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Evolution of Oil Quality Parameters (Peanut, Palm, Soybean and Sunflower) According to the Number of Fryings

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Abstract

Frying is one of the most widespread cooking methods worldwide, particularly in the food industry and catering. It involves the use of oils subjected to high temperatures, which cause physicochemical reactions that can alter their nutritional and organoleptic properties. This work aims to evaluate the quality of four vegetable oils subjected to eight 10-minute frying cycles at 180˚C. After each cycle, a sample is taken to analyze various parameters: acid value, peroxide value, browning, and color variation. The results show that after eight frying cycles, the acid value of all oils exceeds the limit set by the *Codex Alimentarius* (0.60 mg KOH/g of oil), with respective values of 1.98 (peanut), 1.27 (palm), 1.03 (soybean), and 1.19 mg KOH/g (sunflower). Only soybean oil remained compliant with the standard up to the fifth frying (0.58 mg KOH/g). Peroxide values increased progressively in all oils, but remained below the threshold set by ISO 3960 (10 $Meq \cdot O_2 \cdot kg^{-1}$) after eight cycles. In terms of stability to triglyceride degradation and color change, sunflower oil was found to be the most stable, followed by soybean, peanut, and finally palm oil. Regarding oxidation, palm (3.407 $Meq \cdot O_2 \cdot kg^{-1}$) and soybean (3.493 $Meq \cdot O_2 \cdot kg^{-1}$) oils were found to be the most resistant, followed by sunflower (3.994 $Meq \cdot O_2 \cdot kg^{-1}$) and peanut (5.722 $Meq \cdot O_2 \cdot kg^{-1}$) oils. This work highlights the importance of choosing oil based on its behavior when frying.

Keywords

Vegetable Oils, Frying, Peroxide Value, Acid Value, Stability, Color

1. Introduction

Deep frying is a widely used culinary process that involves cooking food by immersing it in oil heated to high temperatures, typically between 155˚C and 190˚C [1]. Beyond its role in heat transfer, deep frying induces complex physicochemical transformations in oils, impacting their stability, fatty acid composition, and promoting the appearance of undesirable substances such as peroxides and polymers [2]. These alterations can significantly modify the nutritional profile as well as the safety parameters of fried products.

Most vegetable oils, especially those rich in polyunsaturated fatty acids such as soybean and sunflower oils, are highly vulnerable to oxidation and thermal degradation [3]-[5]. This process is exacerbated by the high temperature of the oil and the presence of water vapor and other compounds released from the food [6]. Although high temperatures (180˚C) may help reduce the loss of some nutritional compounds, studies have shown that more moderate temperatures (140˚C or 165˚C) can better preserve sensitive nutrients such as carotenoids [6]-[9]. The presence of antioxidants, whether natural or added, can slow down these degradation processes and thus extend the shelf life of frying oils [10]. Some of the most commonly used oils for frying include peanut oil, palm oil, soybean oil, and sunflower oil. The frequent reuse of these oils raises important questions regarding the deterioration of their quality and stability over frying cycles. It is therefore essential to understand how the quality parameters of oils change over time.

This work aims to provide essential information on the quality of cooking oils subjected to the frying process. The methodology will include oil selection, establishment of the frying procedure (defining the temperature, type of food, duration of each cycle, and number of cycles), as well as regular analyses after each cycle to assess chemical and physical changes in the oils. The results will be compared between different oils and according to the number of fryings, using statistical methods to identify trends and correlations. This research is of paramount importance for the preservation of quality and food safety.

2. Materials and Methods

2.1. Materials

The plant material consists of palm, soy, peanut and sunflower oil. The choice of

Figure 1. Peanut oil.

Figure 2. Soybean oil.

Figure 3. Palm oil.

Figure 4. Sunflower oil.

Figure 5. Frozen potato.

frying oils is based on their physicochemical characteristics and their common use. **Figures 1-5** show the samples of peanut, soybean, palm, sunflower oils and frozen potato, respectively.

2.2. Methods

2.2.1. Sample Preparation

Frying without the incorporation of fresh oil was applied. This process causes the evaporation of water present on the surface of the food, thus promoting its dehydration and the formation of a crust [11].

A series of eight fryings at 180˚C/10min, with an initial volume of oil used of 2 liters and 400 g of frozen potato.

The different oil samples analyzed are collected after each 10-minute series of frying.

2.2.2. Determination of Acid Number

The determination of the acid number is based on the official method of the Association of Official Analytical Chemists (AOAC) and ISO 660:2020, which describes methods for titration of free fatty acids in oils and fats [12].

The acid index (AI) is the number of milligrams of potassium hydroxide required to neutralize the free fatty acids present in one gram of fat [13]. This index measures the quantity of free fatty acids resulting from the hydrolysis and oxidation reactions of triglycerides [14]. The acid index is determined by calculation, using the formula:

$$\text{AI} = \frac{56.1 \times N(\text{NaOH}) \times V(\text{NaOH})}{m(\text{prise d'essai})} \quad (1)$$

- ✓ V: Volume of KOH solution used (mL);
- ✓ N: Normality of the KOH solution (Eq/L);
- ✓ 56.1: Molar mass of KOH (mg/mmol);
- ✓ m: Mass of the oil sample analyzed (g).

2.2.3. Determination of the Peroxide Value

The reference peroxide index was determined by the standardized method NF T60-220 [15]. The principle of this method is based on the titration by a sodium thiosulfate solution of the iodine molecules released by oxidation of the iodides by the hydroperoxides of the sample solubilized in an acetic acid/chloroform mixture.

The results are expressed in $\text{Meq}\cdot O_2\cdot \text{kg}^{-1}$.

$$\text{Ip} = \frac{10 \times N(V_1 - V_0)}{m} \quad (2)$$

- ✓ V_1 = Volume of sodium thiosulfate used for the sample (mL);
- ✓ V_0 = Volume of thiosulfate used for the blank (mL);
- ✓ N = Normality of sodium thiosulfate solution (Eq/L);
- ✓ m = Mass of the oil sample analyzed (g).

2.2.4. Determining the Color Parameter

The color of nectar samples was measured using a colorimeter (type: KONICA MINOLTA, Japan) based on the CIELAB color system (L^*, a^*, b^* and L^*, C^*, h, YI). The color parameters (L^*, a^*, b^* and L^*, C^*, h, YI) were measured 3 times for each sample. L^*, a^*, b^* describe black-white, Green-Red and Blue-Yellow colors respectively ($-b$ = Blue, $+b$ = Yellow) (**Figure 6**) [16]. The brownness index (BI) is calculated using the following formula: a positive value indicates a tendency to yellow, while a negative value indicates a tendency to blue the sample. The BI is given by the following formula:

$$\mathrm{BI} = \frac{100\left(X - 0.31\right)}{0.172} \quad X = \frac{\left(a^* + 1.75L^*\right)}{(5.645L^* + a - 3.012b^*} \tag{3}$$

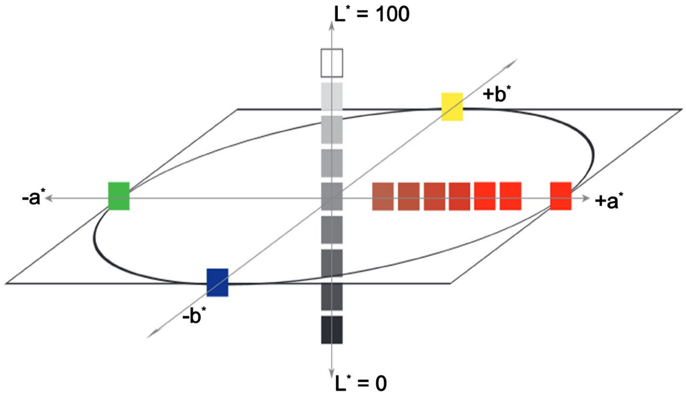

Figure 6. Illustration of color parameters (*a*, *b*, *L*) [16].

2.2.5. Statistical Analyses

Statistical analyses were performed using one-way ANOVA with R software version 3.2.4 Revised (2018-03-16, R-70336). Analyses were repeated three times per sample for each frying series. The *X* value of each sample is assigned a superscript letter ($X(i)$ where i = *a*, *b*, *c*, …). Samples with the same letter are not statistically different at the 5% level.

3. Results and Discussion

This section explores the results on the degradation of peanut, palm, soybean, and sunflower oils after multiple frying cycles. Changes in acid value, peroxide value, and color will be analyzed to understand how frying cycles affect their quality.

3.1. Frying, Samples, and Fried Potatoes

The steps of frying are illustrated in **Figure 7(a)-(c)**.

(a) (b) (c)

Figure 7. Oil, frying, and fried potato.

Figure 8 and Figure 9 show the oil and fried potato samples respectively after each 10-minute frying at 180˚C.

Figure 8. Eight oil samples from the first to the eighth frying.

Figure 9. Samples of French fries.

3.2. Acidity Index

The acidity index (AI) is an indicator of the degradation of oil during cooking. Table 1 shows the acidity index values of each oil sample before the series of fryings at 180˚C for 10 minutes.

Table 1. Acidity index values of each oil sample before the series.

Oils	Peanut oil	Palm oil	Soybean oil	Sunflower oil
Acidity index mgKOH/g oil	0.971 ± 0.003	0.251 ± 0.003	0.111 ± 0.003	0.388 ± 0.003

After the first frying, the results show an increase in the acidity index in each type of oil due to the breakdown of triglycerides (Figure 10).

The evolution of the acid number of oils during frying cycles highlights significant variations depending on the type of oil. From the first frying, an increase is observed for all the oils analyzed. Crude peanut oil, for example, sees its acid number increase from 0.973 ± 0.003 mg·KOH·g^{-1} to 1.119 ± 0.019 mg·KOH·g^{-1}, an increase of 15% compared to the control. Palm oil records an even more marked increase, going from 0.251 ± 0.003 mg·KOH·g^{-1} to 0.446 ± 0.015 mg·KOH·g^{-1}, an increase of 77%. For soybean oil, the acid number increases from 0.111 ± 0.003

mg·KOH·g^{-1} to 0.139 ± 0.009 mg·KOH·g^{-1} (25%), while sunflower oil increases from 0.388 ± 0.003 mg·KOH·g^{-1} to 0.474 ± 0.009 mg·KOH·g^{-1}, a 22% increase.

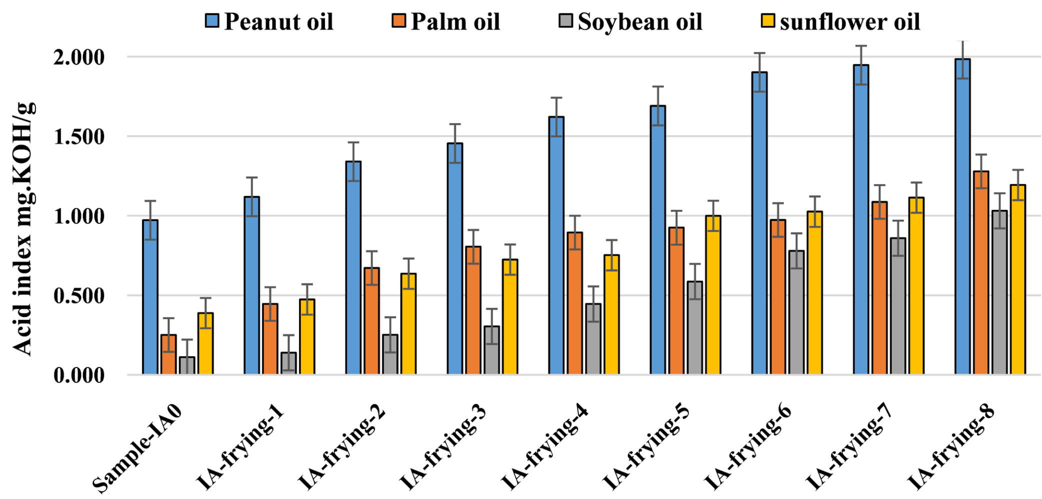

Figure 10. Evolution of acid indices as a function of frying numbers.

After the first round of frying, only crude peanut oil exceeded the standard of 0.60 mg·KOH·g^{-1} set for refined oils. However, after eight frying cycles, all the oils studied saw their acid index exceed this reference value. Sunflower oil reached 1.194 mg·KOH·g^{-1}, while soybean oil recorded 1.032 mg·KOH·g^{-1}. For refined palm oil, the value climbed to 1.179 mg·KOH·g^{-1}, an increase that is consistent with the results obtained by Ndjouenkeu *et al.* (2002), who measured 1.50 mg·KOH·g^{-1} after 120 minutes of frying at 180˚C [17]. Peanut oil shows the highest increase, reaching 1985 mg·KOH·g^{-1} after eight fryings.

These values are significantly higher than those reported by Yilmaz *et al.* (2023), who measured 0.063 mg·KOH·g^{-1} on five brands of oils under similar conditions [18]. Similarly, the indices recorded in this study exceed those obtained by Khelifa (2017) on the mixed oil "Elio" (80% soybean, 20% sunflower), which had an index of 0.735 mg·KOH·g^{-1} after 8 hours of heating [19].

According to Dobarganes and Márquez-Ruiz (2015), free fatty acids can, under the influence of high temperatures, be transformed into glycerols, which in turn lead to the formation of a toxic aldehyde called acrolein [20]. The acidification of a frying oil depends on many factors, including storage conditions before refining, where crude oils are subjected to prolonged temperature variations in sheds or ship holds [21]. This phenomenon accelerates autoxidation, the cause of oxidative rancidity responsible for the loss of quality of oils during storage.

3.3. Peroxide Index

Peroxide value is a parameter used to assess the oxidative stability of oils. Oxidation of oils during high-temperature frying is an unavoidable process that can affect oil quality and food safety. Table 2 shows the peroxide value of each oil sample before the frying series at 180˚C for 10 minutes.

Table 2. Peroxide index values of each oil sample before the series.

Oils	Peanut oil	Palm oil	Soybean oil	Sunflower oil
Peroxide index Meq·O_2/kg oil	0.730 ± 0.006	0.243 ± 0.006	0.248 ± 0.006	0.495 ± 0.006

After the first frying, the results reveal a very rapid increase in peroxide indices in all oil samples, as shown in **Figure 11**.

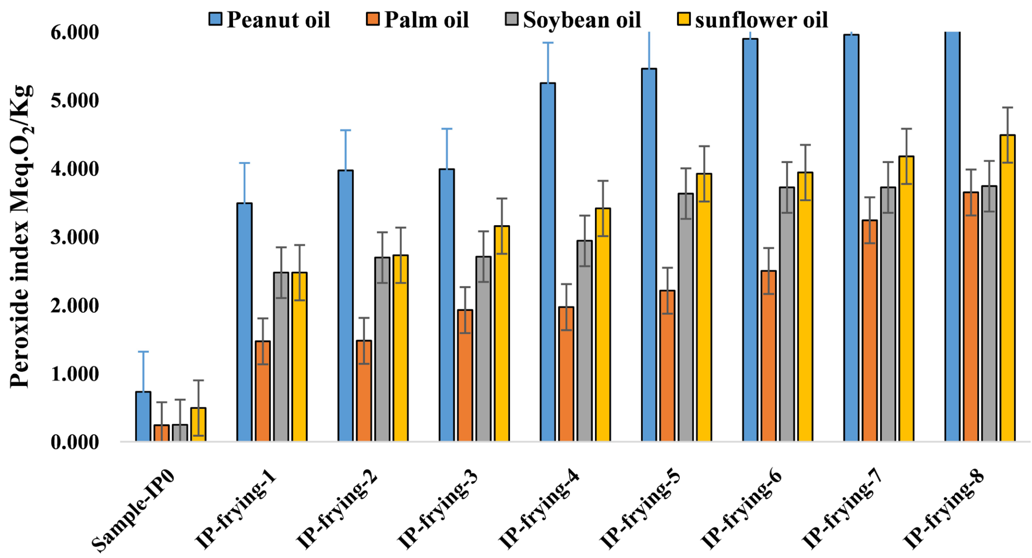

Figure 11. Changes in peroxide value with increasing frying cycles for the different oils.

The increase in the peroxide index (PI) during frying cycles is mainly due to the appearance of peroxidized compounds (ROO˚ peroxides) formed from unstable free radicals (R˚) of unsaturated fatty acids, as highlighted by [3]. This chemical transformation significantly affects the stability of oils used in frying.

In the case of peanut oil, the peroxide value after the first frying is 4.8 times higher than its initial value, and after eight fryings, it reaches 6.452 Meq·O_2·kg^{-1}, which is 8.8 times the control value of 0.730 Meq·O_2·kg^{-1}. However, this value remains below the maximum standard of 10 Meq·O_2·kg^{-1}.

For palm and soybean oils, the effect of frying is even more pronounced at the eighth frying, their peroxide values are 15 times higher than those of the control values. As for sunflower oil, its peroxide value increases from 0.495 to 4.489 Meq·O_2·kg^{-1}, an increase of 9 times compared to the initial value.

Sunflower oil is renowned for its superior food quality, offering a lemon-yellow color, a clear texture, and a mild, pleasant flavor [22]. It is particularly rich in linoleic acid (C18:2) and virtually free of linolenic acid (C18:3) [23]. However, due to its high level of unsaturation, it is very sensitive to heat and should not be heated above 180˚C or for a prolonged time [24]. Under the influence of heat, oxygen, and water, the oil undergoes complex chemical reactions that alter its quality and nutritional properties [25]. During frying, the degradation of fatty acids leads to the formation of products that are harmful to health, such as free radicals and aldehydes [26]. Additionally, polar compounds from these altered oils can cause liver and kidney enlargement, due to their involvement in detoxification mechanisms [27].

3.4. Brown Color Index

The brown color index is a measure to assess the brown tint of edible oils after several frying cycles. It reflects the presence of oxidized and polymerization compounds that form under the effect of heat. The evolution of the brown index over frying reveals distinct behaviors depending on the type of oil (**Figure 12**).

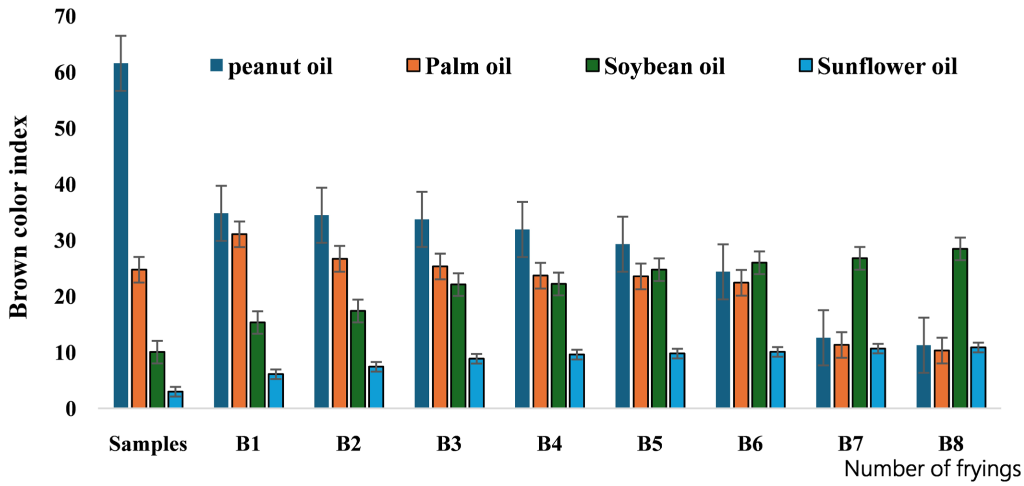

Figure 12. Evolution of the brown index as a function of the number of fritters.

The brown index decreases sharply for peanut oil (from 61.55 to 11.28), reflecting a progressive degradation of the compounds responsible for browning, probably due to oxidation or loss of initial pigments, while palm oil shows a notable reduction (from 24.74 to 10.32), indicating relative stability despite a progressive degradation of the colored constituents; on the other hand, soybean oil shows a significant increase (from 10.00 to 28.45), revealing an accumulation of thermal and oxidative degradation products, while sunflower oil, although subject to progressive oxidation, experiences a more moderate increase (from 2.98 to 10.86), less pronounced than that of soybean oil. According to Kpata-Konan *et al.* (2020), the evolution of the physicochemical indices of frying oils shows that oils rich in unsaturated fatty acids (such as soybean and sunflower oil) tend to brown more after several frying cycles [28].

3.5. Yellow Color Index (*b*)

When frying at high temperature (180˚C/10 min), the yellow color given by parameter (*b*) evolved for all oils (**Figure 13**).

Analysis of the results shows significant variations in the yellow color index depending on the oils and the number of frying at 180˚C.

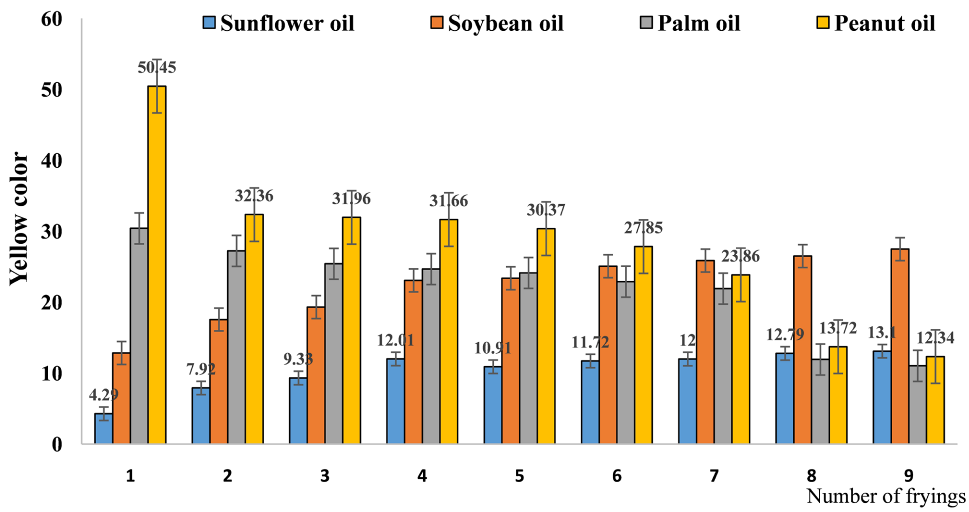

Figure 13. Evolution of the yellow color as a function of the number of fryings.

The yellowness index drops significantly from 50 to 12.34 after eight fryings in peanut oil. This suggests a significant degradation of yellow pigments under the effect of heat and oxidation. For palm oil, a decrease is also observed, from 30 to 11, which indicates a loss of yellow color, probably due to the degradation of carotenoids naturally present in palm oil. In sunflower oil, unlike the previous oils, the yellowness index increases, going from 4.29 to 12.13. This change could be due to the formation of new colored compounds under the effect of heat, resulting from the degradation of fatty acids or Maillard reactions. The increase is even more marked with soybean oil, going from 12.85 to 27.49. This increase suggests that frying causes a chemical change leading to the formation of additional yellow pigments. Several studies converge to demonstrate that repeated exposure of oils to high temperatures, particularly in frying processes, induces notable physicochemical alterations, manifesting mainly through changes in color. Renard highlights that chromatic variations constitute a reliable indicator of the thermal degradation of oils [29]. In a complementary manner, Schlienger emphasizes that the reuse of oils and the prolonged action of heat lead to a degradation of lipids, perceptible through organoleptic changes, particularly in color and odor [30]. Fatima *et al.* confirm the relevance of color as a key parameter for assessing the state of degradation of oils [31]. Jurid *et al.* (2020) report that refined palm oil, after several frying cycles, shows a significant increase in viscosity, marked darkening, and an accumulation of oxidized compounds [32]. Finally, Dodoo *et al.* (2022), through a colorimetric analysis of the oils used for frying sweet potato fries, observed a progressive blackening after five to six cycles of use [33]. Darkening and the formation of oxidized compounds indicate degradation, which makes monitoring the visual characteristics of oils crucial.

4. Conclusion

This work on the evolution of oil quality parameters (peanut, palm, soybean and sunflower) according to the number of frying highlights the impact of frying cycles on the physicochemical properties of vegetable oils, in particular their acidity, oxidative stability and colorimetric evolution. Analysis of acid and peroxide indices reveals a progressive deterioration in the quality of the oils. Sunflower oil is distinguished by better triglyceride stability and less color variation, while soybean oil maintains its compliance with standards up to the fifth frying. These results highlight the importance of choosing oils based on their resistance to thermal processes, in order to ensure optimized use in the food industry and catering, while preserving their nutritional qualities and safety. The absence of oil replenishment between frying cycles serves as a useful stress test to study degradation, but does not reflect real-world practices, where partial renewal limits toxicity and helps preserve quality.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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