International Journal of Multidisciplinary Research and Development
www.allsubjectjournal.com
ISSN Online: 2349-4182 ISSN Print: 2349-5979
Received: 22-10-2025, Accepted: 21-11-2025, Published: 06-12-2025
Volume 12, Issue 12, 2025, Page No. 62-66

Adsorption of lead (II) Ions onto *Mangifera Indica* (Mango) peel: Removal from aqueous lead nitrate solutions

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Abstract
Lead contamination in water represents a serious environmental and public health hazard due to its persistence, bioaccumulation, and chronic toxicity. This study explored the potential of mango (*Mangifera indica*) peels as an inexpensive and environmentally sustainable adsorbent for the removal of Pb^{2+} ions from aqueous lead nitrate solutions. The mango peels were pretreated, characterized, and analyzed using several analytical techniques, including Fourier Transform Infrared Spectroscopy (FTIR), X-ray Diffraction (XRD), Thermogravimetric Analysis (TGA), and Brunauer-Emmett-Teller (BET) surface analysis. Elemental composition analysis indicated that mango peel primarily consists of carbon (75.70%) and nitrogen (19.70%), signifying its strong organic content suitable for metal adsorption. FTIR analysis identified various functional groups contributing to lead ion binding, including a band at 1000 cm^{-1} attributed to amine groups, a distinct peak near 500 cm^{-1} corresponding to C–H bending vibrations, a band at 1620 cm^{-1} associated with N–H stretching, and a broad absorption around 3200 cm^{-1} representing O–H stretching. Post-adsorption spectra exhibited noticeable changes, including a broad O–H peak around 3500 cm^{-1} and sharp bands at 1000 cm^{-1} and 1700 cm^{-1} corresponding to C–H and C=O stretching, respectively, indicating strong chemical interactions between Pb^{2+} ions and surface functional groups. XRD patterns confirmed an amorphous structural nature conducive to adsorption, while TGA results demonstrated thermal stability of the material under experimental conditions. Batch adsorption experiments revealed that adsorbent dosage significantly influenced removal efficiency, with optimal performance achieved at 2.0 g, corresponding to approximately 90% lead removal. These findings highlight mango peels as a readily available, biodegradable, and highly effective adsorbent for mitigating heavy metal contamination in water, offering a cost-efficient and sustainable alternative for wastewater treatment applications.

Keywords: Mango (*Mangifera indica*) peels, lead (II), Fourier-Transform Infrared Spectroscopy (FTIR), adsorption

Introduction

Heavy metal pollution remains one of the most critical global environmental challenges, with lead (Pb^{2+}) ranking among the most hazardous contaminants due to its persistence, capacity for bioaccumulation, and severe health implications. Exposure to lead has been linked to neurological impairment, renal dysfunction, and developmental abnormalities in children (Gómez-Aguilar, Rodríguez-Miranda, & Salcedo-Parra, 2022). Conventional remediation methods—such as chemical precipitation, ion exchange, membrane filtration, and electrochemical treatments—are often associated with high operational costs, substantial energy requirements, and diminished efficiency at low contaminant concentrations (Gómez-Aguilar *et al*., 2022; Bandiola, Galotera, Sampilano, & Medioda, 2020) [1]. These limitations have prompted growing interest in sustainable and cost-effective alternatives.

Biosorption utilizing agricultural byproducts has emerged as a viable, low-cost, and environmentally sustainable strategy for heavy metal removal. Among these materials, fruit peels have attracted considerable research attention due to their abundance, renewability, and richness in surface functional groups—such as hydroxyl, carboxyl, and phenolic moieties—that facilitate strong binding interactions with metal ions (Gómez-Aguilar *et al*., 2022) [5]. Mango peel, in particular, has gained recognition not only for its nutritional and phytochemical properties—including flavonoids, phenols, dietary fiber, and essential minerals—but also for its proven potential as a biosorbent for removing heavy metals from aqueous environments (Roderno, Agoto, Cariño, Padilla, & Rubi, 2025; Gómez-Aguilar *et al*., 2022) [5].

Despite its demonstrated promise, further empirical research is required to optimize the application of mango peel in lead remediation. Specifically, region-specific studies are needed to establish optimal operating parameters such as pH, contact time, adsorbent dosage, and initial concentration, and to evaluate whether these biosorbents can consistently reduce Pb^{2+} levels to meet international standards for potable water or wastewater discharge. Additionally, the mechanistic aspects of adsorption—particularly the roles of temperature, surface functional group interactions, and sorbent regeneration—remain inadequately understood. Addressing these gaps, as highlighted by Roderno *et al*. (2025), is crucial to advancing the sustainable use of mango peel as an efficient biosorbent in environmental remediation.

This study aims to evaluate the removal of lead ions from aqueous solutions using mango peel (*Mangifera indica*), with a focus on characterizing the peel, assessing the influence of operational parameters on biosorption, and examining adsorption capacity, kinetics, and isotherm behavior under local conditions. The primary objective is to determine whether mango peel can serve as an effective, low-cost, and readily available biosorbent for lead ion remediation in wastewater treatment applications.

Conventional methods for heavy metal removal—including chemical precipitation, ion exchange, membrane filtration, and electrochemical techniques—are generally effective but are constrained by high operational costs, sludge generation, and complex management requirements (Barakat, 2011). These limitations have stimulated interest in biosorption, a process in which biological materials, such as agricultural byproducts, passively bind metal ions through functional groups such as hydroxyl, carboxyl, and carbonyl moieties (Volesky, 2007). Biosorption offers the dual benefits of cost-effectiveness and environmental sustainability while also valorizing waste materials that would otherwise be discarded.

Among various fruit-derived wastes, mango peel stands out due to its high availability in tropical regions and its richness in lignocellulosic compounds with surface functionalities capable of binding metal ions. Recent studies have demonstrated its significant adsorption potential. For instance, Zhang *et al*. (2020) produced mango peel biochar at varying pyrolysis temperatures and reported a maximum Cd (II) adsorption capacity of 13.28 mg/g at 500 °C, with ion exchange, complexation, and precipitation identified as the dominant adsorption mechanisms. Similarly, Bose *et al*. (2020) developed a mango peel-derived activated carbon–nickel nanoparticle composite, achieving 93% removal of Mn (II) and 98% removal of Rhodamine B dye, highlighting both multifunctionality and reusability. More recently, Cruz *et al*. (2023) investigated raw "Tommy Atkins" mango peel powder for Pb (II) adsorption, reporting capacities up to 72.6 mg/g, with thermodynamic analysis indicating the process was exothermic and spontaneous.

This research, therefore, provides a reproducible experimental plan to evaluate the effectiveness of mango peel (*Mangifera indica*) as an inexpensive and environmentally sustainable biosorbent for the removal of Pb (II) ions from aqueous solutions under controlled laboratory conditions.

Materials and Methods

1. Materials

Reagent: Lead nitrate Pb $(NO_3)_2$, distilled water

Adsorbent: Fresh mango peels (*Mangifera indica*)

Sample collection

Fresh mango peels were collected from local fruit vendors in Iyana Iba Ojo LGA, Lagos, Nigeria.

1.1 Equipment and Apparatus

The equipment and instruments used in this study included an analytical weighing balance, filter paper, laboratory oven, beakers, volumetric flasks, measuring cylinders, electric blender, mechanical shaker, spatula, conical flasks, sieve, funnel, sample bottles, pH meter, aluminum foil, Atomic Absorption Spectroscopy (AAS), Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscope (SEM), and Thermogravimetric Analysis (TGA) apparatus.

2. Methods

2.1 Preparation of Adsorbent (Mango Peels)

Fresh mango peels were collected and carefully washed with tap water, followed by distilled water to eliminate dirt and impurities. The peels were initially air-dried and subsequently oven-dried to ensure complete moisture removal. Once dried, the peels were ground into a fine powder using a mortar and pestle and passed through a sieve to obtain particle sizes ranging from 100 to 200 µm. The resulting powdered adsorbent was stored in airtight containers until use in the experiments.

2.2 Preparation of Stock Solutions

Stock solutions (1000 mg/L) of our solution were prepared by dissolving 33.12 g/mol of Pb $(NO_3)_2$ in distilled water. Working solutions of desired concentrations (10–100 mg/L) were obtained by serial dilution.

2.3 Batch Adsorption Experiments

Batch adsorption experiments were conducted by mixing 50 mL of a lead nitrate solution of known concentration with predetermined amounts of mango peel powder (0.5 g, 1.0 g, 1.5 g, 2.0 g, and 2.5 g) in 100 mL conical flasks. The mixtures were agitated on a mechanical shaker at room temperature for a specified contact time. After reaching equilibrium, the suspensions were filtered, and the remaining Pb^{2+} concentrations in the filtrates were determined using Atomic Absorption Spectrophotometry (AAS).

2.4 Preparation of pH

Batch adsorption experiments were performed by mixing 50 mL of a lead nitrate solution with 2 g of mango peel powder in 100 mL conical flasks. The pH of the solutions was adjusted to 2.0, 4.0, 6.0, 8.0, and 10.0 using 0.1 M H_2SO_4 or 0.1 M NaOH, and pH values were confirmed with a calibrated pH meter. The flasks were tightly sealed, and the mixtures were agitated on a shaker at a constant speed for 3 hours. At the end of the contact period, the suspensions were filtered for further analysis.

Result and Discussions

To characterize the mango peels, various techniques like scanning electron microscope, Fourier transform infrared spectroscopy, Thermogravimetric Analysis, and X-ray diffraction were employed.

1. X-Ray Diffraction Analysis

The XRD diffraction shows maximum reflection at 2θ with an intensity of 45 ICAL. The diffraction pattern also revealed several major peaks, each with its intensity exceeding 10%.

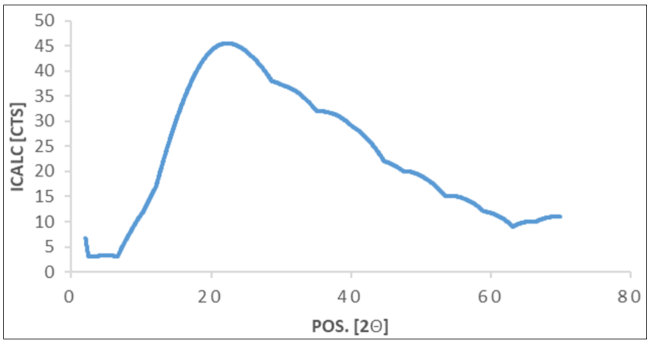

Fig 1: XRD plot of adsorption of *Mangifera indica* peels

2. TGA Analysis

A known mass of the adsorbent was placed in an aluminum pan and heated under a nitrogen atmosphere using a Diamond TG/DTA (Perkin-Elmer) at a temperature ramp of 10 °C/min. No significant weight loss was observed from 0 to approximately 400 °C, indicating high thermal stability. Major decomposition occurred between 400 °C and 600 °C, with the weight percentage decreasing from 80% to 18%, suggesting the breakdown of the primary organic constituents of the material.

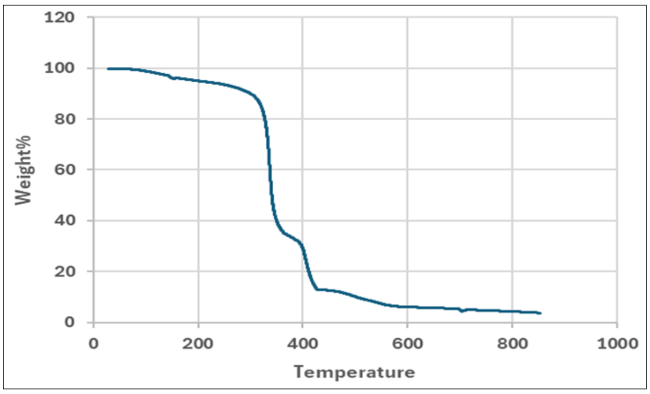

Fig 2: TGA plot of *Mangifera indica* peels

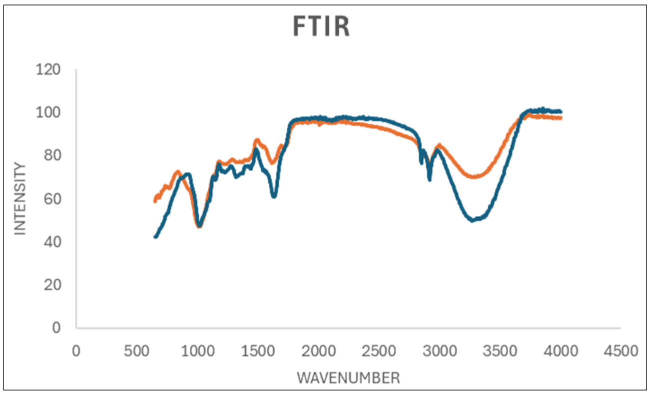

Fig 3: FTIR plot of adsorption of raw *Mangifera indica* peels and after adsorption of Pb (II)

3. Fourier transform infrared spectroscopy (FTIR)

The FTIR spectrum of the mango peels was analyzed to identify functional groups involved in metal ion coordination. The spectrum of the dried mango peel, with a particle size of approximately 1.79 mm, showed bands around 1000 cm^{-1} corresponding to amine groups, while a sharp peak near 500 cm^{-1} was attributed to C–H bending vibrations. A peak at 1620 cm^{-1} indicated the presence of N–H groups, and a broad band around 3200 cm^{-1} was assigned to O–H stretching vibrations. The FTIR spectrum of the residue after adsorption (spectrum B) displayed a broad O–H peak at 3500 cm^{-1}, with sharp bands at 1000 cm^{-1} and 1700 cm^{-1} corresponding to C–H and C=O groups, respectively, indicating interactions between Pb^{2+} ions and the functional groups on the mango peel surface.

4. Scanning Electron Microscope (SEM)

The surface morphology of the peel was composed of granules with irregular shapes with various sizes, and had some deep holes. The result of the deep holes might be swelling in the mango peels during the oxidation process.

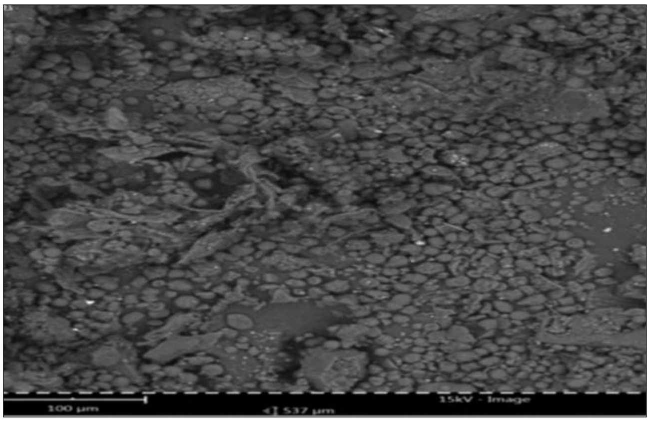

Fig 4: SEM image of *Mangifera indica* peels

5. Energy Dispersive X-Ray Spectrometer (Eds) Result for Mango Peels

The energy-dispersive X-ray spectroscopy (EDS) analysis, coupled with SEM, was employed to obtain structural information and gain insight into the adsorption mechanism of mango peels. The EDS spectra revealed prominent peaks for carbon and nitrogen, indicating that these elements are major constituents of the mango peel material.

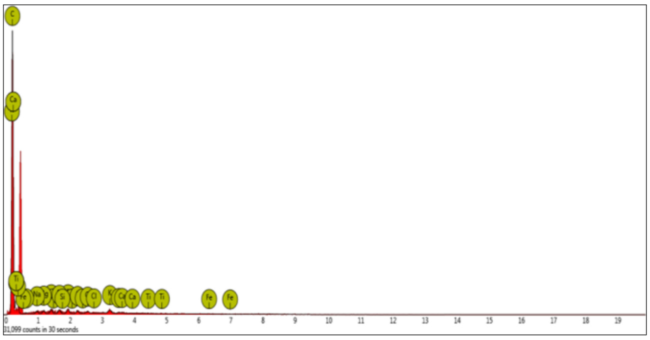

Fig 5: EDS image of *Mangifera indica* peels

Table 1: EDS analysis of *Mangifera indica* peels

Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
6	C	Carbon	80.16	75.70
7	N	Nitrogen	17.89	19.70
19	K	Potassium	0.27	0.82
15	P	Phosphorus	0.29	0.70
13	Al	Aluminium	0.30	0.64
14	Si	Silicon	0.23	0.51
11	Na	Sodium	0.26	0.48
16	S	Sulfur	0.19	0.48
12	Mg	Magnesium	0.23	0.45
17	Cl	Chlorine	0.13	0.36
20	Ca	Calcium	0.05	0.17
26	Fe	Iron	0.00	0.00
22	Ti	Titanium	0.00	0.00

6. Optimization of Adsorbent Dosage and Ph

6.1 Effect of mass of dosage

The adsorption experiment was varied using (0.5-2.5) g doses of the mango peels. The removal efficiency increased with an increasing amount of adsorbent up to 1.5 g. The percent removal efficiency was 90% using 1.5 g of mango peels.

6.2 Effect Of pH

The effect of pH on metal adsorption was investigated over a range of 2 to 10 in the presence of metals such as copper, cobalt, and zinc. The optimum pH for lead adsorption was found to be pH 2, achieving a maximum removal efficiency of 80%, likely due to competition between Pb^{2+} ions and the functional groups on the mango peel surface. Decreased adsorption was observed between pH 6 and 10, which can be attributed to saturation of the functional groups by accumulated lead ions from the aqueous solution.

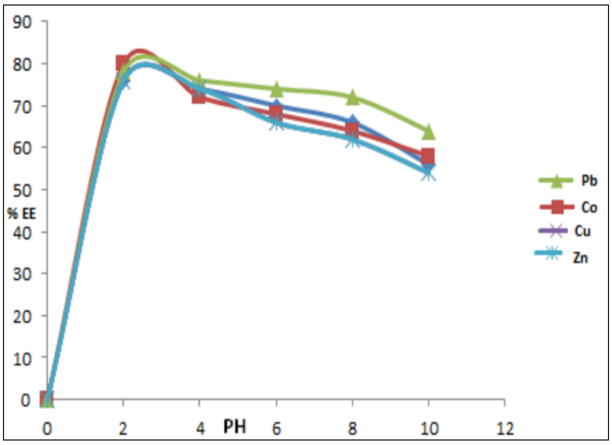

Fig 7: indicates the graph of pH against % removal of Pb(II)

7. Adsorption Isotherm Studies
7.1 Langmuir Adsorption Isotherm

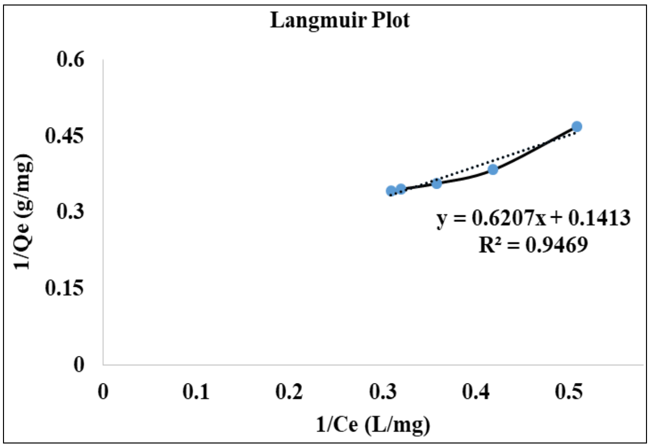

Fig 8: Langmuir plot of adsorption

7.2 Freundlich Adsorption Isotherm

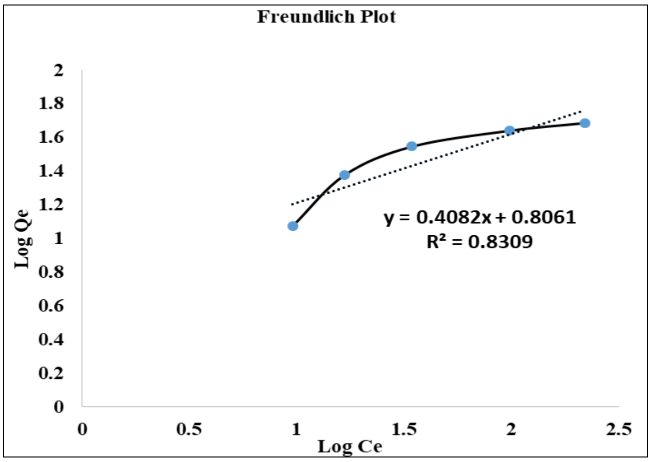

Fig 9: Freundlich Adsorption Isotherm

Adsorption isotherms are commonly used to represent equilibrium data for adsorption processes. This study employed two isotherm models: Langmuir and Frenunlich. The various constants associated with these models are presented in Table 2. The experimental findings aligned best with the Langmuir model, suggesting a monolayer with a uniform adsorption surface with diverse energy sites. Furthermore, the results indicated that as surface coverage increases, the energy of adsorption increases.

Table 2: Adsorption Isotherms Variable/Constant of Lead (II)

ISOTHERMS	Lead (II)
LANGMUIR	
Q_{max}	7.077
K_L	0.08
R_L	0.34
R^2	0.9469
FREUNDLICH	
n	2.448
K_F	5.671
R^2	0.8309

8. Kinetic Studies
8.1 Pseudo First Order

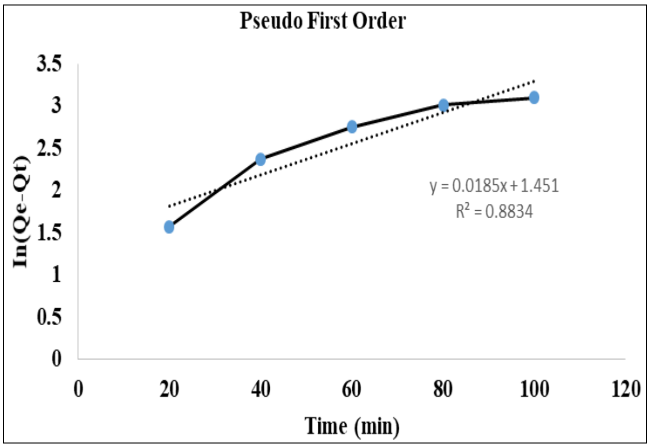

Fig 9: Pseudo-first order

8.2 Pseudo-second order

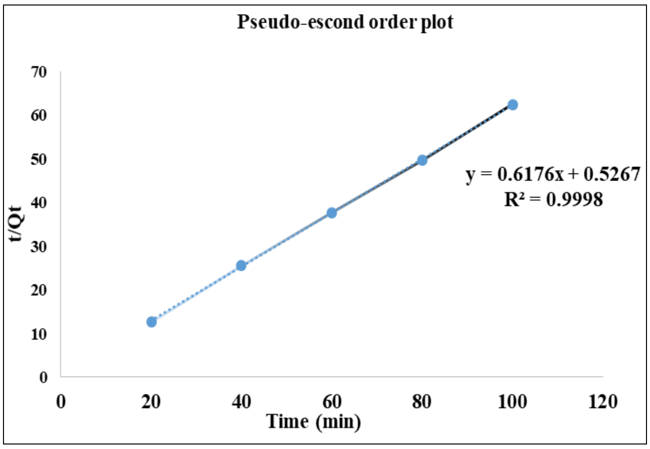

Fig 10: Pseudo-second order plot

The adsorption kinetics of the adsorption experiments were determined by the pseudo-first-order and pseudo-second-order reactions. The contact time ranges from 20-120 minutes. The results in Figures 9 and 10 indicate that the experimental data for this study were fitted for a pseudo-second-order kinetic model due to the R^2 value that is closer to unity.

Conclusion
This study evaluated the use of mango peels (*Mangifera indica*) as a cost-effective biosorbent for the removal of heavy metals from aqueous solutions. XRD analysis indicated that the peels are predominantly amorphous, enhancing surface area and adsorption capacity. FTIR

characterization confirmed the presence of functional groups, including hydroxyl, carbonyl, and carboxyl groups, which act as active sites for metal ion binding. Thermogravimetric analysis showed that mango peels are thermally stable under typical adsorption conditions, supporting their suitability for repeated use.

Batch adsorption experiments demonstrated that metal removal efficiency increased with adsorbent dosage, with maximum efficiency achieved at 1.5 g, reflecting the greater availability of active sites at higher concentrations. These findings align with previous studies on fruit wastes as biosorbents, highlighting the potential of mango peels as an effective, environmentally friendly, and sustainable material for heavy metal remediation. Overall, the results indicate that mango peels offer a viable alternative to conventional adsorbents, combining water purification with agricultural waste management.

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