Feasibility and use of vitamin A–fortified vegetable oils among consumers of different socioeconomic status in Thailand

Laddawan Puysuwan, Visith Chavasit, Pongtorn Sungpuag, Daniela Hediger, and Teerasak Punvichai

Abstract

Background. *Vitamin A losses in fortified vegetable oils can differ, depending upon the cooking and distribution conditions of a country.*

Objective. *To determine vitamin A losses in different vegetable oils during transportation, cooking, and storage among consumers of different socioeconomic status.*

Methods. *Soybean, rice bran, and palm oils were fortified with vitamin A palmitate at 267 µg/15 mL. The oils were packaged in 5-L metal cans and 250-mL polyethylene terephthalate (PET) bottles and then stored under light and dark conditions. Unopened and opened bottles were stored for 13 and 4 weeks, respectively. Fortified palm oil also was bulk transported in trucks and packaged in 1-kg polypropylene bags that were closed with rubber bands. Vitamin losses were measured after cooking at 120° and 170°C for 5 and 10 minutes in iron, aluminum, Teflon, and glass pans.*

Results. *Vitamin A losses of oils in PET bottles stored under light conditions were 20% to 25% at the 5th week and became greater than 80% after 13 weeks, whereas losses under dark conditions and in metal containers were less than 15%. Loss during bulk transportation was 25%, with no change in peroxide value. Losses in opened bottles after 4 weeks under light conditions were 50% to 90% based on the degree of oil unsaturation; however, losses under dark conditions were less than 5%. Losses after cooking at 120° and 170°C for 10 minutes were less than 5% and 15%, respectively. The type of pan did not affect the amount of loss. The peroxide values of oils in bottles increased during storage under light conditions.*

Conclusions. *Fortification of vegetable oils with vitamin A for consumers of different socioeconomic status is feasible; however, light protection is needed for better stability.*

Key words: Fortification, vegetable oil, vitamin A, vitamin loss

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Introduction

Vitamin A deficiency is a common public health problem in developing countries [1, 2]. Vitamin A deficiency in developing countries affects infants, preschool and school-age children, adolescents, and pregnant and lactating women [3–5]. In Southeast Asia, the prevalence of vitamin A deficiency in schoolchildren was estimated to be 23.4%, ranging from 5.2% in Thailand to 34.2% in Indonesia [6]. However, the prevalence, severity, and health consequences of vitamin A deficiency in preschool-aged children and in pregnant and lactating women have still not been clearly evaluated. Vitamin A fortification of frequently consumed regional foods, such as vegetable oil, is a suitable method to prevent and control vitamin A deficiency in various populations around the world [7–10]. Vitamin A can be easily mixed and uniformly distributed in the food and is stable in pure refined vegetable oil without affecting the oil's sensory quality [11]. In addition, oil facilitates the absorption of vitamin A by the body [12, 13].

Vitamin A, however, is sensitive to oxidation caused by light and metal in the presence of oxygen [14]. Free radicals from chain reactions of lipid oxidation can also cause vitamin A oxidation. Other conditions, such as those during packaging, transportation, distribution, and cooking, can cause vitamin A loss. These conditions can be very different among countries due to market preference, socioeconomic status of the consumers, and food cultures. For instance, in Thailand higher-income urban people normally use cooking oils

packaged in clear bottles, whereas repackaged cooking oil is generally used among low-income people. Cooking oil to be repackaged is delivered in either large oil trucks or 20-L metal containers. Consequently, vegetable oil packaged in clear polyethylene terephthalate (PET) bottles accounts for only 20% of the market, and the rest of the market is accounted for by repackaged oil (personal communication, P. Boonumnuai, 2004).

Different types of cooking oils are used in the Southeast Asian region based on availability, accessibility, and health benefits. Palm oil is widely consumed due to its availability and accessibility, whereas soybean and rice bran oils are used by health-conscious consumers. Soybean and rice bran oils are more susceptible to oxidation because of their high degree of unsaturation.

This study examined vitamin A losses in different vegetable oils during transportation, cooking, and storage among consumers of different socioeconomic status.

Materials and methods

Fortification of oil

Commercially refined vegetable oils, including palm oil (55% unsaturated fatty acids), soybean oil (84% unsaturated fatty acids), and rice bran oil (77% unsaturated fatty acids), were fortified with vitamin A palmitate stabilized with tocopherol at 267 μg/15 mL (one-third of the Thai recommended daily intake [RDI]). The calculation was based on an average density of the oils of 0.910 g/mL. The percent vitamin A loss was calculated on the basis of the vitamin A content at day 0.

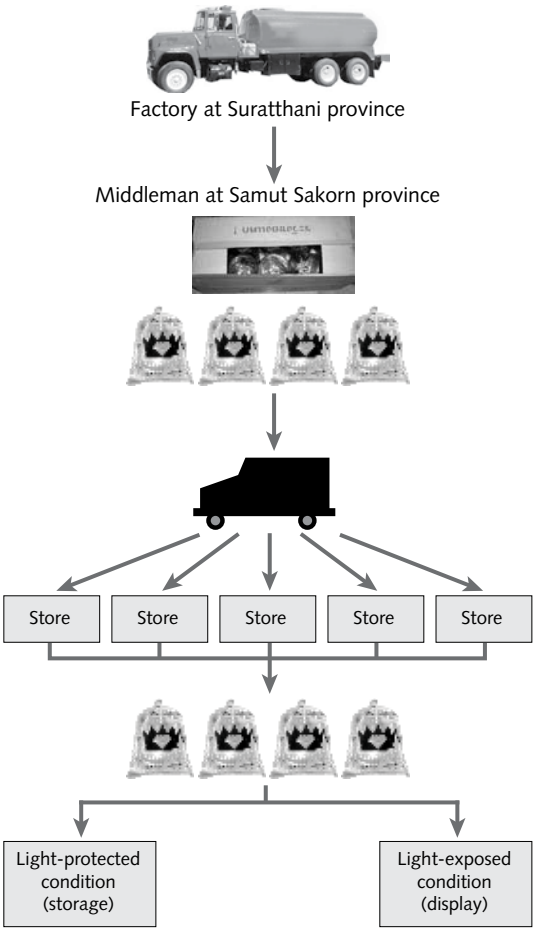

FIG. 1. Distribution of vegetable oils

Losses during distribution

This study evaluated the loss of vitamin A during the normal transportation and distribution of palm oil. This oil is normally consumed by low-income people, who are the target population for prevention of vitamin A deficiency in Thailand (**fig. 1**). At the factory in Suratthani Province, approximately 14,000 kg of palm oil was fortified by adding vitamin A to the tank of the oil truck and vigorously mixing it with oil while the tank was being filled with oil. Fortified oil was transported in the truck to middlemen in Samutsakorn Province (an 800-km, 9-hour drive), who transferred the fortified oil from the truck and repackaged it in 1-kg polypropylene bags that were then closed with rubber bands. The repackaged oil was sent to retailers in roofed pickup trucks. The transportation time at this stage was normally between 2 to 3 hours. Samples were obtained at different points along the distribution route, including the oil truck after fortification of the oil at the factory (three samples), the oil truck after it arrived at the middlemen (three samples), and five local retail stores (three bags per store). The samples were collected in opaque glass bottles, flushed with nitrogen gas, and stored in a freezer at –8°C before analysis. In addition, other samples of palm oil were obtained from retail stores and stored at the Institute of Nutrition, Mahidol University, in order to continue storage tests under retail store conditions. The products in plastic bags were kept under light-protected conditions in Kraft paper cases (as they are kept during storage) as well as under exposure to direct sunlight (the condition in which they are displayed in the store). Three bags of the oil kept in Kraft paper cases were analyzed on the 7th day of storage, and three bags each of the oil that was exposed to sunlight were analyzed on the 3rd and the 7th days.

Losses during storage

Fortified oils (palm, rice bran, and soybean oils) were packaged in 5-L metal containers and 250 mL PET bottles. Losses due to storage aimed to simulate storage conditions in a non air-conditioned retail store for 13

weeks, which allowed sunlight in during the daytime and provided good ventilation. The PET bottled product was also kept under dark conditions within a Kraft paper case. Three PET bottles were sampled every week, and three metal containers were sampled every 2 weeks for analysis.

Losses during use

This part of the study simulated the conditions under which cooking oil was used in the kitchen, where the oil was normally poured out and then the bottle was recapped again. Three kinds of oil were also used in the study. Three recapped bottles (1-L PET bottle) of each oil were stored under two conditions: exposed to light (on a kitchen shelf exposed to sunlight) and protected from light (in a kitchen cabinet protected from sunlight). Two hundred milliliters of fortified oil was drawn from each bottle and collected for analysis every week for 1 month. The study also simulated cooking conditions to evaluate the losses of fortified vitamin A resulting from the traditional cooking methods of stir frying (~120 °C) and deep frying (~170 °C). Four types of cooking pans were tested: aluminum (Fish brand, diameter 33 cm), iron (Color of Kitchen brand, diameter 33 cm), Teflon-coated (Meyer Classic brand, diameter 30 cm), and glass (Chicken Fryer brand, VSF12, diameter 24 cm). The cooking times were 5 and 10 minutes. One liter of the fortified oil was heated in each pan on a gas stove. The temperature was measured with a digital thermometer (Presica Thermometer TE 4000) placed at the center of the oil in the pan. During heating, the oil was stirred with a stainless steel ladle every 30 seconds for 15 minutes. When the desired temperature and time were reached, samples were collected in opaque glass bottles for analysis. Each sample bottle was covered with aluminum foil during a cooling-down period of about 10 to 15 minutes. Thereafter, the sample was flushed with nitrogen before being stored in a freezer at –8°C until analysis. The cooking test was performed in triplicate.

Chemical analysis

Vitamin A retention was determined by normal-phase high performance liquid chromatography (HPLC) according to the modified method of Gundersen and Blomhoff [15] and AOAC Official Method 992.06, 2000 [16]. The oil was dissolved in hexane and directly injected into the chromatograph, which used Luna 5 µ Silica as stationary phase packed in Column Phenomenex 250 × 4.60 mm, hexane-isopropyl alcohol (100+0.25, v/v) as the mobile phase and UV-975 (Jasco) at 336 nm as a detector. The peroxide value was analyzed according to AOAC Official Method 965.33, 2000 [17] by titration with 0.1 N sodium thiosulfate solution.

Statistical analysis

Statistical analysis was performed with the Statistical Package for the Social Sciences for Windows, version 10.0. All analyses were conducted to determine significant differences at $p < .05$ by one-way analysis of variance (ANOVA) and Tukey's multiple comparison test, except for comparison of the losses during storage in PET bottles under light and dark conditions, for which the independent-samples *t*-test was used.

Results and discussion

Losses during distribution

Table 1 shows that significant losses in vitamin A occurred during the transportation and distribution of fortified palm oil to low-income people. However, the loss was less than 25%, even for the longest distribution period (7 days after being sent to the local retail store). Peroxide values remained significantly unchanged as the fortified oil was sent from the factory and distributed to stores (2.57 ± 1.22 vs 7.44 ± 4.72 mEq per kg of oil). The entire process of oil distribution does not take long enough to affect the peroxide value of the product. Consequently, it is feasible to add vitamin A to palm oil that has been repackaged and sold in a cooking oil market that largely caters to low-income people. The product packaged and distributed this way costs at least 30% less than the product packaged in PET bottles due to lower packaging costs and no need for advertisement. This product, moreover, accounts for at least 80% of the cooking oil market in Thailand (personal communication, P. Boonumnuai, 2004).

TABLE 1. Vitamin A retention (%) in palm oil that was bulk-transported, retail-packaged, distributed, and stored*

Day	Location	Vitamin A retention (%)**
0	Factory	100.00 ± 0.00^{A}
1	Middleman	93.26 ± 9.91^{AB}
1	Store 1	93.40 ± 6.30^{AB}
1	Store 2	91.91 ± 6.17^{AB}
1	Store 3	92.25 ± 6.68^{AB}
1	Store 4	92.60 ± 7.02^{AB}
1	Store 5	93.20 ± 8.28^{AB}
1	Mahidol University	93.06 ± 6.70^{AB}
4	In the light	94.51 ± 6.69^{AB}
8	In the dark	80.28 ± 10.51^{BC}
8	In the light	77.82 ± 5.50^{C}

* Results are given as means ± SD.

** Means followed by the same letter are not significantly different ($p > .05$). Initial (day 0) vitamin A content = 264.85 µg/15 mL.

TABLE 2. Vitamin A retention (%) of fortified oils stored in different packages*

Oil	Week	Unopened PET bottle**		Metal container***
		Light	Dark	
Soybean	0	100 (284.94 µg/15 mL)		100 (291.94 µg/15 mL)
	1	*97.69 ± 4.88*	*98.74 ± 0.78*	94.72 ± 1.85^{BC}
	2	85.02 ± 2.89	97.25 ± 1.89	NA
	3	73.05 ± 7.29	95.02 ± 1.26	92.16 ± 1.07^{CD}
	4	75.12 ± 7.97	99.46 ± 1.61	NA
	5	73.65 ± 14.86	98.67 ± 1.63	95.55 ± 1.88^{B}
	6	29.00 ± 11.12	102.74 ± 6.67	NA
	7	20.68 ± 5.85	92.26 ± 1.34	90.45 ± 1.38^{D}
	8	20.14 ± 6.94	96.00 ± 2.13	NA
	9	20.82 ± 6.11	89.08 ± 1.29	83.01 ± 2.80^{E}
	10	15.33 ± 7.13	89.50 ± 1.14	NA
	11	15.39 ± 7.01	86.32 ± 1.12	82.44 ± 1.79^{E}
	12	19.81 ± 8.39	99.71 ± 2.72	NA
	13	18.07 ± 8.93	89.24 ± 1.60	84.84 ± 1.95^{E}
Rice bran	0	100 (290.27 µg/15 mL)		100 (301.58 µg/15 mL)
	1	*98.14 ± 2.47*	*100.64 ± 1.68*	96.84 ± 1.69^{AB}
	2	84.30 ± 3.79	95.42 ± 1.41	NA
	3	83.68 ± 7.03	91.79 ± 2.46	88.31 ± 1.14^{C}
	4	79.18 ± 5.41	96.03 ± 2.05	NA
	5	80.81 ± 5.15	91.97 ± 2.24	94.33 ± 2.85^{B}
	6	30.26 ± 2.90	98.72 ± 2.96	NA
	7	29.14 ± 4.41	95.86 ± 3.89	88.99 ± 2.24^{C}
	8	28.10 ± 4.70	98.35 ± 2.36	NA
	9	28.41 ± 5.02	92.01 ± 1.70	85.18 ± 1.74^{C}
	10	18.96 ± 1.40	91.92 ± 2.30	NA
	11	25.36 ± 4.81	88.56 ± 0.89	78.81 ± 3.61^{D}
	12	25.95 ± 4.72	100.59 ± 2.66	NA
	13	18.92 ± 3.82	93.34 ± 4.09	85.48 ± 2.06^{C}
Palm	0	100 (291.51 µg/15 mL)		100 (288.16 µg/15 mL)
	1	*97.04 ± 3.94*	*97.02 ± 1.56*	99.72 ± 1.74^{A}
	2	80.05 ± 4.28	87.21 ± 1.88	NA
	3	78.84 ± 6.18	85.64 ± 1.66	94.39 ± 1.83^{B}
	4	72.92 ± 12.12	91.66 ± 1.45	NA
	5	82.64 ± 8.59	90.78 ± 2.17	92.56 ± 1.67^{BC}
	6	35.61 ± 8.46	71.87 ± 20.72	NA
	7	26.04 ± 1.47	91.84 ± 2.46	87.21 ± 4.07^{D}
	8	28.22 ± 4.70	95.44 ± 2.37	NA
	9	38.10 ± 5.44	90.93 ± 1.35	87.39 ± 2.64^{D}
	10	21.16 ± 1.50	88.81 ± 1.62	NA
	11	34.50 ± 15.9	84.04 ± 1.75	84.34 ± 2.24^{D}
	12	20.16 ± 10.21	98.92 ± 3.46	NA
	13	15.59 ± 8.82	88.40 ± 2.07	88.94 ± 4.03^{CD}

PET, polyethylene terephthalate; NA, not analyzed.
* Results are given as means ± SD.
** Italicized means in different columns are not significantly different ($p > .05$).
*** Means followed by the same letter in the same column are not significantly different ($p > .05$).

Losses during storage

Vitamin A retention in the oils that were packaged and stored under different conditions for 13 weeks at room temperature is shown in **table 2**. During storage, the losses in PET bottles under light and dark conditions were significantly different after 2 weeks. Light was the most important cause of vitamin A loss in the fortified vegetable oils (up to 80% to 85%). However, the rate of vitamin A loss during the first 5 weeks was not very high (about 20% to 25%) compared with the rate during the 6th week and thereafter. Such losses were not found in samples that were stored in PET bottles under dark conditions and in metal containers. The storage period at the factory, therefore, should not affect vitamin A losses, since the PET bottles are normally packaged in

Kraft paper cases before and during distribution.

Fortification of vegetable oils packaged in PET bottles with vitamin A was technically feasible; however, the fortified products should be displayed on shelves for only 5 weeks. Therefore, marketing feasibility must also be considered. Many researchers have reported the effect of light on vitamin A loss in vegetable oils [9, 10, 18, 19]. Abraham [10] found that vitamin A losses in fortified soybean oil under light conditions at 25° to 28°C were about 55% to 80% after 4 weeks, whereas losses under dark condition were less than 10% after 12 weeks. The loss could be minimized (< 10%) during 3 to 18 months of storage protected from light and air, for example, in sealed, opaque containers [9] or metal cans [18, 19]. The metal of a container also had some effect on vitamin A losses, as could be observed by comparing the retention of vitamin A in oils that were packaged in PET bottles and stored in the dark with its retention in **table 2**. The metal in the container could cause an oxidation reaction that, consequently, could cause loss of vitamin A [20]. Metal containers are normally used for distributing vegetable oil among low-income people in developing countries, as well. Compared with the other oils, soybean oil was the most susceptible to oxidation because of its higher degree of unsaturation [21]. The peroxide value, which represents the process of lipid oxidation, was not significantly different during the storage of soybean oil in PET bottles under light and dark conditions (9.38 ± 1.50 vs 10.20 ± 1.50 mEq per kg of oil). However, the peroxide values were already high at the beginning of the study, which meant that the soybean oil might have been maximally oxidized during the fortification process. Furthermore, the peroxide values in fortified rice bran and palm oils stored under light conditions (10.19 ± 1.10 and 10.00 ± 0.95 mEq per kg of oil, respectively) were significantly different from those in oils stored under dark conditions (7.70 ± 1.89 and 5.12 ± 1.39 mEq per kg of oil, respectively). For oils packaged in metal containers, the peroxide value of soybean oil did not significantly change during storage (11.46 ± 1.30 vs 13.55 ± 2.03 mEq per kg of oil), whereas the peroxide value of rice bran oil significantly increased with time (4.39 ± 1.49 vs 9.44 ± 1.89 mEq per kg of oil). The peroxide values of palm oil stored in metal containers were the lowest and did not change significantly (5.21 ± 0.84 vs 5.86 ± 0.89 mEq per kg of oil). However, the differences in peroxide values due to differences in the degree of unsaturation did not affect the rates of vitamin A losses in all types of oil, a result confirming the significant effect of light (**table 2**).

Losses during use

After oil bottles have been opened and the oils have been used for 1 month, the oil is more exposed to oxygen as the level of oil in the bottle becomes lower. There were no significant losses of vitamin A from any kind of oil in opened bottles stored under dark conditions; the losses were less than 10% after 1 month (**table 3**). When the opened bottles were stored under light conditions, the maximum loss (up to 90%) occurred in the fortified soybean oil. The losses in the other fortified oils were as high as 50% when stored under light conditions. The degree of unsaturation significantly affected the rate of vitamin A loss during use. Soybean oil might not be a suitable vehicle for vitamin A fortification because of high vitamin losses after the bottle is opened, unless consumers are advised to keep the opened bottles in the dark, such as in a cabinet. Favaro et al. [18] indicated that the content of vitamin A–fortified soybean oil in opened metal cans in both the presence and the absence of light at 23°C was unaltered for up to 6 months. At the 18th month in opened cans stored in the dark, 33% of added vitamin A was retained. When the oil was exposed to light, only a trace amount of added vitamin A was retained.

The peroxide values in the fortified soybean oil under dark and light conditions were not significantly different (18.57 ± 2.93 vs 18.72 ± 2.52 mEq per kg of oil). However, the peroxide values of the oils under dark and light storage conditions were significantly different in the case of rice bran (5.22 ± 0.72 vs 18.16 ± 1.57 mEq per kg of oil) and palm oil (5.03 ± 0.69 vs 14.98 ± 1.09 mEq per kg of oil), where the values under light conditions were higher ($p \leq .05$).

Vitamin A retention by different fortified cooking

TABLE 3. Vitamin A retention (%) in fortified oils that had been opened, used. and stored under light and dark conditions*

	Soybean oil		Rice bran oil		Palm oil	
Week	Light	Dark	Light	Dark	Light	Dark
0	100 (284.27 μg/15 mL)^{Aa}		100 (289.79 μg/15 mL)^{Aa}		100 (283.29 μg/15 mL)^{Aa}	
1	56.28 ± 9.76^{Bc}	97.27 ± 2.63^{Aa}	73.58 ± 6.44^{Bb}	95.00 ± 0.94^{Ba}	72.98 ± 7.50^{Bb}	89.71 ± 0.82^{Da}
2	43.90 ± 9.00^{Bc}	93.77 ± 2.08^{Ba}	58.53 ± 10.36^{BCb}	91.18 ± 1.02^{Ca}	61.24 ± 11.18^{Cb}	91.10 ± 1.34^{CDa}
3	28.93 ± 10.08^{Cc}	99.52 ± 1.17^{Aa}	49.18 ± 13.16^{Cb}	99.21 ± 1.64^{Aa}	50.84 ± 3.70^{Cb}	94.32 ± 2.22^{Ba}
4	11.39 ± 1.97^{Dc}	97.38 ± 1.28^{Aa}	46.89 ± 8.74^{Cb}	94.92 ± 2.32^{Ba}	50.62 ± 3.29^{Cb}	92.44 ± 2.13^{BCa}

* Results are given as means ± SD. Means within the same column followed by the same capital letter (represents effect of storage time of each oil at each storage condition) or within the same row followed by the same lowercase letter (represents effect of kinds of oil and storage conditions) are not significantly different ($p > .05$).

TABLE 4. Vitamin A retention (%) in fortified oils after cooking in pans made of different materials*

Temperature (°C)	Time (min)	Oil	Aluminum	Iron	Teflon	Glass
120	5	Soybean	98.73 ± 3.54^{Aa}	99.04 ± 3.54^{Aa}	98.39 ± 3.05^{Aa}	97.12 ± 1.98^{Aa}
		Rice bran	99.06 ± 1.10^{Aa}	98.17 ± 2.13^{Aa}	98.48 ± 0.51^{Aa}	96.03 ± 1.06^{Ab}
		Palm	97.02 ± 2.35^{Aa}	97.58 ± 2.58^{Aa}	97.52 ± 3.05^{Aa}	96.94 ± 2.40^{Aa}
	10	Soybean	97.87 ± 3.17^{Aa}	98.88 ± 1.55^{Aa}	96.64 ± 1.11^{Aa}	96.33 ± 2.18^{Aa}
		Rice bran	98.70 ± 1.34^{Aa}	97.78 ± 2.13^{Aa}	98.00 ± 1.85^{Aa}	96.17 ± 1.62^{Aa}
		Palm	96.56 ± 2.84^{Aa}	95.67 ± 5.69^{Aa}	96.34 ± 2.28^{Aa}	95.39 ± 3.68^{Aa}
170	5	Soybean	94.42 ± 3.25^{Aa}	95.53 ± 4.66^{Aa}	94.84 ± 3.71^{Aa}	92.89 ± 1.48^{Aa}
		Rice bran	90.12 ± 0.97^{Ba}	93.04 ± 4.64^{Aa}	91.28 ± 3.58^{ABa}	91.38 ± 2.84^{ABa}
		Palm	90.71 ± 2.52^{Ba}	89.24 ± 4.46^{Aa}	89.18 ± 1.97^{Ba}	88.89 ± 2.00^{Ba}
	10	Soybean	93.26 ± 5.34^{Aa}	89.48 ± 3.77^{Aa}	90.07 ± 0.79^{Aa}	91.74 ± 2.22^{Aa}
		Rice bran	85.27 ± 2.83^{Ba}	89.01 ± 6.13^{Aa}	86.60 ± 3.32^{Aa}	87.20 ± 1.42^{Ba}
		Palm	87.39 ± 3.16^{ABa}	86.77 ± 3.48^{Aa}	86.53 ± 2.53^{Aa}	86.49 ± 2.29^{Ba}

* Results are given as means ± SD. Means within the same column followed by the same capital letter or within the same row followed by the same lowercase letter with the same temperature and time are not significantly different ($p > .05$). Initial vitamin A contents (100 ± 0.00%) in soybean, rice bran, and palm oils were 268.56, 263.63, and 267.95 µg/15 mL, respectively.

TABLE 5. Effect of temperature and time on vitamin A contents in different types of fortified cooking oils that had been cooked in different pans*

Oil/initial vitamin A content	Pan	Time (min)	Vitamin A content	
			120°C	170°C
Soybean/268.56 ± 11.37^{Aa}	Aluminum	5	265.12 ± 11.84^{Aa}	253.60 ± 11.98^{Aa}
		10	262.82 ± 10.72^{Aa}	250.54 ± 18.20^{Aa}
	Iron	5	266.06 ± 14.18^{Aa}	256.75 ± 18.35^{ABa}
		10	265.61 ± 10.66^{Aa}	240.49 ± 16.12^{Bb}
	Teflon	5	264.30 ± 13.40^{Aa}	254.87 ± 16.30^{ABa}
		10	259.48 ± 6.24^{Aa}	241.88 ± 7.47^{Bb}
	Glass	5	256.33 ± 6.25^{Aab}	249.45 ± 7.82^{Bb}
		10	257.01 ± 12.07^{Aab}	246.36 ± 9.24^{Bb}
Rice bran/263.63 ± 3.54^{Aa}	Aluminum	5	261.16 ± 4.45^{Aa}	237.56 ± 1.95^{Bb}
		10	260.19 ± 4.65^{Aa}	224.77 ± 7.38^{Cb}
	Iron	5	257.99 ± 4.28^{Aab}	245.30 ± 12.64^{Bb}
		10	257.75 ± 4.56^{Aa}	234.63 ± 15.95^{Bb}
	Teflon	5	259.64 ± 3.81^{Aa}	240.65 ± 9.94^{Bb}
		10	258.36 ± 5.72^{Aa}	228.27 ± 8.39^{Cb}
	Glass	5	253.14 ± 3.02^{Bb}	240.84 ± 5.59^{Bc}
		10	253.56 ± 6.84^{Bb}	229.90 ± 4.90^{Cc}
Palm/267.95 ± 5.18^{Aa}	Aluminum	5	259.95 ± 6.15^{Aa}	243.11 ± 9.20^{Bb}
		10	258.71 ± 8.00^{Aa}	234.25 ± 11.72^{Bb}
	Iron	5	261.53 ± 10.22^{Aa}	239.20 ± 14.39^{Bb}
		10	256.51 ± 18.49^{Aa}	232.56 ± 11.76^{Bb}
	Teflon	5	261.32 ± 9.51^{Aa}	238.96 ± 6.04^{Bb}
		10	258.17 ± 8.43^{Aa}	231.90 ± 8.84^{Bb}
	Glass	5	259.77 ± 8.72^{Aa}	238.11 ± 3.28^{Bb}
		10	255.60 ± 10.66^{Ab}	231.74 ± 6.74^{Bc}

* Vitamin A contents are given as means ± SD in micrograms per 15 mL. Means within the same column followed by the same capital letter or within the same row followed by the same lowercase letter with the same kinds of oil and pan are not significantly different ($p > .05$).

oils that had been heated in pans made from different materials at different temperatures is summarized in **table 4**. Since metal is known to be a catalyst for oxidation reactions [20], two kinds of metal normally used for making pans, aluminum and iron, were tested for their effect on vitamin A losses during cooking in comparison with the more inert materials of Teflon and glass. The material of the pan did not significantly affect vitamin A losses at different temperatures and for different cooking times. In addition, the degree of oil unsaturation did not have any significant effect on the losses of vitamin A during cooking at 120°C; however, losses could be observed at 170°C. At 170°C, the losses in rice bran and palm oils were significantly higher than those in soybean oil. Vitamin A loss was found to be directly affected by cooking temperature and time (**table 5**). The cooking time did not have a significant effect on vitamin A losses when cooking was done at a lower temperature (120°C), such as during stir frying; vitamin A losses under these conditions were less than 5%. Atwood et al. [9] and Favaro et al. [18] found that the cooking time could affect vitamin A retention in soybean oils that were cooked at 100° to 120°C for as long as 90 minutes. However the maximum vitamin A loss was only about 10%.

At the deep-frying temperature of 170°C [22], the cooking time significantly affected vitamin A losses in all types of oil. However, the losses of vitamin A during cooking at 170°C were still less than 15%, even after 10 minutes. In some cases, the vitamin A loss from deep frying might have been more, since the oil was normally used several times. Favaro et al. [18] found that after potatoes were fried at 130° to 170°C for four periods of about 3 minutes each, vitamin A retention declined from 83% at the first frying to 52% at the last. Abraham [10] mentioned that vitamin A retention in deep frying ranged from 65% to 97%, depending on the number of repeated fryings. Yeng et al. [23] found that thermal and oxidative decomposition occurred in oils that had been cooked at 170°C. The effect of different pan materials on peroxide values in different kinds of oil that had been cooked at different temperatures was also evaluated. In most cases, the materials did not significantly affect the peroxide values of the cooked fortified oils. The peroxide value was also found to be directly affected by cooking temperature and time. As the temperature was increased from 120° to 170°C, the peroxide values increased significantly. At 170°C, an increase in cooking time significantly increased peroxide values, especially in the case of soybean and rice bran oils (9.00 ± 2.35 and 9.69 ± 0.67 vs 13.21 ± 2.16 and 14.07 ± 2.75 mEq per kg of oil, respectively).

Conclusions

Fortification of different kinds of vegetable oils available in the market with vitamin A to provide one-third of the Thai RDI per 15-mL serving was feasible. Fortified vegetable oils packaged in PET bottles should be protected from light by wrapping them with opaque plastic film; if they are not so protected, they should be shelved for only 5 weeks, since high losses were found after that time. The loss was only 10% when the bottled oil was stored under light-protected conditions in Kraft paper cases. Vitamin A loss in the product that had been transported, repackaged, and distributed to the low-income market was less than 25%. Vitamin A losses were only 10% to 15% during storage of fortified oil in metal containers, the principal means of storage in developing countries. The rate of vitamin A loss was directly related to light exposure and unrelated to the degree of unsaturation of the vegetable oil and its peroxide value. However, a higher degree of unsaturation resulted in a higher loss of vitamin A in an opened PET bottle. Loss of vitamin A in fortified vegetable oil was minimized (< 10%) if the opened PET bottle was kept in the dark. During cooking, vitamin A losses and peroxide values were significantly affected by temperature and time, but not by the materials from which the cooking utensils were made.

The results of this study may help developing countries to determine an appropriate strategy for using cooking oil as a vehicle for vitamin A to reach their target populations of different socioeconomic status.

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