



**Evaluation of vegetable oil blends properties during deep-frying process and their influence on the quality of fried potatoes**

**Avaliação das propriedades de misturas de óleo vegetal durante o processo de fritura profunda e sua influência na qualidade de batatas fritas**

**Evaluación de las propiedades de mezclas de aceites vegetales durante el proceso de fritura profunda y su influencia en la calidad de papas fritas**

DOI: 10.55905/oelv22n2-116

Originals received: 01/02/2024

Acceptance for publication: 01/26/2024

**Nairana Marcondes Cunha**

Master of Food Technology

Institution: Departamento de Ciências Exatas e Tecnologia do Centro Universitário de Belo Horizonte

Address: Av. Prof. Mário Werneck 1685, Belo Horizonte, CEP: 30575-180

E-mail: nairanamc@gmail.com

**Diego Henrique de Souza Chaves**

Master of Chemical Engineering

Institution: Departamento de Engenharia Química da Universidade Federal de Minas Gerais

Address: Av. Pres. Antônio Carlos 6627, Belo Horizonte, CEP: 31270-901

E-mail: diegohschaves@outlook.com

**Tânia Maria Leite da Silveira**

PhD in Food Science

Institution: Departamento de Ciências Biológicas e Saúde do Centro Universitário de Belo Horizonte

Address: Av. Prof. Mário Werneck 1685, Belo Horizonte, CEP: 30575-180

E-mail: tania.silveira@prof.unibh.br

**Viviane Santos Birchal**

PhD in Mechanical Engineering

Institution: Departamento de Engenharia Química da Universidade Federal de Minas Gerais

Address: Av. Pres. Antônio Carlos 6627, Belo Horizonte, CEP: 31270-901

E-mail: vsbirchal@gmail.com

**Maria Aparecida Vieira Teixeira Garcia**

PhD in Food Technology

Institution: Departamento de Alimentos da Faculdade de Farmácia da Universidade  
Federal de Minas Gerais

Address: Av. Pres. Antônio Carlos 6627, Belo Horizonte, CEP: 31270-901

E-mail: mavtgarcia@gmail.com

**ABSTRACT**

Using different vegetable oils, it is possible to obtain blends that are less susceptible to oxidation, improving stability. In this work, the objective was evaluate alterations that occurred with two blends developed using soybean, cottonseed, and palm oils: Blend 1 in the proportions of 20:20:60 and Blend 2, 20:60:20, respectively. Batch frying study was conducted under temperature condition of 185°C for 20 hours. In the oils, the acid index, viscosity, color, composition in fatty acids and polar compounds were determined; and in the fried potato samples, moisture content and total lipids were analyzed. Results show that, in oils, there is an increase in the amount of saturated fatty acids greater for Blend 2 by 12.43% at the end of 20 hours of frying. There was an increase in viscosity during frying and there was no significant difference between the acidity of the blends. Both blends have suffered color change due to oil degradation. Oils with more saturated fatty acids, such as Blend 1, present greater stability during potato frying, however, there is a greater incorporation of oil in the finished product. Blend 1 was considered more stable, as it had the formation of 5.3% less polar compounds, as it has a higher amount of palm oil.

**Keywords:** acidity, blending, color change, viscosity, oil composition.

**RESUMO**

Usando diferentes óleos vegetais, é possível obter misturas que são menos susceptíveis à oxidação, melhorando a estabilidade. Neste trabalho, o objetivo foi avaliar alterações que ocorreram com duas misturas desenvolvidas a partir de óleos de soja, algodão e palma: mistura 1 nas proporções de 20:20:60 e mistura 2, 20:60:20, respectivamente. O estudo de fritura em lote foi realizado sob condição de temperatura de 185°C por 20 horas. Nos óleos foram determinados índice de acidez, viscosidade, cor, composição em ácidos graxos e compostos polares; e nas amostras de batata frita foram analisados teor de umidade e lipídios totais. Os resultados mostram que, nos óleos, há um aumento na quantidade de ácidos graxos saturados maior para o Blend 2 em 12,43% ao final de 20 horas de fritura. Houve aumento da viscosidade durante a fritura e não houve diferença significativa entre a acidez das misturas. Ambas as misturas sofreram alterações de cor devido à degradação do óleo. Óleos com ácidos graxos mais saturados, como o Blend 1, apresentam maior estabilidade durante a fritura da batata, no entanto, há uma maior incorporação de óleo no produto acabado. A mistura 1 foi considerada mais estável, por apresentar a formação de 5,3% menos compostos polares, por apresentar maior quantidade de óleo de palma.

**Palavras-chave:** acidez, mistura, mudança de cor, viscosidade, composição de óleo.

## RESUMEN

Utilizando diferentes aceites vegetales, es posible obtener mezclas que son menos susceptibles a la oxidación, mejorando la estabilidad. En este trabajo, el objetivo fue evaluar alteraciones que ocurrieron con dos mezclas desarrolladas con aceites de soja, semilla de algodón y palma: Mezcla 1 en las proporciones de 20:20:60 y Mezcla 2, 20:60:20, respectivamente. El estudio de fritura por lotes se realizó en condiciones de temperatura de 185°C durante 20 horas. En los aceites se determinó el índice de acidez, viscosidad, color, composición en ácidos grasos y compuestos polares, y en las muestras de papa frita se analizó el contenido de humedad y lípidos totales. Los resultados muestran que, en los aceites, hay un aumento en la cantidad de ácidos grasos saturados mayor para la Mezcla 2 en 12,43% al final de 20 horas de fritura. Hubo un aumento en la viscosidad durante la fritura y no hubo diferencia significativa entre la acidez de las mezclas. Ambas mezclas han sufrido cambios de color debido a la degradación del aceite. Los aceites con ácidos grasos más saturados, como el Blend 1, presentan mayor estabilidad durante la fritura de papa, sin embargo, hay una mayor incorporación de aceite en el producto terminado. La mezcla 1 se consideró más estable, ya que tuvo la formación de 5,3% menos compuestos polares, ya que tiene una mayor cantidad de aceite de palma.

**Palabras clave:** acidez, mezcla, cambio de color, viscosidad, composición de aceite.

## 1 INTRODUCTION

Frying is a widely used technology in food processing, being responsible for the color, crispness, flavor, and other major sensory characteristics of the fried foods (Luo *et al.*, 2022; Oladejo *et al.*, 2017). When food is submerged in hot oil (approximately 150 to 210°C), the temperature of the material rapidly rises and the surface water evaporates almost instantly (Luo *et al.*, 2022; Diaz *et al.*, 1999; Li *et al.*, 2020). However, frying of foods is a complex process in which several factors are relevant, most often dependent on the process itself, such as temperature, time, and method of frying (Garayoa *et al.*, 2021). Other factors, however, extrinsic to the process are also important, such as the type of oil used, its composition and physicochemical characteristics, presence or absence of additives, and the relationship between the surface of the equipment and oil volume or even the relationship between food mass and oil volume (Almeida *et al.*, 2018; Pozo Díez *et al.*, 1995; De Wilde *et al.*, 2004).

During French fries processing, understanding the gradual changes in water and oil content, color, texture, oil absorption and volumetric shrinkage is crucial to produce a

satisfactory product (Li *et al.*, 2020; Costa *et al.*, 2001; Kita and Lisinska, 2005). In this way, the selection of oil is essential because its chemical composition establishes, among other characteristics, the degree of hydrolysis of lipids (Rios *et al.*, 2014). Nowadays, there are several oil alternatives for frying: sunflower, soy, palm, canola, palm olein and their partial or fractionated hydrogenated versions (Hinrichsen, 2016; Almeida *et al.*, 2019). Availability of different edible oils in the market may create dilemma in consumers about choosing the appropriate oil to the frying process. Some studies have reported that the type of oil has a significantly effect on the oil absorption and texture of fried potato (Kita and Lisinska, 2005; Kita *et al.*, 2005).

Production of palm, cottonseed, and soybean oils has grown in recent years representing together almost 70% of the global total for the year 21/22 (USDA, 2022). These vegetable oils are widely used in frying processes, differing significantly in their fatty acid composition; in soybean and cottonseed oil, there is a high content of polyunsaturated fatty acids while in palm oil, saturated fatty acids predominate (Matthaus, 2007). Soybean oil is one of the edible oils most susceptible to oxidation, due to its higher degree of oxidation, characterized by a high content of linoleic acid and a relatively high content of linolenic acid (Clemente and Cahoon, 2009). Oils with a high concentration of unsaturated fatty acids are not indicated for the frying process, serving as sites for electrons in oxidation reactions, which leads to the release of volatile compounds with rancid odor, and increased formation of non-volatile compounds such as polar compounds (Matthaus, 2010).

Furthermore, the choice of the oil is defined not only by the quality of the product obtained, but also its cost. An alternative with a relatively high nutritional aspect and low cost, blend oils are products obtained from mixing oils from two or more vegetable species. The processes that consist of mixing oils that are more susceptible to oxidation, rich in polyunsaturated fatty acids, with those more resistant, rich in saturated fatty acids, aim to improve the shelf life required for fried food and the stability of the products (Vieira *et al.*, 2015). Thus, this study aims to study the physicochemical alterations of vegetable oil blends (soybean, palm, and cottonseed oils) and their influence on lipid absorption and moisture loss of French fries during the discontinuous frying process. For

the blends, alterations in the composition of fatty acids, polar compounds, acidity index, viscosity and color were evaluated.

## 2 MATERIALS AND METHODS

### 2.1 RAW MATERIALS AND BLENDING

Palm oil and cottonseed oil were obtained respectively by donation from the industry *Grupo Agropalma* (Thailand – Brazil) and from the company *Cargill Agrícola S.A.* (Itumbiara – Brazil). Soybean oil, as well as frozen pre-fried potatoes of Asterix variety, were purchased from local market (Belo Horizonte – Brazil). The potatoes were properly stored under freezing at a temperature of  $-18^{\circ}\text{C}$ , until the moment of frying.

Oils with a high concentration of unsaturated fatty acids are not recommended for frying because their instaurations may serve as sites for electrons in the oxidation reactions, which results in the liberation of volatile compounds with a rancid flavor, and increased formation of non-volatile compounds such as polar compounds. Two blends were developed from mixture of vegetable oils in the proportions of 20:20:60 (soybean, cottonseed, and palm respectively) for Blend 1 and 20:60:20 for Blend 2. Blend 1 is supposed to be more stable to the frying process since its composition has higher content of saturated and monounsaturated fatty acids and lower content of polyunsaturated fatty acids compared to Blend 2.

The blends were previously made in a container suitable for oils before being inserted into the fryer. At room temperature, blending was carried out with a glass rod until the mixture was homogeneous.

### 2.2 FRYING PROCESS METHOD

The batch frying of the pre-fried potatoes were carried out in duplicate in a domestic fryer, model FGIB (Tedesco), with a volume of 3000mL and relation surface / initial oil volume ratio of  $0.3\text{cm}^{-1}$ . The frying temperature was  $185 \pm 0.1^{\circ}\text{C}$ , controlled by a thermostat, value monitored using a thermometer. The blended oils were heated, for each test, for a total period of 20 hours without replacing fresh oil, and the test was carried

out in two days, with the fryer turned off and covered during 12 hours between one day and the other.

An initial period of 10 minutes was required for heating the blend until the first frying was performed. The frying cycles lasted 30 minutes and, at each cycle, 300g of frozen pre-fried potato was added to the fryer, with the frying time equal to 3.5 minutes. Samples of 100g of French fries and 100mL of oils were collected after 0.5, 5, 10, 15 and 20 hours of frying. The French fries, after cooling, were stored in polyethylene packages wrapped in aluminum foil and stored at -18°C and they were defrosted for analysis. The collected oil samples were placed in amber bottles wrapped in aluminum foil and immediately sent for analysis. For each sample, analyzes were performed in triplicate. Analysis of variance (ANOVA) was performed using the statistical package present in Minitab (version 16) to identify significant differences between treatments, at a significance level of 5% ( $p$ -value < 0.05).

### 2.3 PHYSICOCHEMICAL CHARACTERISTICS OF OILS

**Color:** according to the Lovibond method (AOCS, 2004), Cc 13e-92. Although subjective, Lovibond color standards are accepted as a method for determining proper color values.

**Viscosity:** based on the D446-12 standard (ASTM, 2017), which describes the procedure for determining the viscosity of a fluid in a glass capillary viscometer. model Cannon Fenske No. 200, properly calibrated, was used in the experiments.

**Free fatty acids:** according to the Ca 5a-40 standard (AOCS, 2004), using phenolphthalein indicator in an Erlenmeyer flask with 75mL of neutralized alcohol solution and titrated with NaOH 0.1N.

**Fatty acids:** determined by gas chromatography according to the Ce 2-66 method (AOCS, 2004), using Shimadzu gas chromatograph model 2010 with flame ionization detector, capillary column DB-23, 30m long, 0.25µm film thickness and 0.25µm internal diameter, programmed temperature between 140-240°C, rate of 2°C/min, using helium at 52.7mL/min as carrier gas and speed of 27.2cm/second, using Accustandard fatty acid

methyl esters as a reference for identification. Methyl esters were prepared with sodium methylate.

**Polar compounds:** Polar compounds were determined by column chromatography according to the Cd 20-91 standard (AOCS, 2004), a method for evaluating the deterioration of oils and fats used in the frying process.

## 2.4 PHYSICOCHEMICAL ANALYZES OF POTATOES

**Moisture content:** obtained before and after the frying process by the gravimetric procedure using an analytical balance (model AY220 Shimadzu Scientific Instruments Inc.) with the methodology determined by test method 984.25 (AOAC, 2019). The foods were properly ground and homogenized.

**Lipid content:** fat extraction, before and after frying, using the Soxhlet method according to standard 945.16 (AOAC, 2019) to assess the degree of fat absorption during the process.

## 3 RESULTS AND DISCUSSION

### 3.1 COLOR OF OILS

The evolution of the red and yellow colors with the frying time can be seen in Table 1 for the blends studied. The ratio of 10 units of yellow to each unit of red can be adopted for oils with a red color below 3.5 and higher yellow thresholds are specified for darker oils (O'Brien *et al.*, 2005).

Table 1. Lovibond color values of blends used in frying frozen pre-fried potatoes (5¼" cuvette).

Frying time (h)	Blend 1 <sup>†</sup>		Blend 2 <sup>†</sup>	
	Red	Yellow	Red	Yellow
0	0.60 <sup>aA</sup>	4.3 <sup>aC</sup>	0.70 <sup>aB</sup>	3.8 <sup>aD</sup>
10	1.56 <sup>bB</sup>	9.2 <sup>bC</sup>	1.45 <sup>bB</sup>	7.4 <sup>bC</sup>
20	2.75 <sup>cA</sup>	19.0 <sup>cC</sup>	2.40 <sup>cB</sup>	15.5 <sup>cD</sup>

<sup>†</sup> a, b, c (column) and A, B, C D (line) – values followed by different letters were significantly different at *p*-value < 0.05. Source: Authors.

From the results found, significant differences of red and yellow colors were verified between blends during the frying process. The color change may have occurred

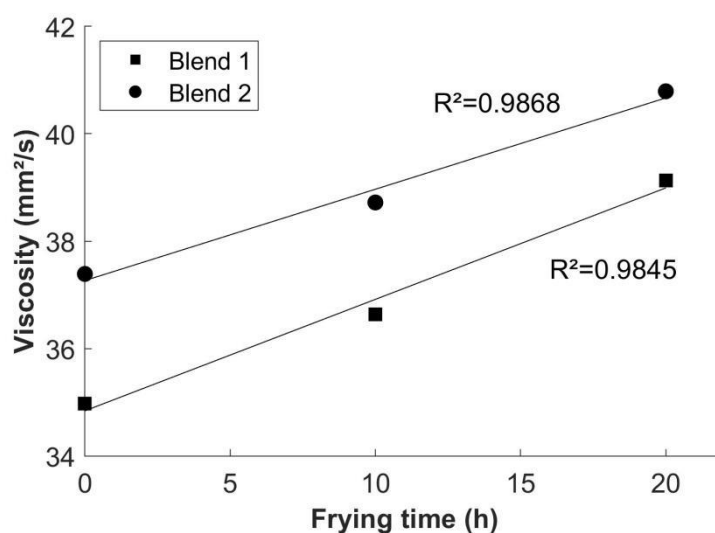
due to oil degradation as well as reactions with potato residues. As there was no filtering of the oil and due to the high temperatures, the particles have caramelized and become carbonized particles in suspension leading to darkening of the oil (Ma *et al.*, 2016; Paul *et al.*, 1997).

It is also necessary to consider the formation of Maillard reaction products in oil darkening (Feng *et al.*, 2022) and the contribution of polymeric compounds in the color of frying oil (Lazarick *et al.*, 2014). In addition, the increase in color may also be related to the conjugated double bonds formed during frying, leading to the absorption of greater amounts of blue light, causing an increase in orange and brown colors in the oil (Osawa and Gonçalves, 2012a).

### 3.2 VISCOSITY OF OILS

A viscosity increasing tendency was observed in both blends over the frying time (Figure 1). It is possible to correlate the absorption acquired by the potato over the frying with the oil viscosity.

Figure 1. Viscosity of oil blends during the frying process.



Source: Authors.

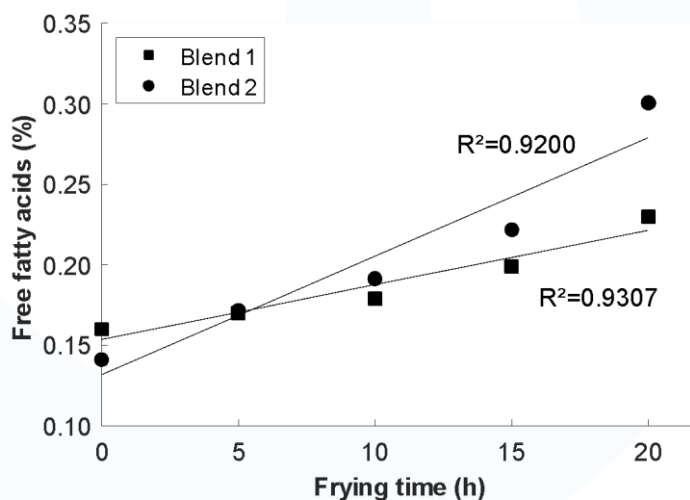
The increase in viscosity is due to the incorporation of saturated fats, with a higher melting point, from the foods used for frying and this contributes to increasing the amount

of oil on the surface of the food leading to a decreasing in the interfacial tension between the food and the oil, facilitating the absorption of the oil by the product (Dobarganes *et al.*, 2000).

### 3.3 FREE FATTY ACIDS OF OILS

In the hydrolysis of frying oil, there is an increase in free fatty acids content as well in monoacylglycerol, diacylglycerol and glycerol. There was an increase in the free fatty acids content from 0.16 to 0.23% for Blend 1 and from 0.14 to 0.30% for Blend 2 during frying (Figure 2), so it is not possible to state statistically that the blends had different contents at the 5% significance level.

Figure 2. Free fatty acids contents for the two blends during the frying process.



Source: Authors.

The acidity found not only reflects the fatty acids formed during the frying process, but also those initially present in oils before heating and in food. The two blends studied did not reach the acidity values for disposal at the end of the 20 hours of experiments. A usual recommendation is to discard frying oils that have a free fatty acid content greater than 1.5% (Esfarjani *et al.*, 2019).

Free fatty acids are moderately volatile, and an unknown amount is lost during heating (Tompkins and Perkins, 2000). Furthermore, free fatty acids can undergo

oxidation and be converted into other products that are not measured by titration methods, commonly used by official methodologies.

### 3.4 FATTY ACIDS AND POLAR COMPOUNDS OF OILS

The results for fatty acids composition are presented in Table 2 for soybean, palm, and cottonseed oils and for the blended oils. The oils used as raw material for the blending have presented composition in fatty acids in accordance with what is established by the Brazilian legislation for refined vegetable oils, according to current resolution at the time (ANVISA, 2005). Considering Brazilian oil market price indexes (Selina Wamucii, 2022), in terms of cost, Blend 2 is 14.1% more expensive compared to Blend 1.

Table 2. Fatty acid composition of soybean, palm and cottonseed and blended oils.

Fatty acid	Soybean	Cottonseed	Palm	Fatty acid content (wt.%)			
				Blend 1 <sup>‡</sup>		Blend 2 <sup>‡</sup>	
				Initial (0h)	Final (20h)	Initial (0h)	Final (20h)
C12:0	n.d. <sup>¶</sup>	n.d. <sup>¶</sup>	n.d. <sup>¶</sup>	0.23 <sup>aA</sup>	0.25 <sup>A</sup>	0.05 <sup>bC</sup>	0.14 <sup>C</sup>
C14:0	0.07	0.64	0.80	0.63 <sup>aA</sup>	0.68 <sup>B</sup>	0.57 <sup>bC</sup>	0.61 <sup>C</sup>
C16:0	11.12	23.30	37.41	29.54 <sup>aA</sup>	32.57 <sup>B</sup>	24.12 <sup>bC</sup>	27.61 <sup>D</sup>
C16:1	0.11	0.40	0.24	0.18 <sup>aA</sup>	0.17 <sup>B</sup>	0.28 <sup>bC</sup>	0.25 <sup>D</sup>
C18:0	3.44	2.24	3.99	3.54 <sup>aA</sup>	3.79 <sup>B</sup>	2.85 <sup>bC</sup>	3.19 <sup>D</sup>
C18:1	22.23	15.69	47.34	35.92 <sup>aA</sup>	37.60 <sup>B</sup>	23.54 <sup>bC</sup>	27.48 <sup>D</sup>
C18:2	55.68	57.13	9.21	28.05 <sup>aA</sup>	23.37 <sup>B</sup>	46.64 <sup>bC</sup>	39.14 <sup>D</sup>
C18:3	6.61	0.14	0.23	1.46 <sup>aA</sup>	1.10 <sup>B</sup>	1.43 <sup>bC</sup>	1.11 <sup>D</sup>
C20:0	0.33	0.22	0.38	0.30 <sup>aA</sup>	0.32 <sup>B</sup>	0.26 <sup>aC</sup>	0.28 <sup>C</sup>
C22:0	0.40	0.18	0.06	0.14 <sup>aA</sup>	0.14 <sup>A</sup>	0.19 <sup>aC</sup>	0.19 <sup>C</sup>
SFA <sup>†</sup>	15.36	26.62	43.03	34.40	37.76 <sup>§</sup>	28.04 <sup>§</sup>	32.02 <sup>§</sup>
MFA <sup>†</sup>	22.34	16.09	47.58	36.09	37.77 <sup>§</sup>	23.83 <sup>§</sup>	27.74 <sup>§</sup>
PFA <sup>†</sup>	62.29	57.27	9.44	29.51	24.47 <sup>§</sup>	48.07 <sup>§</sup>	40.25 <sup>§</sup>

<sup>†</sup> SFA (Saturated Fatty Acids), MFA (Monounsaturated Fatty Acids), PFA (Polyunsaturated Fatty Acids);

<sup>‡</sup> a, b (line, blend); A, B, C, D (line, time) – values followed by different letters were significantly different at  $p$ -value < 0.05; <sup>§</sup> Analysis of variance shown in Table 3; <sup>¶</sup> values not determined. Source: Authors.

The fatty acid composition of the blends before frying differed from each other, except for arachidonic (C20:0) and behenic (C22:0) fatty acids. Vegetable oils with high concentrations of linolenic acid (C18:3) are not indicated in frying, as there is rapid formation of cyclic monomers, which are physiologically considered as toxic compounds (Christie and Dobson, 2000). There was a reduction of linoleic (C18:2) and linolenic (C18:3) acids due to oxidation. The reduction was greater for Blend 1, 16.7 and 24.7%

respectively, due to the greater amount of palm oil present in this blend, with greater reduction of linoleic acid during frying compared to cottonseed oil. The most stable frying oils have a low linolenic acid content (< 3%), oleic acid content greater than 50% and linoleic acid content less than 50% (Warner and Fehr, 2008). Table 3 presents the values of fatty acids and polar compounds for both blends at the beginning and at the end of the frying process.

Table 3. Fatty acids and polar compounds for oil blends used in the frying process.

	Frying time (h)	Content (%)	
		Blend 1 <sup>†</sup>	Blend 2 <sup>†</sup>
Saturated Fatty Acids	0	34.40 <sup>aA</sup>	28.04 <sup>bA</sup>
	20	37.76 <sup>aB</sup>	32.02 <sup>bB</sup>
Monounsaturated Fatty Acids	0	36.09 <sup>aA</sup>	23.83 <sup>bA</sup>
	20	37.77 <sup>aB</sup>	27.74 <sup>bB</sup>
Polyunsaturated Fatty Acids	0	29.51 <sup>aA</sup>	48.07 <sup>bA</sup>
	20	24.47 <sup>aB</sup>	40.25 <sup>bB</sup>
Polar compounds	0	4.3 <sup>aA</sup>	6.2 <sup>bB</sup>
	20	9.5 <sup>aB</sup>	10.0 <sup>bB</sup>

<sup>†</sup> a, b (column) and A, B (line) – values followed by different letters were significantly different (in each category) at *p*-value < 0.05. Source: Authors.

There were significant differences in the content of saturated, monounsaturated, and polyunsaturated fatty acids for both the blends and the frying time. Both blends had an increase in saturated fatty acids and a decrease in polyunsaturated fatty acids as a function of frying time. The reductions in unsaturated fatty acids are attributed to oxidative reactions occurring during frying and with the formation of polar compounds.

Blend 1, before frying, has 22.7% and 51.4% more saturated and monounsaturated fatty acids than Blend 2, respectively. However, Blend 2 has 62.9% more polyunsaturated fatty acids, suggesting that Blend 1 is more stable during the frying process due to the higher content of palm oil. In the frying process, the stability of the fried product is related to the degree of unsaturation of the fatty acids in the oil (Osawa and Gonçalves, 2012b). Palm oil, which is more saturated, has greater stability than cottonseed oil, which is more unsaturated (Zia *et al.*, 2022). The addition of palm olein and antioxidants improves the quality of the fried product and increased the stability of the oil.



According to the results obtained for total polar compounds presented in Table 3, an increase in the values of polar compounds along the frying times, regardless of the type of oil, can be observed. Blend 2 had, after 20 hours, 5.3% more polar compounds than Blend 1, a statistically significant difference, results are at odds with expectations, since higher amounts of total polar compounds are reported in palm oils compared to other vegetable oils (Almeida *et al.*, 2018). The addition of fresh oil, which dilutes the compounds produced during frying and replaces the antioxidants, contributes to reduce oil degradation (Ghidurus *et al.*, 2013). In this work, even without lipid replacement to supply the oil absorbed by the food, at the end of 20 hours of frying, the blends did not reach the level of total polar compounds considered as the discard point (25%) according to the current Brazilian legislation (ANVISA, 2004).

### 3.5 MOISTURE CONTENT OF POTATOES

The frozen pre-fried potato had an initial moisture content of  $69.61 \pm 0.01\%$  and the moisture content values over the frying time are shown in Table 4. The Brazilian Table of Chemical Composition of Foods (TBCA, 2022) shows that Brazilian potatoes have 80.5% moisture and traces of lipids elements.

Table 4. Moisture content over time for potatoes submitted to the frying process.

Frying time (h)	Blend 1 <sup>†</sup>	Blend 2 <sup>†</sup>
0	69.61 <sup>aA</sup>	69.61 <sup>aA</sup>
0.5	45.73 <sup>bB</sup>	45.56 <sup>bB</sup>
5	42.74 <sup>cA</sup>	45.43 <sup>bB</sup>
10	42.72 <sup>cA</sup>	45.36 <sup>bB</sup>
15	41.32 <sup>dA</sup>	45.72 <sup>cB</sup>
20	40.88 <sup>eA</sup>	43.52 <sup>dB</sup>

<sup>†</sup> a, b, c, d, e (column) and A, B (line) – values followed by different letters were significantly different at  $p$ -value < 0.05. Source: Authors.

For both blends, there was a decrease in the moisture content of the food during frying, reaching, at 20 hours, 40.88% moisture content for Blend 1 and 43.52% for Blend 2, i.e., Blend 1 lost more moisture during the discontinuous frying process. Potatoes, when fried in more unsaturated oil, lose less percentage of moisture during the frying process (Nizkad *et al.*, 2021). With the frying process, the moisture contents differed significantly

over time for Blend 1, except between 5 and 10 hours. As for Blend 2, the moisture content had not a significant difference between 0.5 and 10.0 hours, differing for the other times. The moisture loss in the potato differed statistically between the blends after 30 minutes and the water eliminated by evaporation is partially replaced by the oil absorbed by the potato during the process.

### 3.6 LIPID CONTENT OF POTATOES

The frozen pre-fried potato had an initial lipid content of  $4.47 \pm 0.02\%$ , since it is already a pre-fried product, and the lipid content values over the frying time are shown in Table 5.

Table 5. Lipid content over time for potatoes submitted to the frying process.

Frying time (h)	Blend 1 <sup>†</sup>	Blend 2 <sup>†</sup>
0	4.47 <sup>aA</sup>	4.47 <sup>aA</sup>
0.5	14.12 <sup>bB</sup>	13.21 <sup>bB</sup>
5	15.31 <sup>bA</sup>	14.20 <sup>bB</sup>
10	16.43 <sup>cA</sup>	15.16 <sup>cB</sup>
15	16.33 <sup>cA</sup>	15.58 <sup>cA</sup>
20	17.84 <sup>dA</sup>	15.72 <sup>cB</sup>

<sup>†</sup> a, b, c, d (column) and A, B (line) – values followed by different letters were significantly different at  $p$ -value  $< 0.05$ . Source: Authors.

French fries with Blend 1 had higher values of lipid content compared to those fried with Blend 2. Higher levels of saturated fatty acids in oil composition leads to less oil absorption (Yang *et al.*, 2020). Blend 1 composition has an 22.7% higher content of saturated fatty acids and 38.6% less polyunsaturated fatty acids. However, oil absorption and water loss are directly related, a greater loss of water for Blend 1 resulted in a higher lipid content, even containing more saturated acids.

The absorption of oil by food can be described by two mechanisms. First, continuous oil absorption occurs as part of the water evaporated during frying (Saguy and Dana, 2003). In addition, there is increased absorption when the oil is closer to the end of its useful life. As the oil degrades, more surfactants are formed and the contact time between the food and the oil increases. As a result, the amount of oil absorbed by the food

and the rate of heat transfer increases, generating excessive moisture reduction and surface browning, depending on the temperature gradient (Paul *et al.*, 1997).

#### 4 CONCLUSION

Blends of vegetable oils are viable alternatives to the frying process, in terms of cost and physicochemical changes when compared to pure oils. Determinations such as color, viscosity, fatty acid composition, free fatty acid content are complementary techniques in predicting oil disposal, but by themselves they do not define the quality of the frying oil. Color darkening, both for yellow and red, have occurred due to oil degradation at high temperatures as well as reactions with potato residues because there was no filtering. The viscosity of the blends increases, which contributes to increasing the amount of oil on the surface of the food and, furthermore, the interfacial tension between the food and the oil decreases, thus facilitating the oil absorption.

The type of blend had the greatest influence on moisture loss and oil absorption in French fries at a temperature of 185°C. French fries in Blend 1 had lower moisture contents and greater oil absorption during frying. Despite the greater incorporation of oil in the finished product, there is a greater amount of saturated fat, favoring oxidative stability. It was not possible to observe strong evidence that the change in acidity in Blend 1 was different from Blend 2.

There was an increase in the percentage of saturated fatty acids and a decrease in polyunsaturated fatty acids, regardless of the type of blend developed. Blend 1 was considered more stable, because at the end of the 20-hour frying process, it had the formation of 5.3% less polar compounds in relation to Blend 2. Values of total polar compounds have not exceeded the limits recommended for discarding frying oils and/or fats.

It is proposed to carry out the experiments with frying time greater than 20 hours to determine the disposal point of the blends. It is also suggested complementary analyzes such as sensory analysis, Thiobarbituric acid index (TBI), conjugated dienes (CD), conjugated trienes (CT) and trans fatty acids composition.



## ACKNOWLEDGMENTS

The authors would like to thank *Grupo Agropalma* and *Cargill Agrícola S.A.* for supplying the palm and cottonseed oil. We would also like to thank the National Council for Scientific and Technological Development (CNPq) for the financial support. The authors declare no conflict of interest in this work.

## REFERENCES

Almeida, D. T.; Curvelo, F. M.; Costa, M.M.; Viana, T.V.; Lima, P.C. Oxidative stability of crude palm oil after deep frying akara (Fried Bean Paste). **Food Science and Technology**, v. 38, p. 142-147, 2018. <https://doi.org/10.1590/1678-457X.02217>

Almeida, D. T.; Viana, T. V.; Costa, M. M.; Silva, C. S.; Feitosa, S. Effects of different storage conditions on the oxidative stability of crude and refined palm oil, olein and stearin (*Elaeis guineensis*). **Food Science and Technology**, v. 39, p. 211-217, 2019. <https://doi.org/10.1590/fst.43317>

ANVISA (Agência Nacional de Vigilância Sanitária). IT N° 11/2004. Utilization and Disposal of Oils and Fats Employed in Frying Processes, 2004.

ANVISA (Agência Nacional de Vigilância Sanitária). RDC N° 270/2005. Technical Regulation for Vegetable Oils, Vegetable Fats, and Vegetable Cream, 2005.

AOAC (Association of Official Analytical Chemists). Official Methods of Analysis of AOAC International, 21st Edition, AOAC, Washington DC, 2019.

AOCS (American Oil Chemists' Society). Official Methods and Recommended Practices of the American Oil Chemists' Society, 5th Edition, Champaign, 2004.

ASTM (American Society for Testing and Materials). D446-12 - Standard Specifications and Operating Instructions for Glass Capillary Kinematic Viscometers, 2017.

Christie, W. W.; Dobson, G. Formation of cyclic fatty acids during the frying process. **European Journal of Lipid Science and Technology**, v. 102, p. 515-520, 2000. [https://doi.org/10.1002/1438-9312\(200009\)102:8/9%3C515::AID-EJLT515%3E3.0.CO;2-Z](https://doi.org/10.1002/1438-9312(200009)102:8/9%3C515::AID-EJLT515%3E3.0.CO;2-Z)

Clemente, T. E.; Cahoon, E. B. Soybean Oil: Genetic Approaches for Modification of Functionality and Total Content. **Plant Physiology**, v. 151, p. 1030-1040, 2009. <https://doi.org/10.1104/pp.109.146282>

Costa, R. M.; Oliveira, F. A. R.; Boutcheva, G Structural changes and shrinkage of potato during frying. **International Journal of Food Science and Technology**, v. 36, p. 11-23, 2001. <https://doi.org/10.1046/j.1365-2621.2001.00413.x>

De Wilde, T.; De Meulenaer, B.; Mestdagh, F.; Verhé, R.; Govaert, Y.; Fraselle, S.; Degroodt, M.; Vandeburie, S.; Demeulemeester, K.; Calus, A.; Ooghe, W.; Van Peteghem, C. Acrylamide formation during frying of potatoes: thorough investigation on the influence of crop and process variables. **Czech Journal of Food Sciences**, v. 22, p. 15-18, 2004. <https://doi.org/10.17221/10602-CJFS>

Diaz, A.; Trystram, G.; Vitrac, O.; Dufour, D.; Raoult-Wack, A-L. Kinetics of moisture loss and fat absorption during frying for different varieties of plantain. **Journal of Science of**

**Food and Agriculture**, v. 79, p. 291-299, 1999. [https://doi.org/10.1002/\(SICI\)1097-0010\(199902\)79:2%3C291::AID-JSFA194%3E3.0.CO;2-I](https://doi.org/10.1002/(SICI)1097-0010(199902)79:2%3C291::AID-JSFA194%3E3.0.CO;2-I)

Dobarganes, C.; Márquez-Ruiz, G.; Velasco, J. Interactions between fat and food during deep-frying. **European Journal of Lipid Science and Technology**, v. 102, p. 521-528, 2000. [https://doi.org/10.1002/1438-9312\(200009\)102:8/9%3C521::AID-EJLT521%3E3.0.CO;2-A](https://doi.org/10.1002/1438-9312(200009)102:8/9%3C521::AID-EJLT521%3E3.0.CO;2-A)

Esfarjani, F.; Khoshtinat, K.; Zargaraan, A.; Mohammadi-Nasrabadi, F.; Salmani, Y.; Saghafi, Z.; Hosseini, H.; Bahmaei, M. Evaluating the rancidity and quality of discarded oils in fast food restaurants. **Food Science & Nutrition**, v. 7, p. 2302-2311, 2019. <https://doi.org/10.1002/fsn3.1072>

Feng, J.; Berton-Carabin, C. C.; Fogliano, V.; Schroën, K. Maillard reaction products as functional components in oil-in-water emulsions: A review highlighting interfacial and antioxidant properties. **Trends in Food Science & Technology**, v. 121, p. 129-141, 2022. <https://doi.org/10.1016/j.tifs.2022.02.008>

Garayoa, R.; Sanz-Serrano, J.; Vettorazzi, A.; López de Cerain, A.; Azqueta, A.; Vitas, A. I. Practices of deep-frying processes among food handlers in social food services in Navarra, Spain. **International Journal of Gastronomy and Food Science**, v. 26, 100432, 2021. <https://doi.org/10.1016/j.ijgfs.2021.100432>

Ghidurus, M.; Turtoi, M.; Boskou, G. Hazards associated with fried fast-food products. **Romanian Biotechnological Letters**, v. 18, p. 8391-7396, 2013. <https://rombio.unibuc.ro/wp-content/uploads/2022/05/18-4-1.pdf>

Hinrichsen, N. Commercially available alternatives to palm oil. **Lipid Technology**, v. 28, p. 65-67, 2016. <https://doi.org/10.1002/lite.201600018>

Kita, A.; Lisińska, G. The influence of oil type and frying temperatures on the texture and oil content of French fries. **Journal of Science of Food and Agriculture**, v. 85, p. 2600-2604, 2005. <https://doi.org/10.1002/jsfa.2319>

Kita, A.; Lisińska, G.; Powolny, M. The influence of frying medium degradation on fat uptake and texture of French fries. **Journal of Science of Food and Agriculture**, v. 85, p. 1113-1118, 2005. <https://doi.org/10.1002/jsfa.2076>

Lazarick, K.; Aladedunye, F.; Przybylski, R. Effect of breadings and battering ingredients on performance of frying oils. **European Journal of Lipid Science and Technology**, v. 116, p. 763-770, 2014. <https://doi.org/10.1002/ejlt.201300342>

Li, P.; Wu, G.; Yang, D.; Zhang, H.; Qi, X.; Jin, Q.; Wang, X. Effect of multistage process on the quality, water and oil distribution and microstructure of French fries. **Food Research International**, v. 137, 109229, 2020. <https://doi.org/10.1016/j.foodres.2020.109229>

Luo, S.; Xiong, S.; Li, X.; Hu, X.; Ye, J.; Liu, C. Impact of starch–lipid complexes on oil absorption of starch and its mechanism. **Journal of Science of Food and Agriculture**, v. 103, p. 83-91, 2022. <https://doi.org/10.1002/jsfa.12114>

Ma, R.; Gao, T.; Song, L.; Zhang, L.; Jiang, Y.; Li, J.; Zhang, X.; Gao, F.; Zhou, G. Effects of oil-water mixed frying and pure-oil frying on the quality characteristics of soybean oil and chicken chop. **Food Science and Technology**, v. 36, p. 329-336, 2016. <https://doi.org/10.1590/1678-457X.0092>

Matthäus, B. Use of palm oil for frying in comparison with other high-stability oils. **European Journal of Lipid Science and Technology**, v. 109, p. 400-409, 2007. <https://doi.org/10.1002/ejlt.200600294>

Matthäus, B. Oxidation of edible oils. In: **Oxidation in Foods and Beverages and Antioxidant Applications: Volume 2**, edited by Decker, E. A.; Elias, R. J.; McClements, D. J. Woodhead Publishing, Philadelphia, p. 183-238, 2010. <https://doi.org/10.1533/9780857090331.2.183>

Nikzad, N.; Ghavami, M.; Seyedain-Ardabili, M.; Akbari-Adergani, B.; Azizinezhad, R. Effect of deep-frying process using sesame oil, canola and frying oil on the level of bioactive compounds in onion and potato and assessment of their antioxidant activity. **Food Science and Technology**, v. 41, p. 545-555, 2021. <https://doi.org/10.1590/fst.35819>

O'Brien, R. D.; Jones, L. A.; King, C. C.; Wakelyn, P. J.; Wan, P. J. Cottonseed oil. In: **Bailey's Industrial Oil and Fat Products: Volume 2**, edited by Shahidi, F. John Wiley & Sons, Hoboken, p. 173-280, 2005.

Oladejo, A. O.; Ma, H.; Qu, W.; Zhou, C.; Wu, B.; Uzoejinwa, B. B.; Onwude, D. I.; Yang, X. Application of pretreatment methods on agricultural products prior to frying: a review. **Journal of Science of Food and Agriculture**, v. 98, p. 456-466, 2017. <https://doi.org/10.1002/jsfa.8502>

Osawa, C. C.; Gonçalves, L. A. G. Deep-fat frying of meat products in palm olein. **Food Science and Technology**, v. 32, p. 804-811, 2012a. <https://doi.org/10.1590/S0101-20612012005000109>

Osawa, C. C.; Gonçalves, L. A. G. Changes in breaded chicken and oil degradation during discontinuous frying with cottonseed oil. **Food Science and Technology**, v. 32, p. 692-700, 2012b. <https://doi.org/10.1590/S0101-20612012005000098>

Paul, S.; Mittal, G. S.; Chinnan, M. S. Regulating the use of degraded oil/fat in deep-fat/oil food frying. **Critical Reviews in Food Science and Nutrition**, v. 37, p. 635-662, 1997. <https://doi.org/10.1080/10408399709527793>

Pozo Díez, R. M.; Masoud Musa, T. A.; Pérez Camino, M. C.; Dobarganes, M. C. Lipid exchange during the frying of frozen pre-fried potatoes in high oleic sunflower oil. **Grasas y Aceites**, v. 46, p. 85-91, 1995. <https://doi.org/10.3989/gya.1995.v46.i2.907>

Rios, R. V.; Pessanha, M. D. F.; Almeida, P. F.; Viana, C. L.; Lannes, S. C. S. Application of fats in some food products. **Food Science and Technology (Campinas)**, v. 34, p. 3-15, 2014. <https://doi.org/10.1590/S0101-20612014000100001>

Saguy, I. S.; Dana, D. Integrated approach to deep fat frying: engineering, nutrition, health and consumer aspects. **Journal of Food Engineering**, v. 56, p. 143-152, 2003. [https://doi.org/10.1016/S0260-8774\(02\)00243-1](https://doi.org/10.1016/S0260-8774(02)00243-1)

Selina Wamucii. Prices, Trends & Insights, 2022. <https://www.selinawamucii.com/insights/prices/>

TBCA (Tabela Brasileira de Composição de Alimentos). Centro de Pesquisa de Alimentos, 2022. <http://www.fcf.usp.br/tbca>

Tompkins, C.; Perkins, E. G. Frying performance of low-linolenic acid soybean oil. **Journal of the American Oil Chemists' Society**, v. 77, p. 223-229, 2000. <https://doi.org/10.1007/s11746-000-0036-2>

USDA (United States Department of Agriculture). Production, Supply and Distribution - Foreign Agricultural Service, 2022. <https://apps.fas.usda.gov/psdonline>

Vieira, S. A.; McClements, D. J.; Decker, E. A. Challenges of Utilizing Healthy Fats in Foods. **Advances in Nutrition**, v. 6, p. 309S-317S, 2015. <https://doi.org/10.3945/2014.006965>

Warner, K.; Fehr, W. Mid-Oleic/Ultra Low Linolenic Acid Soybean Oil: A Healthful New Alternative to Hydrogenated Oil for Frying. **Journal of the American Oil Chemists' Society**, v. 85, p. 945-951, 2008. <https://doi.org/10.1007/s11746-008-1275-1>

Yang, D.; Wu, G.; Li, P.; Qi, X.; Zhang, H.; Wang, X.; Jin, Q. The effect of fatty acid composition on the oil absorption behavior and surface morphology of fried potato sticks via LF-NMR, MRI, and SEM. **Food Chemistry: X**, v. 7, 100095, 2020. <https://doi.org/10.1016/j.fochx.2020.100095>

Zia, M. A.; Shah, S. H.; Shoukat, S.; Hussain, Z.; Khan, S. U.; Shafqat, N. Physicochemical features, functional characteristics, and health benefits of cottonseed oil: a review. **Brazilian Journal of Biology**, v. 82, e243511, 2022. <https://doi.org/10.1590/1519-6984.243511>