



Research article

Effect of antioxidants on reduction of lipid oxidation in canned coconut milk

Pimonporn Pongtongkam, Siree Chaiseri*

Department of Food Science and Technology, Faculty of Agro-Industry, Kasetsart University, Bangkok 10900, Thailand.

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Abstract

Changes were investigated in the odor of canned coconut milk during storage at ambient temperature (35°C) and their impact on consumer acceptance. Canned coconut milk samples were treated with antioxidants to reduce lipid oxidation that caused off-odor. Butylated hydroxytoluene (BHT), α -tocopherol and quercetin were used as antioxidants. After processing, the relative concentrations of δ -octalactone and ethyl octanoate in canned coconut milk without antioxidant (CCM) were 1,706.87 ng/g and 883.78 ng/g, respectively. Samples treated with BHT (CCM-B) and α -tocopherol (CCM-T) showed significant reductions in the relative concentrations of δ -octalactone (relative concentration in CCM-B = 1,118.06 ng/g and CCM-T = 514.78) and ethyl octanoate (relative concentration in CCM-B = 382.91 ng/g and CCM-T = 172.23 ng/g). In addition, coconut milk treated with α -tocopherol had the lowest relative concentrations of δ -octalactone (499.24 ng/g) and ethyl octanoate (230.67 ng/g) after storage for 2 mth. The coconut milk treated with quercetin (CCM-Q) had the highest δ -octalactone (4,466.43 ng/g) and CCM had the highest ethyl octanoate (3,948.86 ng/g). Sensory analysis of samples after storage for 2 mth showed that the panelists could detect a stronger rancid, creamy odor in CCM, CCM-Q and CCM-B than in CCM-T. The thiobarbituric acid reactive substances value (0.15 mg/L) in canned coconut milk treated with α -tocopherol after storage for 2 mth was significantly lower than for the non-treated one (0.36 mg/L), CCM-B (0.24 mg/L) and CCM-Q (0.29 mg/L). Thus, α -tocopherol could retard or inhibit lipid oxidation in canned coconut milk either after processing or during storage.

Introduction

Coconut milk, a white liquid, is an oil in water (o/w) emulsion, extracted from coconut endosperm either with or without the addition of water and is one of the most popular cooking ingredients for Thai food dishes and desserts (Tansakul and Chaisawang, 2006). Fresh coconut milk is normally used in Thai food and desserts; however, coconut milk products processed using pasteurization, ultrahigh temperature (UHT) sterilization and canning have become more popular due to their longer shelf-life. Lin and Wilkens (1970) reported

that δ -decalactone, δ -octalactone and octanol were the major volatile components of coconut meat. Other compounds that have been identified include: ethyl decanoate, dodecanoic acid, 2-heptanol, 2-nonanone, 2-nonanol, 2-octanol, and benzothiazole (Jirovetz et al., 2003). The odor of coconut milk changes during thermal processing and storage and such change can affect consumer acceptance of the product. For example, Tinchan et al. (2015) reported changes in the volatile compounds of canned coconut milk during storage using gas chromatography (GC). The first major change occurred during 2 mth of storage, with alcohols, acids, lactones and other oxidation products increasing in concentrations (as indicators of lipid oxidation that generates off-odor volatiles) in the canned coconut milk.

* Corresponding author.

E-mail address: siree.c@ku.ac.th (S. Chaiseri)

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Hexanal, δ -octalactone, ethyl octanoate and 3-hydroxy-2-butanone were described as odors of grass, fat and butter, respectively, increased greatly after processing and during storage. The second change was detected in month 5 of storage, when acids and lactones increased greatly, corresponding with the rancid coconut-like, fatty and sweet odors that caused the off-odor in the canned coconut milk.

Butylated hydroxytoluene (BHT) is a common antioxidant recognized as safe for use in foods containing fats, pharmaceuticals, oil industries and petroleum products (Yehye et al., 2015). BHT is a synthetic antioxidant that can be used in low concentrations and acts as an antioxidant to maintain the proper odor and flavor in food products such as chewing gum and milk (Witter, 2005). Nowadays, the trend is to improve the shelf-life of products by using natural antioxidants. For example, α -tocopherol is a natural antioxidant that is soluble in oil; it and ascorbyl palmitate showed antioxidant properties in riboflavin-photosensitized oil in water (o/w) emulsion. Huang et al. (1994) studied the antioxidant activity of α -tocopherol and γ -tocopherol in o/w emulsion and in bulk oil. Their results showed that both α -tocopherol and γ -tocopherol could inhibit hexanal formation. Quercetin, a natural antioxidant, is a natural flavonoid and is most common as a secondary metabolite in plants (Abdelmoaty et al., 2010). Naz et al. (2008) researched the effects of pelargonidin, cyanidin, quercetin, myrecetin and gallic acid on the stability of heated refined corn oil and reported that all these antioxidants effectively reduced the oxidation rate in the oil, as detected by a decrease in the peroxide value. There has been no report on the use of antioxidants in coconut milk, though similar work has been reported in milk. For example, Van Aardt et al. (2005) reported that treatment with tocopherol and ascorbic acid of light-exposed milk could decrease lipid oxidation and significantly lower the thiobarbituric acid reactive substances (TBARS) value compared to light-exposed milk without antioxidant.

The objective of the current study was to determine the effect of antioxidants (BHT representing synthetic antioxidants and α -tocopherol and quercetin representing natural antioxidants) on the aroma and volatile compounds from lipid oxidation during storage of canned coconut milk. This research focused on ethyl octanoate, hexanal and δ -octalactone after storage for 0 mth, 2 mth and 5 mth.

Materials and Methods

Sample preparation

Grated coconut meat without any brown testa was purchased from a local market in Bangkok, Thailand. Deodorized water was added to the grated coconut meat at a weight ratio of 1:1. The mixture was squeezed using a hydraulic press (Sakaya Automate Co. Ltd; Thailand) to obtain fresh coconut milk (FCM).

Preparation of canned coconut milk

Samples of canned coconut milk (CCM), canned coconut milk with BHT (CCM-B), canned coconut milk with α -tocopherol (CCM-T) and canned coconut milk with quercetin (CCM-Q) were prepared from FCM without and with 100 parts per million (ppm) antioxidants to be well within the regulated limit of not exceeding 200 ppm (Ministry of Public Health of Thailand, 2018). BHT $\geq$ 99% purity (GC grade, Sigma-Aldrich; USA.), α -tocopherol $\geq$ 96% purity (HPLC grade, Sigma-Aldrich, USA), quercetin $\geq$ 95% purity (HPLC grade, Sigma-Aldrich; USA.) were used. Samples were preheated at 72°C for 1 min. Heated coconut milk samples were poured into cans (307 mm $\times$ 409 mm; diameter $\times$ height). Water steam was used to heat the coconut milk to 80°C to exhaust gases prior to can sealing. The canned coconut milk samples were sterilized in a gas retort (Knoahaudyu; Thailand) until F_0 at 121°C was equal to 5 min (Seow and Gwee, 1997). The samples were cooled to room temperature in an ice bath before extraction and storage.

Storage conditions

The canned coconut milk samples were stored at ambient temperature (32–35°C) for 6 mth. Canned coconut milk samples were analyzed monthly for off-odor but the current study focused on storage after 0 mth, 2 mth and 5 mth.

Extraction

Canned coconut milk samples (100 mL) were spiked with 10 μ L of 2-methyl-3-heptanone (10.25 mg/mL) in diethyl ether as the internal standard mixture. Diethyl ether (50 mL) was added to extract volatile compounds in a Duran bottle with a magnetic stirrer at low speed for 30 min at room temperature. Extractions were carried out three times. The diethyl ether containing volatile compounds was collected using a Pasteur pipette. High vacuum distillation (vacuum pump model B62426952; Edward; UK) was applied under 1×10^{-5} torr at ambient temperature for 2 hr and at 50°C for 1 hr. Extracts from the first trap were collected, purged under N_2 gas to reach 5 mL and dried over 2 g of anhydrous sodium sulfate to remove any residual water. Extracts were then concentrated to 250 μ L under N_2 gas purging before analysis.

Gas chromatography-mass spectrometry analysis

Gas chromatography-mass spectrometry was used to analyze 1 μ L of solvent extract using a GC-TOFMS that consisted of an Agilent® 7980A gas chromatograph (Agilent Technologies; CA, USA) equipped with a time-of-flight mass spectrometer (TOFMS model Pegasus® 4D GC X GC; LECO; MI, USA). Mass spectra were collected in the range 30–300 m/z. Two capillary columns, namely Rxi5 (30 m length, 0.25 mm internal diameter and 0.25 μ m film thickness; Restek; PA, USA) and Stabilwax (30 m $\times$ 0.25 mm $\times$ 0.25 μ m film thickness; Restek; PA, USA) were used and the carrier gas was helium

at 1.0 mL/min. The injector and the detector temperatures were 250°C. The initial oven temperature was 35°C and was held for 5 min, raised at the rate of 4°C/min to 225°C and finally held for 20 min.

The retention index (RI) was calculated correlated to *n*-alkane standards (C6–C30). Relative concentrations of volatile compounds were calculated from total ion areas relative to those of an internal standard (2-methyl-3-heptanone). Volatile compounds were identified using comparison of the mass spectra of the volatile compounds with the Wiley 275 library, NIST 08 library and by matching RI values from two different columns with RI values in the literature. Selected compounds were positively identified based on comparison with the data of authentic compounds. The odor activity value (OAV) was calculated from the relative concentration of the volatile compound divided by its odor threshold. Because coconut milk is an oil in water emulsion, OAVs were calculated based on both water and oil media.

Rancidity determination using thiobarbituric acid reactive substances

Coconut milk samples were subjected to analysis using 2-thiobarbituric acid (TBA), according to the methodology described by Dunkley and Jennings (1951). For this analysis, 10 mL of coconut milk was placed in a centrifuge tube of approximately 50 mL. Next, 5 mL of the TBA reagent was added to each tube and homogenized. The tubes were boiled for 10 min and subsequently cooled in a water bath (4°C). After cooling, 15 mL of the extraction reagent was added to each tube and mixed homogeneously for 30 s. The extract was obtained by centrifuging the tubes for 5 min at 60 revolutions per second. The reading was conducted at 535 nm in a spectrophotometer (Thermo Scientific; MA, USA).

Sensory evaluation

Panelists were screened and selected using a triangle test. The panelists were trained for 15 h before evaluating the actual samples. The panelists were asked to generate the terminology and select the reference for evaluation. The panelists discussed and agreed on specific odor descriptors for coconut milk samples. The panelists were trained to identify and evaluate odor intensities compared to reference standards before testing. Training continued until the results for individual panelists were consistent. For samples testing, 10 panelists were trained to identify and define terms for coconut milk aroma. Samples (10 g) of coconut milk and references were filled in separate 125 mL Teflon sniff bottles (Nalgene PTFE wash bottle without siphon tube; Nalge Nunc International; NY, USA) at around $25 \pm 2^\circ\text{C}$ for 1 hr before evaluation. Bottles were labeled with random 3-digit codes and covered with aluminum foil to prevent any visual bias. Samples were presented to the panelists at 25°C to evaluate each sample by gently squeezing the bottle and sniffing the air emitted from the nozzle. The panelists were asked to qualify the intensity of each term based on a scale from 0 (none) to 15 (extremely strong) and following discussion they provided an agreed value for the intensity of each odor term. The final values of odor intensities were recorded.

Statistical analysis

A randomized complete block design was applied to evaluate the effect of storage time on volatile compounds of canned coconut milk samples. One-way analysis of variance was used to analyze volatile compound concentrations in the samples. Significant differences were determined at the 0.05 level using Duncan's multiple range test with the SPSS version 12 software (SPSS Inc; IL, USA).

Ethics Statements

This study was approved by the Ethics Committee of Kasetsart University (Approval no. COE62/004).

Results and Discussion

Changes in volatile compounds from canning process

The coconut milk samples (FCM, CCM, CCM-B, CCM-T and CCM-Q) were analyzed for their volatile compounds using GC-TOFMS. Table 1 shows the relative concentrations of volatile compounds in FCM and CCM immediately after the canning process as well as those in CCM-B, CCM-T and CCM-Q. Acids, alcohols, aldehydes, esters, ketones and lactones were the predominant groups of compounds identified. CCM had higher concentrations of volatile compounds than FCM resulting from thermal processing. The thermal process played an important role in the volatile compound formation in canned coconut milk immediately after processing (month 0). The heat process induced lipolysis that increased the levels of free butanoic acid, hexanoic acid and octanoic acid in CCM and CCM-Q. Free fatty acids with carbon atoms fewer than 8 or 10 are known to impart rancid, pungent and acidic odors in food products, while fatty acid with 12 carbon atoms is responsible for a soapy taste (Cadwallader et al., 2007). Free fatty acids and hydroperoxides could result in the formation of aldehydes, alcohols, methyl ketones and lactones as secondary products (Litman and Numrych, 1978; Nawar, 1989). The products of lipid oxidation could result in off-odor in canned coconut milk, with δ -octalactone and ethyl octanoate in relatively high abundance, which was in agreement with other studies (Lin and Wilkens, 1970; Pai et al., 1979). CCM had δ -octalactone and ethyl octanoate at significantly higher levels than in CCM-B and CCM-T but lower than in CCM-Q. BHT is a synthetic antioxidant that is used in the food industry and is the primary antioxidant that interrupts the free-radical chain of oxidative reactions by donating hydrogen from the phenolic hydroxyl groups and forming stable free radicals which do not initiate or propagate further oxidation of lipids (Domingos et al., 2007). α -Tocopherol could play an antioxidant role by interfering with either chain propagation or initiation by readily donating hydrogen atoms to lipid peroxy radicals. α -Tocopherol is known to produce stable and relatively unreactive antioxidant radicals and is able to compete with lipid substrate (Van Aardt et al., 2004). Quercetin is a scavenger of reactive oxygen species and reactive nitrogen species both in vitro and in vivo (Boots et al., 2008).

Table 1 Effect of antioxidants on relative concentrations of selected volatile compounds after canning of coconut milk

Compound	RI ¹	Relative concentration ² (ng/g)											
		FCM			CCM			CCM-B			CCM-T		
		Wax	Rxi-5	M0	M0	M2	M5	M0	M2	M5	M0	M2	M5
Alcohols													
<i>l</i> -Butanol	1,135	<900	0.00 ^m	123.49±3.95 ^a	2,374.89±1.12 ^a	985.89±5.05 ^c	80.25±2.91 ⁱ	144.26±3.90 ^e	264.07±1.98 ^f	71.30±1.19 ^a	751.20±4.94 ^e	766.10±2.99 ^d	87.83±2.94 ^f
2,3-Butanediol	1,567	<900	0.00 ⁱ	769.40±5.12 ^a	3,191.61±2.13 ^a	9,171.56±1.99 ^a	28.26±1.97 ^k	1,621.18±3.11 ^c	121.70±2.10 ⁱ	0.65±0.04 ^f	40.19±1.99 ⁱ	143.62±2.17 ^b	6,885.28±4.93 ^b
Aldehydes													
Hexanal	1,073	n.d.	3.01±0.18 ^a	21.76±1.82 ^a	241.58±1.14 ^a	0.00 ^b	0.00 ^b	165.57±2.72 ^b	0.00 ^b	11.17±0.74 ^f	0.00 ^b	129.90±2.58 ^c	29.68±1.60 ^f
Ketones													
3-Hydroxy-2-butanone	1,285	<900	491.99±2.59 ⁱ	1,794.48±2.67 ^d	2,064.08±4.58 ^c	2,995.05±3.35 ^a	1,714.89±0.95 ^d	1,034.71±4.64 ^d	198.16±2.06 ^k	983.12±3.83 ^b	1,113.38±2.95 ^f	128.56±2.64 ^c	2,438.90±2.99 ^b
2-Heptanone	1,173	<900	16.31±1.06 ^b	93.15±2.96 ^c	1.08±0.14 ⁱ	281.54±1.48 ^a	73.19±1.97 ^d	0.00 ⁱ	66.33±0.99 ^a	48.23±0.98 ^f	22.73±1.04 ^a	97.73±1.95 ^c	145.33±2.90 ^b
Acids													
Acetic acid	1,425	<900	0.00 ⁱ	1,923.11±2.01 ^b	1,743.25±3.08 ⁱ	8,531.41±3.48 ^d	2,389.44±2.41 ^a	249.54±3.46 ⁱ	3,045.01±2.99 ^f	1,574.73±2.01 ^f	724.13±1.86 ^f	12,435.77±1.89 ^c	84,801.79±4.02 ^a
Butanoic acid	1,636	<900	0.00 ⁱ	5.79±0.02 ⁱ	657.44±2.42 ^d	437.54±2.25 ^c	71.02±2.42 ^a	40.78±1.99 ^b	416.87±1.67 ^a	0.00 ⁱ	845.25±1.70 ^c	129.92±3.01 ^f	1,897.08±3.99 ^a
Hexanoic acid	1,849	1,001	0.00 ⁱ	75.83±2.95 ^b	265.07±2.02 ^c	1,200.18±1.96 ^c	0.00 ⁱ	318.21±2.96 ^d	57.41±1.92 ⁱ	0.00 ⁱ	267.57±2.56 ^c	197.52±1.93 ^a	409.62±2.96 ^c
Octanoic acid	2,087	1,130	0.00 ⁱ	459.48±2.51 ^f	570.41±2.86 ^c	2,635.94±1.68 ^a	0.00 ⁱ	676.71±0.96 ^d	76.43±2.73 ^a	0.00 ⁱ	620.41±1.77 ^d	57.38±0.80 ^b	1,453.90±1.93 ^c
Lactones													
δ -Hexalactone	1,789	1,097	7.29±0.02 ^b	162.24±2.35 ⁱ	775.20±2.23 ^c	1,750.73±2.5 ^b	243.60±1.49 ^b	560.03±1.99 ^f	322.25±1.65 ^a	82.53±1.53 ⁱ	547.41±2.10 ^f	1,024.55±2.50 ^c	981.51±2.48 ^d
δ -Octalactone	1,961	1,305	24.44±1.94 ^m	1,706.87±2.44 ⁱ	4,138.49±2.03 ^d	11,058.31±1.97 ^a	1,118.06±2.37 ⁱ	3,437.32±1.75 ^c	2,506.33±2.81 ^a	514.78±1.87 ^b	499.24±1.86 ^f	5,462.28±3.53 ^b	4,466.43±3.21 ^c
δ -Decalactone	2,189	1,496	0.00 ⁱ	432.22±3.12 ^c	1,131.58±3.26 ^b	2,111.75±2.88 ^a	0.00 ⁱ	29.38±4.03 ^b	257.68±2.37 ^a	0.00 ⁱ	0.00 ⁱ	371.40±2.96 ^d	205.19±1.37 ^f
Esters													
Ethyl octanoate	1,496	1,190	54.31±1.94 ^d	883.78±2.09 ^d	3,948.86±2.69 ^a	330.42±2.75 ^b	382.91±2.95 ^b	349.13±2.31 ^b	395.59±2.75 ^a	172.23±2.05 ^f	230.67±2.02 ^f	1,259.06±1.95 ^b	988.66±2.75 ^c
Ethyl decanoate	1,665	1,386	0.00 ⁱ	1,033.23±2.53 ^b	388.34±4.11 ^c	823.69±2.58 ^c	46.71±2.75 ⁱ	279.78±2.62 ^f	0.00 ⁱ	135.02±2.01 ^a	264.64±1.97 ^f	1,070.52±2.69 ^a	475.06±2.50 ^d
Ethyl dodecanoate	1,840	1,595	12.09±1.00 ^b	253.12±1.00 ^b	85.92±2.04 ^c	182.77±2.98 ^c	0.00 ⁱ	25.23±1.86 ^f	48.54±3.13 ^f	13.47±1.21 ^b	0.00 ⁱ	216.09±1.29 ^b	143.17±1.77 ^d

FCM= fresh coconut milk; CCM = canned coconut milk without added antioxidant; CCM-B = canned coconut milk with butylated hydroxytoluene; CCM-T= canned coconut milk with α -tocopherol; CCM-Q = canned coconut milk with quercetin; storage periods, M0 = 0 mth, M2 = 2 mth, M5= 5 mth; nd = not detected

¹ RI = retention indices of Stabilwax (Wax) and Rxi-5 columns.

² Average relative concentrations (n = 3) of volatile compounds

Mean±SD with different lowercase superscripts in the same row are significantly ($p < 0.05$) different.

All the canned coconut milk samples had 3-hydroxy-2-butanone levels higher than that of FCM; therefore, all canned coconut milk samples had a creamier odor than FCM. Fatty acids might be important factors contributing to the flavor of canned coconut milk. Hexanoic acid (having a goat-like odor) was significantly lower in CCM-B and CCM-T than in CCM. OAV is typically used to predict a compound's ability to produce an odor and is defined as the ratio of the concentration of a compound to its odor threshold, so when the OAV of a compound is higher than 1, it is considered to contribute to the overall aroma of a food item (Grosch, 2001). Based on their relatively high OAVs, 3-hydroxy-2-butanone (2.2), δ -octalactone (4.3), δ -decalactone (4.3), ethyl octanoate (12.6) and ethyl decanoate (44.9) contributed to the buttery, sweet, rancid, fruity and coconut-like odors in canned coconut milk after processing (Table 2).

Nine odor attributes were developed by the panelists to represent the aroma profile of coconut milk, namely coconut, creamy, caramel, nutty, rancid, green, jasmine sweet and salty (Fig. 1). The aroma profiles of the fresh and canned coconut milks are shown in Fig. 1. The aroma profile of CCM was different from FCM. The intensities of most attributes in all canned coconut milks were higher than those of fresh coconut milk. It has been reported that the thermal process has a large impact on aroma formation. According to Silanoi (2004), heating coconut milk at 80, 90 or 100°C for 20 min intensified the coconut-like, sweet, creamy and cooked odors. Coconut milk samples that had been heated at 100°C for 20 min had the highest intensities of the creamy odor. The current results were in agreement with Silanoi (2004), who reported that the thermal process caused the formation of sweet and creamy odors. These odors could be either desirable or undesirable but resulted in the aroma quality of the canned coconut milk being different from fresh coconut milk.

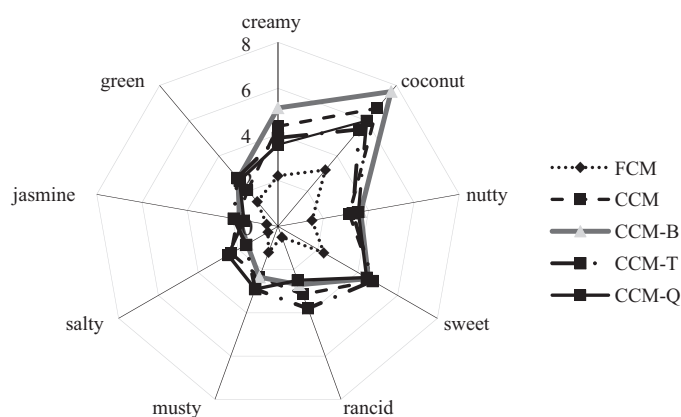


Fig. 1 Aroma profiles of fresh and canned coconut milks after processing (0 mth of storage), where FCM = fresh coconut milk, CCM = canned coconut milk, CCM-B = canned coconut with butylated hydroxytoluene, CCM-T = canned coconut milk with α -tocopherol and CCM-Q = canned coconut milk with quercetin

Table 2 Odor activity value in water of selected volatile compounds in canned coconut milk after storage up to 5 mth

Compound	RI ¹	Odor description ²	Odor threshold ³ (in water, ppb)	OAV in water														
				FCM			CCM			CCM-B			CCM-T			CCM-Q		
				M0	M2	M5	M0	M2	M5	M0	M2	M5	M0	M2	M5	M0	M2	M5
Hexanal	1,073	nd	grassy, green	10.5	<1	2.1	23.0	2.6	3.7	na	15.8	na	1.1	na	na	12.4	2.8	na
3-Hydroxy-2-butanone	1,285	<900	buttery	800	<1	2.2	2.6	2.1	3.7	<1	1.3	<1	1.2	1.4	<1	1.6	<1	3.0
δ -Hexalactone	1,789	1,097	sweet	1,600	<1	<1	<1	<1	1.1	<1	<1	<1	<1	<1	<1	<1	<1	3.4
δ -Octalactone	1,949	1,305	coconut-like	400	1.4	4.3	10.3	27.6	21.1	8.6	2.8	6.3	1.3	1.2	8.0	13.7	11.2	5.1
δ -Decalactone	2,189	1,496	sweet, peach coconut-like	100	1.9	4.3	11.3	21.1	21.1	0.29	na	2.6	na	na	na	3.7	<1	2.1
Ethyl octanoate	1,496	1,190	fruity, fatty	70	<1	12.6	56.4	4.7	35.8	5.0	5.5	5.7	2.5	3.3	7.9	17.9	14.1	7.3
Ethyl decanoate	1,627	1,386	grape	23	na	44.9	16.9	35.8	35.8	12.2	2.0	na	5.9	11.5	na	46.5	20.7	na

OAV = odor activity value; ppb = parts per billion; FCM = fresh coconut milk; CCM = canned coconut milk without added antioxidant; CCM-B = canned coconut milk with butylated hydroxytoluene; CCM-T = canned coconut milk with α -tocopherol; CCM-Q = canned coconut milk with quercetin; storage periods, M0 = 0 mth, M2 = 2 mth, M5 = 5 mth; na = not available; nd = not detected

¹ RI = retention indices of Stabilwax (Wax) and Rxi-5 columns

² Odor description from Rychlik et al. (1998)

³ Odor threshold from Rychlik et al. (1998)

Changes in selected volatile compounds during storage

Table 1 shows that the relative concentrations of ethyl octanoate and δ -octalactone greatly increased during storage. Hydroxy fatty acid could contribute to the increased levels of lactones after 5 mth and could result in significant differences in the volatile profiles between short and the long periods of storage for the canned coconut milk, resulting in the different intensities of the sweet, coconut-like and peach-like odors. Under these circumstances, lipid precursors could also be considered as main factors affecting the occurrence of lipid oxidation. Tinchana et al. (2015) showed that fatty acid levels also increased after 2–3 mth. Free fatty acids with 4–8 carbon atoms were the major products of lipid oxidation and lipolysis that presumably occurred during storage.

The OAVs calculated for the volatile compounds found in canned coconut milk immediately after processing and after 2 mth and 5 mth of storage are shown in Table 2. The OAVs in water were determined.

During storage, the volatile compounds in the food products changed due to the environmental conditions of storage, such as temperature, relative humidity, time of storage, and also the food composition. The storage conditions during the current study were 35°C, relative humidity of 50% and time of storage was up to 6 mth. Changes in the volatile compounds during 2 mth storage were observed. Products of lipid oxidation were observed throughout storage, even in the environment with low oxygen and a low amount of unsaturated fatty acids in the canned coconut milk samples.

Table 2 shows the increases in the OAVs in water of hexanal (23.0), 3-hydroxy-2-butanone (2.6), δ -octalactone (10.3), δ -decalactone (11.3), ethyl octanoate (56.4) and ethyl decanoate (16.9) in the canned coconut milk samples during 2 mth of storage. The changes in the volatile compounds in the canned coconut milk contributed to the green, buttery, sweet, rancid, fruity and coconut-like odor. From Table 2, canned coconut milk treated with α -tocopherol had significantly lower levels of hexanal, ethyl octanoate and δ -octalactone than the control and those treated with quercetin, perhaps because α -tocopherol is a nonpolar antioxidant that is more active in a polar system such as the o/w emulsion of coconut milk. Nonpolar, lipid soluble antioxidants such as α -tocopherol and BHT would locate in the oil phase where oxidation propagated (Jacobsen et al., 2008). Lipid oxidation has been described as an interfacial phenomenon

mainly taking place or being initiated at the interface where different non-polar and polar compounds in the system can interact (McClements and Decker, 2000). However, only α -tocopherol can act as a potent antioxidant in tissue membranes against lipid radicals because of its lipophilic properties that allow it to concentrate in the membrane (Slater, 1978). Quercetin, a polar antioxidant, interacts more easily with aqueous-phase iron that increases its prooxidant activity (Mei et al. 1999). Polar antioxidants can inhibit lipid oxidation in a bulk oil or non-polar system more than in a polar system such as an oil in water emulsion.

Hexanal is usually used as an oxidation index. The OAV of hexanal in CCM at month 2 was higher than OAV at month 0. Furthermore, during 2 mth of storage, the OAV of hexanal in CCM was higher than in other samples treated with the antioxidant (Table 2). CCM-T did not have any hexanal during 2 mth and 5 mth of storage that might have been caused by α -tocopherol.

The effect of antioxidant on lipid oxidation was confirmed using TBARS analysis. Antioxidants affected the TBARS values of the canned coconut milk samples after processing and during storage (Table 3). CCM had a significantly higher TBARS value than CCM-B or CCM-T with antioxidant treatments but not with CCM-Q. CCM-T had the lowest TBARS value, indicating that α -tocopherol could retard or inhibit lipid oxidation in canned coconut milk. BHT and α -tocopherol are known to be the primary or chain-breaking antioxidants that can inhibit or retard lipid oxidation by interfering with either chain propagation or initiation by donating hydrogen atoms to lipid peroxy radicals (Van Aardt et al., 2004). The nutty odor of all coconut milk samples slightly increased after storage (Fig. 2). This might have been due to the off-odor developing during storage. CCM-T had lower levels of rancid, musty and nutty odors than CCM, CCM-B and CCM-Q, confirming the effective antioxidant activity of α -tocopherol.

After 5 mth of storage, the canned coconut milk treated with α -tocopherol had the lowest OAV. Importantly, the dairy, coconut, green and rancid odors in the canned coconut milk samples except for CCM-T increased after storage. This might have been due to the off-odor developing during storage of canned coconut milk. CCM-T had lower intensities of coconut, green and rancid odors than CCM, CCM-B and CCM-Q, confirming the effective antioxidant activity of α -tocopherol (Fig 3).

Table 3 Thiobarbituric acid reactive substances values in samples of canned coconut milk with and without antioxidants after processing and during storage.

Storage time (mth)	TBARS (mg/L)			
	CCM	CCM-B	CCM-T	CCM-Q
0	0.15 $\pm$ 0.01 ^a	0.11 $\pm$ 0.01 ^b	0.10 $\pm$ 0.01 ^b	0.11 $\pm$ 0.01 ^b
2	0.36 $\pm$ 0.03 ^a	0.24 $\pm$ 0.02 ^b	0.15 $\pm$ 0.01 ^d	0.29 $\pm$ 0.02 ^c
5	0.45 $\pm$ 0.03 ^a	0.29 $\pm$ 0.02 ^c	0.20 $\pm$ 0.02 ^d	0.33 $\pm$ 0.03 ^b

TBARS = thiobarbituric acid reactive substances; CCM = canned coconut milk without added antioxidant; CCM-B = canned coconut milk with butylated hydroxytoluene; CCM-T = canned coconut milk with α -tocopherol; CCM-Q = canned coconut milk with quercetin.

Mean $\pm$ SD with the different lowercase superscripts in the same row are significantly ($p < 0.05$) different.

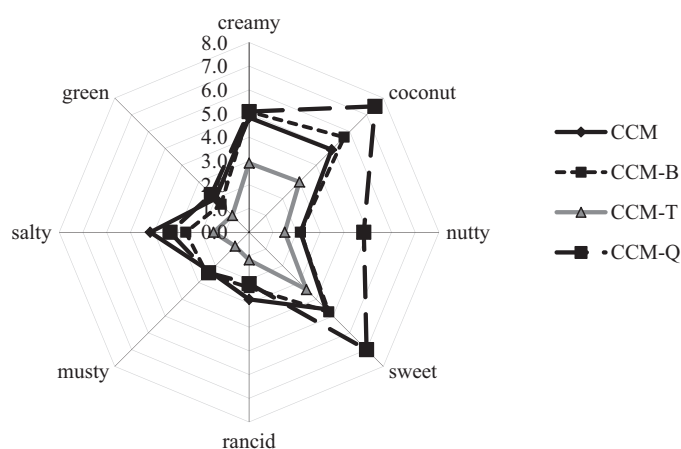


Fig. 2 Aroma profiles after 2 mth storage, where CCM = canned coconut milk, CCM-B = canned coconut with butylated hydroxytoluene, CCM-T = canned coconut milk with α -tocopherol and CCM-Q = canned coconut milk with quercetin

The volatile changes in canned coconut milk after processing and during storage might cause off-odor volatiles. Treatment of canned coconut milk with butylated hydroxytoluene (100 ppm) and -tocopherol (100 ppm) was effective in reducing lipid oxidation and the levels of hexanal, ethyl octanoate and δ -octalactone. α -Tocopherol was more effective in reducing off-odor after processing and during storage for 5 mth. Furthermore, the results of the descriptive analysis showed that CCM-T could reduce creamy, nutty, salty and musty odors during analysis.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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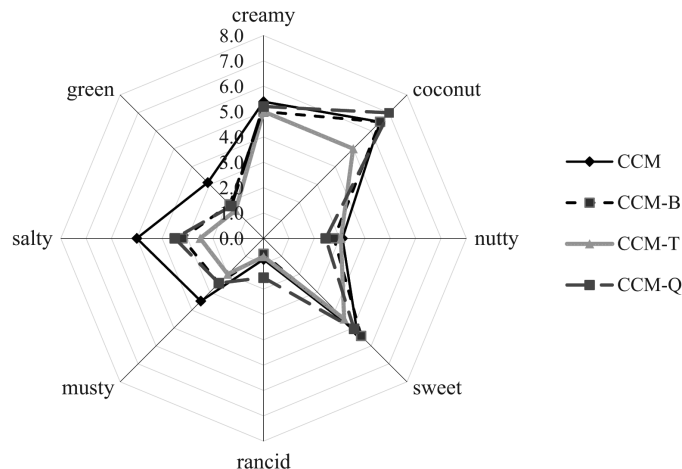


Fig. 3 Aroma profiles after 5 mth storage, where CCM = canned coconut milk, CCM-B = canned coconut with butylated hydroxytoluene, CCM-T = canned coconut milk with α -tocopherol and CCM-Q = canned coconut milk with quercetin

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