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Meta Analysis Validation for Cadmium (CD) Determination in Cosmetic Products: A Literature Review

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ABSTRACT

Cosmetics are widely used daily necessities, with increasing public awareness of personal appearance. These products may be contamined with the heavy metals cadmium (Cd), which poses health risks when concentration exceed established safety limits. Since cosmetics are applied to variuos external parts of the body, from head to the feet, ensuring their safety is essential. This article *review*s the validation of cadmium (Cd) analysis methods in cosmetics using various instruments, including *Atomic Absorption Spectrometry* (AAS), *Flame Atomic Absorption Spectrometry* (FAAS), *Graphite Furnance Atomic Absorption Spectrometry* (GFAAS), *Inductively Coupled Plasma Mass Spectrometry* (ICP-MS*), Inductively Coupled Plasma Atomic Emission Spectrometry* (ICP-AES), and *Inductively Coupled Plasma Optical Emission Spectrometry* (ICP-OES). The *review* indicates that the studies generally satisfy validation parameters, as demonstrated by linearity ($R^2 > 0,99$) in ICP-OES dan AAS, accuracy in FAAS wthin acceptance range (80-110%), precision of GFAAS with low relative standard deviation (%RSD ≤ 2%), and most limits of detection (LOD) and limits of quantification (LOQ) for all instruments below the detected cadmium (Cd) concentrations. Several studies reported cadmium (Cd) concentrations exceeding the safe limits of ≤ 5 ppm, as specified by BPOM Regulation No.16. In summary, selecting appropiate analytical instruments and thoroughly validating methods are esssential to ensure the reliability of cadmium analysis and to improve cosmetic product quality.

INTRODUCTION

Cosmetic products have become an integral part of daily life due to increasing public awareness of personal appereance and self-care. Under Indonesian National Agency of Drug and Food Control (BPOM) regulation No. 18 of 2024, cosmetics are defined as preparations intended for application to the external parts of the body, including the skin, hair, nails, lips, external genital organs, teeth, and oral mucosa for cleansing, protecting, maintaning, or enhancing appearance. Conseqeuntly, the extensive use of cosmetics has raised concerns regarding product safety, particulary contamination by heavy metals such as cadmium (Cd). Cadmium is a toxic heavy metal that has been used as a coloring agent in cosmetic product (Dewi 2020; Fatmawati and Yuliantini 2018), its represent as an impurity originating from contaminated raw materials or manufacturing processes. Acording to the BPOM Regulation No. 16 of 2024, the maximum permissible concentration of cadmium in cosmetic product is 5 ppm. Long-term exposure to cadmium may result in bioaccumulation, primarily in the kidneys and liver, leading to renal dysfunction

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and other adverse health effects (Hernayanti *et al*. 2019). Therefore, reliable analytical methods are essential to ensure the safety and quality of cosmetic product.

Various analytical instruments, including *Atomic Absorption Spectrometry* (AAS), *Flame Atomic Absorption Spectrometry* (FAAS), *Graphite Furnance Atomic Absorption Spectrometry* (GFAAS), *Inductively Coupled Plasma Mass Spectrometry* (ICP-MS*), Inductively Coupled Plasma Atomic Emission Spectrometry* (ICP-AES), and *Inductively Coupled Plasma Optical Emission Spectrometry* (ICP-OES), have been used to determine cadmium in cosmetics. Previous studies have reported acceptable validation results based on parameters such as linearity, accuracy, precision, limit of detection (LOD), and limit of quantification (LOQ) (Pratiwi, Mulyadi, and Anwar 2023). Although, these studies generally evaluated only a single analytical techique or a spesific cosmetic product. Currently, there has been limited literature comprehensively comparing the validation method performance of multiple analytical instruments for cadmium determination in cosmetics.

Therefore, this literature review aims to summarize and compare the validation method performance of various analytical instruments used for cadmium (Cd) determination in cosmetics product. This review is expected to provide a compherensive reference for selecing appropriate analytical methods in cosmetic quality control.

MATERIALS/METHOD

This study employed a literature review approach to evaluate the validation of analytical methods for cadmium (Cd) determination in cosmetic products using various analytical instruments. Relevant literature was collected from Google Scholar, PubMed, and ResearchGate. The literature search included publications published over the past 10 years (2016-2026) using the keywords “cadmium (Cd) analysis”, “cadmium (Cd) in cosmetics”, and “validation of analytical methods for cadmium (Cd) determination in cosmetics”.

The selected articles were included if : 1) original research articles published in journals indexed at least in SINTA 5 or scopus, 2) investigated cadmium (Cd) determination in cosmetics products, 3) reported analytical method validation parameter, including linearity, accuracy, precision, limit of detection (LOD), and limit of quantification (LOQ). Studies were excluded if they were published before 2015, review articles, involved non-cosmetic samplesm or did not report method validation data.

RESULTS AND DISCUSSION

Analytical method validation is a process used to evaluate wheter an analytical method is suitable fot its intended purpose by demonstrating that it meets predetermined performance requirements. A validated method ensures that analytical results are accurate, reliable, and reproducible. Method validation involves the assessment of several analytical performance characteristics, including linearity, accuracy, precision, limit of detection (LOD), and limit of quantification (LOQ), which are essential for evaluating the reliability of analytical instruments and methods (Sahumena *et al*. 2020). The validation results obtained from the

selected studie are summarized and discussed according to each validation parameter.

Table 1. Validation Results for Cadmium (Cd) Analysis

Reference	Instrument	Product	Linearity	Accuracy (%)	Precision (%RSD)	LOD (ppm)	LOQ (ppm)	Cd Concentration (ppm)
(Fatmawati and Yuliantini 2018)	AAS	Lipstick	0.9991	90-120	0.15-0.38	0.038	0.128	0.34-3.88
(Suhardiana and Endah 2020)	AAS	Traditional scrub	0.9982	101.64-105.49	0.22-0.50	0.63	2.11	9.42
(Iswandi, Sari, and Harjanti 2023)	AAS	Serum	0.9999	99	11	-	-	0.7732-0.9871
(Aina *et al*. 2023)	AAS	BB cream	0.9999	-	-	0.33	1.10	0.24-0.885
(Ahmad-Jouibari *et al*. 2017)	GFAAS	Eyeshadow	0.9985	91-108	3.2	0.002	-	3.22-12.24
		Hair dye						7.91-14.58
(Saadatzadeh *et al*. 2019)	GFAAS	Lipstick	0.9940	82.1-93.2	0.0125-0.0375	0.14	-	0.064
(Mohammed, Ahmed, and Oraibi 2023)	FAAS	Lipstick	0.9983	99.55-102.96	1.32	0.33	0.1	0.11-0.88
(Bastiansz *et al*. 2022)	ICP-OES	Lipstick	1.00	-	-	0.02	0.07	0.022
(Tan, Wang, and Wang 2018)	ICP-AES	Cosmetics	0.9992	89.7-103.9	1.4-3	1	10	0.010-0.241
(Mostafa *et al*. 2025)	ICP-MS	Mascara	0.9990	99	2.76	-	-	0.03-0.53

Linearity

Linearity describes the ability of an analytical method to produce test results that are directly propotional to the analyte concentration within a specified range. It is commonly evaluated using the coefficient of determination (R^2) obtained from calibration curve (Susanto, Mulyani, and Nugraha 2021; Wahyuningsih and Kusumowati 2024). According to AOAC guidelines, a method is considered to have acceptable linearity when the coefficient of determination is greater than 0.99 ($R^2 > 0.99$). Higher R^2 values indicate a stronger linear relationship between analyte concentration and instrument response, demonstrating good analytical performance (Sulistyani *et al*. 2021). As summarized in Table 1, all reviewed studies reported R^2 values greater than 0.99, indicating excellent linearity regardless of the analytical instrument used. The highest linearity was reported for ICP-OES ($R^2 = 1.00$) by Bastiansz *et al*. (2022), representing an almost perfect correlation between concentration and analytical response. Similiary, AAS showed excellent linearity, with Iswandi *et al*. (2023) and Aina *et al*. (2023) reporting R^2 values of 0.9999. These findings suggest that all reviewed analytical methods provide reliable responses for cadmium (Cd) determination in cosmetic products.

Accuracy

Accuracy describes the closeness of the measured value to the true or reference value and is commonly expressed as percent recovery (% recovery) of the added analyte (Surani and Asmoro 2025). According to AOAC guidelines, an acceptable recovery value ranges from 80% to 110%, indicating that the analytical method provides accurate and reliable results (Sari, Sari, and Hardani 2023; Sulistyani *et al*. 2021). Recovery values closer to 100% indicate higher analytical accuracy and better agreement between the measured and true values (Malina and Kamelia 2023).

This is consistent with the results of several studies in Table 1, the highest accuracy was observed in the studies by Iswandi *et al*. (2023) using AAS and Mostafa *et al*. (2025) using ICP-MS, both reporting a recovery of 99%. The results that both analytical methods provide highly accurate measurements for cadmium (Cd) determination in cosmetic products.

Precision

Precision represents the closeness of repeated measurements performed under the same analytical conditions and is commonly expressed as the relative standard deviation (%RSD). Lower %RSD values indicate better repeatability and consistency of the analytical method. Acording to the acceptance criteria, a method is considered precise when the %RSD does not exceed 2% (Fatmawati and Yuliantini 2018; Sulistyani *et al*. 2021). Among the reviewed studies GFAAS reported the lowest %RSD values, ranging from 0.0125% to 0.0375% (Saadatzadeh *et al*. 2019), indicating excellent repeatability. Similarly, most studies employing AAS reported %RSD values below 0.5%, reflecting high analytical precision. In contrast, %RSD values exceeding 2% indicate that the analytical method does not meet the acceptable precision criteria due to lower consistency in repeated measurements.

Limit Detection and Limit Quantification

The limit of detection (LOD) is defined as the lowest concentration of an analyte that can be reliably detected by an analtical method, whereas the limit of quantification (LOQ) represents the lowest concentration that can be quantitatively determined with acceptable accuracy and precision (Ola and Tamba 2025; Surani and Asmoro 2025). Lower LOD and LOQ values indicate higher analytical sensitivity. Ideally, both parameters should be lower than the expected analyte concetration in the sample to ensure reliable detection and quantification (Susanto *et al*. 2021). Ahmad-Jouibari *et al*. (2017) reported the lowest LOD (0.002 ppm) using GFAAS, indicating excellent detection capability, although the corresponding LOQ value was not reported. Among the studies that reported both parameters, Bastiansz *et al*. (2022) obtained the lowest LOD and LOQ values using ICP-OES (0.02 ppm and 0.07 ppm). Overall, the reported LOD and LOQ values were lower than the cadmium concentration detected in cosmetic samples.

Cadmium Concentration and Analytical Instrument Performance

Most cosmetic products contaained cadmium levels below the maximum permissible limit of 5 ppm established by BPOM Regulation No. 16 of 2024. However, Suhardiana & Endah (2020) reported cadmium concentrations exceeding the permissible limit in traditional scrub samples, while Ahmad-Jouibari *et al*.

(2017) reported elevated cadmium levels in lipstick, eye shadow, and hair dye products. These findings indicate that although most cosmetic products omply with the regulatory limit, excessive cadmium contamination may still occur in certain products.

The reviewed studies employed different analytical instruments according to their analytical objectives and labolatory facilities. ICP-based techniques, such as ICP-OES are capable of simultaneous multi-element analysis with high sensitivity, making them suitable for trace metal determination (Supardan, 2023). Meanwhile AAS-based techniques are widely used for heavy metal analysis because of their good sensitivity, selectivity, and suitability for determining metals at low concentration (Wahab, Amin, and Prasetya 2024). Therefore, the selection of an analytical instrument should consider the analytical purpose, sample characteristics, and the required analytical performance instead of considering only a single validation parameter.

CONCLUSIONS

This literature review demonstrates that various analytical instruments can be used for cadmium (Cd) determination in cosmetic product. Among the reviewd methoed, GFAAS showed the best validation performance in terms of precision, ICP-OES demonstrated excellent linearity comparable to AAS. FAAS provided the highest accuracy, and most analytical methodes reported LOD and LOQ values lower than detected cadmium concentrations. Therefore, the selection of an appropriate analytical instrument should be based on the analytical purpose, sample characteristics, and the required sensitivity to ensure reliable cadmium determination in cosmetic quality control.

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