VITAMIN E CONTENTS OF PROCESSED MEATS BLENDED WITH PALM OILS

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ABSTRACT

The vitamin E contents of beef burgers and chicken frankfurters blended with palm oil (PO) were determined. PO and red PO cooked beef burgers resulted in a significant ($P < 0.05$) loss of vitamin E from 427.5 to 178.0 μg/g and from 367.0 to 271.0 μg/g, respectively, after 6 months of storage. The concentration of alpha-tocopherol (α-tocopherol) for all retorted chicken frankfurters was reduced ($P < 0.05$) by 66.0–91.50 (16–46%) μg/g while the alpha-tocotrienol (α-tocotrienol) in all retorted chicken frankfurters significantly decreased ($P < 0.05$) by 63.0–95.5 μg/g (28–48%) after 6 months of storage. Both α-tocopherol and α-tocotrienol decreased at a faster rate (62–64% and 53–61% loss, respectively) and was less stable than the gamma-tocotrienol (12–59%) and the delta-tocotrienol (4–28%) in beef burgers. The effect of processing, cooking, frozen storage and the type of fats used could influence vitamin E stability and content in meat products.

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INTRODUCTION

Animal fat and skin are regular raw materials used in formulating emulsion-type products but they are also high in cholesterol and contaminating microorganisms. With the increase in the production of processed meats, animal fats and skin have become essential items in the formulation of meat products such as hot dogs, nuggets, bologna, balls and burgers (Babji *et al.* 1998). Consumers are now more informed about the link between health and diet. With consumers demanding healthy foods, the meat manufacturers have focused their production toward processed meats that are lean, low in fat and high in protein content.

The use of functional palm oils (POs), which are cholesterol free and naturally containing carotenoids, tocopherol and tocotrienols, may generate safer, nutritious and better quality processed meat products to the market. In palm and red PO, vitamin E occurs as a mixture of tocopherols (~30%) and tocotrienols (~70%). Hashimoto *et al.* (1980) reported that crude PO consists of 22% alpha-tocopherol (α-tocopherol), 20% α-tocotrienol, 46% gamma-tocotrienol (γ-tocotrienol) and 12% delta-tocotrienol (δ-tocotrienol).

Vitamin E represents a family of compounds that is further divided into two subclasses of tocopherols and tocotrienols. Tocopherols and tocotrienols have the same basic chemical structures characterized by a long phytyl tail attached to a chromane ring. However, tocopherols have a saturated, whereas tocotrienols have an unsaturated phytyl tail, and individual isoforms of tocopherols and tocotrienols differ from each other based on the degree of methylation of the chromane ring at their positions. The unsaturation of the phytyl tail seems to reduce the biological activities of tocotrienols relative to tocopherols since α-tocotrienols have only 30% of the vitamin E activity of α-tocopherol (Kamal-Eldin and Appelqvist 1996).

Vitamin E compounds (tocopherols and tocotrienols) are well recognized for their effective inhibition of lipid oxidation in foods and biological systems (van Acker *et al.* 1993). Since vitamin E is only synthesized by plants, it is a very important dietary nutrient for humans and animals (Hess 1993). Many researchers here reported that the antioxidant activity of tocopherols and tocotrienols is mainly due to their ability to donate their phenolic hydrogens to lipid free-radicals (Burton and Ingold 1989; Kamal-Eldin and Appelqvist 1996). The relative antioxidant activity of tocopherols *in vivo* is reported in the order $\alpha > \beta > \delta > \gamma$ (Kamal-Eldin and Appelqvist 1996).

Researchers believe that POs make sausages and other meat products better and healthful (Babji *et al.* 2001; wan Sulaiman *et al.* 2001). Improved nutritional properties including vitamin the E content of chicken frankfurter where chicken oil was substituted with red PO was reported by Babji *et al.* (2001). Only a few studies have analyzed the content of vitamin E after

cooking and the during storage of the cooked products (Wen *et al.* 1996). This research focused on the stability of vitamin E in raw and cooked beef burgers and chicken frankfurters substituted with PO and red PO (RPF35 and RPF48, respectively) during cooking and storage. The decrease in the concentration of vitamin E homologues during cooking and storage was also monitored.

MATERIALS AND METHODS

Four beef burger formulations were compared. Each formulation contained 15% of fat from beef (control), PO (slip melting point [SMP] 41–44C, iodine value (IV) 45–50), red PO (RPO35 with SMP 33–37C, IV 48–53) or a blend of PO and RPO35. Chicken frankfurters consisted of chicken fat (control), PO, red PO (RPO48 with SMP 46–50C and IV 42–46) or a blend of PO and RPO48 at a fixed level of fat (15%). PO (white in color) was supplied by Cargill Fats and Oils Specialty Company (Cargill Fats and Oils Specialty, 167 Jalan Kem, 42000 Port Klang, Malaysia) and the red palm fat (yellow in color) was supplied by the Carotino Company (Carotino Pte. Ltd., Jalan Besi Satu, 81700 Pasir Gudang, Johor. Malaysia). Other dry materials such as potato starch, textured vegetable protein, isolated soy protein, salt, sodium tripolyphosphate and seasoning were purchased from Mackessen Pte. Ltd. (11A-3 Jalan SS 15 8A, 47500 Petaling Jaya, Selangor, Malaysia). The finished meat batters were then weighed into 70-g portions, then manually pressed to produce a uniform beef burger. Beef burgers were cooked for 7 min (internal temperature, 74 ± 1C). Meanwhile, finished chicken meat batters were manually stuffed into 26-mm Viscofan Cellulose casings using a stuffer (FDIC, Hamburg, Germany). The cooking schedule was 55C for 20 min, 65C for another 20 min, 75C for 20 min and 80C for 15 min. After cooking, the frankfurters were cooled, weighed, peeled and stored in a freezer at −18C. Another half of the stuffed batters were manually placed into a 17×13-cm retort pouch and kept in a chiller at 2–5C until ready for sterilization. Chicken frankfurters were then sterilized/retorted (Clutch Retort, Model H60, type C50, Tokyo, Japan) at 121C until an F_o of 3.2 was reached. After retorting, the frankfurters were cooled and stored at room temperature. The processing of beef burgers and chicken frankfurters were replicated twice.

Fat Extraction

The fat was extracted according to Kinsella *et al.* (1977). The extracted fats were stored at –18C for further analysis.

Vitamin E Analysis

Vitamin E was analyzed using high-performance liquid chromatography (HPLC, model number LC240, Perkin Elmer) according to the method by

AOCS (1992). Samples were injected (20 μL) as peak responses of tocopherols and tocotrienols measured using a fluorescence detector with the excitation and emission wavelength set at 290 nm and 330 nm, respectively. The analyses used a stainless steel Lichrosorb (250 mm × 4 mm) column, and the solvent system was hexane : isopropyl alcohol (99:1, v/v) at a flow rate of 1.0 mL/min. The vitamin E content of each burger and frankfurter sample was determined in triplicate. The analyses were replicated twice.

Statistical Analyses

Data obtained were tested for significance using the analysis of variance (ANOVA) and Duncan Multiple Range Test with SAS version 6.12 (SAS 1989). Significance was established at $P \leq 0.05$ unless otherwise indicated.

RESULTS AND DISCUSSION

Vitamin E Content in Raw Beef Burger

The content of α-tocopherol was significantly reduced ($P < 0.05$) from 129.5 to 90.5 2 μg/g (30%) and from 61.5 to 40.5 μg/g (34%), respectively, in raw beef burgers substituted with PO and RPO35 (Table 1). The α-tocotrienol also decreased from 132.5 to 94.5 μg/g (29%) and from 83.0 to 55.0 μg/g (34%), respectively, in both raw beef burgers formulated with PO and RPO35. Raw beef burgers which were substituted with PO, RPO35 and oil blend (OB) showed almost a similar loss of α-tocopherol and α-tocotrienol concentrations which were in the range of 29–34% after storage for 6 months at −18C.

The γ-tocotrienol in all burgers showed the highest concentrations after 6 months of storage. This homolog significantly decreased from 221.0 to 159.5 μg/g (28%) and from 200.5 to 136.5 μg/g (32%) in raw beef burgers formulated with RPO35 and PO, respectively. However, the percent loss in γ-tocotrienol was lower than α-tocopherol and α-tocotrienol. Among all treatments, δ-tocotrienol was present at the highest concentration in raw beef burgers substituted with RPO35 compared to the others. The δ-tocotrienol decreased to 48.0 μg/g (24% reduction), 33.0 μg/g (31%) and 19.5 μg/g (32%) respectively, for the raw beef burger blended with RPO35, OB and PO. This data indicates that δ-tocotrienol was more stable in the RPO35 raw beef burger stored for 6 months at −18C rather than the other formulations. The δ-tocotrienol, which recorded the lowest percent loss of vitamin E (24–31%) was the most stable component in raw beef burgers followed by γ-tocotrienol (28–32% reduction) and α-tocotrienol and α-tocopherol (29–34% reduction), respectively, after 6 months of storage.

TABLE 1.
VITAMIN E HOMOLOGS CONCENTRATION OF RAW BEEF BURGERS SUBSTITUTED WITH PALM OIL AND RED PALM OIL DURING 6 MONTHS OF FROZEN STORAGE (−18C)

Vitamin E homolog (μ/g)		FATS			
	Storage (month)	Palm oil (PO)	Red palm oil (RPO35)	Palm oil + Red palm oil (OB)	Beef fat (control)
α-tocopherol	0	$^{p}129.5 \pm 3.9^{a}$	$^{p}61.5 \pm 3.4^{b}$	$^{p}68.0 \pm 2.5^{b}$	$^{p}4.0 \pm 0.0^{c}$
	6	$^{q}90.5 \pm 3.5^{a}$	$^{q}40.5 \pm 2.9^{b}$	$^{q}48.0 \pm 1.2^{b}$	$^{q}0.0 \pm 0.0^{c}$
α-tocotrienol	0	$^{p}132.5 \pm 4.7^{a}$	$^{p}83.0 \pm 4.1^{b}$	$^{p}79.5 \pm 3.5^{b}$	0.0 ± 0.0^{c}
	6	$^{q}94.5 \pm 2.1^{a}$	$^{q}55.0 \pm 2.2^{b}$	$^{q}55.5 \pm 0.7^{b}$	0.0 ± 0.0^{c}
γ-tocotrienol	0	$^{p}200.5 \pm 7.9^{ab}$	$^{p}221.0 \pm 5.4^{a}$	$^{p}184.5 \pm 8.2^{b}$	0.0 ± 0.0^{c}
	6	$^{q}136.5 \pm 2.2^{ab}$	$^{q}159.5 \pm 1.4^{a}$	$^{q}128.0 \pm 4.3^{b}$	0.0 ± 0.0^{c}
δ-tocotrienol	0	$^{p}28.5 \pm 3.5^{c}$	$^{p}63.5 \pm 3.5^{a}$	$^{p}48.5 \pm 3.6^{b}$	0.0 ± 0.0^{d}
	6	$^{q}19.5 \pm 2.9^{c}$	$^{q}48.0 \pm 2.8^{a}$	$^{q}33.0 \pm 2.8^{b}$	0.0 ± 0.0^{d}
Total vitamin E	0	$^{p}486.5 \pm 7.7^{a}$	$^{p}429.0 \pm 8.5^{b}$	$^{p}379.5 \pm 7.8^{c}$	0.0 ± 0.0^{d}
	6	$^{q}350 \pm 6.3^{a}$	$^{q}302.0 \pm 4.4^{b}$	$^{q}266.5 \pm 2.1^{c}$	0.0 ± 0.0^{c}

[a–c] Mean values within the same row bearing different letters differ significantly ($P < 0.05$).
[p–q] Mean values within the same column bearing different superscripts differ significantly ($P < 0.05$).
α-tocopherol, alpha-tocopherol; α-tocotrienol, alpha-tocotrienol; γ-tocotrienol, gamma-tocotrienol; δ-tocotrienol, delta-tocotrienol.

Raw beef burgers substituted with PO recorded the highest total vitamin E concentration at day 0 of processing, reduced from 486.5 to 350.0 μg/g (28%), while beef burgers containing RPO35 and OB reduced from 429.0 to 302.0 (30%) and 379.5 to 266.5 (30%), respectively, after 6 months of storage at −18C.

Vitamin E Content in Cooked Beef Burgers

The α-tocopherol in all stored (−18C) and cooked beef burgers, except the control, decreased significantly ($P < 0.05$) in the range of 62–64% (106.5 to 40.5 μg/g and 54.0 to 19.5 μg/g) with the PO cooked beef burgers having the highest concentration (40.5 μg/g) after 6 months of storage (Table 2). The α-tocotrienol also significantly decreased from 109.0 to 41.5 μg/g (61%) and from 73.5 to 31.0 μg/g (58%), respectively, in both raw beef burgers formulated with PO and RPO35. The α-tocotrienol in stored (−18C) and cooked beef burgers formulated with OB recorded a lower vitamin E depletion (53% or decreased from 76.0 to 36.0 μg/g) compared to other treatments after 6 months of storage. The γ-tocotrienol slightly decreased from 185.5 to 163.5 μg/g (12%) for the beef burger formulated with RPO35. However, γ-tocotrienol in PO and OB cooked beef burger was significantly decreased from 184.0 to 75.5 μg/g (59%) and from 181.0 to 130.5 μg/g (28%), respectively. The beef burger formulated with RPO35 and PO which were stored at −18C and cooked also recorded the lowest loss for δ-tocotrienol, ranging from 56.5 to 54 μg/g (4%) and from 28.5 to 20.5 μg/g (28%), respectively. Again, δ-tocotrienol in cooked beef burgers containing palm-based oil recorded a lower reduction compared to other homologs after storage for 6 months.

Beef burgers formulated with PO, RPO35 and OB which were stored at −18C and cooked significantly decreased ($P < 0.05$) from 427.5 to 178.0 μg/g (58% reduction), 367.0 to 271.0 μg/g (26%) and 369.5 to 251.0 μg/g (32%) in total vitamin E concentration, respectively, after 6 months of storage. However, the beef burger substituted with RPF35 had the lowest rate of vitamin E depletion from 367.0 to 271.0 μg/g (26%) after being stored at −18C for 6 months and then cooked. The rate of reduction for the raw beef burger was slower than that of the cooked beef burger. Wen *et al.* (1996) reported that precooked patties of turkey fed with α-tocopherol supplemented diet decreased by 35–50% during the frozen storage at −20C after 5 months.

Vitamin E Content in Chicken Frankfurters

The α-tocopherol in all retorted and oven-cooked chicken frankfurters, except for the retorted RPO48 chicken frankfurters, significantly decreased ($P < 0.05$) after 6 months of storage. The α-tocopherol was more stable in the retorted chicken frankfurters containing RPO48 which slightly decreased from

TABLE 2.
VITAMIN E HOMOLOGS CONCENTRATION OF BEEF BURGERS SUBSTITUTED WITH PALM OIL AND RED PALM OIL STORED AT −18C FOR 6 MONTHS THEN COOKED

Vitamin E homolog (μ/g)	Storage time (months)	Palm oil (PO)	Red palm oil (RPO35)	Palm oil + Red plam oil (OB)	Beef fat (control)
α-tocopherol	0	$^{p}106.5 \pm 7.6^{a}$	$^{p}54.0 \pm 6.1^{b}$	$^{p}66.0 \pm 6.2^{b}$	0.0 ± 0.0^{c}
	6	$^{q}40. \pm 4.9^{a}$	$^{q}19.5 \pm 6.0^{b}$	$^{q}24.5 \pm 2.7^{b}$	0.0 ± 0.0^{c}
α-tocotrienol	0	$^{p}109.0 \pm 6.3^{a}$	$^{p}73.5 \pm 2.1^{b}$	$^{p}76.0 \pm 2.5^{b}$	0.0 ± 0.0^{c}
	6	$^{q}41.5 \pm 2.8^{a}$	$^{q}31.0 \pm 2.8^{b}$	$^{q}36.0 \pm 2.9^{ab}$	0.0 ± 0.0^{c}
γ-tocotrienol	0	$^{p}184.0 \pm 4.2^{a}$	$^{p}185.5 \pm 6.3^{a}$	$^{p}181.0 \pm 2.2^{a}$	0.0 ± 0.0^{b}
	6	$^{q}75.5 \pm 2.0^{c}$	$^{q}163.5 \pm 5.4^{a}$	$^{q}130.5 \pm 6.3^{b}$	0.0 ± 0.0^{d}
δ-tocotrienol	0	$^{p}28.5 \pm 3.4^{b}$	$^{p}56.5 \pm 3.8^{a}$	$^{p}48.0 \pm 4.9^{a}$	0.0 ± 0.0^{c}
	6	$^{q}20.5 \pm 0.7^{c}$	$^{p}54.0 \pm 3.6^{a}$	$^{q}35.0 \pm 3.5^{b}$	0.0 ± 0.0^{d}
Total vitamin E	0	$^{p}427.5 \pm 6.3^{a}$	$^{p}367.0 \pm 3.6^{b}$	$^{p}369.5 \pm 5.7^{b}$	0.0 ± 0.0^{c}
	6	$^{q}178.0 \pm 2.6^{b}$	$^{q}271.0 \pm 10.5^{a}$	$^{q}251.0 \pm 9.9^{a}$	0.0 ± 0.0^{c}

[a–c] Mean values within the same row bearing different superscripts differ significantly ($P < 0.05$).
[p–q] Mean values within the same column bearing different superscripts differ significantly ($P < 0.05$).
α-tocopherol, alpha-tocopherol; α-tocotrienol, alpha-tocotrienol; γ-tocotrienol, gamma-tocotrienol; δ-tocotrienol, delta-tocotrienol.

109.0 to 91.5 μg/g (16%) compared to OB retorted chicken frankfurters which significantly decrease ($P < 0.05$) from 123.0 to 66.0 (46%) after 6 months of storage. However, all oven-cooked chicken frankfurters, except control, significantly decreased ($P < 0.05$) in the α-tocopherol concentration to a range of 12.0–21.5 μg/g (83–89%) during the frozen storage at −18C after 6 months (Table 3). A similar trend of reduction in the α-tocotrienol concentration was also detected in both retorted and oven-cooked chicken frankfurters. The α-tocotrienol in all oven-cooked chicken frankfurters significantly decreased ($P < 0.05$) by 11.5–20.5 μg/g (84–91%) with oven-cooked chicken frankfurters containing OB being the lowest in α-tocotrienol concentration after 6 months of storage. However, the α-tocotrienol in retorted chicken frankfurters only decreased by 63.0–95.5 μg/g (28–48%) with the retorted chicken substituted with OB being the highest in α-tocotrienol concentration after 6 months of storage at room temperature.

The γ-tocotrienol in all retorted and oven-cooked chicken frankfurters recorded the highest concentrations and significantly decreased ($P < 0.05$) after 6 months of storage time. However, the percentage of loss in γ-tocotrienol was lower than that of α-tocopherol and α-tocotrienol, being reduced by 36–50% or from 98.0 to 123.5 μg/g in retorted chicken frankfurters and by 28–49% or from 101.0 to 141.5 μg/g in oven-cooked chicken frankfurters after 6 months of storage. Among all treatments, δ-tocotrienol is present at the highest concentration in oven-cooked chicken frankfurters substituted with RPO48 after 6 months of storage at −18C. The δ-tocotrienol decreased to 40 μg/g (16% reduction), 20.5 μg/g (48%) and 23 μg/g (42%), respectively, for oven-cooked chicken frankfurters which were prepared with RPO48, PO and OB. However, the retorted chicken frankfurters substituted with RPO48 recorded the lowest concentration in δ-tocotrienol (19.5 μg/g) after 6 months, but there was no significant difference ($P > 0.05$) with the other treatments.

All retorted and oven-cooked chicken frankfurters substituted with RPO48 decreased significantly ($P < 0.05$) from 481.5 to 290.5 μg/g (40% reduction) and to 208.5 μg/g (57%) in the item total vitamin E concentration, respectively, after 6 months of storage. The reduction was not significantly different ($P > 0.05$) with the other treatments which decreased to 287.5 (41%) and 312.0 (36%) for retorted chicken frankfurters containing PO and OB in total vitamin E concentration, respectively, after 6 months of storage.

The initial amount of vitamin E in animal tissues may influence the rate of lipid oxidation in the products. However, the limited natural antioxidant benefit from vitamin E available in beef fat treatment may be because of the result of denaturation of muscle microstructure during cooking. α-Tocopherol was also detected in the muscle tissues of beef, pork, chicken and fish, the levels of which depend on the diet composition. Marmer (1995) reported that chicken fat had tocopherol amounting to 2.7 mg, compared to PO which had

TABLE 3.
THE CONCENTRATION OF VITAMIN E HOMOLOGS FOR RETORTED CHICKEN FRANKFURTERS FORMULATED WITH PALM-BASED OILS DURING STORAGE FOR 6 MONTHS

Vitamin E homolog (μ/g)	Cooking method	Storage time (months)	Chicken fat (control)	Palm oil (PO)	Red palm oil (RPO48)	Palm oil + Red palm oil (OB)
α-tocopherol	Raw fat		0.0 ± 0.0^{b}	$^{p}125.5 \pm 8.5^{a}$	$^{p}109.0 \pm 8.3^{a}$	$^{p}123.0 \pm 6.7^{a}$
	Retort	0	0.0 ± 0.0^{c}	$^{p}109.0 \pm 8.4^{a}$	$^{p}102.5 \pm 3.6^{a}$	$^{r}84.5 \pm 2.3^{b}$
		6	0.0 ± 0.0^{c}	$^{q}84.5 \pm 3.4^{a}$	$^{q}91.5 \pm 3.7^{a}$	$^{s}66.0 \pm 1.6^{b}$
	Oven	0	0.0 ± 0.0^{c}	$^{p}112.5 \pm 5.4^{a}$	$^{q}93.0 \pm 6.4^{b}$	$^{q}105.0 \pm 5.8^{ab}$
		6	0.0 ± 0.0^{c}	$^{r}21.5 \pm 2.8^{a}$	$^{r}12.0 \pm 1.4^{b}$	$^{t}16.0 \pm 2.8^{ab}$
α-tocotrienol	Raw fat		0.0 ± 0.0^{b}	$^{p}129.5 \pm 8.5^{a}$	$^{p}122.0 \pm 4.1^{a}$	$^{p}130.0 \pm 4.2^{a}$
	Retort	0	0.0 ± 0.0^{c}	$^{q}105.5 \pm 3.2^{a}$	$^{q}88.0 \pm 6.6^{b}$	$^{qr}104.5 \pm 3.7^{a}$
		6	0.0 ± 0.0^{c}	$^{r}82.5 \pm 6.3^{a}$	$^{r}63.0 \pm 3.1^{b}$	$^{r}95.5 \pm 6.9^{a}$
	Oven	0	0.0 ± 0.0^{b}	$^{pq}113.0 \pm 8.3^{a}$	$^{q}100.5 \pm 6.7^{a}$	$^{q}110.5 \pm 5.1^{a}$
		6	0.0 ± 0.0^{d}	$^{s}20.5 \pm 1.2^{a}$	$^{s}15.0 \pm 1.1^{b}$	$^{s}11.5 \pm 0.8^{c}$
γ-tocotrienol	Raw fat		0.0 ± 0.0^{b}	$^{p}196.5 \pm 4.8^{a}$	$^{p}201.0 \pm 9.8^{a}$	$^{p}194.0 \pm 4.7^{a}$
	Retort	0	0.0 ± 0.0^{c}	$^{q}155.5 \pm 2.7^{b}$	$^{q}157.5 \pm 6.4^{b}$	$^{q}170.5 \pm 3.2^{a}$
		6	0.0 ± 0.0^{c}	$^{r}98.0 \pm 4.2^{b}$	$^{s}116.5 \pm 3.5^{a}$	$^{r}123.5 \pm 3.6^{a}$
	Oven	0	0.0 ± 0.0^{c}	$^{q}160.0 \pm 2.6^{b}$	$^{p}181.5 \pm 9.8^{a}$	$^{p}188.0 \pm 3.8^{a}$
		6	0.0 ± 0.0^{c}	$^{r}101.0 \pm 9.6^{b}$	$^{r}141.5 \pm 5.5^{a}$	$^{r}120.0 \pm 9.8^{b}$
δ-tocotrienol	Raw fat		0.0 ± 0.0^{b}	$^{p}39.5 \pm 4.8^{a}$	$^{p}49.5 \pm 5.6^{a}$	$^{p}39.5 \pm 4.9^{a}$
	Retort	0	0.0 ± 0.0^{c}	$^{q}24.5 \pm 2.6^{b}$	$^{p}40.0 \pm 4.8^{a}$	$^{p}37.5 \pm 1.7^{a}$
		6	0.0 ± 0.0^{b}	$^{q}22.5 \pm 2.5^{a}$	$^{q}19.5 \pm 3.7^{a}$	$^{q}27.0 \pm 3.9^{a}$
	Oven	0	0.0 ± 0.0^{c}	$^{q}23.5 \pm 1.4^{b}$	$^{p}45.0 \pm 3.2^{a}$	$^{p}39.0 \pm 3.0^{a}$
		6	0.0 ± 0.0^{c}	$^{q}20.5 \pm 1.7^{b}$	$^{p}40.0 \pm 4.9^{a}$	$^{q}23.0 \pm 2.8^{b}$
Total vitamin E	Raw fat		0.0 ± 0.0^{b}	$^{p}491.0 \pm 8.5^{a}$	$^{p}481.5 \pm 8.3^{a}$	$^{p}486.5 \pm 8.4^{a}$
	Retort	0	0.0 ± 0.0^{b}	$^{q}394.5 \pm 7.8^{a}$	$^{r}388.0 \pm 7.3^{a}$	$^{r}397.0 \pm 6.9^{a}$
		6	0.0 ± 0.0^{b}	$^{r}287.5 \pm 5.2^{b}$	$^{s}290.5 \pm 5.9^{b}$	$^{s}312.0 \pm 6.8^{a}$
	Oven	0	0.0 ± 0.0^{b}	$^{q}409.0 \pm 6.8^{b}$	$^{q}420.0 \pm 5.7^{b}$	$^{q}442.5 \pm 7.6^{a}$
		6	0.0 ± 0.0^{c}	$^{s}163.5 \pm 3.5^{b}$	$^{t}208.5 \pm 3.7^{a}$	$^{t}170.5 \pm 3.6^{b}$

[a–c] Mean values within the same row bearing different superscripts differ significantly ($P < 0.05$).
[p–t] Mean values within the same column bearing different superscripts differ significantly ($P < 0.05$).
α-tocopherol, alpha-tocopherol; α-tocotrienol, alpha-tocotrienol; γ-tocotrienol, gamma-tocotrienol; δ-tocotrienol, delta-tocotrienol.

38.4 mg/100 g of fat. The initial amount of vitamin E detected in beef fat during this study was 4 μg/g. However, this amount is completely destroyed after storage.

The mean values of vitamin E content in raw and cooked beef burgers stored at −18C significantly decreased during storage. During storage in frozen state (−18C), some catalysts and antioxidants may be trapped in the solid (frozen) phase, and antioxidant activity of the cytosolic phase may no longer function optimally (Wen *et al.* 1996). Lipid free radicals are soluble in the oil fraction and are more stable at low temperatures; this allows them to diffuse to longer distances and spread the reaction (Kanner 1994). Therefore, these radicals may escape the antioxidants in the frozen aqueous phase and diffuse into the membrane lipid system, where they initiate and promote lipid peroxidation. Lipid soluble vitamin E now becomes the first line of antioxidant defenses and may be consumed.

Vitamin E is reduced or degraded after processing and during storage in both beef burger and chicken frankfurters. After processing and storage, vitamin E depletion in raw beef burgers was 30 ± 5%. The loss of vitamin E during storage may possibly be bacause of the peroxides formed during lipid oxidation which may have occured during processing and in the presence of oxygen (mixing and chopping) and hence are degraded at higher temperatures but are stable at a temperature below 0C and as a consequence can react with the vitamin E (IFST 1989). This observation suggests that vitamin E is highly stable to sterilization (high temperature and short time) compared to oven cooking (low temperature and longtime cooking). Another reason may possibly be because of the storage conditions where the retorted frankfurters were stored at room temperature while the oven-cooked frankfurters were stored at −18C. According to Ottaway (1993), vitamin E is unusual in that it exhibits reduced stability at temperatures below freezing.

Vitamin E was found to be more stable in retorted than oven-cooked chicken frankfurters. Marinova and Yanishlieva (1992) explained that at high temperatures, oxygen has lower solubility in fats/oils so that autoxidative peroxide formation proceeds at lower rates and becomes gradually substituted by polymerization reactions. Another reason why vitamin E is stable in retorted chicken fankfurters may be because of the higher hydroperoxide (prooxidant) decomposition at a higher temperature (Kamal-Eldin and Appelqvist 1996).

When comparing vitamin E retention or loss in both beef burgers and chicken frankfurters, the results clearly show that their reductions are affected by cooking the method and storage. This study also showed that both α-tocopherol and α-tocotrienol decreased faster than the other two vitamin E homologs in both beef burgers and chicken frankfurters. This observation could be because of their chemical structures which differ from each other

based on the degree of the methylation of the chromane ring. The presence of more methyl substituents in the phenolic ring of the α-tocopherol and α-tocotrienol not only enhances their antioxidant activity but also increases their lipophilic properties, making the α-homologs the most soluble vitamin E in lipid substrates (van Acker *et al.* 1993).

The fast reduction of vitamin E in meat products could be because of the degradation of the chromanol ring of α-tocopherol and α-tocotrienol during heating because of the donation of the phenolic hydrogen to a lipid peroxyl radical (Burton *et al.* 1985). Wen *et al.* (1996) reported that the number of thiobarbituric acid-reactive substances in precooked patties of turkey fed an α-tocopherol-supplemented diet was significantly reduced in both raw and cooked burgers (by 35–50%) during frozen storage at −20C after 5 months. However, this study showed that vitamin E is more stable in beef burgers than in chicken frankfurters. This could be because of the fact that the usage of chicken trimming in formulated frankfurters contained higher concentrations of monounsaturated and polyunsaturated fatty acids compared to beef. The more highly unsaturated the fatty acid, the greater its susceptibility to oxidation. The oxidative stability of chicken meat is greater than that of turkey but lower than that of beef. This difference in stability could be caused by the presence of higher concentrations of polyunsaturated fatty acids in chicken meat (Wen *et al.* 1996). Another reason why the vitamin E reduction in chicken frankfurters was higher than that of beef burgers is possibly because of the different methods of cooking. Chicken frankfurters were cooked in the oven for about 75 min with gradient thermal increment from 55C (20 min), 65C (20 min), 75C (20 min) and finally 80C (15 min) while beef burgers were only cooked for 7–8 min until the internal temperature reached 74 ± 1C.

Heating involves reaction with oxygen from the air. Oxidation can take place when the fat is stored in the presence of oxygen at room or even at refrigerator temperature, but it is greatly enhanced by heating and in the presence of trace metal catalysts (e.g., iron or copper). However, the vitamin E reduction caused by free iron and calcium ions in the meat system is also controlled by phosphates which are added during the processing to enhance the water-holding and binding properties of finished processed meat products (Pearson and Gillet 1996).

CONCLUSIONS

Total vitamin E concentration in raw beef burgers stored at −18C decreased with frozen storage. The rate of total vitamin E reduction in cooked beef burgers was higher than that for raw beef burgers substituted with palm-based oils. Vitamin E was more stable in retorted chicken frankfurters than in

oven-cooked chicken frankfurters. γ- and δ-tocotrienol decreased faster than either γ- or δ-tocotrienol. γ- and δ-tocotrienols were quite stable in beef burgers and chicken frankfurters with the latter being a more stable homolog. In summary, the effect of cooking, frozen storage and the type of fats used could influence vitamin E stability and content in meat products. This study showed the potential of utilizing red PO as animal fat substitutes in improving the nutritional quality (vitamin E) of processed meats.

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