-style sausage after frying in canola- and soybean oils showed significantly higher values in relation to the respective raw products. This favorable variation from the nutritional point of view occurred in these treatments due to the higher contents of hypocholesterolemic fatty acids and lower contents of hypercholesterolemic fatty acids transferred from these two lipid sources to the products. Similarly, Domínguez et al. (2017), after partial replacement of pork fat by polyunsaturated oils (25% fish oil and 25% olive oil), observed a change in the fatty acid profile that led to an increase in h/H. In another study, in which beef fat was partially or completely replaced by tiger nut (rich in oleic and linoleic acids) to produce beef burger, a reduction in AI and TI as well as an increase in h/H were observed (Barros et al., 2020).

The promising results of this study suggest the need for further sensory studies based on consumer perception (Paglarini et al., 2020; Vidal et al., 2020).

4 Conclusions

Frying breaded chicken and Tuscan-type sausage at 120 °C by immersion in canola, sunflower and coconut oils and in swine fat for approximately 10 to 15 minutes promoted changes in the contents of most of the unsaturated fatty acids present in the products. In particular, coconut oil led mainly to the inclusion of short- and medium-chain fatty acids, canola oil to an increase in omega-3 and monounsaturated fatty acid contents, and swine fat to an increase in palmitic, stearic and arachidonic acids in both products subjected to frying. With regard to omega-6 polyunsaturated fatty acids, their content decreased in breaded chicken fried in coconut oil and swine fat and increased in Tuscan-type sausage after frying, especially in soybean, sunflower and canola oils.

The results of this work suggest that the use of lipid sources alternative to soybean oil in immersion frying, provided that it is performed in a favorable time-temperature combination, can change the lipid profile of these foods, thus bringing diversity in the consumption of various types of fatty acids. To reduce the content or change the profile of saturated fatty acids, it would be interesting to use vegetable oils such as canola, sunflower and soybean oils. To generally improve the fatty acid profile and nutritional quality indices of deep-fried products, canola oil can be considered the most effective lipid source.

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