International Journal of Agriculture and Biosciences 2025 xx(x): xx-xx.
https://doi.org/10.47278/journal.ijab/2025.079

RESEARCH ARTICLE
eISSN: 2306-3599; pISSN: 2305-6622

Evaluation of Snake Plant (Sansevieria trifasciata) Extracts as Lead Biosorbents: Maceration vs Microwave-Assisted Extraction

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ABSTRACT

The rapid growth of industries and motorized vehicle use has increased heavy metal contamination, particularly lead (Pb), which is toxic even at low concentrations. Biosorption using Sansevieria trifasciata (snake plant) extract offers a natural alternative due to its bioactive compounds with metal-binding abilities. This study examined the effects of extraction time and ethanol solvent ratio on lead absorption using maceration and microwave-assisted extraction (MAE). Response Surface Methodology (RSM) with a central composite design was applied, testing extraction times (1, 3, 5 days for maceration; 60, 120, 180 seconds for MAE) and ethanol ratios (5:1, 8.5:1, 12:1 for maceration; 8:1, 10:1, 12:1 for MAE). Lead absorption was measured using Atomic Absorption Spectrophotometry (AAS), and phytochemical tests were conducted for phenols, flavonoids, tannins, and saponins. The extraction time and solvent ratio interaction significantly influenced both lead absorption and bioactive compound levels. Optimal maceration conditions (1 day 21 hours, 5.40:1 ethanol ratio) achieved 74.02% absorption, while MAE (60s, 12:1 ratio) reached 78.45%. MAE extracts contained higher levels of bioactive compounds than fresh leaves, but concentrations decreased after biosorption, likely due to binding with lead ions. The most notable reductions occurred in phenolic and saponin contents, indicating their vital role in metal chelation. MAE showed better efficiency than maceration. These findings confirm that extraction conditions critically affect biosorption performance and highlight S. trifasciata extract as a promising, eco-friendly biosorbent for lead removal in food and environmental applications.

Keywords: Biosorption, Lead, Microwave-assisted extraction, *Sansevieria trifasciata*.

Article History
Article # 25-158
Received: 08-Apr-25
Revised: 24-Apr-25
Accepted: 12-May-25
Online First: 26-May-25

INTRODUCTION

Industrial development is crucial for economic growth, especially for developing countries. Rapid industrialization and the widespread use of motorized vehicles often pose significant environmental and public health risks. One such risk is pollution from heavy metals, particularly lead (Pb), which seriously threatens human health and ecosystem balance. Prolonged exposure to lead, even at low concentrations, can lead to severe health issues, including neurological damage, cardiovascular disorders, kidney dysfunction, and reduced fertility (Xu et al., 2025). To address this challenge, biosorption—a sustainable process utilizing biomass to adsorb metal ions and pollutants—has gained recognition as a cost-effective and eco-friendly remediation strategy (Gu & Lan, 2023). Recent studies have focused on identifying natural biosorption agents, with particular interest in plant-derived materials due to their abundance and renewability (Rehman et al., 2023). Research demonstrates that particular plant species exhibit exceptional biosorption capabilities, attributed to their high polyphenol content, which facilitates strong binding interactions with metal ions through chelation and ion exchange mechanisms (Nobahar et al., 2021; Karim et al., 2023). Among the potential biosorbents, the Snake plant (*Sansevieria trifasciata*) stands out due to its ability to bind

Cite this Article as: Nugrahini NIP, Yunisa TR, Susanto NS, Chomsy IN and Auzan A, 2025. Evaluation of snake plant (Sansevieria trifasciata) extracts as lead biosorbents: Maceration vs microwave-assisted extraction. International Journal of Agriculture and Biosciences xx(x): xx-xx. https://doi.org/10.47278/journal.ijab/2025.079

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hazardous metals like lead (Pb), cadmium (Cd), chromium (Cr), and other pollutants such as chlorine and benzene. This capability stems from the plant's rich content of bioactive compounds (Cheng and Wen, 2022).

One natural agent with significant potential as a biosorbent is known to be the Snake Plant (*Sansevieria trifasciata*). This plant, known for its hardiness and adaptability, thrives in tropical and subtropical regions, often in arid or low-nutrient environments. Its robust growth and ability to withstand harsh conditions make it an attractive candidate for environmental applications. Recent studies have highlighted the biosorption capabilities of *Sansevieria trifasciata*, particularly its ability to adsorb heavy metals and pollutants from contaminated environments (Alwi et al., 2018; Li and Yang, 2020). This potential is attributed to the plant's unique biochemical composition, including its high content of bioactive compounds such as polyphenols and flavonoids, which facilitate metal ion binding (Tariq et al., 2017; Alwi et al., 2018). As a result, the snake plant has garnered attention as a sustainable and cost-effective solution for environmental remediation, offering a promising alternative to conventional methods.

Bioactive compounds from natural biosorption agents such as *Sansevieria trifasciata are* known to be extracted through several methods. One of the methods known for its efficient work is microwave-assisted extraction (MAE) and maceration. MAE offers rapid and efficient extraction; maceration is a more straightforward, time-tested technique (Mishra et al., 2024). In maceration, plant material is broken into smaller particles to increase surface area, enhancing solvent interaction and extraction efficiency (Shikov et al., 2022). The plant material and solvent mixture are left to soak for a specific period, with occasional stirring, before filtration. The success of this method depends on factors such as solvent type, plant material characteristics, and solvent polarity, which significantly influence extraction efficiency. Maceration disrupts cell structures, allowing chemical compounds to react with the solvent and facilitating the separation of plant components (Ling et al., 2019; Farooq et al., 2022). Despite its simplicity, maceration requires optimization of variables like solvent ratio, temperature, and extraction time to achieve the best results. Research into the optimal conditions for extracting snake plant leaves is essential, as it can enhance the plant's potential as an effective biosorbent for lead removal and other environmental applications.

Microwave-assisted extraction (MAE) is an advanced technique that utilizes microwave radiation to heat solvents, rapidly enabling a faster, more efficient, and selective extraction process. Microwaves act as energy vectors, absorbing electromagnetic energy and converting it into heat through two primary mechanisms: ionic conduction and dipole rotation. Ionic conduction occurs when ions and electrons within a material move in response to the microwave's electric field, generating heat due to friction between charged particles and the surrounding medium. Dipole rotation, on the other hand, involves polar molecules aligning themselves with the oscillating electric field of the microwave, causing collisions that produce heat (Mishra et al., 2024). These simultaneous processes convert microwave energy into heat energy, which the material absorbs, particularly polar molecules like water. This condition leads to a rapid temperature increase within the matrix, causing overheating that ruptures cell walls and plasma membranes. As a result, active compounds are released and extracted more efficiently (López-Salazar et al., 2023). In the context of natural biosorbents such as Sansevieria trifasciata, the use of MAE allows for the efficient recovery of chelating agents, such as polyphenols and flavonoids, essential for metal ion adsorption.

Furthermore, the rapid heating profile of MAE minimizes the degradation of sensitive phytochemicals, preserving their functional properties during extraction (Chan et al., 2011). This process is particularly critical for maintaining the integrity of bioactive components intended for food or pharmaceutical applications. In addition, MAE is considered a green extraction method due to its energy efficiency and compatibility with environmentally friendly solvents like ethanol and water. The scalability of MAE and its adaptability to industrial processes further increase its appeal as a sustainable technology. However, optimal performance depends on several variables, including microwave power, solvent polarity, solid-to-liquid ratio, and extraction duration, all of which must be carefully controlled to maximize the quality and efficacy of the extract. Thus, systematic evaluation of these parameters is essential to harness the full potential of MAE in producing high-quality biosorbents from plant matrices such as S. trifasciata.

Despite its potential, the use of the Snake plant (*Sansevieria trifasciata*) in food applications remains underutilized. Its extract holds promise as a natural metal chelator (sequestrant) in food products, offering a safer alternative to synthetic additives. Additionally, it can be incorporated into food packaging as a metal-binding agent, leveraging its ability to adsorb heavy metals. Further research is needed to optimize extraction parameters, such as extraction time and solvent-to-material ratios, to harness these benefits fully. Therefore, this research investigates the effects of extraction time and ethanol solvent ratio on lead absorption using maceration and microwave-assisted extraction (MAE). This research aims to find the best method for Snake plant extraction and develop a versatile, eco-friendly solution for food safety and preservation by identifying the most effective extraction conditions. Specifically, this study aims to determine the optimal extraction parameters that maximize the lead adsorption capacity of *Sansevieria trifasciata* extract, thereby enhancing its application potential as a natural sequestrant in food systems.

MATERIALS & METHODS

Study Design

This experimental research was conducted at the Laboratory of Food and Agricultural Product Processing and Engineering and the Laboratory of Food and Agricultural Product Chemistry and Biochemistry, Faculty of Agricultural

Technology, Brawijaya University, Malang. Lead biosorption testing by snake plant leaf extract was conducted at the Chemistry Laboratory, Faculty of Mathematics and Natural Sciences, Brawijaya University, Malang. The research began in September 2022 to June 2023.

The study used the Response Surface Method with a Central Composite Design (CCD) factorial 2^2. In the extraction experiment with the maceration method, there were two factors in this study: the extraction time of 1 day, 3 days, and 5 days, and the ratio of material: solvent (b: v) of 5: 1; 8.5: 1; and 12: 1, both of which formed the code (-1.414, -1, 0, +1, +1.414) where the value of -1 is the minimum value, the value of 0 is the middle value and the value of +1 is the maximum value of the factor. In the experiment with the microwave-assisted extraction (MAE) method, there were two factors used: the extraction time (X1) of 60 s, 120 s, and 180 s, and the solvent ratio (X2) of 8: 1, 10: 1, and 12: 1, both of which formed the code (-1.414, -1, 0, +1, +1.414). The values -1.414 and +1.414 are generated by comparing the values of the two factors. The centralized composite design matrix data used in the experimental design can be seen in Table 1.

This research was conducted in 4 stages: production of snake plant leaf powder, extracting snake plant leaves, production of lead solution, and measurement of lead biosorption with snake plant leaf extract from the results of MAE extraction optimization and maceration.

Production of Snake Plant Leaf Powder

Fresh snake plant leaves were sorted to obtain leaves with uniform sizes and separated from the dry and brownish parts, then cut and sliced to a uniform size (± 2x2 cm). Then, it was dried in a greenhouse with sunlight for 6 days at Materia Medica, Batu, to obtain uniform results. Snake plant leaf powder was sieved with a 40 mesh sieve to get a fine powder and then stored in silica gel in a plastic jar wrapped in aluminum foil (Fig. 1).

Extraction of Snake Plant Leaves with the MAE Method

This extraction method was modified by Darvishzadeh & Orsat (2022). Snake Plant powder was weighed as much as 25g, then put into an Erlenmeyer flask, and ethanol solvent was added with a volume according to the experimental design (v/b). The Erlenmeyer was placed on a magnetic stirrer for 15min to allow solvent penetration time into the material. Then, it was put into a microwave oven with a temperature set at 30°C and an extraction time according to the experimental design (s). After the extraction process with MAE was complete, the sample was cooled to room temperature. The supernatant was then separated from the filtrate by passing it through filter paper to obtain a pulp-free Snake Plant filtrate. The filtrate was concentrated with a rotary vacuum evaporator at a temperature of 50°C and a speed of 65rpm to get a concentrated Snake Plant leaf extract concentrate.

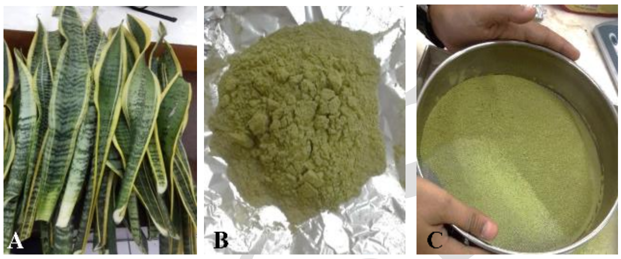

Fig. 1: The material used in this research consisted of (A) Snake Plant (*Sansevieria trifasciata*) and (B) leaf extract powder, and (C) shieved powder with a 40 mesh sieve.

Snake Plant Extraction with Maceration Method

Snake Plant extraction with the maceration method was modified from the study of Ibrahim et al., 2025. Snake Plant powder was weighed according to the RSM experimental design, then put in an Erlenmeyer flask, and ethanol solvent was added with a volume according to the experimental design (b/v). The Erlenmeyer flask was put in a shaker for extraction time according to the experimental design (minutes) for 1 day, 3 days, and 5 days. After the extraction process with maceration was complete, it was filtered using a filter cloth and then fine filter paper. The supernatant was separated from the filtrate by passing it through filter paper to obtain a dregs-free Snake Plant filtrate. The Snake Plant filtrate obtained was then concentrated with a rotary vacuum evaporator at a temperature of 50°C and a speed of 65rpm to get a focused concentrate of Snake Plant extract. Both Snake Plant leaf extract concentrates were stored in bottles and placed in the refrigerator until ready to be analyzed.

Table 1: Centralized Composite Design Matrix Used in Extraction Experiment Design by Maceration and MAE Method

Run	X1	X2	Maceration		MAE	
			Extraction duration (X1, day)	Material: solvent ratio (X2,gram/ml)	Extraction duration (X1, second)	Material: solvent ratio (X2, ml)
1	-1	-1	1	8:1	60	8:1
2	1	-1	5	8:1	180	8:1
3	-1	1	1	12:1	60	12:1
4	1	1	5	12:1	180	12:1
5	-1.414	0	0.17	10:1	35.16	10:1
6	1.414	0	5.83	10:1	204.84	10:1
7	0	-1.414	3	7.17:1	120	7.17:1
8	0	1.414	3	12.83:1	120	12.83:1
9	0	0	3	10:1	120	10:1
10	0	0	3	10:1	120	10:1
11	0	0	3	10:1	120	10:1
12	0	0	3	10:1	120	10:1
13	0	0	3	10:1	120	10:1

Production of lead Solution and measurement of lead biosorption

A 1000mL lead stock solution was pipetted, and as much as 50mL was then put into a 100mL measuring cup. Distilled water was added to the limit mark to produce a lead solution with a concentration of 500ppm. The 500ppm lead solution was put into an Erlenmeyer flask, and then 1 gram of Snake Plant leaf extract concentrate was added. The Erlenmeyer flask was placed on a magnetic stirrer for 10min at a scale speed of 9 (maximum). The solution was left for 240min to give the Snake Plant leaf extract time to contact the lead. The calculation of lead absorption is as follows:

$$\%\,Lead\ absorption = \frac{absorbance\ (ppm)}{500\ ppm} \times 100\%$$

Data Analysis

The results of Snake Plant leaf extraction using the maceration and MAE methods were analyzed using Design Expert 7.1.5 software to see the optimum lead absorption percentage response from the AAS analysis results and to obtain the optimum extraction time and solvent: material ratio for the lead absorption response. Data were validated using the optimum extraction time and material, and the response was obtained using the analysis results of Design Expert 7.1.5 software.

Data on the response of lead metal absorption of Snake Plant leaf extract were analyzed using one-way Analysis of variance (ANOVA) on SPSS ver. 21 with a significance level of p-value = 0.05. Model selection was carried out in 3 stages, namely based on the sum of squares of the model sequence (Sequential Model Sum of Squares), based on the test of model inaccuracy (lack of fit), and based on the summary of statistical models (Summary of Statistic). Model selection based on the sum of squares of the model sequence (Sequential Model Sum of Squares) is based on a P value of less than 0.05.

RESULTS

This study uses the RSM analysis method with factor 1 (X1) extraction time and factor 2 (X2) for the ratio of material: solvent extract of Snake Plant with the response to be analyzed, is the concentration of lead obtained as follows can be seen in Table 2. In the results of the analysis of the lead absorption response with the maceration method, the highest lead metal absorption was in the variable extraction time of 0.17 days and a solvent ratio of 10:1, while the lowest lead metal absorption was in the variable extraction time of 3 days and a solvent ratio of 10: 1. While the results of the analysis of the lead absorption response with the MAE method, the highest lead metal absorption was in the variable extraction time of 60 s and a solvent ratio of 12: 1, while the lowest lead metal absorption was in the variable extraction time of 60 s and a solvent ratio of 8:1.

The results of the selection of the order model of the sum of squares of the lead absorption response can be seen in Table 3 to 5. The best design is focused on the maximum value of adjusted R2 and predicted R2 (Sai Datri et al., 2023). Based on these results, it is known that the model recommended by Design Expert 7.1.5 is Quadratic.

Table 2: Results of lead absorption response analysis using the maceration and MAE method

Run	Maceration			MAE		
	Extraction duration (X1, day)	Extraction duration (X1, day)	Lead absorbtion (%)	Extraction duration (X1, second)	Material: solvent ratio (X2,ml)	Lead absorbtion (%)
1	1	08.01	39.16	120	10	31.11
2	3	7,17:1	57.6	120	10	23.78
3	5.83	10.01	50.28	60	12	80.35
4	3	10.01	26.24	180	12	16.00
5	5	12.01	27.73	120	7.17	42.43
6	3	10.01	21.12	180	8	70.68
7	3	10.01	31.42	120	10	20.50
8	1	12.01	51.15	204.85	10	20.35
9	3	10.01	26.73	60	8	6.25
10	5	08.01	44.64	120	10	29.82
11	0.17	10.01	57.01	120	10	23.06
12	3	12,83:1	36.4	120	12.83	51.06
13	3	10.01	29.51	35.15	10	37.86

Table 3: Description of the sum of squares of the response of lead absorption by the maceration and MAE methods

Maceration						
Variance	Sum of squares	dF	Mean square	F	p-value	Result
Mean vs. total	19153.77	1	19153.77			*Suggested*
Linear vs Mean	270.75	2	135.38	0.84	0.46	
2FI vs. Linear	208.77	1	208.77	1.34	0.27	
Quadratic vs 2FI	1083.94	2	541.97	11.76	0.00	*Suggested*
Cubic vs Quandra	261.66	3	87.22	5.71	0.06	*Aliased*
Residual	61.06	4	15.227			
Total	21039.96	13	1618.46			
MAE						
Mean	15802.74	1	15802.74			
Linear	201.17	2	100.59	0.19	0.83	
2FI	4146.07	1	4146.07	30.43	0.00	
Quadratic	1000.57	2	500.29	15.51	0.00	*Suggested*
Cubic	83.65	2	41.83	1.47	0.31	*Aliased*
Residual	142.14	5	28.43			
Total	21376.34	13	1644.33			

Table 4: Model selection analysis based on the lack of fit test of lead absorption response with the maceration and MAE methods

Variance	Sum of squares	dF	Mean square	F	p-value	Result
Maceration						
Linear	1554.37	6	259.06	16.97	0.01	
2FI	1345.6	5	269.12	17.63	0.01	
Quadratic	261.66	3	87.22	5.71	0.06	Suggested
Cubic	0	0				Aliased
Pure Error	61.06	4	15.27			
MAE						
Linear	5288.51	6	881.42	42.01	0.00	
2FI	1142.43	5	228.49	10.89	0.02	
Quadratic	141.87	3	47.29	2.25	0.22	Suggested
Cubic	58.21	1	58.21	2.77	0.17	Aliased
Pure Error	83.93	4	20.98			

Table 5: The results of the model selection analysis are based on summary statistics of lead absorption responses using the maceration and MAE methods

Linearity Source	SD	*R-squared*	*Adjusted R-squared*	*Predicted r-squared*	*Press*	Result
Maceration						
Linear	12.71	0.14	-0.03	-0.56	2936.06	
2FI	12.50	0.25	0.01	-0.47	2777.18	
Quadratic	6.79	0.83	0.71	-0.19	2253.52	*Suggested*
Qubic	3.91	0.97	0.90		+	*Aliased*
MAE						
Linear	23.18	0.04	-0.16	-1.03	11333.52	
2FI	11.67	0.78	0.71	0.41	3289.30	
Quadratic	5.68	0.96	0.93	0.80	1139.96	*Suggested*
Cubic	5.33	0.97	0.94	0.31	3856.71	*Aliased*

Table 6: Results of Analysis of Variance (ANOVA) on Lead Absorption Response by Maceration and MAE Methods

Source	Sum of Squares	df	Mean Square	F-value	p-value	Result
Maceration						
Model	1563.47	5	312.69	6.78	<0.001	S
Extraction duration (A)	14.87	1	14.87	0.32	<0.59	NS
Material Ratio (B)	563.96	1	563.96	12.23	0.01	S
AB	208.77	1	208.77	4.53	0.07	NS
A^2	787.62	1	787.62	17.08	0	S
B^2	356.18	1	356.18	7.73	0.02	S
Residual	322.73	7	46.1			-
Lack of fit	261.66	3	87.22	5.71	0.06	NS
Pure error	61.06	4	15.27			-
Cor Total	1886.19	12				-
MAE						
Model	5347.82	5	1069.56	33.16	<0.001	S
Extraction duration (A)	76.16	1	76.16	2.36	0.17	NS
Material Ratio (B)	125.01	1	125.01	3.88	0.08	NS
AB	4146.07	1	4146.07	128.54	<0.001	S
A^2	65.75	1	65.75	2.04	0.19	NS
B^2	984.16	1	984.16	30.51	0.001	S
Residual	225.79	7	32.26			
Lack of fit	141.87	3	47.29	2.25	0.22	NS
Pure error	83.93	4	20.98			
Cor Total	5573.61	12				

Notes: S: significant; NS: not significant

The results of the analysis of variance (ANOVA) of the lead metal absorption response by the ethanol extract of Snake Plant leaves can be reviewed from the p-value and inaccuracy (lack of fit) with a p-value <0.05 (P <0.05) and an insignificant lack of fit value. The results of the ANOVA analysis of the lead absorption response can be seen in Table 6. The analysis of variance (ANOVA) with the extraction time factor and the ratio of material: solvent significantly reduces lead concentration. The maceration method resulted in p-value= 0.013 (p-value<0.05), which indicates a significant effect. Therefore, the quadratic model is appropriate for showing the pattern of lead concentration response. The MAE method suggests that the ANOVA results of the quadratic model response significantly affect lead metal absorption, with a p-value <0.0001. Thus, the quadratic model is appropriate for showing the pattern of lead metal absorption response values. The extraction time (A) and the ratio of ethanol solvent: material (B) do not have a significant effect on the lead absorption response because the p-value A = 0.17 and p-value B = 0.08. The ANOVA table shows that the interaction between factors, namely between the extraction time and the volume of ethanol solvent (AB), has a significant effect on the lead absorption response with a P-value <0.0001 (P<0.05). According to Pereira et al. (2021), an insignificant Lack of Fit value can indicate that the model can predict the response data appropriately.

Based on the Analysis of Variance (ANOVA) results on the quadratic model's response yield, the Design Expert 7.1.5 program will provide a model equation. This equation can be used to determine the value of the lead absorption response that will be obtained if the extraction time and the ratio of the ethanol solvent required are different or vice versa. This equation can be used to determine the value of the lead absorption response that will be obtained if the extraction time and the ratio of the ethanol solvent required are different or vice versa. The following is the actual equation of the selected model for the resulting lead absorption response:

Maceration method:

$$Y = 220.33 + 0.48\,X_1 - 36.73X_2 - 1.81\,X_1X_2 + 2.6\,X_1^2 + 2.03\,X_2^2$$

MAE method:

$$Y = -0.24 + 2.43X_1 - 1.01X_2 - 0.012X_1X_2 + 8.54 \text{ x } 10^{-4}X_1^2 + 4.76 \text{ x } 10^{-3}X_2^2$$

Description:

Y = Lead absorption response

X1 = Extraction time

X2 = Ethanol solvent ratio

The normal plot of the residuals curve of the model can be used to determine whether the quadratic model of the lead absorption response is significant. If the average residual point is along the center line, then it can be assumed that the normality of the selected model is correct. Fig. 1a, b shows that the average residual point formed is precise and spread along the line, which means that the lead metal absorption response by the snake plant leaf extract has a good model and is normally distributed. This is in accordance with the criteria for the Normal Plot of the Residuals curve so that the normality of the model is met.

Determination of the optimum point on the extraction time factor and the solvent: material ratio to the lead absorption response is determined based on the highest value of the lead concentration absorbed by the snake plant leaf extract. The results of the optimum point solution provided can be seen in Table 7. After obtaining the optimum point, the optimization results are verified. Model verification is needed to test the model's accuracy and prove whether the optimum point prediction suggested by the Design Expert 7.1.5 program is in accordance with the research results. The results of the verification analysis can be seen in Table 8. The optimization results are verified after obtaining the optimum point (Table 8). Model verification is needed to test the model's accuracy and to prove whether the optimum point prediction suggested by the Design

Table 7: Optimum Point Solution on Extraction Time Factor and Solvent: Material Ratio on Lead Adsorption Response

Metode	Extraction duration (day)	Material: solvent ratio (v/b)	Lead absorbtion (%)	Desirability	Result
Maseration	1.87	5,40:1	73.08	1	Selected
MAE	60	12.01	79.86	0.993	Selected

Table 8: Verification Results of Lead Absorption Response by Snake Plant Extract

Method		Variables		Lead absorption response (%)
		Extraction duration	Ethanol: solvent ratio (mL/g)	
Maceration	Predicted*	1.87 days	5.4:1	73.08
	Verified**	1.87 days	5.4:1	74.02
	Difference			0.94
MAE	Predicted*	60 s	12:1	79.86
	Verified**	60 s	12:1	78.45 ± 0.2
	Difference			1.41

Description: * Data obtained from Design Expert 7.0.0; ** Data obtained from this research; The analysis result data is the average of 2 replications ± standard deviation.

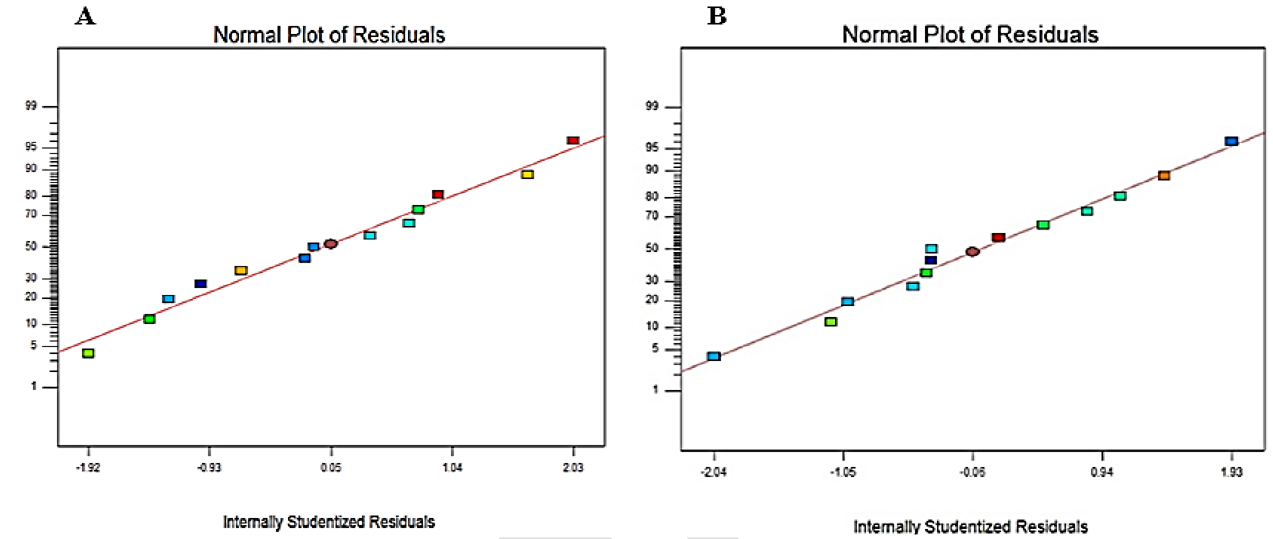

Fig. 2: Normal Plot of Residuals Curve Methods: (a) Maceration and (b) MAE.

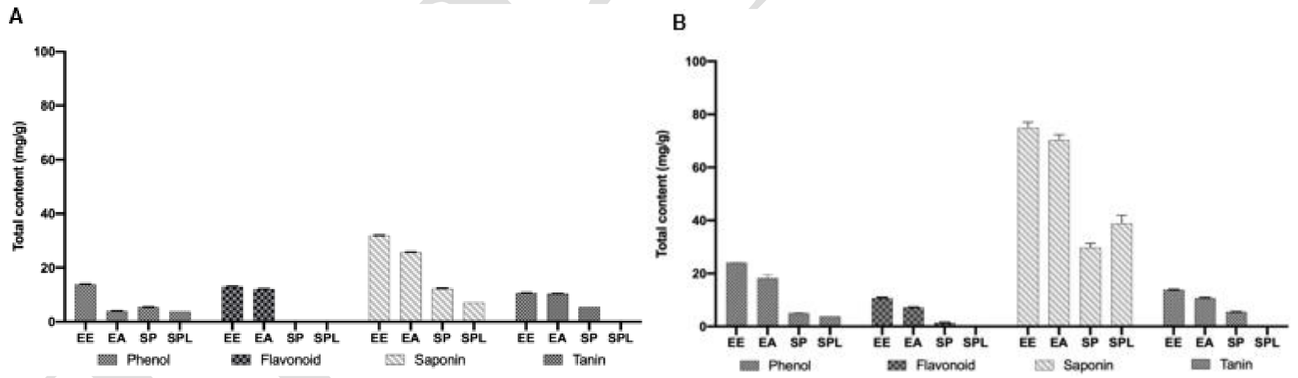

Fig. 3: Phytochemical analysis of total phenol, flavonoid, saponin, and tannin total content (mg/g) was carried out using UV-VIS spectrophotometry. (A) Maceration and (B) MAE method. Note: EE: ethanol extracts; EA: ethanol extracts used for biosorption of lead metal (Pb2+); SP: snake plant; SPL: snake plant leaves.

Expert 7.1.5 program is in accordance with the research results. The results of the verification analysis can be seen in Table 8. If the difference in verification results is less than 5%, the prediction value and analysis results are not much different, indicating the model's accuracy (Khan et al., 2021).

Extraction also affects the phytochemical content of leaves, such as total phenols, flavonoids, tannins, and saponins (Fig. 3). This study showed that the extraction of snake plant leaves using both methods and ethanol solvents can extract chemical compounds from the sample. The largest decrease after the lead biosorption process with the maceration method was in the phenol compound of 9.64 mg/g sample and the saponin compound of 6.27 mg/g sample. Similar to the MAE method, the largest decrease after the biosorption process was in the phenol compound of 5.81 mg/g sample and the saponin compound of 4.52 mg/g sample. It is suspected that during the biosorption process, the chemical compounds in the optimum snake plant leaf ethanol extract bind to lead metal. This lead absorption reduction process is due to the snake plant leaves' OH or phenolic hydroxyl groups (Saridewi et al., 2023).

DISCUSSION

The findings of this study underscore the efficacy of Sansevieria trifasciata (snake plant) extract as a sustainable biosorbent for lead (Pb^{2+}) removal, with microwave-assisted extraction (MAE) outperforming conventional maceration due to its advanced mechanistic advantages. The 78.45% lead absorption achieved via MAE highlights its superiority over maceration (74.02%), aligning with emerging trends in green extraction technologies. MAE's efficiency arises from its unique heating mechanisms, dipole rotation, and ionic conduction, which generate rapid internal thermal energy, disrupting plant cell walls and enhancing solvent penetration. This process not only accelerates extraction but also preserves heat-sensitive phytochemicals critical for metal chelation, a feature often compromised in prolonged conventional methods (Darvishzadeh & Orsat, 2022). Comparatively, maceration relies on passive diffusion, which is slower and less effective in recovering bound phytochemicals, particularly from fibrous tissues like those in Sansevieria. The 4.43% difference in absorption between MAE and maceration, though seemingly modest, is statistically significant in industrial contexts where scalability and resource efficiency are paramount. Furthermore, MAE's reduced solvent consumption and shorter processing time (minutes vs. days) enhance its sustainability profile, making it a preferable choice for large-scale applications (López-Salazar et al., 2023).

The optimization of extraction parameters via Response Surface Methodology (RSM) revealed intricate interactions between time and solvent ratio, particularly in MAE. The synergistic effect of these variables underscores the importance of factorial optimization in maximizing phytochemical yield. For instance, shorter extraction times in MAE (e.g., 10–15 minutes) coupled with moderate ethanol concentrations (60–70%) achieved optimal results, as prolonged exposure risks degrading thermolabile compounds like flavonoids. In contrast, maceration required ~1.87 days to reach equilibrium, beyond which compound leaching plateaued or declined due to oxidative degradation (Shikov et al., 2022). This kinetic variability emphasizes the need for method-specific optimization frameworks.

Phytochemical analysis confirmed the dominance of phenols, flavonoids, tannins, and saponins in the extract, with phenols and saponins showing the most significant post-adsorption reduction. Phenolic hydroxyl (-OH) groups are particularly reactive, engaging in ion exchange and surface complexation with Pb^{2+}, while saponins' glycosidic moieties facilitate electrostatic interactions (Nobahar et al., 2021). Flavonoids contribute via carbonyl and carboxyl groups, forming stable metal-ligand complexes. This multi-mechanistic action explains the extract's high affinity for lead, though the exact stoichiometry of these interactions warrants deeper investigation. Comparative studies on other biosorbents, such as *Moringa oleifera* (85% Pb^{2+} removal) or algae (70–80%), suggest that the Snake Plant holds competitive potential, especially given its low cultivation costs and drought resilience (Gulcin & Alwasel, 2022).

Ethanol's selection as a solvent was strategic: its intermediate polarity enables the extraction of diverse phytochemicals, while its GRAS (Generally Recognized as Safe) status ensures compatibility with food and pharmaceutical applications. Unlike methanol or acetone, ethanol minimizes toxicity concerns, aligning with global shifts toward eco-friendly solvents. Furthermore, ethanol's compatibility with MAE enhances compound solubility, as microwaves disrupt hydrogen bonds between ethanol and water, improving diffusion rates (Ling et al., 2019). Future studies could explore solvent blends (e.g., ethanol-water) to target specific compound groups, though trade-offs between yield and selectivity must be evaluated. Sansevieria extract's metal-binding properties offer innovative applications in active food packaging. Incorporating the extract into biopolymer films could mitigate heavy metal migration from packaging materials into foods, a concern in canned and processed products. For instance, chitosan films infused with Sansevieria extract could adsorb residual lead during storage, enhancing food safety (Cheng & Wen, 2022). Additionally, its antioxidant-rich profile may counteract metal-induced lipid oxidation, extending shelf life. However, regulatory hurdles, such as FDA or EU approval for novel food-contact materials, necessitate rigorous toxicity and migration testing to ensure compliance.

The RSM model's high accuracy, <2% deviation between predicted and observed values, validates its utility in optimizing multi-variable biosorption systems. The quadratic model's reliability, evidenced by normal residual distribution, supports its adoption in industrial process design. Future work could integrate adsorption isotherm models (e.g., Langmuir or Freundlich) to elucidate capacity and affinity parameters, further refining scalability predictions. Despite these advancements, the study's limitations highlight critical research gaps. Molecular-level characterization via FTIR and SEM-EDS is essential to map functional group interactions and surface morphology changes post-adsorption. For example, FTIR could identify shifts in -OH or C=O peaks, confirming their role in Pb^{2+} binding, while SEM-EDS would visualize lead distribution on the biosorbent. Additionally, testing real wastewater, which contains competing ions (e.g., Cu^{2+}, Cd^{2+}), is vital to assess selectivity and practical efficacy. Pilot-scale trials using continuous-flow systems could also bridge the lab-to-industry gap, evaluating parameters like flow rate and regeneration cycles.

The economic viability of MAE hinges on energy costs and equipment availability, which must be evaluated against long-term operational savings. While microwave systems require a higher initial investment (approximately 20–30% more than maceration setups), their faster throughput—reducing extraction times from days to minutes—drastically lowers labor and energy expenditures per batch. For instance, MAE's targeted heating minimizes energy waste, consuming ~0.5–1.5 kWh per cycle compared to maceration's prolonged ambient heating, which can exceed 5 kWh over 48 hours (Yusoff et al., 2022). These efficiencies make MAE economically competitive in high-volume settings, such as municipal wastewater treatment plants, where rapid processing is critical. However, accessibility to industrial-scale microwave reactors remains a barrier in developing regions, necessitating partnerships with equipment manufacturers or government subsidies to offset upfront costs (Radoiu & Mello, 2022).

In contrast, the Snake plant's minimal water and nutrient requirements position it as a low-cost biomass source, particularly advantageous in arid or resource-limited regions. Its ability to thrive in marginal soils with annual rainfall as low as 200 mm reduces irrigation demands, lowering cultivation costs by 40% compared to water-intensive alternatives like *Eichhornia crassipes* (Pandey et al., 2016). This resilience enables dual-purpose cultivation strategies such as phytoremediation of metal-contaminated soils and subsequent harvest for biosorbent production. This closed-loop system not only mitigates soil toxicity but also generates revenue streams from remediation services and biosorbent sales. Scalability studies suggest that integrating MAE with on-site Sansevieria cultivation could reduce biosorbent production costs, enhancing feasibility for rural communities. However, logistical challenges, such as biomass transportation and storage, require decentralized processing units. Thus, coupling MAE's technical efficiency with Sansevieria's agroecological benefits creates a sustainable, cost-effective paradigm for heavy metal remediation.

Conclusion

This study concludes that the Snake Plant (*Sanseviera trifasciata*) contains active ingredients and can act as biosorbents of lead metal. Extraction with the MAE method is faster than maceration, and the percentage of lead absorption obtained by the MAE method is more significant than maceration. However, the solvent: material ratio required in the MAE method is more significant than maceration. Extraction also affects the phytochemical content of leaves, such as total phenols, flavonoids, tannins and saponins, powder, and extract of the Snake Plant (Sanseviera trifasciata). However, an FTIR (Fourier Transform Infra Red) analysis test is needed to see the groups that change after the salak leaf extract is contacted with lead (Pb) metal and to determine the components in Snake Plant leaves more completely. Further research is needed on the application of Snake Plant leaves in food products and their binding to other metal ions.

DECLARATIONS

Funding: The research work was funded by the Non-Tax State Revenue (PNBP) Fund of the Faculty of Agricultural Technology, Universitas Brawijaya (Grant No. 1709/UN10.10/PG/2016).

Acknowledgement: None.

Conflicts of Interest: None.

Data Availability: All the data is available in the article

Author's Contribution: Nur Ida Panca Nugrahini: Conceptualization, Resources, Supervision, Project Administration, Funding Acquisition, Writing Original Draft. Tiara Rahmania Yunisa: Methodology, Software, Validation, Formal Analysis, Investigation. Natalia Sari Susanto: Data Curation, Resources, Software, Supervision, Project Administration. Teti Estiasih: Supervision, Methodology, Project Administration. Asyrafly Auzan: Software, Writing Original Draft, Review & Editing.

Generative AI Statement: The authors declare that no Gen AI/DeepSeek was used in the writing/creation of this manuscript.

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