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Natural Coagulants Extracted from Jatropha Curcas: Detoxification of Leaves and Shells Extracts for Sustainable Turbidity Removal

Soraya Mercedes Pérez*[1], Amal Al-Hanaktah[1] and Suhail Sharadqah[1]

*[1]*Department of Natural Resources and Chemical Engineering, Faculty of Engineering, Tafila Technical University, P.O. Box 66110, Tafila- Al Ais, Jordan*

Abstract

Jatropha is a plant whose leaf and shell fractions exhibit promising coagulating properties. Phorbol esters (PEs) —constituted 12-deoxy-16-hydroxy phorbol as core structure—, is the main toxic that restrict its application in water treatment intended for human and animal consumption. PEs detoxification in Jatropha coagulant extracts, their effect on Turbidity removal (coagulating activity) and Chemical Oxygen Demand (COD) was investigated in synthetic samples of wastewater. Additionally, coagulating activity was evaluated in samples of different turbidity (tap water, Dead Sea water and groundwater), which were treated with the best detoxified coagulants. Detoxification was performed through ethanol extraction, adsorption with activated carbon, thermal and lime treatments. Finding that detoxification exerted a positive effect, enhancing turbidity removal to levels between 87% to 98%. Particularly for ethanol-detoxified leaf extract, which was able to reduce by 98.6% turbidity, 53% PEs and COD 18%. Even for samples of different turbidity, the assessment of coagulating activity revealed that the detoxified extracts by ethanol, especially leaf coagulants, were better coagulants than other ones detoxified by another treatments. Improving significantly the turbidity removal efficiency (17%), even under saline stress and in the presence of natural minerals, as observed in tap and Dead Sea water. The innovative application of coagulant extracts, chemical-free and detoxified using environmentally friendly methods, renders this approach novel, sustainable and feasible. The findings led to conclude that Jatropha coagulants applied as aqueous liquid extracts facilitate the detoxification (PEs removal and other hydrophobic toxins), enhancing the coagulating activity. Discovering that the detoxified leaf extract is a more efficient coagulant than the shell extract. Being detoxification by ethanol the best treatment among those analysed in this study.

Paper type: Research Paper

Keywords: Coagulating activity, Dead sea, COD, phorbol esters, wastewater

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1. Introduction

Jatropha Curcas belongs to the *Euphorbiaceae* family, sharing the same taxonomic group as the Castor plant (Escrivane et al., 2014). It is a shrub that typically thrives in tropical regions, with approximately 170 varieties identified to date (Nazir et al., 2017). The genus name derives from the Greek words jatr'os (doctor) and troph'e (food), indicating its traditional association with therapeutic applications (Kumar et al., 2022). This specie has been widely employed for oil extraction, with applications in lubricants, soap production, and the wood industry. Recent studies have demonstrated that the high degree of unsaturation in Jatropha oil—attributed to its elevated levels of unsaturated fatty acids (-C=C-) (Lye et al., 2021; Arbain et al., 2022), free amines, and phenolic compounds—enhances its potential as an effective natural coagulant (Al Hanaktah & Pérez, 2026). Although Jatropha plants are recognized as potential raw material for the production of food derivatives due to their high protein content, experimental proofs

* Corresponding author: E-mail: soraya@ttu.edu.jo ORDIC: https://orcid.org/0000-0003-1089-3597
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demonstrate their toxicity in mice, rabbits, goats, and humans (Escrivane et al., 2014). The toxicity of J. Curcas is mainly attributed to the presence of high concentrations of toxic and antinutritional compounds, including trypsin inhibitors, lectins, saponins, phytates, and phorbol esters (Khodapanah et al., 2018). Among these, phorbol esters are recognized as the principal toxic constituents (Adolf et al., 1984). J. Curcas, phorbol esters occur in six isomeric structural forms (Abdelgadir & Van Stader, 2013). All share a common diterpene core structure, 12-deoxy-16-hydroxyphorbol (DHPB) (**Figure 1A**). This DHPB backbone can be esterified with different Rn radical side chains, giving rise to six distinct phorbol ester isomers (**Figure 1B–G**). Notably, the isomers shown in **Figures 1D** and **1E** are epimeric forms that cannot be separated by conventional chromatographic techniques.

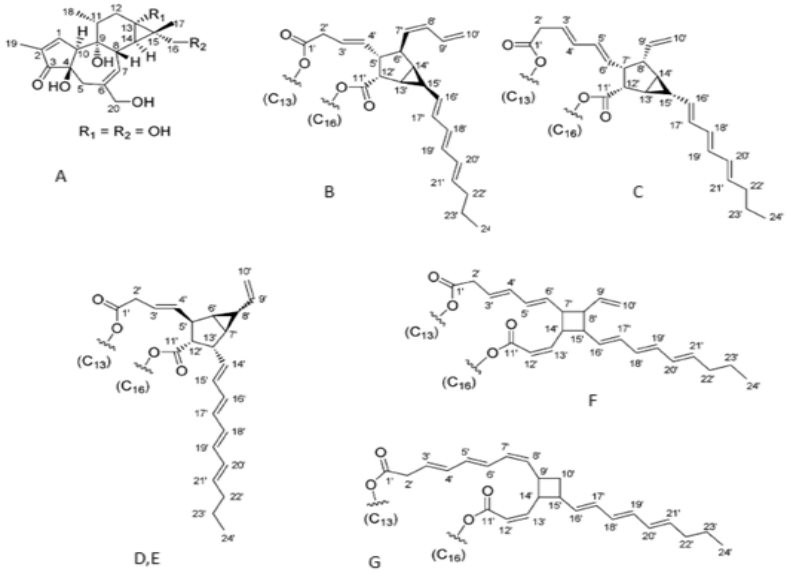

Fig. 1. DHPB backbone presents in some chemical structures of Phorbol Esters. *Adapted from (De Barros et al., 2024)*

Phorbol esters are secondary metabolites found in plants such as J. Curcas, and rather have suspension stabilizing properties. Therefore, their presence has negative effects on turbidity reduction. (Al-Hanaktah & Pérez, 2026). This is because PEs can dilute the concentration of active coagulant compounds such as proteins, polysaccharides and polyphenols. Also, the hydrophobic characteristics of PEs modify surface charges and flocculation mechanisms, acting as surfactants and stabilizing colloids. Jatropha-based coagulants without detoxification pose a risk to health and the environment. Even when turbidity is removed, residual toxins remain in the treated water. Therefore, it is essential to reduce PEs content in water intended for human and animal consumption. The presence of PEs can cause gastrointestinal problems, skin irritation, and can even promote tumors (De Barros et al., 2024). Coagulation sludge may also contain PEs, making it unsafe for reuse. From what is known, solid Jatropha derivatives such as powder and seeds are currently detoxified using processes such as solvent extraction, heat, and chemical treatments (Gogoi & Tyagi, 2015) (Pereira et al., 2017). However, to date, there is no research on the detoxification of liquid coagulant extracts of Jatropha fractions. This scientific deficiency demonstrates the importance of this innovative study, exploring detoxification methods to make these liquid coagulants safe for human consumption. Thus, the application of detoxification strategies—such as solvent extraction, carbon adsorption, thermal degradation and lime treatment—like those focused on in this study, are essential to eliminate phorbol esters prior to coagulant use.

2. Materials and Methods

2.1 Preparation of extracted coagulants from J. Curcas *(without detoxification)* and evaluation of coagulating activity.

Seeds and leaves of Jatropha *Curcas* were purchased from a supplier, in Saudi Arabia and the south of Jordan. Jatropha fruits (seeds) were acquired at full physiological maturity, corresponding to 75–78 days post-anthesis. The soil sample, used for synthesizing the turbid water (770 NTU), was passed through a 300 µm sieve, ASTM No 50. The leaves and seeds were dried overnight at 80 °C. Posteriorly, the seeds were peeled and separated into kernels and external shells. The three parts or fractions were ground and sifted through a 300 µm sieve, ASTM No 50. The powder originating from each fraction was stored in well-sealed containers until used. The extract solutions were prepared using distilled water at a ratio of 1:50 (g/ml) and stirred for 30 minutes. The resulting solution was filtrated, and the filtrate was conducted as original coagulant extract (without detoxification).

Calcium Hydroxide 90% (lime), activated carbon and ethanol 95% were acquired from Sigma-Aldrich and used for detoxification treatment. Synthetic samples (770 NTU) were used to analyze coagulating activity of extract coagulants. Samples of different turbidity such as tap water, ground water, and Dead Sea water from Ain Lahda, southern Jordan, also were collected. The preparation of original coagulant extracts, optimum doses identification and coagulating activity evaluation were performed under the method established by (Al Hanaktah & Pérez, 2026).

2.2 Phytochemical Composition of Natural Coagulants J. Curcas

Phytochemical compounds were measured using liquid chromatography coupled with mass spectrometry (HPLC/ MS) analyzer, following the methodologies stablished by(Xu et al., 2020).

2.3 Detoxification treatments for natural coagulants of J. Curcas

Several detoxification processes were operated to reduce or eliminate toxins from leaf and shell extracts. First, the filtered extract was heated to approximately 70 ℃ for 30 minutes. Then allow the solution to cool until it reaches room temperature (Hass & Mittelbach, 2000). The second process, solvent extraction, involved treating the powdered leaves and shells with ethanol in a 1:5 (g/mL) ratio and stirring for 1-2 hours at room temperature. The powder was then filtered, washed with distilled water, and dried at 80 ℃ to ensure complete evaporation of ethanol (Nokkaew & Punsuvon, 2013). Subsequently, the treated leaves and shells were used to prepare a stock solution, following the methodology stablished by (Al Hanaktah & Pérez, 2026). Furthermore, the adsorption by activated charcoal was proposed to detoxify the leaf and shell extracts. Activated charcoal was added to the extract at a concentration of 5 g/L and stirred for 30 minutes. Then, mixture was filtered using a PTFE syringe filter (0.22 µm) to separate activated charcoal-bound toxins (Gomes et al., 2018). Calcium hydroxide (1g/l) was added for react with the toxins conten in the leaf. The suspension was agitated during 1 h and posteriorly filtrated (Hass et al., 2002).

2.4 Infrared spectroscopy

Functional groups in the extracts of Jatropha fractions were identified by comparing the vibration frequencies from the FTIR spectrograph of the samples with an IR correlation chart. Coagulant extracts of Jatropha leaves, kernels, and shells were analysed by FTIR (Bruker ALPHA) together with the readings from Infrared correlation chart.

2.5 Phorbol esters content

Phorbol ester content was measured by the method established by (Makkar et al., 1998)

2.6 Chemical oxygen demand (COD)

The chemical oxygen demand (COD) test for jatropha extracts was conducted following the procedures outlined in Standard Method 5220D, known as the closed reflux colorimetric method (APHA, 2012)

2.7 Evaluation of turbidity removal using detoxified coagulants

The best detoxified coagulants derived from shells and leaves (which were obtained from ethanol treatment), were tested on synthetic wastewater (770 NTU) and the samples of different turbidity (Dead sea water, tap water and ground water). The optimum dosage, at which the highest removal efficiency was observed, was determined in section 2.1. The optimal doses found were 1% (v/v) for the detoxified leaf extract and 0.5% (v/v) for the shell extract, both added to 200 ml of synthetic turbid water. The initial and final turbidity levels were measured using a Milwaukee Mi 415 turbidimeter.

2. Results and Discussion

Samples were taken by triplicated and analyzed statistically. Statistical differences were assessed using standard deviation (STD), error bars and t-test, with a significance level ≤ 0.05.

3.1 Evaluation of Coagulating Activity Previous Detoxification

Coagulant extracts from the leaf, shell and kernel fractions of Jatropha were initially analyzed. Percentage of turbidity removed evaluated the coagulanting activity of the original extracts (without detoxification) **(Figure 2)**.

The results showed maximum turbidity removal levels of 81.2%, 76.6%, and 66.7% for the leaf, shell and kernel extracts, achieved at optimal doses of 1%, 0.5%, and 4% v/v for each fraction. The highest coagulating activity was observed in the leaf extract, followed by the shell and kernel fraction. This elevated coagulating activity is possibly associated with the high levels of free amino acids, total phenolic compounds, and flavonoids. Which contain oxygen- and nitrogen-bearing functional groups that enhance the coagulation potential of Jatropha extract (Benalia et al., 2024). This occurs because certain asymmetric oxygenated and nitrogenous molecules—such as free amino acids, total phenols, and flavonoids—present in Jatropha-based coagulants, tend to form dipole–dipole interactions promoted by their high dipole moments between 1.3 to 1.5 characteristic of the H-O and H-N functional groups (Farouk, 2017). These dipoles are easily attracted and bound by Van der Waals forces, leading to the neutralization of the electrostatic repulsion of the electric double layer surrounding the colloid, thus destabilizing it and favouring coagulation (Khosnevisan & Barkhi, 2025).

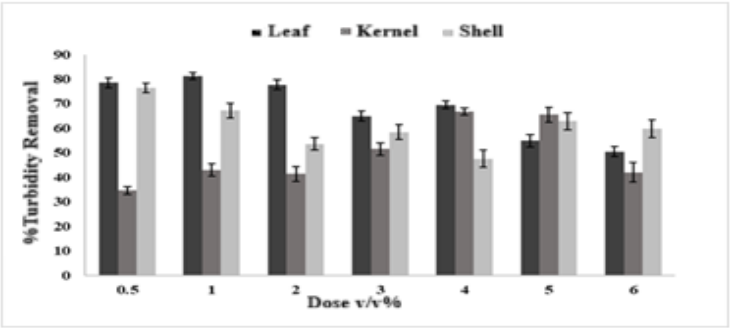

Fig. 2. Turbidity Removal (Coagulation activity) of original coagulant extracts and identification of optimum doses. Three replicates were obtained for each sample, with significance defined at $p \leq 0.05$.

Previous studies conducted by (Kurniawan et al., 2023) demonstrated the high coagulation capacity of J. Curcas seed extracts chemically treated with sodium hydroxide and chloride. This coagulation mechanism is justified by the electrochemical double-layer phenomenon, consistent with the analysis of this research. **Table 1** presents the phytochemical content of the Jatropha curcas fractions. High coagulating activity registered in J. Curcas aligns with previous findings reported by (Bravo, M. 2017). Although Bravo's investigation focused on comparing the coagulating efficiency of powdered fractions or solids of Jatropha extracts, Moringa oleifera and Opuntia ficus, the present study differs because it employs liquid coagulants. Even so, both studies concur that Jatropha exhibits the highest coagulation efficiency, followed by solid coagulants obtained from Moringa olifera and Opuntia ficus.Phytochemical composition of all fractions of J. Curcas is presented in **Table 1**. Results of Jatropha leaf concentrates showed the highest levels of free amino acids (15.09 mg/g), total phenolic compounds (27.7 mg GAE/g) and flavonoids (4.4%), followed by shell (11.13 mg/g; 9.16 mg GAE/g; 0.6%) and kernel fraction (9.07 mg/g; 3.6 mg GAE/g; 0.04%).

Table 1. Phytochemical analysis of Jatropha Curcas expressed in mg/g. (*Per gram of dry matter)

	Crude Protein	Total Phenolic*	Free Amino Acid*s	Flavonoids
leaf	37.10±0.30	27.70±0.20	15.09±0.10	44.0±0.94
shell	58.70±0.55	9.16±0.71	11.13±0.60	6.0±0.56
kernel	618.0±0.48	3.60±0.03	9.07±0.70	0.4±0.37

Infrared (IR) spectra of the coagulant extracts of all fractions studied are presented in **Figure 3**. IR spectrometric analysis clearly indicates the presence of total aromatic amines characteristic of Jatropha coagulants. The high transmittance values of leaf extract observed suggest low absorbance associated with a low concentration of total amino acids in the coagulants of this fraction. This indicates an inverse relationship between total amino acids (quantified by total protein) and free amino acids. Finding that the high concentration of free amino acids are the main promoters of the increase in coagulant activity. Consequently, the leaf coagulant had the lowest total protein content (3.71%), followed by shell extract (5.87%) and kernel extract (61.80%). These results demonstrated an inverse relationship between total protein content and free amino acids for leaf coagulant extracts (15.09 mg/g), shell (11.13 mg/g), and kernell (9.07 mg/g). IR spectra of the extracts from the three fractions confirmed the presence of aromatic amino acids, as observed in the characteristic peaks of this functional group between range 3000–3300 cm^{-1}, corresponding to C–H stretching vibrations and aromatic rings. Additionally, typical C=C stretching bands are observed within the aromatic ring structure at 1500–1600 cm^{-1}. These results support the existence of aromatic amino acids such as tyrosine, phenylalanine, and tryptophan, which were recorded at concentrations of 11; 49; and 26 $g/kg_{protein}$, according with studies conducted by (Gámez-Meza et al., 2013). Also highlighting that the physical form of the IR sample analyzed significantly influences the appearance of the spectrum. Although the spectra of the coagulant extracts presented in **Figure 3** reflects the presence of aromatic amino acids of proteins, the spectral peaks are not sharp or well-defined as typically expected for such compounds. Instead, they appear as broad and rounded bands characteristic for samples in aqueous solution, such as the extract coagulants of J. Curcas. In spectra of samples containing water,

bands associated with water are typically observed around 1650 cm^{-1}. This water absorption elevates the spectrum in that region, resulting in less pronounced and more rounded bands (Larkin, 2018). The comparative study of the coagulating activity of the original (non-detoxified) Jatropha extracts showed that the highest results of turbidity removal were obtained from the leaf and shell fractions (**Figure 2**). For this reason, the detoxification assessment focuses exclusively on the coagulant extracts of these two fractions.

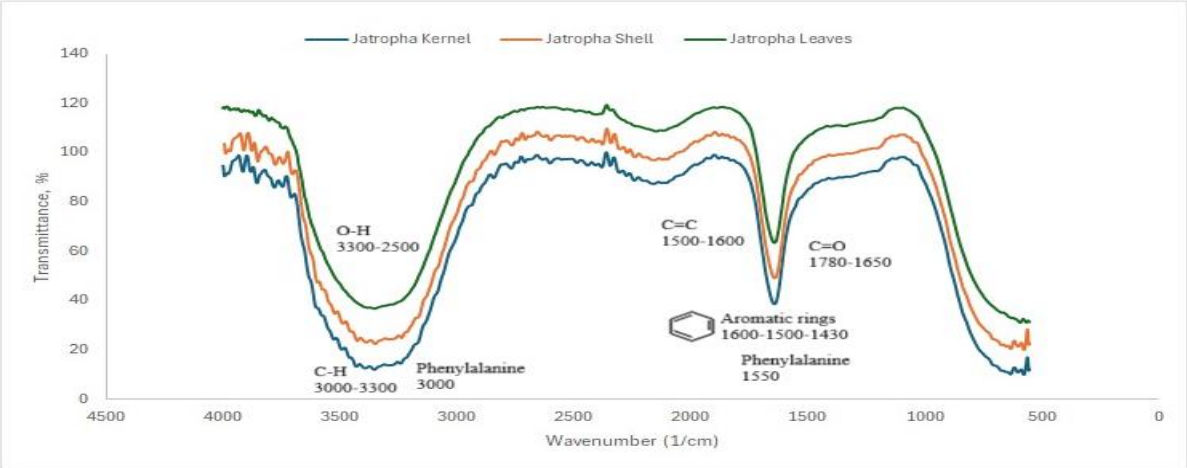

Fig. 3. Infrared (IR) spectra of the coagulant extracted from all fractions. Three replicates were obtained for each sample, with significance defined at $p \leq 0.05$.

3.2 Coagulating Activity Assesment after Detoxification

This study focuses on four detoxification treatments (activated carbon adsorption, ethanol extraction, lime and heat treatment) applied to coagulant extracts of leaves and shell. Figure 4 shows the turbidity removal results associated with these coagulant extracts, before and after detoxification. The results revealed a significant improvement in turbidity removal using detoxified coagulants derived from leaves and shell of J. Curcas in all detoxification methods evaluated in this study. This leads us to think that, in general, detoxification improves coagulant performance. High turbidity reduction efficiencies were recorded with ethanol-detoxified coagulants, reaching levels of 98.65% for leaf extracts and 87.36% for shell extracts. These results represent an improvement in turbidity removal of Δ17.33% (leaves) and Δ11.1% (shell), compared to the original (non-detoxified) coagulants.

Conversely, the lowest turbidity removal values were observed with lime treatment for the leaf extract (86.53%) and charcoal treatment for the shell extract (83.31%). The highest turbidity removal percentages registered confirm that ethanol extraction is the most effective detoxification method for to enhance turbidity reduction among the approaches assessed in this study. The efficacy of ethanol is primarily attributed to its ability to form hydrogen bonds with the hydroxyl groups present in phorbol esters (PEs), facilitating the efficient removal of this hydrophobic and toxic compound and other ones such as non-polar compounds, fatty acids, and various antinutritional factors—including trypsin inhibitors, lectins, saponins, and phytates (Makkar et al., 1998). These substances are known to hinder colloid aggregation, thereby reducing coagulant performance. The mechanism of transesterification which describe how ethanol removes PEs, — through reaction between ethanol and phorbol esters — is depicted in **Eq. (1)**. In this process, the organic moiety R'' of the phorbol ester is exchanged with the R' group of ethanol, resulting in the formation of a different alcohol and a new ester soluble in nonpolar toxins. Such reactions are commonly catalysed under acidic or basic conditions, by enzymes, or can even proceed under thermal activation. Solubilization of PEs essentially involves the hydrolysis of soluble esters into non-polar toxins. The mechanism of PEs hydrolysis is presented by (Chemistry Steps, 2025). Phorbol esters solubilized become electrically charged at the carbocation stage, destabilizing the suspension and enhancing flocculation.

$$R'OH + R''COOR \rightleftharpoons R'COOR + R''OH \quad (1)$$

Figure 4 also shows the results belong to the activated carbon treatment. The leaf-based coagulant achieved a notable turbidity removal efficiency of 94.52%, corresponding to a turbidity reduction of Δ13.22% compared to non-detoxified extracts. Ranking as the second most effective detoxification method for the leaf fraction, but not for the shell fraction (83.31% turbidity removal, Δ 6.95%). It is justified because the addition of $Ca(OH)_2$ during the activated carbon treatment creates a mildly basic medium that promotes precipitation of residual PEs and other organic contaminants in the leaf extract. Nevertheless, detoxification is primarily attributed to the activated carbon itself, whose pore size (mostly ≤ 2 nm) appears well-matched to the contaminant particle diameter, enabling effective adsorption and floc formation. Heat treatment proved to be the third most effective detoxification method for both

coagulant extracts, achieving turbidity removal efficiencies of 92.47% for leaf extracts and 84.99% for shell extracts. These values represent turbidity reductions of Δ11.17% (leaf) and Δ8.63% (shell) compared to their non-detoxified counterparts.

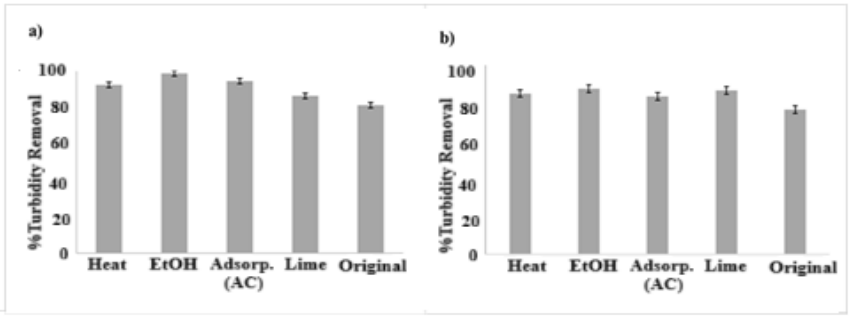

Fig. 4. Turbidity removal applying coagulants treated by different detoxification methods a) Leaf and b) Shell. Three replicates were obtained for each sample, with significance defined at $p \leq 0.05$.

The observed improvement may be attributed to the denaturation and partial degradation of PEs and other coagulation-inhibiting compounds due to the temperature (Abou et al., 2010). Nevertheless, this approach is not considered optimal, consistent with the analysis carry out by (Makkar & Bekker, 1997a; Makkar & Bekker, 1997b), who demonstrated that phorbol esters are highly thermostable and can withstand temperatures up to 160 °C for 30 minutes without significant degradation. Likewise, results reported by (Aregheore et al., 2003) demonstrated that thermal treatment alone is insufficient to achieve substantial reductions in PEs content. Interestingly, lime treatment yielded the lowest turbidity removal efficiency for the leaf coagulant extract yet ranked as the second most effective method for the shell extract. Rates of Turbidity removal reached 86.53% for leaf and 86.56% for shell extracts, corresponding to reductions of Δ5.23% and Δ10.2% respectively, compared with original samples. Turbidity removal rates reached 86.53% for leaf extract and 86.56% for shell extract, corresponding to reductions of Δ5.23% and Δ10.2%, respectively, compared to the original samples. These results suggest that for coagulants with higher PEs concentrations, highly alkaline treatments are more effective. This improvement is attributed to strongly basic environment generated by lime. Which promotes the hydrolysis of abundant PEs in shell extracts through saponification reactions—typical for esters under alkaline conditions (Martínez-Herrera et al., 2006).

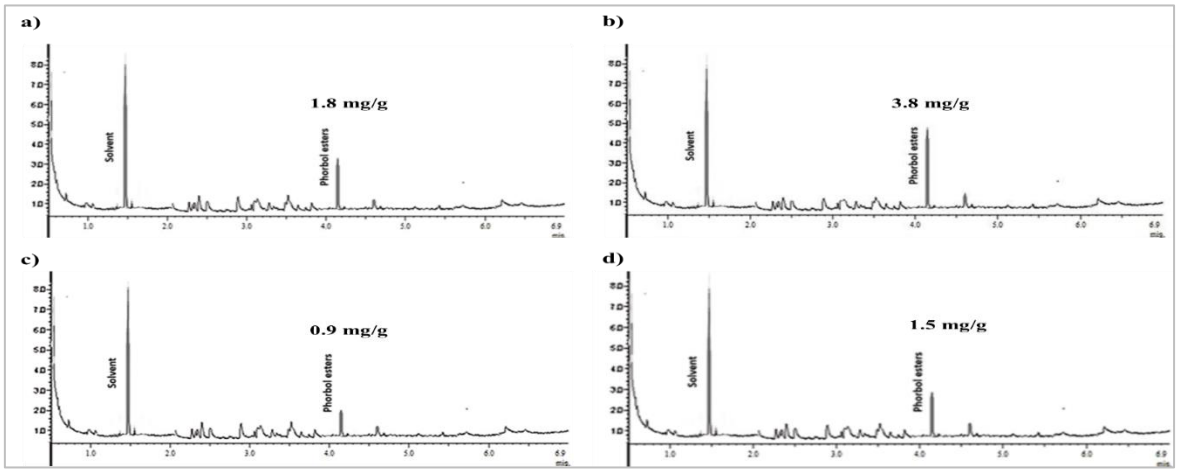

Fig. 5. Phorbol Esters (PEs) spectrophotograms. PEs initial concentration (mg/g) in original coagulants extracted from leaves (a) and shell (b). PEs final concentration of leaves (c) and shell (d) coagulants detoxified by ethanol. (X-axis = retention time in minutes, Y-axis = response). Three replicates were obtained for each sample, with significance defined at $p \leq 0.05$.

PEs spectograms presented in **Figure 5**, indicate its initial and final concentration for coagulants of each fraction. Inital PEs concentration were 1.8 mg/g and 3.8 mg/g for original leaf and shell extracts. They were reduced at 0.9 mg/g and 1.5 mg/g by treatment with ethanol. Representing a reduction in PEs contente between 50% -53% . These results are consistent with outcomes by (Vittaya & Rayakorn, 2013; Ahluwalia, et al., 2017). They employed pure ethanol and ethanol–methanol mixtures for the detoxification of Jatropha seed cake, achieving PEs reductions around 60% and 80%. However, due to the inherent toxicity of methanol, Vittaya's process can be considered relatively aggressive and nocive for health and enviroment. Although the reduction in phorbol esters (PEs) is significant, it remains insufficient to reach the non-toxic threshold. Which has been referred at a maximum concentration of 0.11 mg PEs/g in non- toxic J. Curcas varieties from Mexico (Makkar & Bekker, 1997a; Makkar & Bekker, 1997b).

This suggests the potential benefit of combining methods of different chemical natures—physical approaches such as the use of adsorbents, nanoparticles, synthetic or solar ozonation (Pérez, 2024), adsorption, radiation, light, microbial treatment, or their combinations, to enhance the detoxification of coagulant extracts (Adolf et al., 1984).

Although the primary objective of this work was the detoxification by removing of PEs and the assessment on the turbidity removal, this study also evaluated its influence on COD levels. **Table 2** also summarizes the Chemical Oxygen Demand (COD) of the coagulant extracts before and after detoxification. The results reveal that ethanol treatment yielded the lowest COD values for both leaf (23 mg/L) and shell (17 mg/L). Water samples treated with non-detoxified coagulants exhibited turbidity removal efficiencies of 85.10% (28 ppm COD) and 78.2% (21 ppm COD), when were added leaf and shell extracts, respectively (**Table 4)**. Upon applying ethanol-detoxified coagulants to the same water samples, turbidity removal increased to 98.63% with a COD of 23 pm for the leaf extract, and 87.36% with a COD of 17 ppm for the shell extract

Table 2. COD* (ppm) reports for coagulants detoxified by different treatments

	Before Detoxification	After detoxification treatments			
		Lime	Activated Carbon	Heat	Ethanol
Leaf	28±0.50	50±1.00	42±0.80	27±1.00	23±0.90
Shell	21±0.50	26±0.70	28±0.70	23±1.00	17±0.80

*Chemical Oxygen Demand

Although COD reduction is notable (18–19%), COD results remain outside of the range for drinking water (≤ 10 mg/L). Effectiveness of this treatment is attributable to ethanol's oxidative degradation, whereby it reacts with oxygen to form CO_2 and H_2O (Eq. 2), thereby consuming dissolved oxygen and contributing to COD reduction (Kinidi & Salleh, 2020). It is also worth emphasizing that coagulation mechanism itself plays a crucial role in COD reduction. Particularly in wastewater treatment and surface water. This correlation is mainly due to turbidity mechanism is often caused by suspended particles, including organic matter wich contributes to chemical oxygen demand. Enhanced coagulation–flocculation efficiency, as observed with detoxified extracts, promoting the particulate matter remotion, thereby simultaneously reducing both turbidity and COD. These findings are consistent by (Taype & Paucar, 2024), who reported concurrent reductions of COD and turbidity for water treated with both synthetic aluminum-based coagulants and natural coagulants derived from *Opuntia ficus* (prickly pear cactus).

$$C2H5OH + 3O2 \rightarrow 2CO2 + 3H2O \quad (2)$$

Lower values of COD indicate a reduction organic matter, enhancing water safety and quality, —particularly relevant for application of plant-based coagulants in drinking water treatment. These results align with investigation presented by (Florindo et al., 2018). Where COD reductions achieved values around ~ 75%, using Jatropha coagulants combined with $Ca(OH)_2$. In contrast to the present work, which exclusively employed J. Curcas extracts chemical-free. Heat-treated leaf extract exhibited a slightly higher COD of 27 mg/L, comparable to ethanol treatment. This is likely due to heat-induced denaturation of soluble proteins and volatile organic compounds, particularly the hydrophilic compounds predominant in the leaf extract, which reduces organic content in the treated water, although not as effectively as ethanol. Unexpectedly, the shell extract treated with heat, activated carbon and lime, showed an increase in COD (**Table 2**). For activated carbon treatment, this may result from leaching of organic substances from residual impurities in the carbon itself, or from concentration of dissolved organic compounds in the filtrate. The lime-treated extract exhibited the highest COD at 50 mg/L among all treatments. Possibly, lime may solubilize organic material or alter pH, enhancing the extractability of humic-like or lignin-derived compounds. While lime improves coagulation and turbidity removal, it appears to increase organic contamination. In accordance with research carry out by (Kinidi & Salleh, 2020), who also explored the use of lime treatment, followed by acid precipitation and subsequent adsorption with activated carbon, for wastewater treatment. Then considering elevated results of COD, the application of lime and activated carbon are not suitable tretaments for the detoxification of Jatropha extracts. Heat treatment resulted in a minor increase of COD for shell extract. It is attributable to its higher content of hydrophobic compounds, including phorbol esters (PEs). Hydrophobic interactions are more stable and are favoured at elevated temperatures (Quintero & Rodríguez, 2018).

Table 3 presents some physical-chemical properties of wastewater samples of different turbidity used in the evaluation of turbidity removal applying detoxified coagulants. These results reveal the impact of water salinity on the other properties analysed. High salinity levels increase Electric conductivity (EC) and dissolved solids (TDS), because both depend on the concentration of dissolved ions. Of course, pH would depend on H^+ and OH^- ions available in the solution.

Table 4 summarizes the turbidity removal efficiencies in water samples of different turbidity using both the original (non-detoxified) leaf and shell coagulants detoxified by ethanol (the best treatment for PEs reduction). Overall, ethanol-detoxified extracts consistently improved coagulation performance include for wastewater of different turbidity, with the greatest enhancements observed in tap water and saline water. This effect was most evident in leaf extracts, which were already highly effective in the presence of natural minerals.

For leaf coagulants, turbidity removal increased from 81.3% to 98.63% in tap water and from 66.73% to 82.92% in Dead Sea water, corresponding to improvements of 17.33% and 16.19%, respectively. A marginal increase of 0.4% was recorded in groundwater. Shell coagulants exhibited the same general trend but with smaller gains: 11% in tap water and 0.39% in Dead Sea water. Significante reduction of 3.34% turbidity removal was observed when ethanol-detoxified shell coagulant was applied to groundwater.

Table 3: Physical-chemical properties for samples of different turbidity

	Tap water	Groundwater	Dead Sea Water
*** Salinity**	81.30±1.50	66.73±1.60	91.08±1.50
EC (us/cm)	76.36±2.00	86.60±1.90	89.43±1.60
TDS (ppm)	0.02±0.01	0.01±0.01	3.37±0.300
pH	512±1.00	371±1.50	63000±4.00
Turbidity (NTU)	253±1.20	187±1.50	30000±2.50

*g salt/100g of sea water solution

However, in groundwater, detoxification yielded only marginal improvement (0.4%) or was even counterproductive, as in the case of the shell extract. Findings de este estudio suggest that moderate water hardness (Ca^{2+}, Mg^{2+}) may hinder the efficiency of coagulant, limiting the benefits of detoxification under such conditions. For coagulants of shell, ethanol detoxification did not substantially increase turbidity removal; however, remained high the removal efficiencies (≈86–87%) while ensuring PEs elimination.

Table 4. Turbidity removal percentage for different samples using ethanol detoxified coagulants

	Before Detox			After Detox		
	Tap water	**Dead Sea Water**	**Groundwater**	**Tap water**	**Dead Sea Water**	**Groundwater**
Leaf	81.30±1.50	66.73±1.60	91.08±1.50	98.63±1.50	82.92±1.30	91.48±1.70
Shell	76.36±2.00	86.60±1.90	89.43±1.60	87.36±2.00	86.99±1.20	86.09±1.60

3. Conclusions

High coagulant activity observed for leaf (81.3%) and shell extracts (76.3%) prior to detoxification, directed the evaluation of detoxification processes toward these two fractions. This study demonstrates that a elevated coagulant activity is associated positively with higher content of free amino acids, flavonoids, and total phenols, being inversely related with levels of total amino acids and total protein. Likewise, the results revealed that coagulanting activity is inhibited by the hydrophobic nature of toxic compounds, particularly Phorbol Esters (PEs). This innovative study demonstrated that J. Curcas-based coagulants formulated in form of aqueous liquid extracts (chemical-free) facilitate PEs removal and other hydrophobic toxins through hydrolysis of these compounds. The results also indicate that the detoxification of coagulant extracts using ethanol, achieves more than 50% of PEs reductions for both fractions. In contrast, previous studies report comparable reduction levels adding solid J. Curcas coagulants—such as cakes, powders, or crushed fractions—chemically treated with methanol–ethanol, or other chemical compounds, which represent health hazards.

These results underscore the safety and sustainability of the processes implemented in this work. Finding that Phorbol Esters (PEs) extraction by ethanol is the most efficient detoxification method among those evaluated in this study. Include for wastewater of different turbidity, application of detoxified coagulant extracts enhance turbidity removal and COD reduction. High efficiency of ethanol-detoxified coagulants is denoted even in presence of natural minerals and saline stress, as occurs for Dead Sea and tap water samples. The best detoxified extract was J. Curcas leaf coagulant. For this one, the turbidity removal increased from 81.3% to 98.63% and a reduction of 19% in COD was achieved, compared to original (non-detoxified) coagulants. Successful reduction of PEs content from 0.9 to 1.8 mg PEs/g for detoxified leaf and shell extracts, respectively, was achieved. However, this decrease is still insufficient to be considered non-toxic coagulants (≤0.1 mg PEs/g). So, taking account the substantial reductions in PEs and COD denoted for detoxified J. Curcas leaf coagulants, further researches of coagulants extracted from this fraction is recommended for potential application in drinking water treatment. Activated carbon and lime treatments, while improving coagulation, may increase the organic burden, necessitating methods of post-treatment like aeration of filtration. Heating treatment offers a good compromise between environmental and simplicity safety.Therefore, detoxification in coagulants of Jatropha is strongly recommended, but it require the implementation of an effective combination of extraction methods for improving COD reduction and turbidity removal efficiency.

CRediT Author Contribution Statement

The authors were involved in all stages of the manuscript's development: conceptualization, investigation, research design, analysis - interpretation of the data, methodology, writing and original draft, editing and critical review and approval of the final version. All authors have read and approved this manuscript.

Declaration Statements

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Conflicts of Interest

The reserchers declare no conflict of interest.

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Nomenclature

Symbol	Description	Unit
COD	Chemical oxygen demand	ppm
DHPB	12-Deoxy-16-hydroforbol(abbreviation)	-
EC	Electrical Conductivity	µs/cm
FTIR	Infrared Spectroscopy(abbreviation)	-
TDS	Total dissolved solids	ppm

References

Abdelgadir, H. A., & Van Staden, J. (2013). Ethnobotany, ethnopharmacology and toxicity of Jatropha curcas L. (Euphorbiaceae): A review. *South African Journal of Botany*, *88*, 204–218. https://doi.org/10.1016/j.sajb. 201307.021.

Abou, A., Azza, A., & Ferial, M. (2010). Detoxification phorbol esters of Jatropha curcas seeds by some technological treatments. *Journal of Food and Diary Sciences, 1*(4), 193-208. https://doi.org/10.1016/S0308-8146(97)00183-0

Adolf, W., Opferkuch, H. J., & Hecker, E. (1984). Irritant phorbol derivatives from four Jatropha species. *Phytochemistry, 23*(1), 129-132. https://doi.org/10.1016/0031-9422(84)83091-5

Ahluwalia, S., Bidlan, R., Gopal-Sharma, J., & Singh, P. (2017). Review on Phorbol ester degradation of Jatropha seed cake for its use as animal feed. *International Journal of Pharmacy and Pharmaceutical Sciences*, *9*(1), 7–13. https://doi.org/10.22159/ijpps.2017v9i1.15380

Al Hanaktah, A., & Pérez, S. M. (2026). Natural coagulants extracted from leaves, shell and kernel of Jatropha curcas for turbidity treatment. *Applied Science and Engineering Progress*, *19*(1), 1-11. https://doi.org/10.14416/j.asep.2025.08.003

Clesceri, L., Greenberg, A., & Eaton, L. (1999). *Standard Methods for The Examination of Water and Wastewater* (20th ed.). American Public Health Association, American Water Works Association and Water Environment Federation Publishers.

Arbain, N., Salimon, J., & Salih, N. (2022). Optimization for epoxidation of malaysian Jatropha Curcas oil based trimethylolpropane ester bio lubricant. *Applied Science and Engineering Progress*, *15*(3), Art. no. 5552. https://doi.org/ 10.14416/j.asep.2021.10.009

Aregheore, E. M., Abdulrazak, S. A., & Fujihara, T. (2003). Evaluation of some agri-industrial by-products available in Samoa for goats. *Asian-Australasian Journal of Animal Science*, *16*(11), 1593-1598. https://doi.org/10.5713/ajas.2003.1593

Benalia, A., Derbal, K., Amrouci, Z., Baatache, O., Khalfaoui, A., & Pizzi, A. (2024). Application of Plant-Based Coagulants and Their Mechanisms in Water Treatment: A Review. *Journal Renewable Materials*, *12*(4), 1–10. https://doi.org/10.32604/jrm.2024.048306

Bravo, M. (2017). Coagulantes y Floculantes Naturales usados en la reducción de turbidez, solidos suspendidos, colorants y metales pesados en aguas residuales (master's tesis). Distrital University Francisco José de Caldas. https://repository.udistrital.edu.co/server/api/core/bitstreams/3b06ce66-d2f8-4c9a-98a7-a44c907d7a57/content

Sargsyan, G. (2025, October 19). Ester Hydrolysis: Acid and Base-Catalyzed Mechanism. Chemistry steps https://www.Ester Hydrolysis: Acid and Base-Catalyzed Mechanism - Chemistry Steps

De Barros, C. R., Ferreira, C. R., Fraga, L. M. M., Mourão, I., & Rodrigues, M. A. M. (2024). Detoxification methods of Jatropha curcas seed cake and its potential utilization as animal feed. *Fermentation*, *10*(5), 1–17. https://doi.org/ 10.3390/fermentation10050256

Escrivane, R., De Almeida, F., De Lima, M., De Oliveira, L., Castro, R. & Fernandes, M. (2014). Detoxification of Jatropha curcas seed cake using chemical treatments: Analysis with a central composite rotatable design. *Industrial Crops and Products*, *52*, 537-543. https://doi.org/10.1016/j.indcrop.2013.11.024

Farouk, N. (2017). Removal of Water Turbidity Using Different Coagulants. *Journal Zankoy Sulaimani ParK. Manoharant-A- (Pure and Applied Sciences)*, *19*(2), 115-126. https://doi.org/y10.17656/jzs.10617

Florindo, C., Romero, L., Rintoul, I., & Branco, L. (2018). From Phase Change Materials to Green Solvents: Hydrophobic Low Viscous Fatty Acid-Based Deep Eutectic Solvents. *ACS Sustainable Chemistry & Engineering*, *6*(3). https://doi.org/ 10.1021/acssuschemeng 7b04235

Gámez-Meza, N., Alday-Lara, P. P., Makkar, H. P., Becker, K., & Medina-Juárez, L.A. (2013). Chemical characterisation of kernels, kernel meals and oils from Jatropha Cordata and Jatropha Cardiophylla seeds. *Journal of The Science of Food and Agriculture*, *93*(7), 1706–1710. https://doi.org/10.1002/jsfa.5955.

Gogoi, R., Niyogi, U. K., & Tyagi, A. K. (2015). Methods of detoxification of Jatropha curcas L. Seed cake for its use as protein supplement in animal feed overview. *Indian Journal of Natural Products and Resources*, *6* (3), 176–182.

Gomes, T. G., Hadi, S. I. I. A., Costa Alves, G. S., Mendonça, S., De Siqueira, F. G., & Miller, R. N. G. (2018). Current Strategies for the Detoxification of Jatropha curcas Seed Cake: A Review. *Journal of Agricultural and Food Chemistry*, *66*(11), 2510–2522. https://doi.org/10.1021/acs.jafc.7b05691\

Haas, W., & Mittelbach, M. (2000). Detoxification experiments with the seed oil from Jatropha curcas L. *Industrial Crops and Products*, *12*(2), 111–118. https://doi.org/10.1016/S0926-6690(00)00043-1

Hass, W., Sterk, H., & Mittelbach, M. (2002). Novel 12-deoxy-16 hydroxyphorbol diesters isolated from de seed oil of Jatropha curcas. *Journal of Natural Products*, *65*, 1434–1440. https://doi.org/10.1021/np020060d

Khodapanah, N., Idris, A., Khodapanah, L., Soltani, S. M., & Yunus, R. (2018). Enhanced coagulant extraction from Jatropha curcas in aqueous solutions and its application in turbidity removal. *Desalination and Water Treatment*, *129*, 227–233. https://doi.org/10.5004/dwt.2018.22793

Kinidi, L., & Salleh, S. F. (2020). The COD Removal of Lime and Subsequent Acid Pretreated Partially Stabilised Leachate via Granular-Activated Carbon First. *International Journal of Chemical Engineering*, *2020*, 1-9, https://doi.org/10.1155/2020/3687165

Kumar, M., Kavitha, B., & Saritha, V. (2022). Chitin and Sago as coagulants for the optimization of process parameters focusing on coagulant dose and mixing speed. *Journal Watershed Ecology and the Environment*, *4*, 112–24. https://doi.org/ 10.1016/j.wsee.2022.10.001

Kurniawan, S. B., Ahmad, A., Imron, M. F., Abdullah, S. R., Abu Hasan, H., Othman, A. R., & Kuncoro, E. P. (2023). Performance of Chemical-Based vs Bio-Based Coagulants in Treating Aquaculture Wastewater and Cost-benefit Analysis. *The Polish Journal of Environmental Studies*, *32*(2), 1177-87. https://doi.org/10.15244/pjoes/156419

Larkin, P. J. (2018). *Infrared and Raman spectroscopy: principles and spectral interpretation* (2end ed.). Elsevier Press.

Lye, Y. N., Salih, N., & Salimon, J. (2021). Optimization of partial epoxidation on Jatropha curcas oil-based methyl linoleate using urea-hydrogen peroxide and methyltrioxorhenium catalyst. *Applied Science and Engineering Progress*, *14*(1), 89–99. https://doi.org/10.14416/j.asep.2020.12.006

Makkar, H. P. S., & Becker, K. (1997a). Jatropha curcas toxicity: Identification of toxic principles. Proceedings of the 5 th International Symposium on Poisonous Plants. https://www.scirp.org/reference/referencespapers?referenceid=1079891

Makkar, H. P. S., & Becker, K. (1997b). Potential of Jatropha seed cake as protein supplement in livestock feed and constrains to its utilization. Proceedings of Jatropha 97: International Symposium on Biofueland Industrial Products from Jatropha curcas and other Tropical Oil Seed Plants. https://jfds.journals.ekb.eg/article_82108_68f5891019985703818f6fdeeb078dce.pdf

Makkar, H. P. S., Aderibigbe, A., & Becker, K. (1998). Comparative evaluation of non-toxic and toxic varieties of Jatropha Curcas for chemical composition, digestibility, protein degradability and toxic factors. *Journal of Food Chemistry*, *62*(2), 207–215. https://doi.org/10.1016/S0308-8146(97)00183-0

Martinez-Herrera, J., Siddhuraju, P., Francis, G., Davila-Ortiz, G., & Becker, K. (2006). Chemical composition, toxic/anti-metabolic constituents, and effect of different treatments on their levels, in four provenances of Jatropha curcas L. from Mexico. *Food Chemistry*, *96*(1), 80–89, https://doi.org/10.1016/j.foodchem.2005.01.059

Nazir, N., Mangunwidjaja, D., Jarmo, M. A., & Malakul, P. (2017). Life cycle assessment studies of Jatropha (Jatropha curcas) biodiesel production processed by In-situ Transesterification Method. *Applied Sciences and Engineering Progress*, *9* (2), 115-126.

Nokkaew, R., & Punsuvon, V. (2013). Multistage solvent extraction for high-yield oil and phorbol esters removal from Thai toxic Jatropha curcas meal. *Walailak Journal of Science and Technology*, *12*(4), 299–310. https://doi.org/ 10.2004/wjst.v12i2.835

Pereira, I., De Carvalho, T., Romão, W., & Filgueiras, P. R. (2017). Differentiation of Toxic and Non-Toxic Leaves of Jatropha curcas L. Genotypes by Leaf Spray Mass Spectrometry. *Journal Brazilian of Chemical Society, 28* (8), 1461–1466. https://doi.org/10.21577/0103-5053.20160325

Pérez, S. M. (2024). Sustainable use of solar energy to produce methanol from sugar industry waste. *Ecological Engineering & Environment Technology*. *25*(12), 147–157. https://doi.org/10.12912/27197050/193619.

Quintero, Y., & Rodriguez, V. (2018). Evaluation of natural extracts coagulants of Moringa oleifera and Jatropha curcas in coffee wastewater. *Cenicafé*, *69*(1), pp.68-82.

Taipe, A., & Paucar, M. (2024). Analisis de la eficiencia de remoción de turbidez y materia orgánica con sulfato de aluminio y Opuntia ficus indica del camal Santo Domingo de Guzmán del distrito de Sicaya, Huancayo-2023 (master's thesis). Continental University. https://IV_FIN_107_TE_Taipe_Paucar_2024.pdf

Vittaya, P., & Rayakorn, N. (2013). Comparison of detoxification methods on phorbol esters in deoiled Jatropha curcas meal for animal feeds. *Journal of Chemistry and Chemical Engineering, 7*, 533-538.

Xu, W., Zhong, Ch., Zou, Ch., Wang, B., & Zhang, N. (2020). Analytical methods for amino acid determination in organism. *Journal Amino Acids, 5*, 1071-1088. https://doi.org/10.1007/s00726-020-02884-7