Original Article

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Fluoride concentration and pH of commercial oat milk products in Thailand

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Objective: To determine the fluoride concentration and pH of commercially available oat-milk products sold in Thailand.
Materials and Methods: Thirty-seven oat-milk products (unsweetened n = 14, sweetened n = 23; pasteurized n = 7, UHT n = 30) were analyzed. Fluoride concentration was measured using an ion-selective electrode and pH with a calibrated pH meter. Independent t-tests compared fluoride concentrations between sweetness types and processing methods (α = 0.05).
Results: Fluoride concentration ranged 0.0058–4.853 ppm (mean 0.95 ± 1.25 ppm) and pH 6.26–7.72 (mean 6.98 ± 0.41). No significant differences were found between sweetened vs unsweetened (p = 0.404) or pasteurized vs UHT (p = 0.098) products.
Conclusion: Oat-milk products in Thailand show wide variation in fluoride concentration and near-neutral pH. Differences by sweetness type and processing method were not statistically significant.

Keywords: fluoride concentration, oat milk, pH, pediatric dentistry, plant-based beverages

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Introduction

The consumption of plant-based milk alternatives has increased rapidly worldwide due to growing health, environmental, and ethical concerns [1, 2]. Among these, oat milk has gained popularity because of its nutritional value, pleasant taste, and suitability for individuals with lactose intolerance or cow's-milk protein allergy [3,4]. However, as with other beverages that use water as the main ingredient, the fluoride content of oat milk depends greatly on the fluoride level of the production water and the processing technique used [5–7].

Previous studies on conventional dairy milk have reported fluoride concentrations generally ranging from 0.02 to 0.30 ppm, while plant-based alternatives such as soy or rice milk may reach values above 1 ppm depending on the water source and manufacturing process [5,8,9]. Such variation can influence total dietary fluoride exposure, particularly in children who frequently consume these beverages.

Fluoride plays a crucial role in preventing dental caries by promoting remineralization and reducing enamel demineralization through the formation of fluorapatite crystals [8,9]. Nevertheless, excessive fluoride intake during tooth development can lead to dental fluorosis [8,9]. The World Health Organization (WHO) recommends a daily fluoride intake of 0.05–0.07 mg/kg body weight for children under six years old [10]. Therefore, monitoring the fluoride content of commercial beverages is essential to prevent overexposure, especially in young children.

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Oat-milk products have become more widely produced and available in supermarkets and convenience stores in Thailand in recent years, reflecting the global trend toward plant-based diets [3,4]. Although statistical data on national consumption are limited, the number of domestic and imported brands has increased markedly, indicating greater consumer demand.

Previous Thai studies have measured fluoride in soy milk, nut-based milk, and rice milk and reported variations related to production water sources [5-7]. In addition, surveys of fluoride levels in groundwater and tap water across Thailand have revealed regional variability that may influence manufacturing water quality [11, 12]. However, no published data exist regarding oat-milk products currently available in Thailand. Evaluating the fluoride concentration and pH of oat milk is important for pediatric oral health.

The composition of oat milk varies depending on formulation. Sweetened products generally contain added sugars, which may dilute fluoride concentration or slightly affect pH, while unsweetened products rely on the natural carbohydrate content of oats. Furthermore, processing conditions may influence fluoride content through water evaporation or dilution. Pasteurization involves moderate heating (60–90 °C for 15–30 min), whereas UHT processing uses higher temperatures (135–150 °C for 2–5 s) [13,14]. These thermal differences may lead to variations in fluoride concentration and pH among products.

Therefore, this study aimed to determine the fluoride concentration and pH of commercially available oat-milk products in Thailand.

Materials and Methods

Sample Collection

Thirty-seven commercially available oat-milk products were collected from supermarkets, convenience stores, and online platforms in Thailand between May and August 2024. Inclusion criteria comprised products labeled as “oat milk,” “oat drink,” or those containing oats as the primary ingredient. Both imported and locally manufactured brands were included. Each sample was categorized by sweetness type and processing method. Three different packages of each product were collected and analyzed independently to account for product-level variability.

Sweetness classification was based on the total sugar content stated on the nutrition label: products containing ≥ 5 g sugar per 100 mL were classified as sweetened, whereas those containing < 5 g sugar per 100 mL were classified as unsweetened.

Storage conditions: Pasteurized samples were kept refrigerated at 4 °C and analyzed within 48 h of purchase, while UHT samples were stored at room temperature until testing. Product labels were recorded for brand name, country of origin, production date, and batch number. Samples were shaken thoroughly before analysis to ensure homogeneity.

Fluoride Analysis

Fluoride concentration was determined using an ion-selective electrode (Orion 96-09, Thermo Scientific, USA) connected to an Orion Star A214 ion analyzer (Thermo Scientific, USA). The analytical procedure followed the standard ion-selective electrode technique. Each 1 mL sample was mixed with 1 mL of Total Ionic Strength Adjustment Buffer III (TISAB III) to maintain constant ionic strength and pH. The electrode was calibrated daily using standard fluoride solutions (0.1, 1.0, 10.0 ppm). Measurements were performed in triplicate, and the mean fluoride concentration (ppm) was recorded.

pH Measurement

pH values were measured using a calibrated digital pH meter (Mettler-Toledo FiveEasy Plus, Switzerland). Calibration was performed daily with standard buffer solutions (pH 4.0, 7.0, 10.0). All measurements were performed in triplicate at room temperature (25 ± 2 °C).

Statistical Analysis

Data were analyzed using SPSS version 29 (IBM Corp., USA). Descriptive statistics (n, mean ± SD) were computed for each group (sweetened/unsweetened; pasteurized/UHT). Descriptive information, including the number of milk brands in each group, total number of samples, percentage of total sugar, country of manufacture, and flavor, was also collected and reported. Normality of data was verified by the Shapiro–Wilk test and homogeneity of variance by Levene's test before performing independent Student's *t*-tests. Statistical significance was set at $p<0.05$.

Results

The fluoride concentrations and pH values of the 37 commercially available oat-milk products analyzed in this study are summarized in Table 1. Fluoride concentration ranged from 0.0058 to 4.853 ppm (mean ± SD = 0.95 ± 1.25 ppm) and pH values ranged from 6.26 to 7.72 (mean ± SD = 6.98 ± 0.41), indicating wide variation among products. Values below 0.1 ppm (the lower calibration limit) were reported as "below detection limit."

Most UHT products were imported, particularly from Australia, New Zealand, Singapore, and Europe, whereas all pasteurized samples were produced locally in Thailand. Imported products tended to show higher fluoride levels than locally manufactured ones. Detailed product information, including brand name, country of origin, sweetness type, processing method, fluoride concentration, and pH, is provided in Supplementary Table S1.

Table 2 shows the mean fluoride concentration and pH values categorized by sweetness type (sweetened vs unsweetened). Unsweetened products (1.14 ± 1.34 ppm; n = 14) had slightly higher fluoride levels than sweetened products (0.81 ± 0.98 ppm; n = 23), but the difference was not statistically significant ($p = 0.404$).

Table 3 presents the comparison by processing method. UHT products (0.94 ± 1.25 ppm; n = 30) showed higher fluoride concentrations than pasteurized products (0.16 ± 0.08 ppm; n = 7), but this difference was also not statistically significant ($p = 0.098$).

Overall, no significant differences were found in fluoride concentration between the sweetness or processing groups. All samples exhibited near-neutral pH, indicating low erosive potential.

Table 1 Descriptive statistics of fluoride concentration and pH of commercially available oat-milk products (n = 37)

Parameter	n	Range	Mean ± SD
Fluoride (ppm)	37	0.0058 – 4.853	0.95 ± 1.25
pH	37	6.26 – 7.72	6.98 ± 0.41

Note: Values below 0.1 ppm were reported as "below detection limit."

Table 2 Comparison of mean fluoride concentration and pH of oat-milk products by sweetness type and processing method

Variable	Group	n	Fluoride (ppm, Mean ± SD)	pH (Mean ± SD)	*p*-value
Sweetness type	Sweetened	23	0.81 ± 0.98	6.94 ± 0.39	0.404 [1]
	Unsweetened	14	1.14 ± 1.34	7.03 ± 0.43	–

[1] Independent Student's *t*-test comparing sweetened vs unsweetened groups.
No statistically significant difference was observed ($p>0.05$).

Table 3 Comparison of mean fluoride concentration and pH values according to processing method

Variable	Group	n	Fluoride (ppm, Mean ± SD)	pH (Mean ± SD)	*p*-value
Processing method	Pasteurized	7	0.16 ± 0.08	6.91 ± 0.36	0.098 [1]
	UHT	30	0.94 ± 1.25	6.99 ± 0.42	–

[1] Independent Student's *t*-test comparing pasteurized vs UHT groups.
Differences were not statistically significant ($p>0.05$).

Discussion

The present study evaluated the fluoride concentration and pH of commercially available oat-milk products in Thailand. A wide variation in fluoride levels was observed, ranging from below detection limit to 4.853 ppm, while pH values were near neutral. Differences between sweetness types and processing methods were not statistically significant, indicating that brand-to-brand variability may be the key determinant of fluoride content rather than sweetness or processing technique [5, 7].

Previous studies on dairy and plant-based milk alternatives have reported similar fluoride variability, mainly due to differences in fluoride concentrations of the manufacturing water rather than the product formulation [5–7, 11,12]. This explanation is consistent with the observation that most UHT products were imported while pasteurized samples were locally produced, which may account for their slightly different fluoride levels.

The lack of significant difference between sweetened and unsweetened oat-milk products agrees with prior studies on soy and nut-based milks. Sugar addition likely exerts only a dilution effect, as no evidence supports chemical interaction between fluoride ions and carbohydrate components in beverage matrices [15,16].

Regarding processing, pasteurized milk is typically heated at 60–90 °C for 15–30 minutes, whereas UHT treatment applies higher temperatures of 135–150 °C for 2–5 seconds [13]. Pasteurization may cause minor physicochemical changes in milk proteins or minerals, potentially altering pH slightly [16], but fluoride, as an inorganic ion, remains chemically stable under such thermal conditions. Studies on thermal processing of bovine and plant-based milks have shown minimal differences in pH between pasteurized and UHT products, supporting the current findings that temperature and duration have negligible effects on fluoride concentration and pH [16].

UHT treatment influences flavor and protein structure and appears to have a limited effect on mineral-ion stability or acid–base balance in current evidence [16, 17]. Thus, fluoride levels in oat-milk products are more likely determined by the fluoride content of the production water and formulation practices rather than heating conditions.

The near-neutral pH values (6.26–7.72) observed in this study are comparable to those reported for other plant-based milks, suggesting low erosive potential [18, 19]. Hence, under normal consumption conditions, oat milk is unlikely to contribute to enamel erosion.

Limitations of this study include its cross-sectional design, limited sample size, and lack of information regarding fluoride levels in manufacturing water. Future research should include additional physicochemical parameters such as calcium concentration and buffering capacity to clarify the role of processing and formulation on fluoride stability.

Conclusion

Oat milk products in Thailand vary widely in fluoride content, mainly influenced by production water and processing type. Most have near-neutral pH and low erosion risk. Imported high-fluoride products may raise fluorosis concern, while sweetened low-fluoride types increase caries risk. Regular monitoring and fluoride labeling are recommended for consumer safety.

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Supplementary Table S1 Fluoride concentration and pH of commercially available oat-milk products in Thailand

No.	Country	Brand / Product name	Sweetness type	Processing	Fluoride (ppm)	pH
1	Thailand	Good Mate Chocolate	Sweetened	Pasteurized	0.0058	6.58
2	Thailand	Good Mate Original	Sweetened	Pasteurized	0.0112	6.66
3	Thailand	Uoat organic original	Unsweetened	Pasteurized	0.124	6.67
4	Thailand	Uoat organic vanilla	Sweetened	Pasteurized	0.105	6.76
5	Thailand	Dairy origin: natural taste	Sweetened	Pasteurized	0.207	6.58
6	Thailand	Dairy origin: malt	Sweetened	Pasteurized	0.230	6.60
7	Thailand	Dairy origin: cocoa	Sweetened	Pasteurized	0.298	6.26
8	Thailand	Oatly Barista Edition	Unsweetened	UHT	0.624	7.02
9	Thailand	Oatly Chocolate	Sweetened	UHT	0.533	6.88
10	Thailand	UFC Velvet Oat	Unsweetened	UHT	0.015	6.62
11	Thailand	UFC Velvet Oat Chocolate	Sweetened	UHT	0.042	7.12
12	Thailand	UFC Velvet Oat Barista	Unsweetened	UHT	0.014	6.66
13	Thailand	Alpro Oat Original	Sweetened	UHT	0.321	7.16
14	Thailand	Alpro Oat Unsweetened	Unsweetened	UHT	0.290	6.96
15	Thailand	Alpro Oat Black tea	Sweetened	UHT	1.77	6.66
16	Thailand	Oatte Original	Sweetened	UHT	0.009	7.17
17	Thailand	Oatte Chocolate	Sweetened	UHT	0.008	7.01
18	Thailand	Tipco Original	Sweetened	UHT	0.156	6.63

Supplementary Table S1 Fluoride concentration and pH of commercially available oat-milk products in Thailand (continued)

No.	Country	Brand / Product name	Sweetness type	Processing	Fluoride (ppm)	pH
19	Thailand	Tipco Black sesame	Sweetened	UHT	0.026	6.54
20	Singapore	Oatside Original	Sweetened	UHT	0.576	6.96
21	Singapore	Oatside Deluxe	Sweetened	UHT	0.214	7.35
22	Singapore	Oatside Barista	Unsweetened	UHT	0.339	7.41
23	Singapore	Oatside Chocolate	Sweetened	UHT	0.224	7.11
24	Indonesia	Oatside Barista	Unsweetened	UHT	0.077	7.29
25	Indonesia	Oatside Chocolate	Sweetened	UHT	0.081	7.35
26	Australia	Pure Harvest Unsweetened	Unsweetened	UHT	4.853	7.11
27	Australia	Pure Harvest Organic Original	Sweetened	UHT	3.214	6.90
28	Australia	Vitasoy Oat Milk Unsweetened	Unsweetened	UHT	0.102	7.12
29	Australia	Vitasoy Oat Milk Original	Sweetened	UHT	0.102	7.72
30	Australia	Sanitarium So Good Oat Unsweetened	Unsweetened	UHT	0.226	7.23
31	Australia	Sanitarium So Good Oat Original	Sweetened	UHT	0.124	7.12
32	Australia	Sanitarium So Good Oat Barista	Sweetened	UHT	0.208	7.29
33	Australia	Milk lab	Unsweetened	UHT	0.561	7.19
34	New Zealand	Boring Oat milk	Unsweetened	UHT	0.014	6.93
35	New Zealand	Boring Oat milk Barista	Sweetened	UHT	0.014	7.33
36	UK	Minor Figures Barista	Unsweetened	UHT	0.048	7.19
37	Italy	Riso Scotti	Unsweetened	UHT	0.964	6.99