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Loss of Vitamin E While Baking and Heating French Fries

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Abstract: Vitamin E, as the most important lipophilic antioxidant of eukaryotic cells, plays an important role in human nutrition. So far, information has focused on the content of vitamin E in raw food materials or foods, and its losses under various processes and culinary treatments. However, the different degradation rates of its eight different forms, four tocopherols and four tocotrienols, during the preparation of oven-ready products have not been clearly and in detail described. Therefore, the aim of our research was to determine the changes in the content of tocochromanols and to evaluate the risks of the loss of these substances while preparing frozen French fries baked in classic and microwave ovens. The tocochromanols were determined using reverse-phase high-performance liquid chromatography with an amperometric detector. The results showed a statistically insignificant loss of γ-tocopherol (γ-T), δ-tocopherol (δ-T), γ-tocotrienol (γ-T3) and δ-tocotrienol (δ-T3). Conversely, the losses of α-tocopherol (α-T), α-tocotrienol (α-T3), the total content of tocochromanols and the vitamin E content in α-tocopherol equivalents (α-TE) were statistically significant ($p < 0.01$). These losses were independent of the type of baking (conventional heating, heating with air circulation, grill, microwave heating, microwave and grill heating) and averaged at 0.80 mg/kg of the original fries (9.1% of the original content) for α-T, 0.44 mg/kg (36.6%) for α-T3, 1.11 mg/kg (12.7%) for the sum of the tocochromanols and 0.92 mg/kg (12.6%) for the vitamin E content expressed as α-TE. These dishes contained 0.4% to 26% of the daily requirement of vitamin E, based on a 100 g portion, depending on the fat used in the manufacture of the products. The choice of the right frying medium on the part of the manufacturer can increase the content of vitamin E both in the semi-finished product and in the final food, and consequently also its dietary intake.

Keywords: pre-fried products; tocopherol; tocotrienol; grill

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1. Introduction

Tocochromanols (vitamin E, i.e., tocopherols and tocotrienols, particularly α-tocopherol) are important in vivo lipophilic antioxidants that protect unsaturated fatty acid bonds in tissue lipids from radical oxidation reactions. Their action is indispensable, especially to protect bio-membranes and low-density lipoproteins [1]. Sufficient vitamin E intake can be an important factor in preventing the onset and development of cardiovascular diseases [2].

One of the most important and richest sources of vitamin E in the diet is vegetable oils [3,4]. Large quantities of vegetable oils are consumed as part of culinary processed foods [5,6]. Significant losses of tocochromanols can occur during this process, reaching up to 100% of the original content [1,7–9]. In the case of frying, the rate of loss was rapid when oxygen was available during the early stages of heating and decreased with prolonged heating. Other factors influencing vitamin E loss included the oil-surface-to-air ratio and the physical mixing of oxygen into the oil during heating. Some volatilization of vitamin E can also occur during prolonged frying operations, further decreasing the antioxidant capacity of the oil. Within this context, the complete depletion of tocopherols was described

in some vegetable oils markedly before reaching a content of polymerized triacylglycerols of 12% (i.e., before the end of lifetime of these oils). This may be a reason of inadequate vitamin E intake, at least in part of the population, according to some studies. Inadequate intake is more prevalent in females than males [3,5,7,10].

The losses of vitamin E during frying have been studied extensively [9,11–13]. However, the losses of tocochromanols during other culinary food processing methods such as baking, cooking and microwave heating have not been studied to such a large extent and the results of some published studies are striking [14,15]. Thus, the aim of this paper was to study the loss of tocopherols and tocotrienols while preparing food in an oven and in a microwave oven. The model food was pre-fried frozen fries, which are usually prepared by baking rather than frying in households. The loss of tocochromanols during the heating of fried fries in a microwave oven was also studied. This study is essential for public health, accurate dietary recommendations, food industry standards and consumer awareness.

2. Materials and Methods

2.1. Samples

The 11 samples of frozen pre-fried French fries included products from various local and multinational European producers purchased from a retail chain. The samples were stored at −18 °C before culinary processing and analysis. Four samples of fried fries purchased from various Prague (Czech Republic) fast food chains were processed immediately.

2.2. Culinary Conditions

The baking times and temperatures were derived from the preparation instructions on the product packaging. In a standard stainless steel kitchen oven (5H-496X; Fagor Industrial, Oñati, Spain), samples of pre-fried French fries (160 g distributed in one layer on the baking paper) were heated in three ways: (i) without air circulation at 200 °C for 15 min, (ii) with air circulation at 200 °C for 10 min and (iii) using a built-in grill at 200 °C for 15–18 min. Approximately halfway through the baking process, the fries were flipped.

Next, the pre-fried fries were prepared in a microwave oven (MW 4-17EG X; Fagor Industrial, Spain) with a frequency of 2450 MHz, a microwave power of 700 W and a grill power of 1000 W, in three ways: (i) using microwave irradiation at 100% device power for 8–10 min (160 g in a plastic bowl); (ii) using a combination of microwave irradiation at 55% power and the built-in grill at 45% power for 10–12 min (80 g in a ceramic bowl); (iii) by grilling them at 85% power for 20–22 min (80 g in a ceramic bowl). The finished samples were golden brown in colour and of standard sensory quality.

The samples of fried French fries from fast food chains were tempered to room temperature (60 g each), then spread in a single layer on a microwave-safe plate and re-heated in the microwave oven (EMM 2005; Electrolux, Stockholm, Sweden) at 700 W for 45 s.

All samples were homogenized on a laboratory grinder (Grindomix GM 200; Retsch, Haan, Germany) and kept in the freezer at −55 °C until they were analyzed.

2.3. Analytical Methods

2.3.1. Determination of Tocopherols and Tocotrienols

The sample (approximately 2.5 g) was mixed with 5 g of anhydrous sodium sulfate and fat was extracted three times with 40 mL of hexane. The resulting suspension was filtered, hexane evaporated and the residue dissolved in acetone (50 mL). The tocochromanols in the extracts were determined using reverse-phase high-performance liquid chromatography (LCP4020.31; Ecom, Prague, Czech Republic) with an amperometric detector (HP 1049A; Agilent Technologies, Santa Clara, CA, USA) and a working glass carbon electrode (Agilent Technologies, USA) under the conditions described by Fišnar et al. [9]. Two parallel determinations were performed on all 11 samples prepared in the six ways mentioned above and on 4 samples from fast food chains. The content of vitamin E in the total α-TE was calculated according to the formula [16] α-TE = α-T + 0.5 β-T + 0.1 γ-T + 0.03 δ-T + 0.3

α-T3 + 0.05 γ-T3. Use of the α-TE unit has been the accepted way of reporting vitamin E concentration in foods.

2.3.2. Determination of Dry Matter

Dry matter determination was based on drying to a constant weight (AB204-S; Mettler Toledo, Greifensee, Switzerland) according to ISO 1026:1982 [17]. Dry matter analyses were carried out in duplicate.

2.3.3. Determination of Fat

The fat content was determined gravimetrically according to EN ISO 659:2009 [18], adapted for Soxtec System HT 1043 (Tecator, Höganäs, Sweden), at a moisture content lower than 15% in the samples pre-dried at 45 °C. Fat analyses were carried out in duplicate.

2.3.4. Determination of Polymerized Triacylglycerols

The polymerized triacylglycerols (pTAG) were determined using high-performance size exclusion chromatography with refractometric detection as described by Sabolová et al. [19]. Polymerized triacylglycerol analyses were carried out in duplicate.

2.3.5. Determination of Fatty Acid Composition

Fatty acids were first converted into fatty acid methyl esters according to EN ISO 12966-2:2011 [20] and then analyzed using gas chromatography (Agilent 6890; Agilent Technologies, USA) with a flame ionization detector under the conditions described by Sabolová et al. [19]. Fatty acid analyses were carried out in duplicate.

2.3.6. Result Processing

All statistical calculations were performed using Microsoft Excel 2019 (Microsoft Corporation, Redmond, WA, USA). A paired *t*-test (p = 0.01) was used to assess the differences between the content of individual tocochromanols, the total tocochromanols and the vitamin E in frozen pre-fried fries and the losses of these analytes during culinary preparation. The effect of the baking method on the amount of tocochromanol losses was tested using a two-sample *t*-test at a probability level of p = 0.01. The loss of individual tocochromanols, the total content of tocochromanols and the vitamin E content in fried French fries heated in a microwave oven was assessed using a paired *t*-test at a probability of p = 0.05.

3. Results and Discussion

3.1. Content of Tocochromanols in Frozen Pre-Fried French Fries and Factors Affecting It

The information on the composition of the analyzed frozen pre-fried French fries is summarized in Table 1. The contents generally correspond with previously published data [21,22]. However, as Table 1 illustrates, the content of tocochromanols in the analyzed samples is within a relatively wide range. This concurs with a previous study about fried French fries from various restaurants and fast food establishments, fried potato chips and other similar fried snack products from the common market network [19].

Table 1. Composition of pre-fried French fries (11 samples).

	Content of Tocochromanols (mg kg^{-1})							
	α-T	**γ-T**	**δ-T**	**α-T3**	**γ-T3**	**δ-T3**	**T + T3**	**Vit. E (α-TE)**
Minimum	0.34	n.d.	n.d.	0.49	n.d.	n.d.	1.31	0.54
Maximum	16.63	1.81	0.55	2.85	0.44	0.19	18.27	16.85
Average	6.61	0.34	0.22	0.95	0.20	0.06	8.37	6.94
Median	5.13	0.23	0.23	0.65	0.20	n.d.	6.92	5.36

Table 1. *Cont.*

	Other Parameters							
	Water	**Fat**	**pTAG**	**SFA**	**O**	**L**	**ALA**	**TFA**
	(g 100 g^{-1})	**(g 100 g^{-1})**	**(% in Fat) ***			**(%)**		
Minimum	61.79	2.04	0.73	9.85	27.81	8.15	0.19	0.19
Maximum	76.18	4.59	6.15	51.28	66.72	58.13	1.99	0.99
Average	70.29	2.96	4.51	30.39	40.22	27.05	0.40	0.52
Median	72.11	2.78	5.49	18.37	39.16	21.86	0.24	0.52

* % in fat—percentage of polymerized TAG of the total amount of TAG; %—percentage of individual fatty acid in the total amount of fatty acids; SFA—saturated; O—oleic; L—linoleic; ALA—linolenic; TFA—*trans*-unsaturated fatty acid. Note: According to the manufacturers' data, sunflower oil was used to fry the analyzed semi-finished products in six cases, palm oil in four cases and a mixture of rapeseed and sunflower oil in one case. In two cases, these data do not correspond at all, and in two cases, they partially do not correspond with the established composition of fatty acids. In fact, the study noted five cases of palm oil, two of sunflower oil, two of sunflower oil with a small amount of palm oil, one mixture of sunflower and palm oil and one mixture of rapeseed and sunflower oil. The fat or oil used to prepare (fry) the food was estimated based on the typical fatty acid composition of common fats and oils [23,24].

It can be assumed that the content of tocochromanols (and vitamin E) in fried potato foods is affected by three factors: (i) fat content, (ii) type of fat or oil used for frying and (iii) tocopherol losses during frying, i.e., the conditions of previous use in the fryer and the degree of oxidative damage in the frying fat or oil. The initial sample of potatoes contains an insignificant amount of tocochromanols [25] and the vast majority of tocochromanols present in fried potatoes come from the fat or oil used for frying. However, it is not possible to neglect a loss of vitamin E during the frozen food storage [26].

The α-tocopherol content, the total tocochromanol content and the content of vitamin E in the α-TE in the commercially available pre-fried French fries was analyzed and processed using statistical processes. Multidimensional linear correlation and regression analysis were used to infer causal relationships between the independent and dependent variables and to assess the effect of the above-mentioned factors (with the exception of possible losses during freezing storage of pre-fried French fries). Three parameters were chosen as possible independent variables that potentially affect the α-tocopherol content, total content of tocochromanols and vitamin E content in α-TE in the analyzed foods. They were fat content; the content of pTAG in the fat of the analyzed food, characterizing the degree of oxidative and high-temperature damage of the frying oil [27]; the content of saturated fatty acids, oleic acid, linoleic acid and α-linolenic acid (always as a proportion of the sum of all fatty acids present), characterizing the type of fat or oil used for frying. Collinearity, which refers to a linear relationship between variables, was not detected among these parameters [28].

The content of α-tocopherol had a statistically significant effect ($p < 0.05$) [29] only on the linoleic acid content. The linoleic acid, the saturated fatty acids and the fat content had statistically significant effects ($p < 0.05$) on the total tocochromanol and vitamin E content in the α-TE (see Table 2). The content of all the analytes was mainly influenced by the linoleic acid content, i.e., the unsaturation of the fat or oil used to prepare pre-fried French fries (see Table 3) [30].

Table 2. Models describing α-tocopherol content, total tocochromanol content and vitamin E content in α-TE in commercially available pre-fried frozen French fries as a function of fat content and the frying medium used (the degree of oxidative and high-temperature damage caused by the frying bath on the monitored analytes is not statistically significant at, $p < 0.05$).

Analyte	**Obtained Model**	***p***
α-T	$=(0.25 \pm 0.02)$ L	$<10^{-4}$
T + T3	$=(0.13 \pm 0.05)$ L $-$ (0.12 ± 0.04) SFA + (2.86 ± 0.85) Fat	$<10^{-5}$
Vitamin E (α-TE)	$=(0.15 \pm 0.05)$ L $-$ (0.10 ± 0.04) SFA + (2.02 ± 0.85) Fat	$<10^{-5}$

Table 3. Determination coefficients characterizing the effect of selected factors on the content of tocochromanols and vitamin E in commercially available frozen pre-fried French fries.

	α-T	T + T3	Vitamin E
The whole model (see Table 2)	0.917	0.965	0.954
Linoleic acid *	0.917	0.915	0.919
Saturated fatty acids *	-	0.688	0.716
Fat content *	-	0.786	0.706

* A high coefficient of determination indicates the high influence of the relevant factor (independent variable) on a given dependent variable (i.e., the content of tocochromanols or vitamin E) [30].

Thus, the content of pTAG, characterizing the degree of oxidation and further damage of the fryer [27] used to prepare the pre-fried French fries, did not affect the analytes. This contrasts with the previous study where the content of pTAG had a statistically significant effect on the α-tocopherol, total tocochromanols and vitamin E within French fries from a variety of restaurants and fast food establishments and within fried potato chips and other similar fried snack products from the commercial network [19]. The analytes decreased with an increase in the content of pTAG in this study because the content of tocochromanols in the fryer generally decreases as the frying process is repeated [31]. This decrease can be expressed as a function of time (the number of times the frying process is repeated) or as a function of the pTAG content [11], which increases with repeated frying [27,31] and characterizes the degree of the oxidative and high-temperature damage of the frying fat or oil [31]. In contrast, in the case of a continuous process, typical in the production of pre-fried products, the level of the monitored substances can be expected to be roughly constant.

In all the cases, the content of the analytes in the analyzed pre-fried French fries (i.e., α-tocopherol, total tocochromanols and vitamin E content in α-TE) increased with the fat content (if its content had a statistically significant effect on the analyte) and the linoleic acid content, and decreased with the total content of saturated fatty acids (if their content had a statistically significant effect on the analyte). This is logical and corresponds with the previous literature (see below).

A positive correlation between linoleic acid and α-tocopherol ($p < 0.05$) and γ-tocopherol was found in the content of individual tocopherols under the different heat-free treatments for fats and oils [32]. Unsaturated vegetable oils generally have a higher tocopherol content than saturated oils, which is related to the main biochemical function of the tocopherols in plants, i.e., the protection of polyunsaturated fatty acids against peroxidation [33]. Furthermore, during repeated frying, the tocopherols decreased faster in less unsaturated fats and oils [31]; as a result, found in fats and oils after frying under commercial conditions was the presence of typically higher levels of vitamin E in highly unsaturated vegetable oils (i.e., sunflower, cottonseed and corn oil) than in less unsaturated vegetable oils (i.e., palm kernel oil and partially hydrogenated soybean oil) [34].

The effect of the oil used on the vitamin E content in fried foods is derived from previous literature [35] and has been confirmed in a study of fried French fries from various restaurants and fast food establishments, fried potato chips and other similar fried snack products [19]. This can also be seen in Figure 1, which compares the vitamin E content of the analyzed frozen pre-fried French fries depending on the frying medium used.

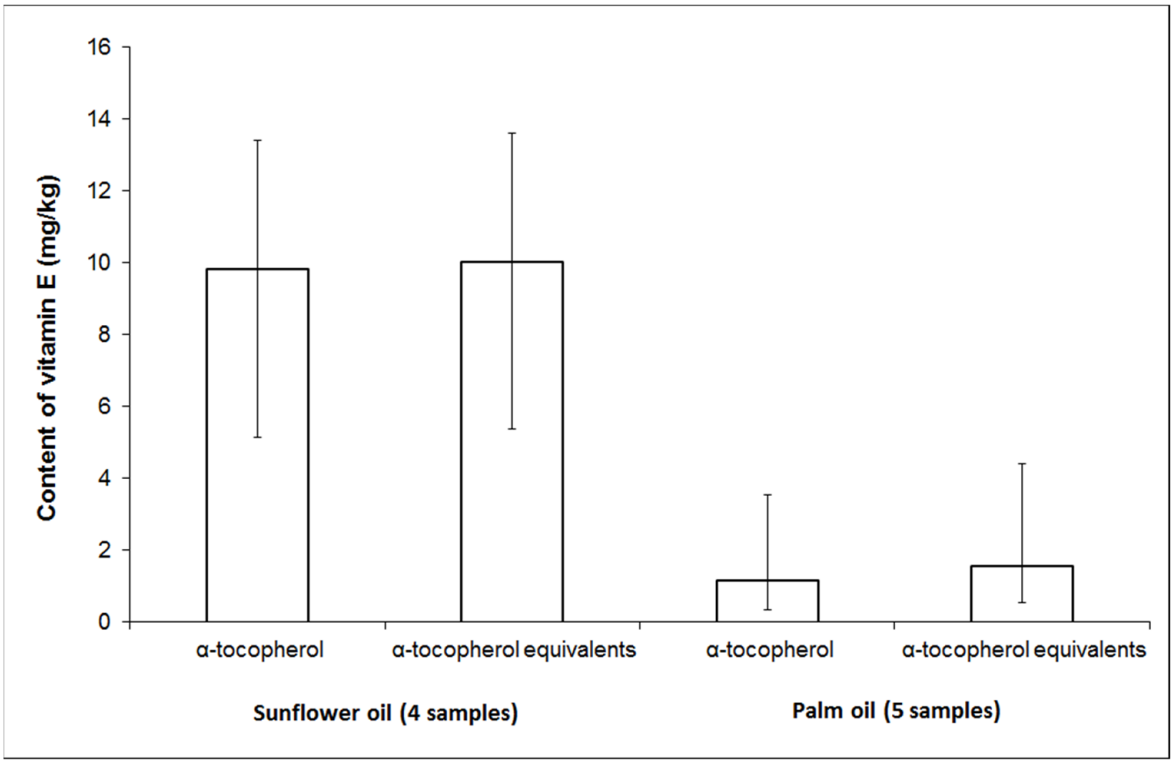

Figure 1. The content of vitamin E in the analyzed pre-fried frozen French fries depending on the frying medium used. The results are presented as averages and spreads of the values for fries prepared using sunflower oil (four samples) and palm oil (five samples).

3.2. Losses of Tocochromanols While Preparing French Fries Using Commercially Available Pre-Fried Frozen Products by Baking Them in Conventional and Microwave Ovens

Table 4 documents the content of the individual tocochromanols, the total tocochromanol content and the vitamin E content in the α-tocopherol equivalents analyzed in the baked French fries. The baking method used did not have a statistically significant effect on the content of any of the monitored analytes ($p < 0.01$). However, the content of the monitored analytes was significantly higher among baked French fries than in the pre-fried frozen products (compare Tables 1 and 4). Significant moisture losses occurred during baking (irrespective of the appliance used and the method of heating), ranging from 22.0 to 57.3% of the weight of the starting pre-fried frozen products (on average 39.5%). If these weight losses while baking French fries were accounted for and the results of all baking methods were processed together, the γ-T, δ-T, γ-T3 and δ-T3 losses were statically insignificant, while losses of α-T, α-T3, total tocochromanols and the vitamin E content in α-tocopherol equivalents were statistically significant ($p < 0.01$). These losses were independent of the baking method used ($p < 0.01$) and averaged at 0.80 mg/kg (maximum 4.85) of the original pre-fried frozen products for α-T, 0.44 (1.52) mg/kg for α-T3, 1.11 (5.20) mg/kg for the sum of tocochromanols and 0.92 (4.92) mg/kg for the α-TE content of vitamin E. These values represent an average of 9.1 (maximum 53.4)% of the original α-T content, 36.6 (98.4)% of α-T3, 12.7 (37.2)% of the sum of tocochromanols and 12.6 (51.4)% of the content of vitamin E expressed in α-TE.

Table 4. Content of tocochromanols (mg/kg) in French fries prepared from pre-fried frozen material by baking them in a conventional and a microwave oven.

	α-T	γ-T	δ-T	α-T3	γ-T3	δ-T3	T + T3	Vit. E (α-TE)
Minimum	0.49	n.d.	n.d.	0.48	n.d.	n.d.	1.63	0.71
Maximum	34.27	3.83	1.17	3.82	2.32	0.74	37.13	34.58
Average	9.90	0.71	0.39	1.13	0.45	0.14	12.71	10.34
Median	6.63	0.31	0.36	0.77	0.20	n.d.	9.48	7.26

n.d. = not detected.

The results from classic baking are comparable to those of an analogous study from 1965 [29] and also to the loss of tocochromanols and vitamin E found generally in studies about the loss of these analytes during the baking of different foods [25,36,37]. In these works, the losses of tocochromanols and vitamin E during baking typically ranged from 0 to 30%. The only exception were the losses noted in the production of rye bread (30–50% of the original content), which also included growth time (18 h) [25] and wheat bread (47.6%), which has a low origin content of tocochromanols [37].

There is a relatively large number of studies about microwave heating that have studied the losses of tocochromanols and vitamin E in vegetable oils [38–41]. Contrasting this study, the analytes typically lost 10% of the original content (compared to the heating time for baking French fries this study). These studies of vegetable oil and this study may differ in the temperatures achieved while microwave-heating the vegetable oils compared to other foods (due to the presence or absence of water in the material). Oils typically reach temperatures of 200–250 °C after 20 min of heating in the microwave oven [42,43]; water-containing foods have significantly lower temperatures during and after microwave heating [44]. This, for instance, leads to low tocochromanol losses (up to 20% of the original content) which were observed when warming various plant seeds and seed oils in a microwave oven for 15 to 20 min [45–47].

3.3. Evaluation of French Fries, Prepared from Commercially Available Pre-Fried Frozen Products Baked in Conventional and Microwave Ovens, as a Source of Vitamin E

Previous estimates of the biological activity among individual tocopherols and tocotrienols were obtained via experiments with laboratory animals. These estimates expressed the vitamin E activity in α-tocopherol equivalents (α-TE). β-tocopherol displayed approximately 50% activity of α-T, γ-T 10% and δ-T 3%. Tocotrienols have about two-thirds less biological activity than the corresponding tocopherols (i.e., α-T3 30% α-T activity and β-T3 5% α-T activity; otherwise, T3 activity is not considered or is neglected) [44]. The recommended dietary allowance (RDA) of vitamin E has been identified as 12 mg α-TE [48].

However, cotemporary research, based on the α-tocopherol transfer protein, suggests that the human metabolism is only selective for 2R isomers of α-tocopherol. Therefore, recent literature suggests that only 2R isomers of α-tocopherol exhibit vitamin activity for humans. The other vitamin E vitamers (i.e., β-, γ- and δ-tocopherol and tocotrienols) and 2S isomers of α-tocopherol are absorbed from the human digestive system but not recognized in the liver by the α-tocopherol transfer protein. They therefore do not contribute to the vitamin E requirement. These compounds are then excreted into the bile and only very small quantities enter the cells. The current estimated average requirement (EAR) for vitamin E (i.e., the value of the intake estimated to meet the need for half of healthy individuals) is 12 mg of 2R-α-tocopherol per day. This need correlates with the level of 12 µmol of α-tocopherol/L in the blood serum, where the rate of oxidative-induced hemolysis is normal. The recommended dietary allowances (RDA, i.e., dietary intake that adequately meets the need for 97–98% of healthy individuals in the group) of 2R-α-tocopherol (vitamin E) is 15 mg/day [44,49].

French fries prepared from frozen pre-fried semi-finished products by baking (always 100 g) fulfill between 0.6% to 28.8% of the daily requirement for vitamin E (average 8.6%, median 6.1%) considering older recommendations for vitamin E intake (i.e., 12 mg α-

TE/day), or, more precisely, between 0.3% to 22.8% (mean 6.6%, median 4.4%) considering newer recommendations for vitamin E intake (i.e., 15 mg α-tocopherol per day). However, it is advisable to discuss the content of tocopherols in the fat of the analyzed foods rather than in the analyzed foods themselves while assessing individual foods as a source of vitamin E because it is undesirable to increase vitamin E intake while increasing excess fat intake (and energy: the composition of the consumed fat is a risk factor in the origin and development of many diseases, especially cardiovascular ones) [50,51].

In the analyzed samples of baked French fries, the content of α-tocopherol in fat ranges from 13.4 to 441.9 mg/kg (mean 176.7 mg/kg, median 149.1 mg/kg), the total tocochromanol content ranges from 44.5 to 482.3 mg/kg (mean 230.0 mg/kg, median 196.1 mg/kg) and the vitamin E content in α-TE ranges from 19.4 to 447.0 mg/kg (mean 185.3 mg/kg, median 157.3 mg/kg). This are values comparable to those reported in the previous literature [22,26]. If we consider the reference value of the fat intake at 70 g [48] and the older recommendation for vitamin E intake (see above), then the vitamin E content of the fat intake should be at least 171 mg α-TE/kg (to ensure sufficient vitamin E intake and adequate fat intake). Considering the same fat intake reference value and newer recommendations for vitamin E (see above), the vitamin E content in the fat intake should be at least 214 mg α-tocopherol/kg.

However, as illustrated by the histograms in Figures 2 and 3, a significant proportion of the baked French fries analyzed do not reach the given level. This is observed as 54.8% of the samples analyzed according to the older recommendations for vitamin E and 57.1% of samples according to the newer recommendations (i.e., a recommendation considering only activity of α-tocopherol and recommending higher intakes of the vitamin, see above). That is, these foods are, in more than half of cases, a richer source of fat than vitamin E (accounting for the reference intakes of these nutrients). As Figures 2 and 3 show, baked pre-fried French fries, fried in palm fat, are a richer source of fat than vitamin E. On the other hand, baked pre-fried French fries in which sunflower oil was used as the frying medium are in most cases a richer source of vitamin E than fat (accounting for the reference intakes of these nutrients). This confirms the significant influence of the frying oil used on the quality of the food.

3.4. Loss of Tocochromanols during the Re-Heating of Fried French Fries in a Microwave Oven

Table 5 documents the content of the individual tocochromanols in fried French fries before and after heating them in a microwave oven. The content of the monitored analytes was always slightly higher in fries after microwave heating than before heating. Meanwhile, heating the fries in the microwave oven lead to some moisture losses, ranging from 6.5% to 9.1% of the original weight of the fries (on average 7.9%). Considering these weight losses, it was found that there were no statistically significant changes in the tocochromanol content ($p < 0.05$) while heating fried French fries in the microwave oven. There was no heat loss of tocochromanols (and vitamin E) while heating the fried French fries in the microwave oven.

These results are somewhat different from the previous literature about the loss of tocopherols during microwave heating but are fully consistent with the other experiments carried out in this study.

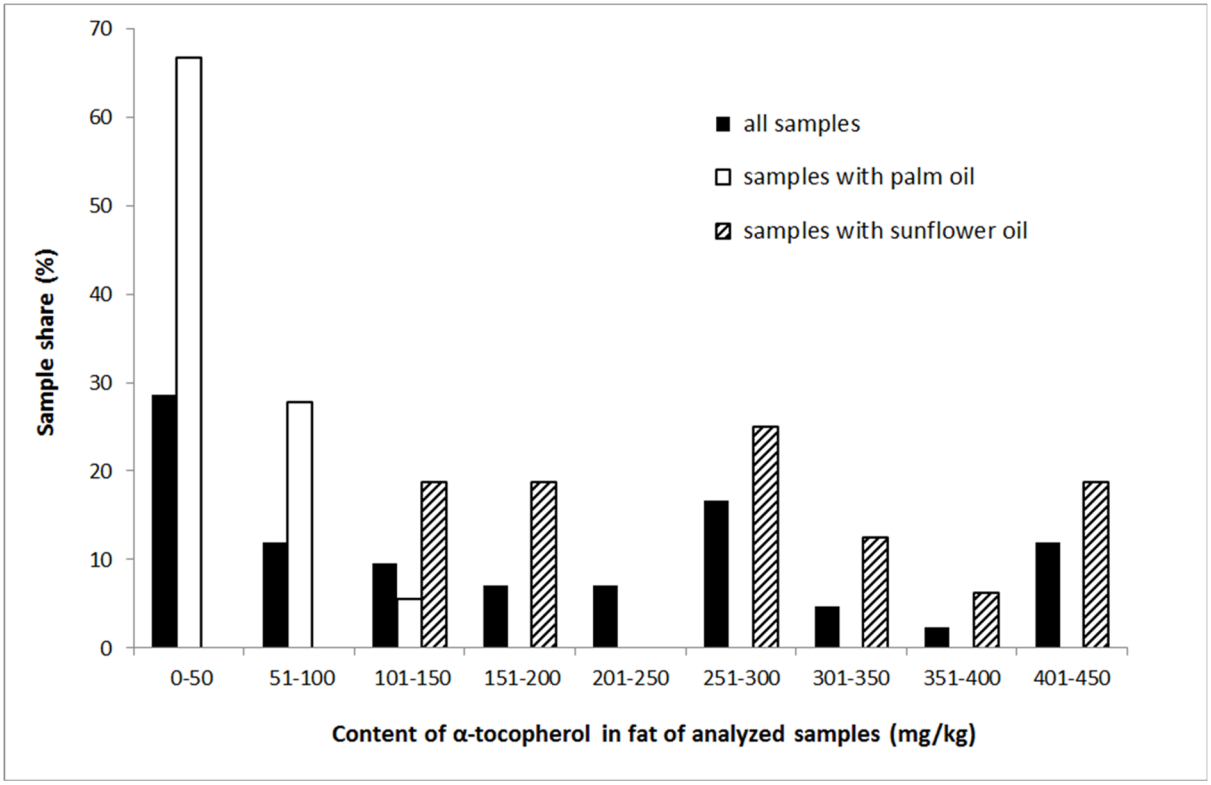

Figure 2. Relative frequency histograms of the content of α-tocopherol in the fat of the analyzed baked French fries (all samples $n = 70$)).

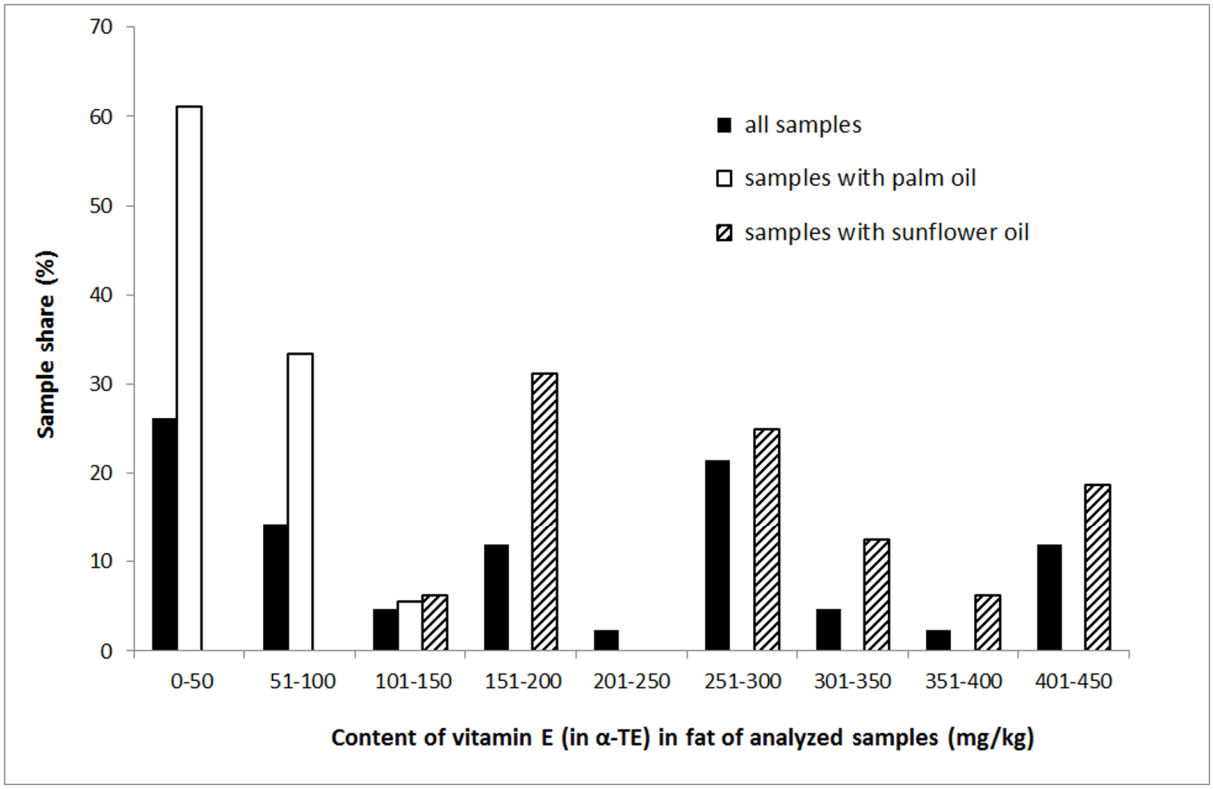

Figure 3. Relative frequency histograms of the content of vitamin E in α-TE in the fat of the analyzed baked French fries (all samples $n = 70$).

Table 5. Content of tocochromanols (mg/kg) in fried French fries before and after microwave heating.

	Tocochromanol Content in Fried French Fries Before Heating in a Microwave Oven							
	α-T	**γ-T**	**δ-T**	**α-T3**	**γ-T3**	**δ-T3**	**T + T3**	**Vit. E (α-TE)**
Minimum	1.17	0.13	n.d.	0.30	0.33	0.15	3.77	1.58
Maximum	46.08	10.72	3.35	18.78	16.19	2.66	75.13	47.50
Average	26.07	3.40	1.18	7.07	6.15	1.15	45.03	28.84
Median	32.46	1.47	0.27	1.32	0.86	0.55	55.17	39.03
	Tocochromanol Content in Fried French Fries After Heating in a Microwave Oven							
	α-T	**γ-T**	**δ-T**	**α-T3**	**γ-T3**	**δ-T3**	**T + T3**	**Vit. E (α-TE)**
Minimum	1.08	0.12	n.d.	0.43	0.36	0.17	3.60	1.46
Maximum	52.58	12.48	3.78	20.66	18.89	3.47	85.78	55.06
Average	31.82	4.78	1.21	7.28	6.78	1.38	53.25	34.82
Median	36.60	1.71	0.26	2.33	2.70	0.84	68.06	43.88

4. Conclusions

There is no statistically significant loss of tocochromanols while heating fried French fries in a microwave oven. The loss of vitamin E, which occurs while preparing pre-fried frozen French fries by baking and microwave-cooking them, is only approximately 10% of the original content. Thus, the vitamin E content of the cooked French fries comes, almost entirely, from the vitamin content in the original product and is mainly influenced by the fat or oil used to pre-fry them. From the manufacturer's point of view, it is necessary to look for compromises and choose the right frying medium. The high vitamin E content is an important factor, but other factors to consider include the different resistance of different fats and oils to oxidation, the other changes that take place during frying, the different risks of different fats and oils with regard to the development of cardiovascular disease and the different sensory quality of fried foods prepared with different fats and oils. For individuals, knowledge of nutrient depletion is important to enable them to make informed dietary choices and ensure they meet their vitamin E requirements. It can motivate a diversified diet to compensate for potential nutrient losses in oven-prepared products. Awareness can prevent over-reliance on a single food source, leading to a more balanced nutrient intake.

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