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Tocochromanol Content in Commercially Prepared Fried Foods

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Abstract

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In the scientific literature, there is not reliable information about the vitamin E content of commercially prepared fried foods. Therefore, tocochromanols were determined in 44 samples of french fries and 33 samples of potato chips and similar fried snacks. The total tocochromanol content of the french fries varied in the range of 1.7–96.9 mg/kg, α-tocopherol 0.3–76.1 mg/kg, and vitamin E (expressed in α-tocopherol equivalents) 0.6–76.4 mg/kg. The total content of tocochromanols in the fried snack products varied in the range of 39.9–204.6 mg/kg, α-tocopherol 20.4–133.7 mg kg, and vitamin E 29.8–134.6 mg α-tocopherol equivalent/kg. After a comparison of fat content, and taking into account the reference intake of fat and vitamin E, the french fries were generally a worse source of vitamin E than fat. The fried snack products were usually a better source of vitamin E than fat. In the both types of fried foods, the total content of tocochromanols was most influenced by the total content of fat. The content of α-tocopherol and the vitamin E content were mainly affected by the kind of fat (oil) used for frying.

Keywords: fatty acids; french fries; polymerized triacylglycerols; potato chips; vitamin E

Vitamin E is the most important *in vivo*-acting lipophilic antioxidant that protects unsaturated fatty acids bonded in tissue lipids against oxidation by free radicals (Eitenmiller & Lee 2004a). Its action is indispensable, especially for the protection of biomembranes and low-density lipoproteins (Eitenmiller & Lee 2004a; Niki 2011). Sufficient intake of vitamin E could therefore be a significant factor in preventing cardiovascular diseases (Niki 2011). In addition, α-tocopherol operates through cell signaling at the posttranscriptional level or at the gene expression level, and thus participates, for example, in the regulation of cell growth, death, and stress responsiveness (Eitenmiller & Lee 2004a).

Vegetable oils contribute significantly to vitamin E intake (Murphy *et al.* 1990; Wyatt *et al.* 1998; Ahuja *et al.* 2004; Maras *et al.* 2004), whereas a significant proportion of the total intake of vegetable oils is consumed in the form of processed foods (Murphy *et al.* 1990; Freedman & Keast 2012). However, significant losses of tocopherols have been reported during culinary food preparation (Piironen *et al.* 1987; Wyatt *et al.* 1998; Steinhart & Rathjen 2003). In particular, the total destruction of naturally present vitamin E can occur during frying (Réblová *et al.* 2009; Fišnar *et al.* 2014). This may cause the intake of vitamin E (from food alone) to be insufficient, at least for a part of the popula-

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tion, as has been shown by various studies (Bunnell *et al.* 1965; Murphy *et al.* 1990; Rodríguez-Palmero *et al.* 1998; Wyatt *et al.* 1998; Ahuja *et al.* 2004; Maras *et al.* 2004).

Losses of vitamin E during frying have already been widely studied (Choo *et al.* 2007; Réblová *et al.* 2009; Casal *et al.* 2010; Fišnar *et al.* 2014). However, in the scientific literature (and analogous sources of information, such as nutrient databases), there is not enough reliable information about the vitamin E content of commercially prepared fried foods (Scura *et al.* 1988; Eitenmiller & Lee 2004b). Therefore, the aim of the present study was to determine tocochromanols (tocopherols and tocotrienols) in a number of commercially available fried foodstuffs with medium- and high-fat content. The effect of selected factors on tocochromanol content was also studied. For this purpose, fat content and polymerized triacylglycerol content (characterizing the degree of oxidation and high temperature damage of the frying bath, Stier 2013) and fatty acid composition were determined in all analysed samples.

MATERIAL AND METHODS

Samples. Samples of french fries were purchased in various Prague restaurants, fast food chains, and small fast food stands in the period from August 2014 to October 2015. A basic set of 26 samples was purchased from 26 different companies. In addition, 6 samples were purchased on the same day (within approximately 2 h) from various stores of the same international fast food chain, 6 samples were purchased over 1 week from the same store of an international fast food chain, and 6 samples were purchased over 1 week from the same small fast food stand. The samples were stored at –18°C until they were analysed. Tocopherols and tocotrienols were determined within 3 weeks of the date of purchase.

Samples of potato chips and other similar fried snack products (such as fried extruded corn or potato snacks and fried vegetable chips) were purchased at Czech retail markets in the period from August 2014 to July 2015. This basic series consisted of 28 samples, with no samples being repeated. In addition, 5 different batches of potato chips from the same manufacturer were purchased and analysed. The unopened packages were stored in the dark at room temperature, and tocopherols and tocotrienols were determined within 2 weeks of the purchase of the sample. After opening the packages, the remainders of the samples were stored at –18°C until other analytical procedures were carried out.

Analytical methods

Tocopherols and tocotrienols. The samples (approx. 50 g) were ground using a laboratory mill, Grindomix GM 200 (Retsch, Germany), at 4 000 rpm for 10 s in the case of french fries, or 7 s in the case of the other samples. Then, approximately 2.5 g (± 0.1 g; with an accuracy of 1 mg) of the ground sample was weighed into a beaker (volume 100 ml) and mixed with 5 g of anhydrous sodium sulphate. The mixture obtained was extracted 3 times with 40 ml of hexane. In each extraction step, the sample suspension was homogenized using Ultra & Turrax T25 (IKA Werke, Germany) for 20 s (6 400 rpm) and then filtered through filter paper. The combined extracts were evaporated using a vacuum rotary evaporator at a maximum bath temperature of 40°C and the residue was dissolved in acetone (50 ml) (Fišnar *et al.* 2014).

In the extracts, the tocochromanols were determined by reverse-phase HPLC with amperometric detection (Trojáková 2001; Fišnar *et al.* 2014) under the following conditions: mobile phase methanol/acetonitrile (1 : 1, v/v) with $LiClO_4$ (0.02 mol/l) and NaCl (0.005 mol/l); flow rate 1 ml/min (LCP 4020.31 non-steel pump; Ecom, Czech Republic); injected volume 20 µl (a manual sample injector Rheodyne 7725i; Rheodyne, USA); column Hypersil ODS, 200 × 4.6 mm, a particle size 5 µm (Hewlett-Packard, USA); column temperature 28°C (LCO 101 column heater; Ecom); detection potential 0.7 V (HP 1049A amperometric detector equipped with a glassy-carbon working electrode and a solid state, in situ Ag/AgCl reference electrode; Hewlett-Packard). Quantification was achieved by external calibration using the respective tocopherol and tocotrienol standards. Under the chromatographic conditions used, β- and γ- tocopherol and β- and γ-tocotrienol, respectively, did not separate. Their common chromatographic peaks were quantified as γ-tocopherol and γ-tocotrienol, respectively, due to the prevalence of these isomers in common vegetable oils (AOCS 1995; Eitenmiller & Lee 2004b).

Two parallel determinations were performed on all samples with a typical repeatability (expressed

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as a standard deviation) of 1.8 mg/kg in the case of α-tocopherol and 0.4 mg/kg in the case of the other analytes. The extraction recovery of the determined analytes varied from 96% to 102% and was not statistically different from 100% ($P < 0.05$). For all analytes, the limit of detection was approximately 0.03 mg/kg and the limit of quantification 0.1 mg/kg. The vitamin E content expressed in α-TE (α-tocopherol equivalents) was calculated according to the relation α-TE = α-tocopherol + 0.1 γ-tocopherol + 0.03 δ-tocopherol + 0.3 α-tocotrienol + 0.05 γ-tocotrienol (Eitenmiller & Lee 2004c).

Fat. Fat was determined using a standard extraction method according to Soxhlet with petroleum ether as the extraction solvent (Czech Technical Standard 1995) and using a Soxtec HT 1043 (Tecator, Sweden) extraction system. Two parallel determinations were performed on all samples. The repeatability achieved was characterized by standard deviations of less than 0.2% in the case of french fries, and less than 0.4% in the case of potato chips and similar fried snack products.

Polymerized triacylglycerols. The polymerized triacylglycerols (pTAG) were determined using high-performance size-exclusion chromatography (HP-SEC) with refractometric detection (Réblová 1999; Mekhanoshina & Réblová 2016) after fat extraction. The samples (approx. 50 g) were ground using a laboratory mill, Grindomix GM 200 (Retsch, Germany), at 4 000 rpm for 10 s in the case of french fries or 7 s in the case of the other samples. The ground samples (2.5 g) were extracted with 50 ml of petroleum ether (30 min in a laboratory shaker). Subsequently, the extracts were filtered through filter paper and the solvent was evaporated using a rotary vacuum evaporator in a bath at 40°C. The final residues were dissolved in an amount of tetrahydrofuran suitable for providing approximately 50–70 mg of fat in 1 ml of the resulting solution, dried out by anhydrous sodium sulphate and 5 µl of the solution was injected.

The HPLC system consisted of a high-pressure pump, LCP 4000.11 (Ecom, Czech Republic), a HP 1050 series autosampler, and a HP 1047A series refractometric detector (Agilent Technologies, USA). The chromatographic separation was performed at room temperature using a PL gel MIXED-E SEC column (7.5 mm × 300 mm, 3 µm) equipped with a guard column (7.5 mm × 50 mm, 5 µm; Agilent Technologies). Tetrahydrofuran was used as the mobile phase at a flow rate of 0.6 ml/min.

The percentage of polymerized TAG was quantified using the area normalization method. The only quantified substances were those with a retention time lower than or equal to the retention time of free fatty acids. Polymerized TAG was recognized in all substances with a retention time lower than the retention time of monomeric TAG. The result obtained was the content of polymerized TAG in the fat of the analysed food product, expressed as a percentage. Every sample was analysed at least twice and the match between the parallel results was characterized by a relative standard deviation of less than 7%.

Fatty acids. For determination of the fatty acid composition, the extracts obtained during the determination of fat were used, because the extraction used did not cause statistically significant changes ($P < 0.05$) in the fatty acid composition.

Determination of the fatty-acid composition was completed using GC after derivatization, catalysed by boron trifluoride (using KOH-methanol as the reagent) and subsequent extraction with hexane (Zamora & Hidalgo 2015). The GC analysis was carried out on an Agilent Technologies 6890N gas chromatograph (Agilent Technologies, USA) equipped with a flame ionization detector and a capillary column Supelco SP 2560 with a bis(cyanopropyl) siloxane stationary phase (100 × 0.25 mm i.d., thickness of 0.2 µm; Supelco, USA). The injector (split 75 : 1) and detector were maintained at 220°C, the column temperature was programmed from 175°C to 210°C at the rate of 1°C/min, with a delay of 30 min at 175°C and 40 min at 210°C. Helium, at a flow rate of 0.7 ml/min, was used as the carrier gas, and a 1 µl sample was injected. Confirmation of identity was made by GC-MS. The results obtained by GC-FID were expressed in relative percentages of each fatty acid and calculated by an internal normalization method using the chromatographic peak areas. Based on the fatty-acid composition, the origin of the frying medium used (i.e., fat or oil used for frying) was estimated (AOCS 1995; Velíšek 2014).

RESULTS AND DISCUSSION

Tocochromanol content in analysed samples. As is evident from Table 1, the content of tocochromanols in the samples analysed varies within a very wide range, much like the other parameters characterizing the composition of these samples (Table 2), and

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Table 1. Tocochromanol content in analysed samples (mg/kg)

	α-T	γ-T	δ-T	α-T3	γ-T3	δ-T3	T + T3	Vit. E (α-TE)
French fries: 26 samples purchased in Prague restaurants, fast food chains and stands								
Minimum	0.3	n.d.	n.d.	n.d.	n.d.	n.d.	1.7	0.6
Maximum	76.1	40.7	2.0	12.2	7.6	2.4	96.7	76.4
Mean	20.6	5.7	0.2	1.7	1.1	0.3	29.6	21.8
Median	11.0	2.9	n.d.	1.0	0.4	0.1	23.5	12.2
French fries: 6 samples purchased on the same day in various stores of the same international fast food chain								
Minimum	19.2	3.0	0.6	0.6	0.1	n.d.	23.5	19.7
Maximum	50.6	12.5	1.6	0.8	0.2	n.d.	65.6	52.1
Mean	34.4	5.4	1.0	0.7	0.2	n.d.	41.7	35.2
Median	34.2	4.4	1.0	0.7	0.2	n.d.	40.5	34.9
French fries: 6 samples purchased during 1 week in the same store of an international fast food chain								
Minimum	27.3	2.4	0.8	0.6	0.1	n.d.	31.2	27.7
Maximum	49.8	11.7	1.6	0.8	0.2	n.d.	63.9	51.2
Mean	35.0	4.7	1.1	0.7	0.1	n.d.	41.6	35.7
Median	32.5	3.3	1.0	0.6	0.1	n.d.	37.2	33.0
French fries: 6 samples purchased during 1 week in the same small fast food stand								
Minimum	0.8	0.4	0.1	0.7	0.2	n.d.	2.2	1.1
Maximum	1.5	0.5	0.2	0.8	0.3	n.d.	3.2	1.8
Mean	1.2	0.5	0.1	0.7	0.2	n.d.	2.7	1.4
Median	1.2	0.5	0.1	0.7	0.2	n.d.	2.8	1.5
Fried potato chips and similar fried snack products: 28 various samples								
Minimum	20.4	n.d.	n.d.	n.d.	n.d.	n.d.	39.9	29.8
Maximum	133.7	69.0	11.4	70.7	62.9	12.3	204.6	134.6
Mean	79.0	7.9	1.5	19.0	15.8	2.7	126.0	86.4
Median	87.1	3.7	n.d.	3.3	2.3	0.5	126.4	91.3
Fried potato chips: 5 different batches from the same manufacturer								
Minimum	72.4	2.0	5.9	24.5	21.1	3.1	132.4	82.3
Maximum	76.4	2.5	6.8	27.9	23.4	3.7	137.6	85.3
Mean	74.5	2.2	6.5	26.0	22.6	3.5	135.3	83.8
Median	74.8	2.2	6.6	26.0	23.1	3.6	135.5	83.6

α-T – α-tocopherol; γ-T – γ-tocopherol; δ-T – δ-tocopherol; α-T3 – α-tocotrienol; γ-T3 – γ-tocotrienol; δ-T3 – δ-tocotrienol; T + T3 – sum of tocopherols and tocotrienols; Vit. E (α-TE) – α-tocopherol equivalents; n.d. – not detected

as has been observed in previous studies (Franke *et al.* 2007; Tabee *et al.* 2008a). Exceptions are groups of samples with a similar history, i.e., French fries purchased at the same fast food chain and, especially, different manufacturing batches of the same fried snack. For these samples, the variation in tocochromanol content was significantly smaller (Table 1).

In general, the content of tocochromanols determined in this study (Table 3) is consistent with the existing literature (Bunnell *et al.* 1965; Piironen *et al.* 1986; Franke *et al.* 2007; Tabee *et al.* 2008a, b). However, in some previous studies, higher levels of γ-tocopherol and vitamin E expressed in α-TE were found in fried potato chips (Piironen *et al.* 1986; Franke *et al.* 2007). This may be related to the more frequent use of rapeseed, soybean, and corn oil [each having a high γ-tocopherol content (Eitenmiller & Lee 2004b)] as the frying medium in these studies (compared with palm oil and sunflower oil with negligible amounts of γ-tocopherol, which were the most common frying medium for potato chips in this study).

Commercially prepared fried foods as a source of vitamin E. Initially, the biological activity of individual tocopherols and tocotrienols was estimated from experiments with laboratory animals. Based on these estimations, the activity of vitamin E was expressed in α-TE. β-tocopherol has approximately 50% of the α-tocopherol activity, γ-tocopherol 10%, and δ-tocopherol 3%. Tocotrienols have a biological

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Table 2. Other characteristics of the analysed samples

	Fat content (%)	pTAG (% in fat)	SFA	O	L	α-Ln	*trans*-FA
			(% of all fatty acids)				
French fries: 26 various samples purchased in Prague restaurants, fast food chains and stands							
Minimum	6.4	1.1	8.0	29.8	5.7	0.1	0.2
Maximum	20.0	21.8	55.2	59.2	54.7	7.2	2.7
Mean	12.5	8.4	23.1	49.0	19.9	3.8	0.8
Median	12.2	8.2	14.2	54.0	17.9	4.8	0.6
Fried potato chips and similar fried snack products: 28 various samples							
Minimum	20.1	0.4	8.1	29.6	7.3	0.1	0.1
Maximum	49.3	4.9	55.8	82.6	56.1	0.5	1.7
Mean	31.3	1.4	27.6	58.8	11.6	0.2	0.4
Median	31.0	1.3	23.4	52.3	9.4	0.2	0.4

pTAG – polymerized triacylglycerols; SFA – saturated fatty acids; O – oleic acid; L – linoleic acid; α-Ln – α-linolenic acid; *trans*-FA – *trans*-fatty acids

activity approximately two-thirds lower than the corresponding tocopherols (i.e., α-tocotrienol is 30% of the α-tocopherol activity and β-tocotrienol 5%; the activity of the other tocotrienols is usually neglected or not considered) (Eitenmiller *et al.* 2008). However, in the literature, there are slightly different ways to calculate the vitamin E content expressed in α-TE (see also Materials and Methods, Eitenmiller & Lee 2004c). The recommended daily allowance (RDA; i.e., the dietary intake which sufficiently meets the needs of 97–98% of healthy individuals in a group) of vitamin E has been set at 12 mg α-TE (Regulation EU No. 1169/2011).

However, according to current knowledge, due to the specific α-tocopherol transport protein, the human metabolism is selective only for the 2R isomers of α-tocopherol. Therefore, in the recent literature only these isomers are admitted as compounds with vitamin E activity for humans. Other vitamers of vitamin E (i.e., β-, γ- and δ-tocopherol and tocotrienols) and 2S isomers of α-tocopherol, which are also absorbed from the human gastrointestinal tract, are not recognized by the α-tocopherol transport protein in the liver. These compounds are subsequently excreted in bile and only a very small amount of them is transported into the cells. Currently, the estimated average requirement of vitamin E (EAR, i.e., the intake value that is estimated to meet the need for half of healthy individuals) is 12 mg of 2R-α-tocopherol per day. This amount correlates to a level of 12 micromoles of α-tocopherol per liter in blood serum, from which a degree of oxidative-induced erythrocyte hemolysis is considered as acceptable. The RDA of 2R-α-tocopherol (vitamin E) is proposed at 15 mg per day (Institute of Medicine (US) Panel on Dietary Antioxidants and Related Compounds 2000; Eitenmiller *et al.* 2008). However, only 2R-α-tocopherol (RRR-α-tocopherol) is found in the nature (Eitenmiller & Lee 2004c). Therefore all free α-tocopherol determined by standard analytical methods (i.e. methods not separating individual optical isomers) can be considered as vitamin E, because tocopherol esters, which are more stable than free α-tocopherol, are usually used for food fortification (Velíšek 2014).

In view of these facts, the french fries analysed in this study fulfil the daily vitamin E requirement within the range of 0.5–63.6% per 100 g (mean 18.1%; median 10.2% – if we consider older recommendations for vitamin intake, i.e.,12 mg α-TE per day) or in the range of 0.2–50.7% (mean 13.7%, median 7.3% – in the case where we consider recent recommendations for intake of vitamin E, i.e.,15 mg of 2R-α-tocopherol per day). These values are comparable to previous data from the literature (Chiou *et al.* 2012). The fried potato chips and other fried snack products analysed in this study fulfil daily requirements for vitamin E, ranging from 24.8% to 112.1% per 100 g (mean 72.0%, median 76.1% – related to the earlier recommendations for intake of vitamin E) or in the range of 13.6 to 89.1% (mean 52.7%, median 58.0% – if we consider recent recommendations for intake of vitamin E).

From the point of view of general nutrition, the content of tocochromanols (vitamin E) in the fat of the analysed foods can be considered as more significant

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Table 3. Results of some analogous studies mapping the content of tocochromanols in commercially prepared fried foods

Study	Number of samples	Sample description	Content (mg/100 g)										Refe-rences
			α-T	β-T	γ-T	δ-T	α-T3	β-T3	γ-T3	δ-T3	total toco-pherols	total toco-trienols	vitamin E in α-TE	
USA 1965	1	potato chips	6.4	–	–	–	–	–	–	–	11.4	–	–	Bunnell *et al.* (1965)
Finland 1984	1 pooled sample from 8 samples	potato chips	5.2	0.2	14.2	1.4	0.6	n.d.	0.4	n.d.	–	–	–	Piironen *et al.* (1986)
Hawaii 2006	6	potato chips	2.4–9.4	≤ 0.05–0.2	0.2–14.5	≤ 0.05–0.4	≤ 0.05–0.1	≤ 0.05–2.0	≤ 0.05–0.7	≤ 0.05–0.2	–	–	5.8–21.0	Franke *et al.* (2007)
Sweden 2008	16	potato chips	–	–	–	–	–	–	–	–	n.d.–10.2	0.5–10.3	–	Tabee *et al.* (2008b)
Sweden 2008	4	french fries	–	–	–	–	–	–	–	–	0.1–6.3	n.d.–1.2	–	Tabee *et al.* (2008a)

α-T – α-tocopherol; α-TE – α-tocopherol equivalents; β-T – β-tocopherol; γ-T – γ-tocopherol; δ-T – δ-tocopherol; α-T3 – α-tocotrienol; β-T3 – β-tocotrienol; γ-T3 – γ-tocotrienol; δ-T3 – δ-tocotrienol

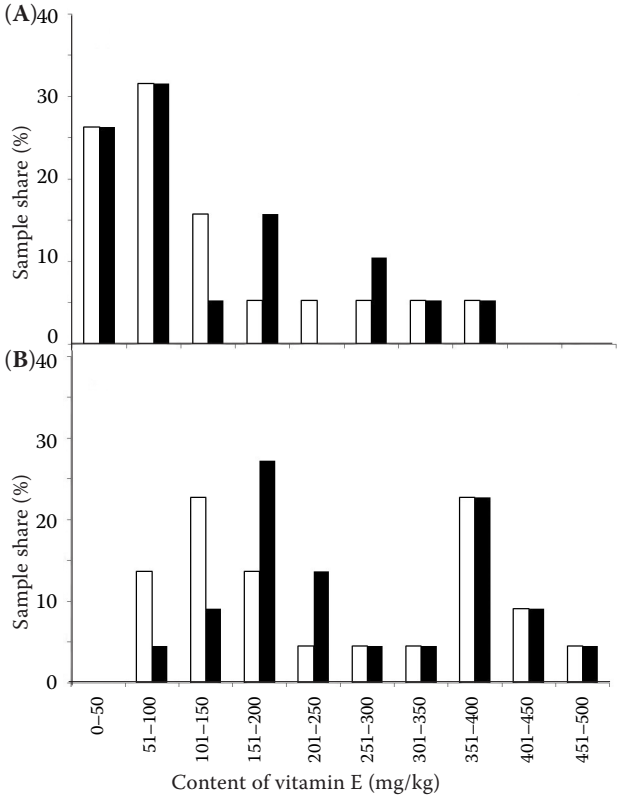

Figure 1. Content of vitamin E in the fat of french fries (**A**), and in the fat of potato chips and similar fried snack products (**B**) (relative frequency histogram)

□ α-tocopherol; ■ α-tocopherol equivalents

(than that in the analysed foods as such). Because it is undesirable to increase the intake of vitamin E while simultaneously increasing fat intake [even if fat composition is a more important factor affecting risk of cardiovascular and other diseases than total fat intake (Bruckner 2007; Glauert 2007)].

In the samples of french fries analysed, the content of α-tocopherol in fat from these products ranged from 4.7 mg/kg to 358.1 mg/kg (average of 117.9 mg/ kg; median 76.5 mg/kg), the total content of tocochromanols from 22.9 to 484.0 mg/kg (average 185.0 mg/kg; median 164.5 mg/kg), and the content of vitamin E expressed in α-TE from 9.2 to 361.1 mg/kg (average of 126.4 mg/kg; median 87.0 mg/kg). In the analysed potato chips and similar fried snacks, the α-tocopherol content in fat of these products ranged from 58.4 to 494.3 mg/kg (average of 242.7 mg/kg; median 190.2 mg/kg), the total content of tocochromanols 198.9–560.5 mg/kg (average of 400.3 mg/kg; median 396.0 mg/kg), and the content of vitamin E expressed in α-TE in range 85.3–497.4 mg/kg (average of 268.3 mg/kg; median 237.3 mg/kg). These values are comparable with those

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Table 4. The content of α-tocopherol, tocochromanols, and vitamin E (expressed in α-TE)

Samples analysed	Analyte	Model obtained	*P*
French fries	α-T	= (0.73 ± 0.20) L + (1.11 ± 0.42) Fat – (1.17 ± 0.38) pTAG	$< 10^{-5}$
	T + T3	= (0.59 ± 0.27) L + (2.59 ± 0.58) Fat – (1.92 ± 0.51) pTAG	$< 10^{-6}$
	vitamin E	= (0.71 ± 0.20) L + (1.27 ± 0.43) Fat – (1.24 ± 0.38) pTAG	$< 10^{-6}$
Fried potato chips and other similar fried snack products	α-T	= (0.67 ± 0.25) O + (1.94 ± 0.62) L – (1.75 ± 0.35) SFA + (2.78 ± 0.75) Fat – – (17.48 ± 6.00) pTAG	$< 10^{-11}$
	T + T3	= (1.53 ± 0.70) L + (4.37 ± 0.26) Fat – (20.20 ± 6.58) pTAG	$< 10^{-14}$
	vitamin E	= (0.61 ± 0.25) O + (1.93 ± 0.62) L – (1.45 ± 0.35) SFA + (2.96 ± 0.76) Fat – – (18.68 ± 6.04) pTAG	$< 10^{-11}$

α-T – α-tocopherol; FA – fatty acids; L – linoleic acid; O – oleic acid; pTAG – polymerized triacylglycerols; SFA – saturated fatty acids; T + T3 – sum of tocopherols and tocotrienols; the models describes the content in commercially prepared fried foods from potatoes as a function of the fat content, used frying medium, and the degree of oxidative and high temperature damage of frying medium

published in analogous studies from Sweden and Greece (Andrikopoulos *et al.* 2003; Tabee *et al.* 2008a, b).

If we consider the reference value of dietary fat intake as 70 g (Regulation EU No 1169/2011) and earlier recommendations for vitamin E intake (see above), the level of vitamin E in fat from diet should be at least 171 mg α-TE/kg. Furthermore, if we consider the same reference fat intake and recent recommendations for the intake of vitamin E, the content of vitamin E in the fat of consumed foods should be at least 214 mg 2R-α-tocopherol/kg.

However, as seen from the histograms in Figure 1, significant amounts of the analysed fried foods do not reach these levels, i.e., these foods (especially fried potato chips) are in many cases a richer source of fat than vitamin E. For french fries, the portion of samples which are a richer source of fat than vitamin E is 73.7% or 78.9% of the samples analysed, and for fried potato chips (and similar fried snack products) 27.3% or 54.5% of the samples analysed, while higher values respond to the more recent recommendations regarding the intake of vitamin E (see above).

This contrasts with some of the literature, which considers fried foods to be a rich source of vitamin E (Saguy & Dana 2003; Kologeropoulos *et al.* 2007). The authors of these papers emphasize that the frying process enriches fried foods with vitamin E. However, enrichment of these foods with fat, and significant tocopherol and tocotrienol losses during this process, must be also taken into account (Eitenmiller & Lee 2004d). According to the presented results, fried foods can be a good source of vitamin E, but this is not necessarily the rule. Commercially prepared french fries, especially, can be a negligible source of tocochromanols.

Factors influencing tocochromanol content in commercially prepared fried foods. Because raw potatoes have only a negligible content of tocochromanols (Piironen *et al.* 1986) and the tocochromanol content in the fat of fried potatoes corresponds to their content in the frying medium (Chiou *et al.* 2012), following hypothesis was established: the content of tocochromanols (and vitamin E) in commercially prepared fried potato foods can be influenced by three factors: (i) fat content; (ii) type of frying medium; and (iii) loss of tocopherols during frying, i.e., the degree of oxidative damage of the frying medium. To confirm our hypothesis and to evaluate the influence of these factors on the α-tocopherol content, the total content of tocochromanols, and the content of vitamin E (expressed in α-TE) in the commercially prepared fried foods analysed, the obtained results were processed by multivariate linear correlation and regression analysis. As possible independent variables (potentially affecting the α-tocopherol content, the total content of tocochromanols, and the content of vitamin E in the α-TE – separately for french fries and for potato chips and other similar fried snack products), the following parameters were selected: fat content, the content of polymerized TAG in the fat of analysed food products, and the content of selected fatty acids (saturated fatty acids, oleic acid, linoleic acid and α-linolenic acid). Among these parameters, colinearity was not detected (Belsley *et al.* 2004).

In the case of fried potato chips and other similar fried snack products, linoleic acid, oleic acid, saturated fatty acids, polymerized TAG, and fat had a statistically significant effect ($P < 0.05$) (Montgomery & Runger 2003) on α-tocopherol content and vitamin E content, while the total content of

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Table 5. The coefficients of determination characterizing the influence of individual factors on the content of α-tocopherol, the total content of tocochromanols, and the vitamin E content (expressed in α-TE) in commercially prepared fried foods from potatoes

	Fried potato chips and other similar fried snack products			French fries		
	α-T	T + T3	vitamin E	α-T	T + T3	vitamin E
Whole model (see Table 4)	0.967	0.973	0.970	0.840	0.857	0.847
Linoleic acid only*	0.524	0.520	0.545	0.731	0.658	0.729
Oleic acid only*	0.881	–	0.900	–	–	–
Saturated fatty acids only*	0.624	–	0.471	–	–	–
Polymerized TAG only*	0.618	0.526	0.622	0.197	0.256	0.203
Fat content only*	0.768	0.959	0.848	0.612	0.693	0.633
Model without linoleic acid**	0.947	0.966	0.953	0.701	0.813	0.725
Model without oleic acid**	0.953	–	0.960	–	–	–
Model without saturated fatty acids**	0.916	–	0.940	–	–	–
Model without polymerized TAG**	0.950	0.959	0.953	0.742	0.731	0.746
Model without fat content**	0.940	0.554	0.943	0.772	0.679	0.765

α-T – α-tocopherol; T + T3 – sum of tocopherols and tocotrienols; TAG – triacylglycerols; *the high value of a coefficient of determination indicates a high impact of the relevant factor (independent variable) on the dependent variable (i.e., the content of α-tocopherol, the total content of tocochromanols, and the vitamin E content) (Meloun & Militký 2002); **a low coefficient indicates a high influence of the omitted factor (independent variable) on the dependent variable (Meloun & Militký 2002)

tocochromanols was only influenced by linoleic acid, polymerized TAG, and fat. In the case of french fries, the α-tocopherol content, the total content of tocochromanols, as well as the vitamin E content were influenced by linoleic acid, fat, and polymerized TAG.

The models obtained (Table 4) explain the content of the analytes (i.e., α-tocopherol, total tocochromanols, and vitamin E expressed in α-TE) with greater reliability in the case of fried potato chips and other similar fried snack products than in the case of french fries. This may be related to greater variability between conditions of the preparation of french fries in individual companies (restaurants etc.) than during the production of fried potato chips and other similar snack products in different companies, where a continuous frying process dominates (Dobarganes & Márquez-Ruíz 1998).

In all cases, the content of the analytes (i.e., α-tocopherol, total tocochromanols, and vitamin E expressed in α-TE) grew with the content of fat, linoleic acid, and oleic acid (if this parameter had a statistically significant effect on the analyte content – see above) and decreased with the content of polymerized TAG and saturated fatty acids. This is consistent with previous literature.

The content of tocochromanols in the frying bath decreases during repeated frying (Chiou *et al.* 2012) and the kinetics of their degradation can be expressed as a function of time (number of repeated frying processes) or as a function of polymerized TAG content (Réblová *et al.* 2009).

In thermally unstressed fats and oils, a positive correlation between linoleic acid and α-tocopherol has been found ($P < 0.05$), and a positive correlation between linolenic acid and γ-tocopherol has been suggested (Kamal-Eldin & Andersson 1997). It means that more unsaturated vegetable oils have a higher content of tocopherols, which is related to the main biochemical function of tocopherols in plants, i.e., the protection of polyunsaturated fatty acids against peroxidation (Kamal-Eldin & Appelqvist 1996). Moreover, tocopherols decrease at a faster rate during repeated frying in less unsaturated fats and oils (Chiou *et al.* 2012). Therefore, higher levels of vitamin E were typically found in high-unsaturated vegetable oils (i.e., sunflower, cottonseed, and corn oil) than in low-unsaturated vegetable oils (i.e., palm oil, partially hydrogenated palm kernel oil, and partially hydrogenated soybean oil) after frying (Andrikopoulos *et al.* 2003).

However, the factors in view (i.e., fat content, type of frying medium, and degree of oxidative damage of the frying medium) do not affect the content of tocochromanols (vitamin E) in fried foods individually, but they interact mutually. For example, in

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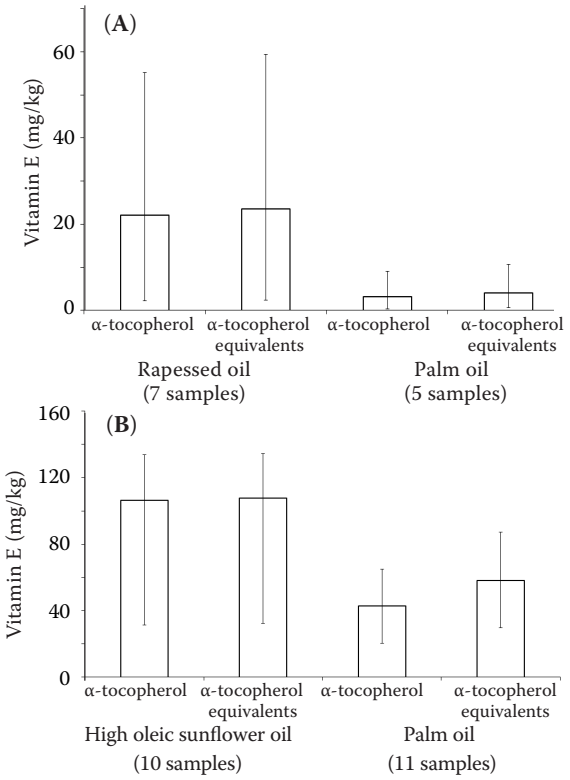

Figure 2. Influence of the frying medium on vitamin E content in (**A**) french fries and (**B**) potato chips and similar fried snack products

Results are presented as mean and range; for the figure construction, samples were only selected where a single fat or oil was used as the frying medium (only with the admixture of another fat or oil up to a maximum of 3%) and error bars represent the range of observed values

a previous study, only slight correlation was found between vitamin E levels in french fries and the deterioration of the frying medium (Carlson & Tabacchi 1986). Although tocopherol concentrations in the oil decreased with increasing usage, there was no significant change in the vitamin E content of the french fries, because the effect of decreasing vitamin E levels in the oil was countered by a significant increase in the fat uptake (Carlson & Tabacchi 1986; Eitenmiller & Lee 2004e).

To assess which factors (i.e., fat content, type of frying medium, and degree of oxidative damage of the frying medium) are more significant for the content of tocochromanols (and vitamin E) in the analysed fried foods, different coefficients of determination were calculated (Meloun & Militký 2002) (Table 5). In both types of fried foods, the total content of tocochromanols is affected, above all, by the total fat content, while the content of α-tocopherol and the vitamin E content expressed in the α-TE are mainly affected by the type of frying medium. The dominant effect of frying medium on the vitamin E content in fried foods has been already described (Eitenmiller & Lee 2004e), and is also apparent from Figure 2, which compares the content of vitamin E in the analysed fried foods depending on the frying medium used.

CONCLUSIONS

The following conclusions can be deduced from the present study: (i) In commercially produced french fries, and potato chips and other fried snack products, the content of tocochromanols (vitamin E) may vary within a wide range; (ii) Although these foods can be a rich source of vitamin E, in a number of cases (especially in french fries) they are a richer source of fat than vitamin E (in relation to the dietary reference intakes for fat and vitamin E); (iii) Vitamin E content in these foods is mainly influenced by the type of fat or oil used for frying. Therefore, the selection of a suitable frying medium can increase vitamin E content in fried foods, and thus also the intake of this vitamin.

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