Retention of Vitamin E and Added Retinyl Palmitate in Selected Vegetable Oils during Deep-Fat Frying and in Fried Breaded Products

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Changes of natural vitamin E (tocopherols and tocotrienols) and added retinyl palmitate (12.5 μg/g or 250 IU/100 kcal) in soybean oil, corn oil, and palm olein were evaluated during stimulated deep-fat frying. Total vitamin E (milligrams per 100 g) decreased more rapidly in palm olein than in soybean or corn oil. The relative stabilities of the vitamin E homologues in the oils were α-T > δ-T > β-T > γ-T (soybean oil), α-T > γ-T > δ-T > γ-T3 (corn oil), and α-T > δ-T3 > α-T3 > γ-T3 (palm olein). Retinyl palmitate was more stable in palm olein than in soybean or corn oil. Feasibility to fortify frying oils with retinyl palmitate was demonstrated. The increased level of retinyl palmitate in the fried foods indicates that fortification of retinyl palmitate to frying oils can be a useful tool for delivery of vitamin A activity.

Keywords: *Frying oils; tocopherol and tocotrienol stability; vitamin E; retinyl palmitate fortified oils*

INTRODUCTION

Vitamin and mineral deficiencies along with protein-energy malnutrition are worldwide problems, affecting millions of people (Bauernfeind, 1991). If an appropriate food carrier exists for vitamin A, fortification is the cheapest and most effective means to eradicate vitamin A deficiency (Bauernfeind, 1986). Because retinyl palmitate is fat soluble and more stable than other forms of vitamin A, addition of retinyl palmitate to edible oils presents a potentially viable vehicle to increase vitamin A activity in areas of the world where vitamin A deficiency exists. However, little information exists on the stability of retinyl palmitate in frying oils. Favaro et al. (1991, 1992) studied the feasibility of fortifying soybean oil with retinyl palmitate in Brazil. They reported that the fortified oil retained 99% of the added vitamin A activity after 9 months of storage at 23 °C in sealed cans. More than 58% of the vitamin A activity was retained after four pan-fryings of potatoes at 115−117 °C. Residual vitamin A activity remained after 12 fryings. The authors concluded that soybean oil fortified with retinyl palmitate could significantly increase the intake of vitamin A in areas of marginal vitamin A intake.

Because vegetable oils maintain considerable vitamin E levels after refining, the natural antioxidant activity provided by the tocopherols and tocotrienols should provide protection against thermal oxidation of retinyl palmitate without the need for synthetic antioxidants. Early studies on the antioxidant effects of tocopherols in fats and oils generally showed that γ-tocopherol is the most effective antioxidant. Lehmann and Slover (1976) were the first to provide definitive information on the oxidative stability of the individual tocopherol and tocotrienol homologues and their interactions through the use of gas chromatography. Their work showed that during autoxidation in methyl myristate, stabilities were α-tocopherol (α-T) = α-tocotrienol (α-T3) < β-tocotrienol (β-T3) < γ-tocotrienol (γ-T3) < δ-tocotrienol (δ-T3) < γ-tocopherol (γ-T) < δ-tocopherol (δ-T) = β-tocopherol (β-T). In methyl linoleate stabilities were α-T < α-T3 < γ-T3 < β-T < γT < δ-T. α-Tocopherol was the least stable in both systems. The reported relative stabilities were similar to the relative antioxidant activities reported by Lea and Ward (1959) in earlier studies on lard and methyl linoleate (γ-T > δ-T > β-T > α-T). Lehmann and Slover (1976) pointed out that the role of α-T in terms of antioxidant interaction contrasts with the antioxidant activities of γ-T and δ-T, which are more effective antioxidants than α-T in fats and oils. Furthermore, they postulated that α-T would decrease first during cooking or storage of vegetable oils.

Niki et al. (1986) studied the antioxidant properties of α-, β-, γ-, and δ-T in methyl linoleate. When the four tocopherols were used together, α-T was consumed first, then β- and γ-T. δ-T did not decrease in concentration until most of the α-, β-, and γ-T were depleted. When studied individually, each of the tocopherols was effective as an antioxidant in the methyl linoleate solution. Frankel et al. (1959) and Yuki and Ishikawa (1976) reported greater tocopherol stability in more highly unsaturated oils. Yoshida et al. (1991, 1993) studied tocopherol stability in vitamin E stripped soybean, corn, rapeseed, palm, and olive oils during microwave heating. In each oil, α-T content decreased at the fastest rate and total tocopherol loss was dependent upon the exposure time to microwave heating. The stabilities of the individual homologues in each oil were δ- > β- > γ- ≫ α-T. Little information exists on tocotrienol antioxidant properties or stability other than that provided by

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Lehmann and Slover's original work (1976) in model systems, especially during deep-frying.

The objectives of this study were to (a) determine changes in the tocopherols and tocotrienols and added retinyl palmitate in soybean oil, corn oil, and palm olein during simulated deep-fat frying and (b) assess vitamin E and added retinyl palmitate in fried breaded products after deep-fat frying with fortified and nonfortified oils.

EXPERIMENTAL PROCEDURES

Materials. Soybean oil, corn oil, and palm olein were selected in this study because of their differences in tocotrienol and tocopherol profiles; soybean oil represents an oil without tocotrienols, and corn oil and palm olein represent oils with low and high tocotrienols, respectively (Salankhe et al., 1992). Soybean oil (Hunt-Wesson Inc., Fullerton, CA) and corn oil (Mazola, Best Food Division, CPC International Inc., Englewood Cliffs, NJ) were purchased locally in Athens, GA. Double-fractionated palm olein was provided by Misr Gulf Oil Processing Co., Cairo, Egypt. Retinyl palmitate was from Fluka (Ronkonkoma, NY). Two commercial breaded products for deep-fat frying were chosen for the study. Frozen chicken nuggets (Tyson Foods, Inc., Springdale, AR) represented a flash-fried product, and breaded shrimp basket style (Rich-Seapak Corp., St. Simons Island, GA) represented a breaded product sold without prior heating. Both products were purchased from a local wholesaler.

Simulated Frying Study. Sixteen hundred grams of each oil was heated to 185 ± 2 °C in a deep-fat fryer (National Presto Industries Inc., Eau Claire, WI). Temperature was controlled by a variable autotransformer (STACO Inc., Dayton, OH). Come-up time was ~15 min. Frying was simulated using the method of Chang et al. (1978). Five wet cotton balls (15−18 g) containing 75% H_2O by weight were deep-fried for 30 min and then removed. Residual oil from cotton balls was drained back into the fryer, and the procedure was repeated for a total of 20 times during the course of the day (10 h total frying time per day). The oil was allowed to cool overnight, and the frying cycle was repeated on two more consecutive days to reach a total of 30 h frying time. Frying studies were completed in duplicate. Frying studies using retinyl palmitate fortified oil (250 IU/100 kcal or 12.5 μg/g) were completed in the same manner. Oil samples (2 g) were removed after 1, 3, 6, 10, 20, 25, and 30 h of simulated frying for analysis of retinyl palmitate, tocopherols, tocotrienols, and free fatty acids. Viscosity and color were measured at 0, 10, 20, and 30 h of frying.

Frying of Breaded Products. Chicken nuggets (200 g) and breaded shrimp (200 g) were fried independently in soybean oil, corn oil, and palm olein at 176 °C (350 °F) as directed on the packages of the products. Levels of addition of retinyl palmitate were 0 and 12.5 μg/g (250 IU/kcal). All of the fryings were completed in triplicate.

Evaluation of Frying Oils. Total free fatty acids were determined by titration using AOAC 28.032b−AOCS Ca5a-40 (AOAC, 1990). Color of oil samples was measured by a Hunter color/difference meter D25-2 (Hunter Associates Laboratory, Inc., Fairfax, VA) standardized against a yellow chromatic standard ($L = 78.5$, $a = -2.2$, $b = 22.6$). Triplicate measurements were made with inclusion of UV radiation (1.5 cm aperture). Oil samples were placed in a special cylindrical glass cell 2 cm long with 2.5 cm i.d. The cell was placed on the surface of a glossy chromatic standard to provide an even surface. The cell, except the top and bottom, was covered with aluminum foil to prevent light scattering. Oil viscosity was measured at 25 °C with a Brookfield model RVTD rotational viscometer (Brookfield Engineering Laboratories, Inc., Stoughton, MA) with a No. 2 spindle.

Tocopherols, Tocotrienols, and Retinyl Palmitate Determinations. Tocopherols and tocotrienols were quantified by normal phase HPLC (Håkansson et al., 1987; Yao et al., 1992). The system consisted of a Rheodyne 7125 injector (Cotati, CA), a Shimadzu LC-6A solvent delivery system (Shimadzu Scientific Instruments Inc., Norcross, GA), a Shimadzu CR601 Chromatopac integrator, a Perkin-Elmer 650-15 fluorescence spectrophotometer (Hitachi, Norwalk, CT), a 25 cm × 4 mm, 5 μm, Lichrosorb Si60 column (Hibar Fertigsäule RT, Darmstadt, Germany), and a precolumn packed with Perisorb A 30−40 μm (Darmstadt, Germany). The mobile phase contained 0.9% 2-propanol (J. T. Baker Chemical Co., Phillipsburg, NJ) in hexane (J. T. Baker Chemical Co.). The flow rate was 1 mL/min. Immediately before use, the mobile phase was filtered through a 0.2 μm nylon 66 (MSI Inc., Westboro, MA) membrane filter and degassed by stirring under vacuum. The excitation and emission wavelengths were 290 and 330 nm, respectively. The oil samples in duplicate were dissolved with appropriate dilution for each vitamin E homologue and injected directly after filtering through a 0.2 μm membrane filter. Vitamin E standards α-, β-, γ-, and δ-tocopherols were obtained from Henkel Corp. (La Grange, IL). Purity and stability of the standards were monitored with a diode array spectrophotometer (Hewlett-Packard Co., Palo Alto, CA). Standard curve preparation, detection limits, and identification were completed according to methods of Yao et al. (1992).

Retinyl palmitate was quantified simultaneously with the tocopherols and tocotrienols by connecting a UV−vis detector (SPD-6AV, Shimadzu Scientific Instruments Inc.) in series with the spectrofluorometric detector. Retinyl palmitate was monitored at 325 nm (0.04 AUFS). The retinyl palmitate procedure was based on studies by Woollard and Woollard (1988).

Biological activities of vitamin E in terms of RRR-α-tocopherol equivalents (α-Ts) were calculated following a guideline by the National Research Council (1989), where 1 α-TE is equal to 1 mg of RRR-α-tocopherol. Factors for activities of other natural forms of vitamin E homologues are β-tocopherol, mg × 0.5; γ-tocopherol, mg × 0.1; δ-tocopherol, mg × 0.03; α-tocotrienol, mg × 0.3; and β-tocotrienol, mg × 0.05; activities of γ- and δ-tocotrienols are unknown.

Statistical Analysis. A randomized block design with two replications was employed, and the data were analyzed with ANOVA and Duncan's multiple range test (SAS, 1987).

Table 1. Changes in Viscosity, Color, and Free Fatty Acids after 30 h of Frying at 185 °C[a]

vegetable oil	viscosity (cP)	color (L)[b]	free fatty acids (% oleic)
soybean oil	+63.7[a]	−5.9[a]	+0.59[a]
corn oil	+26.2[a]	−3.2[a]	+0.52[a]
palm olein	+34.6[a]	−6.0[a]	+0.87[a]

[a] Numbers with superscript "a" are significantly different ($P < 0.05$) from the initial value according to Duncan's multiple range test. [b] L = Hunter L (lightness) values.

RESULTS AND DISCUSSION

Retention of Vitamin E during Simulated Frying. Table 1 summarizes changes in viscosity, color (L value), and percent free fatty acids present in the oils after the 30 h frying at 185 °C. Significant changes ($P < 0.05$) from the initial values, which were within reported ranges for commercial oils, indicated severe abuse after 30 h of deep-frying. Viscosity increase produced extensive foaming, and the color ranged from brown in corn oil to dark brown in soybean oil and palm olein during the later stages of the frying period. Free fatty acid levels increased to slightly higher levels in palm olein than noted in soybean and corn oils.

Changes in total vitamin E and concentrations of the specific vitamin E homologues in milligrams per 100 g and α-tocopherol equivalents (α-TE) during simulated deep-fat frying are given in Table 2. α-TE levels decreased significantly in each oil, with vitamin E being completely absent in palm olein after 30 h of frying.

Table 2. Total Vitamin E[a] (Milligrams/100 g), Vitamin E Homologues (Milligrams/100 g), and α-Tocopherol Equivalents (α-TE)[b] of Soybean Oil, Corn Oil, and Palm Olein during Simulated Frying

vegetable oil	time (h)	α-T	β-T	γ-T	δ-T	α-T3	β-T3	γ-T3	δ-T3	total	α-TE
soybean oil	0	7.9 ± 0.2	1.1 ± 0.0	47.4 ± 1.0	12.0 ± 0.5					68.3 ± 0.7	12.7 ± 0.7
	1	7.4 ± 0.1	1.0 ± 0.0	42.0 ± 1.4	11.5 ± 1.0					61.5 ± 2.6	12.3 ± 0.2
	3	7.2 ± 0.0	0.8 ± 0.1	41.6 ± 0.6	11.3 ± 0.7					61.2 ± 0.8	11.9 ± 0.2
	6	6.9 ± 0.6	0.8 ± 0.1	38.9 ± 2.0	10.8 ± 0.5					57.2 ± 3.2	11.4 ± 0.8
	10	6.0 ± 0.3	0.7 ± 0.1	27.5 ± 7.2	9.8 ± 1.0					43.9 ± 5.8	9.4 ± 0.4
	14	5.9 ± 0.3	0.7 ± 0.1	26.8 ± 4.5	8.6 ± 1.9					42.2 ± 6.1	9.2 ± 0.3
	20	5.3 ± 0.4	0.7 ± 0.1	26.0 ± 2.0	6.7 ± 3.5					38.6 ± 5.8	8.5 ± 0.7
	25	2.8 ± 0.3	0.5 ± 0.0	8.9 ± 0.5	6.2 ± 0.4					19.4 ± 1.1	4.2 ± 0.3
	30	0.7 ± 0.4	0.4 ± 0.0	0.9 ± 0.1	3.9 ± 0.6					5.9 ± 0.3	1.5 ± 0.8
corn oil	0	12.3 ± 0.2	0.5 ± 0.1	58.5 ± 2.6	2.6 ± 0.5	1.2 ± 0.2		1.1 ± 0.1		76.7 ± 3.2	18.8 ± 0.4
	1	12.0 ± 0.5	0.3 ± 0.2	53.5 ± 3.9	2.3 ± 0.1	1.1 ± 0.2		0.9 ± 0.1		71.3 ± 4.8	18.1 ± 1.1
	3	11.8 ± 0.6	0.3 ± 0.2	53.0 ± 5.7	2.2 ± 0.1	1.0 ± 0.2		0.9 ± 0.1		66.1 ± 2.2	16.8 ± 0.2
	6	11.8 ± 0.5	0.3 ± 0.2	52.6 ± 5.4	2.2 ± 0.1	0.9 ± 0.2		0.8 ± 0.2		66.1 ± 2.1	16.3 ± 0.6
	10	11.7 ± 0.5	0.2 ± 0.2	51.7 ± 5.1	2.1 ± 0.1	0.9 ± 0.1		0.8 ± 0.1		65.6 ± 5.9	16.0 ± 1.0
	14	11.5 ± 0.9	0.2 ± 0.2	49.7 ± 4.0	2.1 ± 0.1	0.8 ± 0.3		0.7 ± 0.1		61.8 ± 0.1	15.9 ± 0.5
	20	11.1 ± 0.2	0.2 ± 0.2	46.1 ± 5.0	1.9 ± 0.1	0.8 ± 0.3		0.6 ± 0.0		60.4 ± 0.6	15.2 ± 0.1
	25	10.4 ± 1.0	0.2 ± 0.2	36.9 ± 3.4	1.7 ± 0.0	0.7 ± 0.3		0.5 ± 0.1		48.0 ± 3.8	13.6 ± 0.1
	30	9.3 ± 0.5	0.2 ± 0.2	20.6 ± 1.4	1.5 ± 0.3	0.7 ± 0.4		0.2 ± 0.2		33.1 ± 0.9	11.9 ± 0.6
palm olein	0	15.5 ± 0.5			1.5 ± 0.4	16.5 ± 0.6	1.4 ± 0.3	20.7 ± 0.7	4.2 ± 0.5	59.6 ± 0.6	19.4 ± 1.6
	1	12.5 ± 1.1			0.8 ± 0.1	12.8 ± 1.3	0.9 ± 0.1	15.6 ± 1.4	3.1 ± 0.7	45.7 ± 4.4	16.3 ± 1.4
	3	10.2 ± 1.2			0.5 ± 0.1	10.0 ± 1.8	0.8 ± 0.2	9.7 ± 1.0	2.6 ± 0.3	34.2 ± 1.5	13.0 ± 1.0
	6	7.7 ± 3.1			0.1 ± 0.1	6.8 ± 3.4	0.6 ± 0.3	4.8 ± 1.1	2.0 ± 0.3	22.1 ± 1.4	8.9 ± 2.7
	10	6.4 ± 4.4				5.2 ± 3.8	0.5 ± 0.3	3.3 ± 1.1	1.9 ± 0.4	17.5 ± 1.3	3.4 ± 0.9
	14	5.2 ± 4.1				4.1 ± 1.8	0.3 ± 0.2	2.2 ± 1.3	1.3 ± 0.4	13.3 ± 1.4	0.8 ± 0.2
	20	4.4 ± 3.2				3.1 ± 1.6	0.2 ± 0.2	0.8 ± 0.4	0.9 ± 0.1	9.5 ± 1.2	0.7 ± 0.2
						1.3 ± 0.6		0.2 ± 0.1	0.3 ± 0.1	4.7 ± 1.7	0.3 ± 0.1
										0.5 ±0.3	

[a] Rounded means of four observations. [b] One α-TE is equal to 1 mg of α-T, and activities of other homologues are β-T, 0.5; γ-T, 0.1; δ-T; 0.03; α-T3, 0.3; and β-T3, 0.05. Activities of γ-T3 and δ-T3 are unknown.

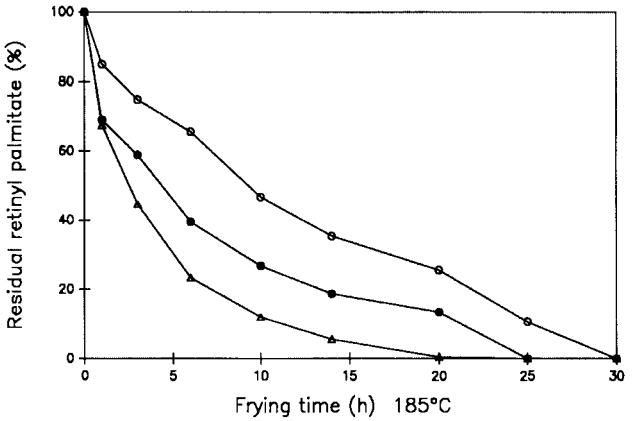

Figure 1. Residual retinyl palmitate in soybean oil (△), corn oil (●), and palm olein (○) during simulated frying at 185 °C.

Corn oil retained 63.3% of the α-TE after 30 h, whereas soybean oil retained only 11.8% of the α-TE activity. It is evident that the stabilities of the specific vitamin E homologues under simulated frying conditions vary according to the oils under study. The relative stabilities of the vitamin E homologues after 6 h of simulated deep-fat frying were α-T > δ-T > β-T > γ-T (soybean oil), α-T > γ-T > δ-T > γ-T3 (corn oil), and α-T > δ-T3 > α-T3 > γ-T3 (palm olein). This finding is in contrast to the statement of Lehmann and Slover (1976) that α-T was the most labile vitamin E homologue during cooking and storage of vegetable oils and the statement of Yoshida et al. (1993) that α-T is the least stable tocopherol during microwave heating.

From this study, it appears that the tocotrienols are less stable under thermal oxidations than the tocopherols. Thus, it can be assumed that they are interacting as more effective antioxidants in the simulated frying environment. The complexity of the simulated frying curves (time versus concentration) prohibited calculation of accurate half-lives for the total vitamin E activity or for the individual vitamin E homologues. Reaction rates did not follow first-order kinetics. The results show that under the conditions of the study the stabilities of the vitamin E homologues are not directly related to the degree of unsaturation of the oils. The rapid loss of vitamin E in palm olein was not unexpected because Frankel et al. (1959) showed tocopherol loss to be less in highly unsaturated oils than in more saturated oils during autoxidation at 60 and 100 °C. These authors suggested that polyunsaturated fat hydroperoxides decomposed quickly during initial autoxidation and that the decomposition products did not appear to react with tocopherols. Yuki and Ishikawa (1976) also reported greater tocopherol stability in more highly unsaturated oils during simulated deep-fat frying. They postulated that decreasing stabilities of more saturated oils as temperatures approach frying temperature led to rapid tocopherol loss during thermal oxidation. Yoshida et al. (1990) also found that after 8−10 min of microwave heating, the amount of tocopherol decreased substantially in linseed, olive, and palm oils, whereas

Table 3. Vitamin E (TVE) and Retinyl Palmitate (RP) Retention in Soybean Oil, Corn Oil, and Palm Olein after One Frying of Breaded Products[a]

vegetable oil	chicken nuggets		breaded shrimp	
	TVE	RP	TVE	RP
soybean oil	81 ± 0.3	62 ± 5.2	91 ± 3.0	83 ± 1.1
corn oil	87 ± 7.8	54 ± 3.8	86 ± 1.9	60 ± 8.5
palm olein	65 ± 2.5	72 ± 6.3	62 ± 2.6	74 ± 3.8

[a] Means were calculated from three independent fryings.

Table 4. Vitamin E Homologues, Total Vitamin E (TVE), and Retinyl Palmitate (RP) of Chicken Nuggets and Breaded Shrimp before and after Frying in Palm Olein

		vitamin E homologues (mg/100 g) and retinyl palmitate[d] (μg/100 g)								
product		α-T	β-T	γ-T	δ-T	α-T3	γ-T3	δ-T3	TVE[f]	RP[e]
chicken nuggets	initial[a]	0.8	0.1	3.1	0.7	ND[e]	ND	ND	4.6[b]	6.2[a]
	AF[b] (0 IU[c])	1.1	0.7	ND	0.9	1.0	1.4	0.3	4.4[b]	ND
	AF (250 IU)	1.1	0.6	ND	0.9	1.0	1.4	0.3	4.9[c]	165[b]
breaded shrimp	initial	0.5	ND	0.1	ND	ND	ND	ND	0.6[a]	3.4[a]
	AF (0 IU)	1.6	0.2	ND	0.1	1.3	1.7	0.4	5.1[c]	ND
	AF (250 IU)	1.7	0.2	ND	0.1	1.4	1.8	0.4	5.8[d]	166[b]

[a] The initial value is retinol (μg/100 g). [b] AF, after frying. [c] Fortification levels = number of IU/100 kcal of oil. [d] Measurements are the means of three independent observations. [e] ND, not detected (detection limit is 0.001 mg/100 g). [f] Numbers within a column followed by different letters are significantly different ($P < 0.05$) according to Duncan's multiple range test.

90% of tocopherols remained in corn and soybean oils. They concluded that the reduction in tocopherols in oils is not necessarily in agreement with chemical properties of the oils.

Retention of Retinyl Palmitate during Simulated Frying. Retention of retinyl palmitate was greatest in palm olein followed by corn oil and least in soybean oil (Figure 1). Loss of retinyl palmitate during simulated frying did not follow first-order reaction kinetics. The plots of residual retinyl palmitate versus time show rapid losses in each oil during the initial stages of the frying period followed by slower rates of loss as frying time increased. The residual level of retinyl palmitate was significantly greater ($P < 0.05$) in palm olein compared to the other two oils at each observation point. It is possible that a presence of tocotrienols in the oils may affect the stability of retinyl palmitate; the percentages of tocotrienols in soybean oil, corn oil, and palm olein were 0, 2, and 72, respectively (Table 2). However, the fact that retinyl palmitate survives in the oils for several hours under thermal oxidation conditions indicates that edible oil fortified with retinyl palmitate can provide a viable approach for delivery of vitamin A activity. Under these conditions, retinyl palmitate stability was greater in the more saturated palm olein (IV = 56.5−60.6) than in the more unsaturated soybean oil (IV = 120−143) and corn oil (IV = 103−128) (Rossell, 1991).

Retention of Vitamin E and Retinyl Palmitate in Oils after Frying of Breaded Products. Table 3 gives retention data for total vitamin E and added retinyl palmitate in the three oils after a frying of breaded chicken nuggets and breaded shrimp. Total vitamin E retention was lower in palm olein compared to the other oils as noted during the simulated frying. Vitamin E retention ranged from 62 to 91%, depending on the oils used and the products being fried. Percentage of retention values found for retinyl palmitate ranged from 62 to 83% in soybean oil, from 54 to 60% in corn oil, and from 72 to 74% in palm olein.

Vitamin E and Retinyl Palmitate in Breaded Products after Frying. Vitamin E contents of chicken nuggets and breaded shrimp before and after frying are given in Table 4. Data for products fried in soybean and corn oils are not presented because they are similar to those noted for palm olein fried products. Because chicken nuggets were previously flash-fried during the manufacturing process, the increase in total vitamin E was not substantial (from 4.6 mg/100 g before frying to 4.9 mg/100 g after frying). However, in breaded shrimp total vitamin E increased from 0.6 mg/100 g before frying to 5.1 mg/100 g after frying in the nonfortified oil and to 5.8 mg/100 g after frying in the oil fortified with retinyl palmitate. Retinyl palmitate concentrations in the products fried in the retinyl palmitate fortified oil were similar (165 μg/100 g in chicken nuggets and 166 μg/100 g in breaded shrimp).

The study shows that vitamin E decreased at a more rapid rate in palm olein compared to soybean oil and corn oil during simulated frying and frying of breaded products. Retinyl palmitate retention was greater in palm olein compared to the other two oils. Substantially increased levels of retinyl palmitate in fried products and its stability indicate that oil fortified with retinyl palmitate can be a useful vehicle for delivery of vitamin A activity.

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