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Analysis of natural coagulants from *Solanum tuberosum* and *Tropaeolum tuberosum* in the treatment of an environmental liability, Huancayo – Peru

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Abstract

Environmental liabilities are the environmental situations, generated by anthropogenic activities in the past, which cause progressive deterioration to the environment. This study aimed to analyze the coagulants of *S. tuberosum* (potato) *T tuberosum* (Mashua) in the treatment of an environmental liability in the city of Huancayo – Peru. For this, the explanatory, experimental level methodology was used; where, a stock solution was prepared, made from the shell of S. tuberosum and T. tuberosum; The doses of this solution were 5, 7, 9 and 11ppm which were applied to the sample of water from an environmental liability, through the jug test; for this; in addition, a pre-treatment analysis was performed. The results in relation to the optimal dose of S. tuberosum showed that 90 ppm were sufficient to reduce Cr, 70 ppm was the best dose in the removal efficiency of Turbidity, Cd, and Pb. Likewise, for the physicochemical parameters of the study, the optimal dose of *T. tuberosum* was 11 ppm. The removal efficiency of the coagulant *S. tuberosum* was 76.61%, 50.55%, 99.94% and 45.63% for turbidity, Cd, Cr and Pb, respectively. There was also a significant difference in the means of coagulants used and control (p-value < 0.05; 95% confidence). The conclusion was that the use of coagulants of *S. tuberosum* and *T. tuberosum* are effective in the removal of contaminants such as turbidity, chromium and lead. However, only Cr meets Environmental Quality Standards (ECA).

Keywords: Heavy metals, Natural coagulants, *S. tuberosum*, *T. tuberosum*

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1. Introduction

Environmental liabilities encompass diverse structures and areas affected by mining activities, encompassing facilities, infrastructure, land impacted by leaks, altered watercourses, waste deposits, and residual materials present in decommissioned mines [1]. These components continue to present a persistent threat to both human well-being and the natural ecosystem [2]. Abandoned mining tailings are classified as environmental liabilities due to their elevated concentrations of heavy metals and other pollutants [3], which remain in direct interaction with the environment for extended periods [4]. Frequently, these environmental liabilities arise from prolonged mining activities during which waste generated was released directly into the environment without prior treatment, resulting in significant harm to nearby communities and the ecosystem. Consequently, in the city of Sonora, situated in northwest Mexico, there are several abandoned mining tailings enriched with metals (Zn = 18% and Pb = 1.5%), covering an expanse of 40,000 m². These tailings are located adjacent to agricultural fields and the Sonora River, posing latent risks to the population and the environment [5]. Likewise, specific regions within the same city exhibit heightened concentrations of contaminants in tailings (Zn = 92,540; Pb = 21,288; As = 19,740 mg kg^{-1}). The average concentrations in agricultural soils are Zn = 4755, Pb = 2840, and As = 103 mg kg^{-1} [6]. Toxicity evaluations have demonstrated that Pb and as surpass reference values for daily oral intake in both adults and children, particularly in cases of children exposed to sulfide-rich tailings and agricultural soils [6]. Similarly, Bolivia has recently seen mounting concern regarding escalating environmental liabilities stemming from a refinery, attributed to the detrimental impact of elevated hydrocarbon levels on its residents [7]. Additionally, in Spain's Sierra de Cartagena, the Las Matildes River bed has revealed significantly elevated contents of As, Cd, Cu, Fe, Pb, and Zn, resulting from open-pit mining activities that have disrupted drainage patterns and submerged the origins of ephemeral channels [8]. Moreover, Morrill's study found that one in ten tailings facilities have reported significant apprehensions about their stability or lack of confirmed certification at some point in their history. Furthermore, recent collapses of tailings dams have led to over 300 fatalities, contamination of extensive river systems, and ecosystems, and have incurred substantial financial losses and expenses for mining enterprises [9]. According to Willick, Country Harbor Mines in Canada still house approximately 13,000 tons of tailings, spread over roughly 42 hectares and encompassing 46 abandoned mines [10], some of which pose hazardous risks due to their lack of fencing or backfilling. In Peru, up to the present time, 3231 environmental liabilities attributed to mining and hydrocarbon activities have been identified, with 152 being categorized as high-risk, predominantly affecting the communities of Piura, Puno, Tumbes, and Loreto [11]. Annually, these toxic residues infiltrate the subsoil and often overflow during rainfall, polluting rivers, lakes, mountains, natural formations, and impacting the local populace and wildlife. These environmental liabilities involve extremely hazardous waste products from historical mining operations that have not undergone any remediation for several decades [12]. Moreover, in Huancayo - Junín, a prevailing environmental liability arises from the former Yauris metallurgical plant within the city limits, causing harm to humans, animals, rivers, and agricultural lands. The presence of lead concentrations exceeding environmental quality standards by 20 times (DS N° 004-2017-MINAM) and chromium levels surpassing the norm by 25 times (0.1 ppm) underscores the latent danger posed by this liability [13]. Ferric chloride and aluminum sulfate are the most commonly utilized coagulants in wastewater treatment due to their efficacy. Nonetheless, there exists a potential that residual elements present in treated water, such as aluminum, might be linked to neurodegenerative ailments like Alzheimer's, in addition to adverse impacts on the nervous system and potential carcinogenic risks [14]. The utilization of natural coagulants in addressing environmental liabilities presents a promising avenue, as these substances contain organic compounds like carboxyls (-COOH) and hydroxyls (-OH), which interact with metallic ions [15]. The mechanism of natural coagulation aims to counterbalance electrical charges through the incorporation of natural compounds derived from biological sources, such as polyphenols (tannins), gums, mucilages, or proteins. Additionally, these components lead to the destabilization of colloidal particles by elevating the ionic strength of the environment and nullifying the double electric layer, thereby abolishing the repulsion between particles [16]. The above mentioned illustrates that treatments with natural coagulants are an efficient and environmentally friendly alternative. In this context, [17]) used seeds of Moringa oleifera, Opuntia ficus, Aloe vera, and Pinus halepensis in their research and achieved 100% removal of synthetic wastewater turbidity. Additionally, they generated less sludge compared to chemical coagulants (aluminum sulfate and ferric chloride), with optimal doses of 1.5, 3, and 3.5 mL/200mL. Similarly, [18] employed *Strychnos potatorum* and *Eichorrnia crassipes* seeds as natural coagulants in treating wastewater from a textile industry, obtaining good results both when used alone and in combination with a chemical coagulant. These natural coagulants produced fewer flocs, reducing the cost of sludge treatment. Karnena et al. used natural coagulants from chitin and *Moringa oleifera* seeds and compared their efficiency with ferric chloride. The results showed that chitin and Moringa oleifera achieved a 50% reduction in parameters such as turbidity, total solids, and pH in industrial wastewater from aquaculture [19]. Furthermore, the disposal of organic waste like potato peels, mashua, and yucca constitutes 69.3% of general waste. However, many Peruvian cities lack proper landfill facilities or treatments for their appropriate disposal [20]. In light of this, studies like Ramesh et al. explored the use of natural coagulants derived from neem, tamarind, baqueta, potato peel (*S. tuberosum*), and banana seeds, comparing them to lime and aluminum-based coagulants. These natural coagulants achieved a 70% removal of contaminants present in surface water, presenting a sustainable and environmentally friendly alternative [21]. Similarly, Septya et al. achieved a 96% removal of turbidity using a natural coagulant derived from *Ipomoea batatas* leaves at a concentration of 10 g/L within 2 minutes and at 150 rpm [22]. Camacho et al. utilized *S. tuberosum* peels as a natural coagulant, resulting in an 81.32% reduction in turbidity with a dose of 10 mg/L. This affirms that potato peels hold potential as a viable option for treating synthetic industrial wastewater [23]. Villabona et al.'s investigation harnessed starch from name (*Dioscorea rotundata*) as a natural coagulant using the NaOH method, achieving a 92.48% reduction in turbidity at an agitation speed of 40 rpm and a coagulant concentration of 250 ppm. This underscores the suitability of natural ñame-based coagulant for surface water treatment [24]. In a study by Vera et al. sugarcane bagasse was employed as a bioabsorbent for contaminants in mining wastewater, yielding a 98% removal rate for Pb and a 75% removal rate for Cd [25]. Lastly, in Albis et al.'s work yucca peel was utilized for the removal of contaminants from mining wastewater. Preparing solutions of 75 mL and 40 mL, an absorption capacity of 7 mg/g for Pb was determined within 60 minutes [26]. While information regarding the use of natural coagulants for treating mining wastewater remains limited, the growing interest in this research avenue is evident. Building upon the aforementioned, this study aims to evaluate the efficacy of natural coagulants derived from S. tuberosum and *T. tuberosum* peel in treating water from an environmental liability in the city of Huancayo, Peru.

2. Materials and Methods

The research possesses an explanatory nature, employing a 2-factor experimental arrangement utilizing the deductive approach. The origin of the wastewater employed in the study can be traced back to the historical environmental impacts of the former metallurgical facility situated in Yauris. The collection of samples occurred at five distinct geographical points identified by their UTM coordinates: (8666200N, 474500E; 8666200N, 474600E; 8666300, 474600E; 8666300N, 484583E; 8666256N, 474550E) [27]. Following this, the preparation stage encompassed the utilization of nine glass beakers, each having a capacity of 1L. Out of these, four beakers were allocated for the application of natural coagulants derived from *T. tuberosum*, and an equivalent set of four beakers for coagulants originating from *S. tuberosum.* For both types of coagulants, a control group involving untreated water was established, alongside multiple dosages (5, 7, 9, and 11 ppm). This research methodology was adapted from prior studies by Ramesh et al. [21] and Sedolfo et al. [28]. The natural coagulants were procured by gathering peels sourced from *T. tuberosum* and *S. tuberosum*, procured from local markets and street vendors. These peels were utilized to extract the coagulants required for the experimental process.

2.1. Sample Collection

In accordance with the regulations for surface water monitoring, the option of conducting composite sampling was considered. This methodology involved collecting samples from 5 designated points, which were subsequently homogenized, following the guidelines established by the National Water Authority [27]. The primary objective of employing this technique was to attain a water sample that holds statistical relevance concerning the surrounding environmental conditions. To facilitate this process, two plastic containers, each with a capacity of 10 liters, were utilized. Subsequently, these containers were transported to an accredited laboratory where the subsequent analysis encompassed pH levels, turbidity, and the concentrations of lead (Pb), cadmium (Cd), and chromium (Cr) parameters. In Table 1, it is presented the characterization of the sampled water from the environmental liability of the city of Huancayo, Junín.

2.2. Preparation of natural coagulants

The methodology of Kumar et al. [29] and Karnena [30] was adapted to obtain natural coagulants. Initially, a quantity of 2 kg of residual peels from *T. tuberosum* and *S. tuberosum* was gathered from local markets and mobile vendors situated in Huancayo, Peru. These residues underwent a thorough cleansing using potable water to eliminate any impurities. Subsequently, they were placed in a receptacle containing 5 liters of water, to which 5 drops of sodium hypochlorite (NaClO) were added, and left for a duration of 3 minutes. Following this step, the peels were rinsed with distilled water to eliminate any remaining colloidal particles. The next stage involved subjecting the peels to a drying process in an oven set at a temperature of 200°C for a span of 72 hours. Once the drying was complete, the peels were finely ground into a powder, followed by a sieving procedure employing a mesh size of 0.4 mm. The resulting fine particles of both coagulants were then packed into polyethylene containers and stored at a controlled temperature of 15°C.

2.3. Mother Solution

The original method of Hussain et al. [31] and Zedan et al. [32] was adapted to create the mother solutions of *T. tuberosum* and *S. tuberosum*, each with a mass concentration of 1%. To achieve this, 3g of the natural coagulant was combined with 300 mL of distilled water. This mixture was then subjected to a magnetic stirrer set at 400 rpm for 60 minutes. After this agitation period, the mixture was allowed to settle for 30 minutes, resulting in the formation of the parent solution for both plant species. The prepared solution was preserved at a temperature of 4°C for future utilization. The pH of the mother solution was assessed, providing recorded values of 6.87 for *T. tuberosum* and 6.84 for *S. tuberosum.*

2.4. Jar test

In the control sample, no coagulant was utilized. This indicates the untreated mining tailings sample, which served as a baseline to ascertain whether concentrations of contaminants, decreased when employing natural coagulants. Four distinct treatments were carried out, involving dosages of 5, 7, 9, and 11 ppm of each natural coagulant: *T. tuberosum* (Mashua) and *S. tuberosum* (Potato). The jar test was conducted using equipment consisting of a 4-paddle apparatus (DLAB-OS20S). Four 1L beakers were labeled with their respective doses of 1% stock solutions (5, 7, 9, and 11 ppm), each containing the respective natural coagulant. Subsequently, the equipment was set to operate at 100 rpm for 10 minutes, after which the speed was reduced to 40 rpm over a 20-minute period. Following this, the system was allowed to settle for 10 minutes [28] Next, 500 mL samples were extracted from each beaker for analysis of parameters such as turbidity, pH, lead (Pb), cadmium (Cd), and chromium (Cr). An identical procedure was applied for both coagulants [33]. This test facilitated the observation of coagulation, flocculation, and sedimentation processes [34].

2.5. Analysis of Parameters

To analyze the pH, an ion-selective electrode pH meter (SMEWW-APHA-AWWA-WEF Part 4500 - H+ B, 23rd Ed. 2017) was employed using the electrometric method. For turbidity analysis, the Nephelometric method was utilized (SMEWW-APHA-AWWA-WEF Part 2130 B, 23rd Ed. 2017). Furthermore, Chromium and Cadmium values were determined using the atomic absorption spectrometry method (SMEWW-APHA-AWWA-WEF Part 3500-Cr B, Cd B 23rd Ed. 2017). Furthermore, Lead concentration was determined through the atomic absorption spectrometry method (SMEWW-APHA-AWWA-WEF Part 5210 Pb B, 23rd Ed. 2017).

2.6. Determination of Removal Efficiency

To determine the efficiency of natural coagulants, the following equation was used.

$$Efcicency(\%)r = \frac{Concentration_{initial} - Concentration_{final}}{Concentration_{initial}} \quad (1)$$

2.7. Research Design

The methodological approach known as a 2-factor experimental design involves an investigation into the combined effects of multiple independent variables on a dependent variable [35]. In this particular study, a 2-factor experimental design incorporating both pre- and post-tests was utilized. The primary objective of this design was to evaluate the influence of various doses (5, 7, 9, and 11 ppm) of coagulants on a sample of environmental liability water. The subsequent assessment involved a comparison of this impact with the initial baseline measurement. As previously emphasized by Gutiérrez and De la Vara, the application of a group design featuring pre- and post-tests facilitates the measurement of treatment efficacy by means of a contrast with the initial measurement [36].

2.8. Statically Analysis

For the determination of the normal distribution, the Shapiro-Wilk test was employed. It was noted that the data's origin followed a normal distribution pattern. This facilitated the choice of the Analysis of Variance (ANOVA) test, succeeded by the utilization of the Tukey method for comparing means, maintaining a significance level defined as $\alpha < 0.05$. Furthermore, the Pearson correlation was applied to ascertain the connection or interdependence between the dosage and the reduction in levels of turbidity, chromium, cadmium, and lead concentrations, as outlined in the work by Gutiérrez and Vladimirovna in 2016.

3. Results and Discussion

3.1. pH

The results demonstrate that applying the natural coagulant based on *S. tuberosum* (potato) peels led to a tendency of increasing the pH. In other words, the introduction of increasing dosages of this coagulant resulted in a progressive rise in pH levels, moving closer to a nearly neutral state. Conversely, in the case of the coagulant obtained from *T. tuberosum* (mashua) peels, an opposing trend to the initial coagulant was observed. With escalating dosages, there emerged a tendency for the pH to diminish, indicating a slight shift towards acidity in the treated water. This observed pattern is visually represented in Figure 1 - A. This phenomenon is ascribed to the inherent capability of the natural coagulants to counterbalance electric charges present on particles and metal ions. Such interactions can consequently induce alterations in the concentration of hydrogen ions within the water, thus impacting its pH. It's noteworthy to mention that these natural coagulants carry a negative charge and function as anions, employing patch and bridging mechanisms when employed within systems that also exhibit a negative charge [38] [39]. The findings obtained from *S. tuberosum* align with the conclusions drawn by Choque et al., who, in their investigation, identified a similar pattern of pH elevation in all treatments involving natural coagulants (Echinopsis pachanoi, Neoraimondia arequipensis, and Opuntia ficus). Similarly, the study conducted by Cevallos et al., which employed Aloe and Salvia hispanica coagulants, demonstrated that both types of coagulants effectively normalized the initial pH (which was 9.21) [40]. In a related context, Barbarán et al. carried out a study using natural coagulants derived from Prunus persica and *Persea americana* seeds. They noted a minor increase in pH, from 6.3 to 6.7, with the P. persica-based coagulant, while the P. americana-based coagulant showed negligible variance (from 6.3 to 6.4) [41]. Drawing from the aforementioned evidence, it is affirmed that the application of natural coagulants from *S. tuberosum* contributes to the neutralization of water. Conversely, the application of *T. tuberosum*, as its concentrations escalate, induces a reduction in pH. This is attributed to the presence of acids in Mashua that can release hydrogen ions, leading to a decline in pH [42]. Lastly, upon comparing the outcomes of the treatments involving *T. tuberosum* and *S. tuberosum* with the Environmental Quality Standards (ECA) DS 004-2017 [43]. It was evident that the treatments adhered to the stipulated regulations (where pH is expected to fall between 6.5 and 8.5), except for the *S. tuberosum* treatment at a concentration of 5 ppm, and the *T. tuberosum* treatment at a concentration of 11 ppm. Furthermore, there was no significant divergence among the means of the groups, as depicted in Figure 1-B.

3.2. Turbidity

The initial turbidity level of the wastewater was measured at 416 NTU (Nephelometric Turbidity Units). Utilizing a natural coagulant derived from potato (*S. tuberosum*) peel, a concentration of 7 ppm resulted in a noteworthy decrease in turbidity to a minimum of 50.3 NTU. However, as the coagulant dosage was increased to 11 ppm, the turbidity subsequently rose to 216 NTU. When considering the treatments involving Mashua (*T. tuberosum*), the application of the coagulant exhibited a gradual reduction in turbidity with increasing dosage. The turbidity declined from 273 NTU at 5 ppm to 97.3 NTU at 11 ppm, as graphically represented in Figure 2. This reduction can be attributed to the inherent electric charges carried by natural coagulants, which counterbalance the charges of suspended particles in the water, thus promoting the formation of flocs, as described by Kurniawan et al. [44]. These findings are consistent with the research conducted by Barbarán et al., showcasing a substantial decrease in turbidity from 1302 to 91.8 NTU using natural coagulants sourced from P. persica and P. americana [41]. Additionally, they align with the outcomes observed by Moreira and Moreira, who utilized *Vicia faba* (broad bean) and *P. persiaca* (peach) seeds in their study, achieving impressive turbidity removal rates of 93.13% and 89.07%, respectively [45]. Similarly, the conclusions drawn by Moreno et al. demonstrate concurrence with the current study, where *S. tuberosum* peels were employed as a natural coagulant, reducing turbidity from 8.52 NTU to 0.57 NTU [46]. Furthermore, Figure 2-B visually represents a significant variance in means across the various experimental groups.

3.3. Chromium

The initial chromium content present in the water sample derived from the environmental liability was 0.328 mg/L. Treatment using the natural coagulant derived from *S. tuberosum* peels yielded values lower than 0.001 mg/L at doses of 5, 7, and 9 ppm. Similarly, treatment with the natural coagulant obtained from *T. tuberosum* peels achieved values lower than 0.001 mg/L for all tested doses. The significant reduction of the heavy metal chromium upon application of the two natural coagulants is evident. These results can be attributed to the interaction between the negative charges of the natural coagulants and the positively charged chromium ions, resulting in charge neutralization. Additionally, both potato and Mashua peels contain pores capable of absorbing contaminant ions, such as Cr [47]. These findings are in line with Gayda et al. who employed Vitis vinifera (grape) seeds as a natural coagulant, demonstrating approximately 99% reduction in chromium [48]. Likewise, they agree with Abd et al., who employed *Leucaena leucocephala* (guaje) as a natural coagulant, observing the removal of chromium from 0.432 to 0.0001 mg/L, thus affirming the efficacy of the natural coagulant in

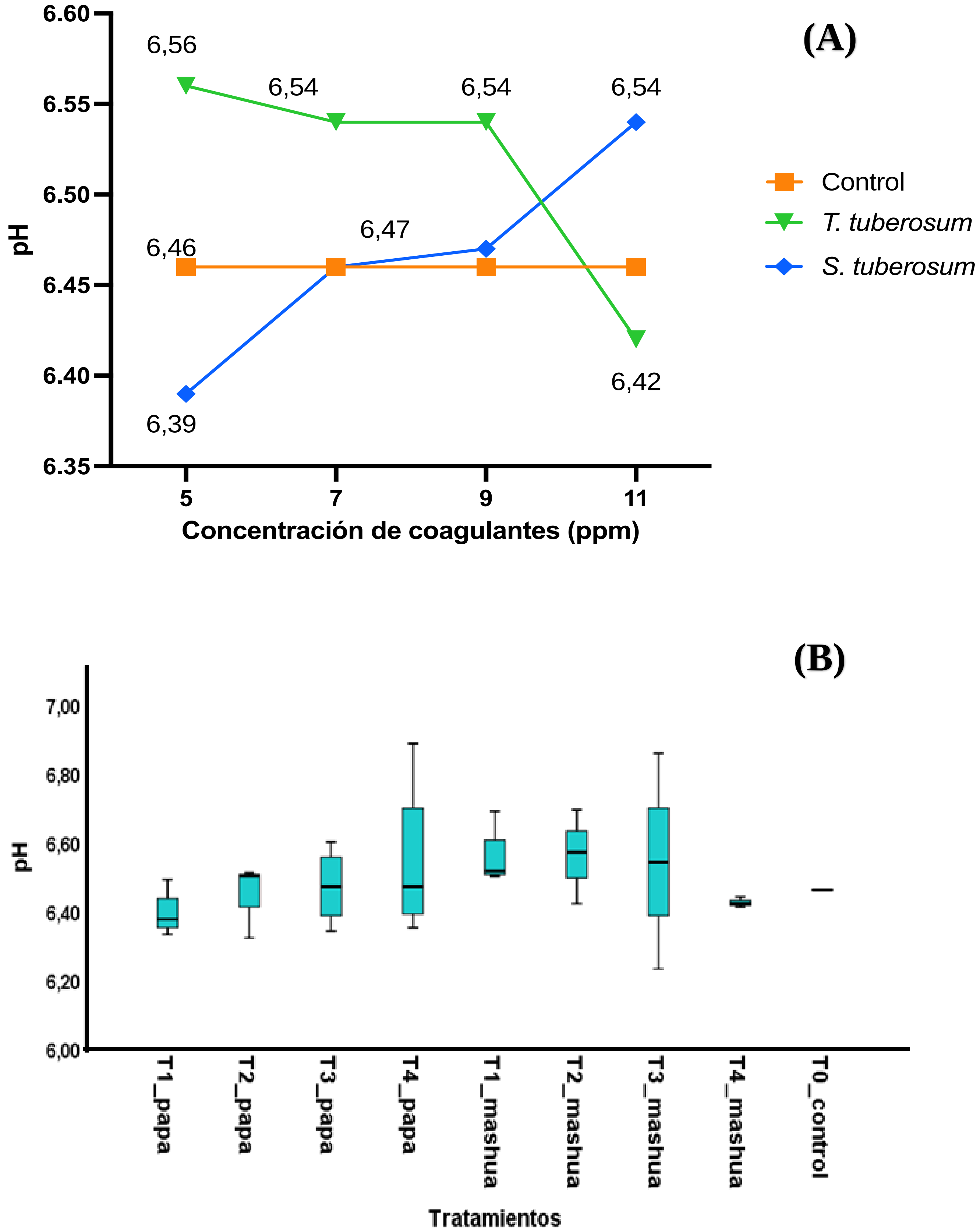


Figure 1. Average pH value of water of environmental liability in relation to the concentration of coagulants from *S. tuberosum* (potato) and *T. tuberosum* (Mashua).

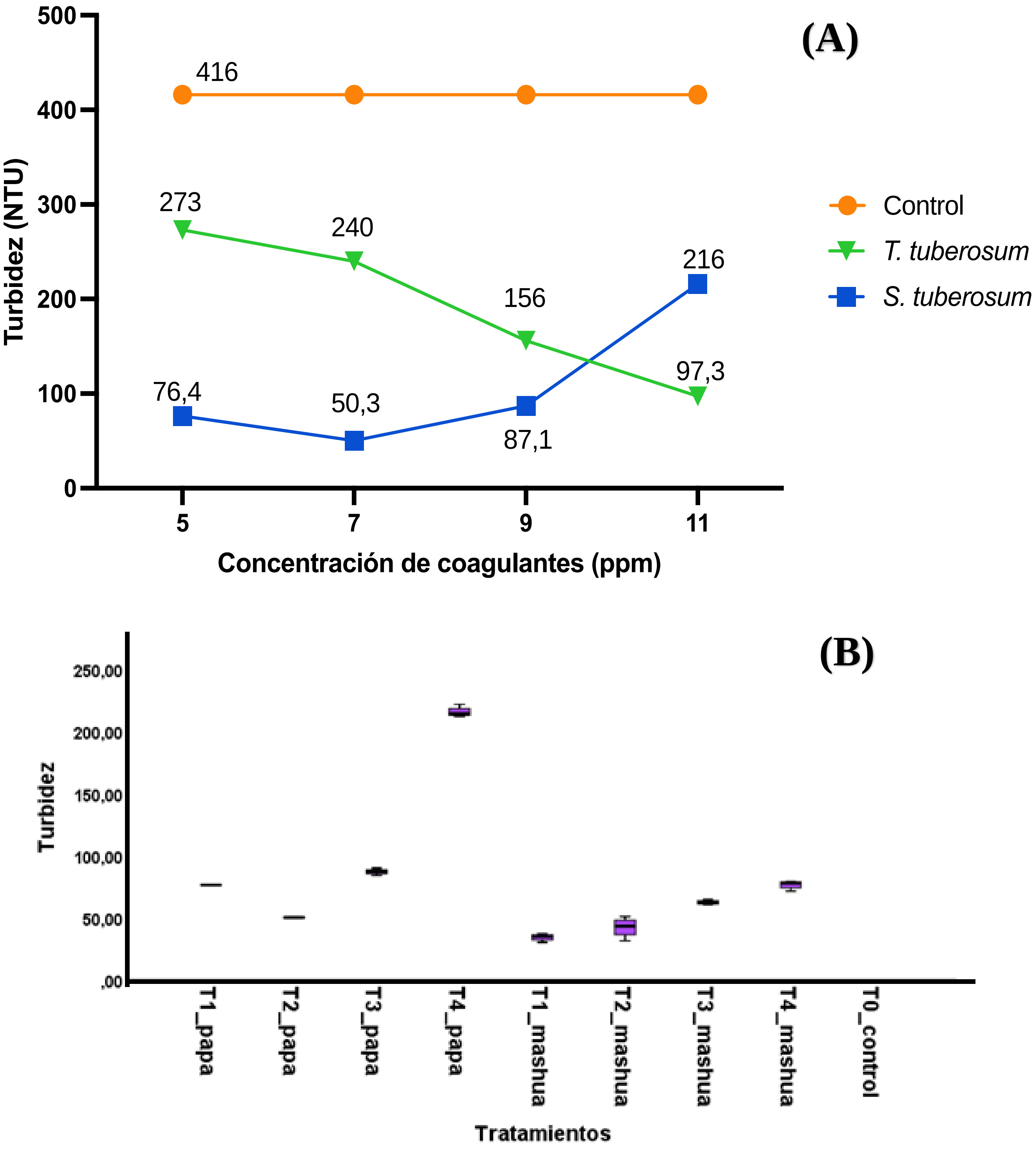


Figure 2. Average water turbidity value of environmental liabilities in relation to the concentration of coagulants of S. *tuberosum* (potato) and *T. tuberosum* (Mashua).

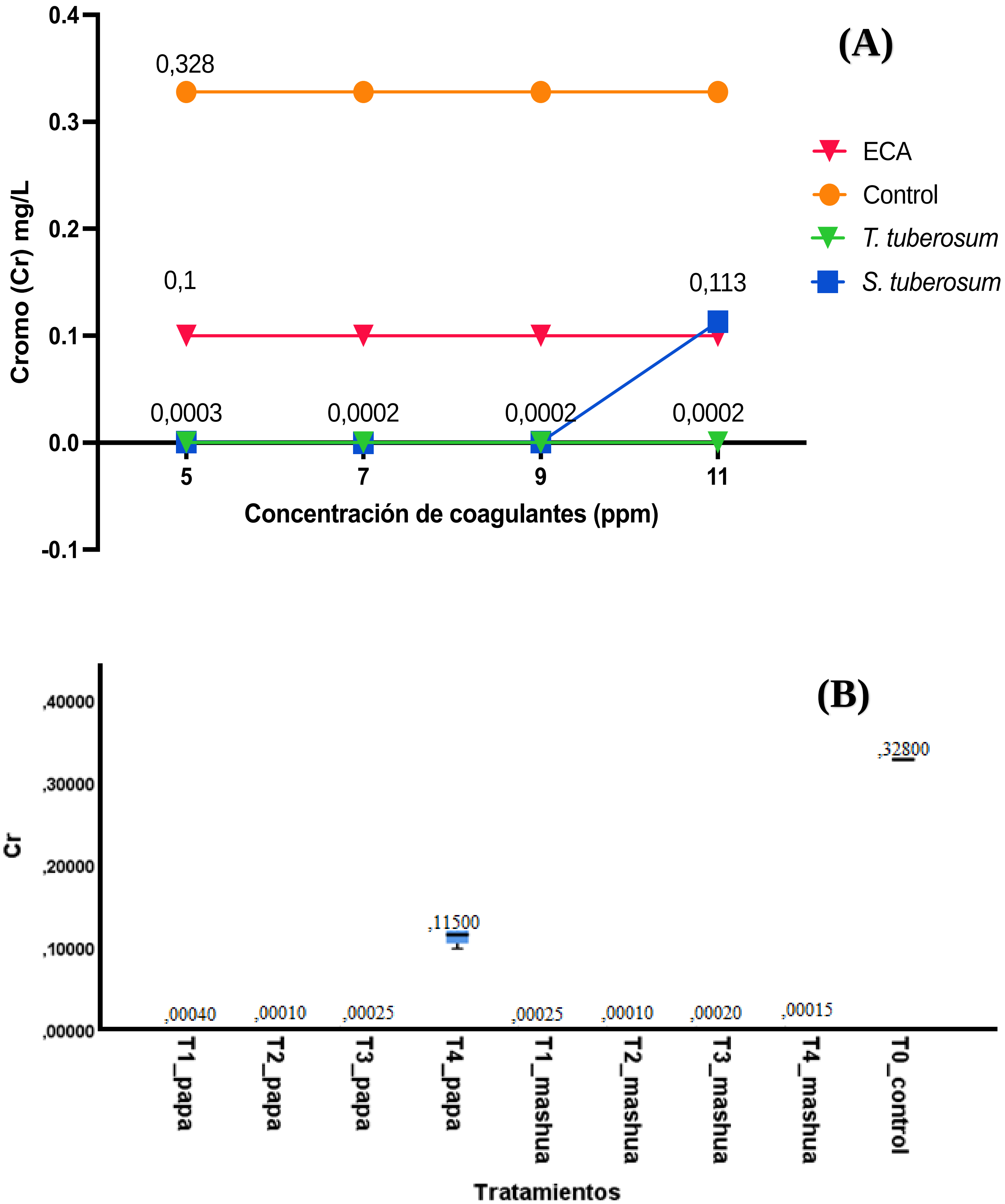
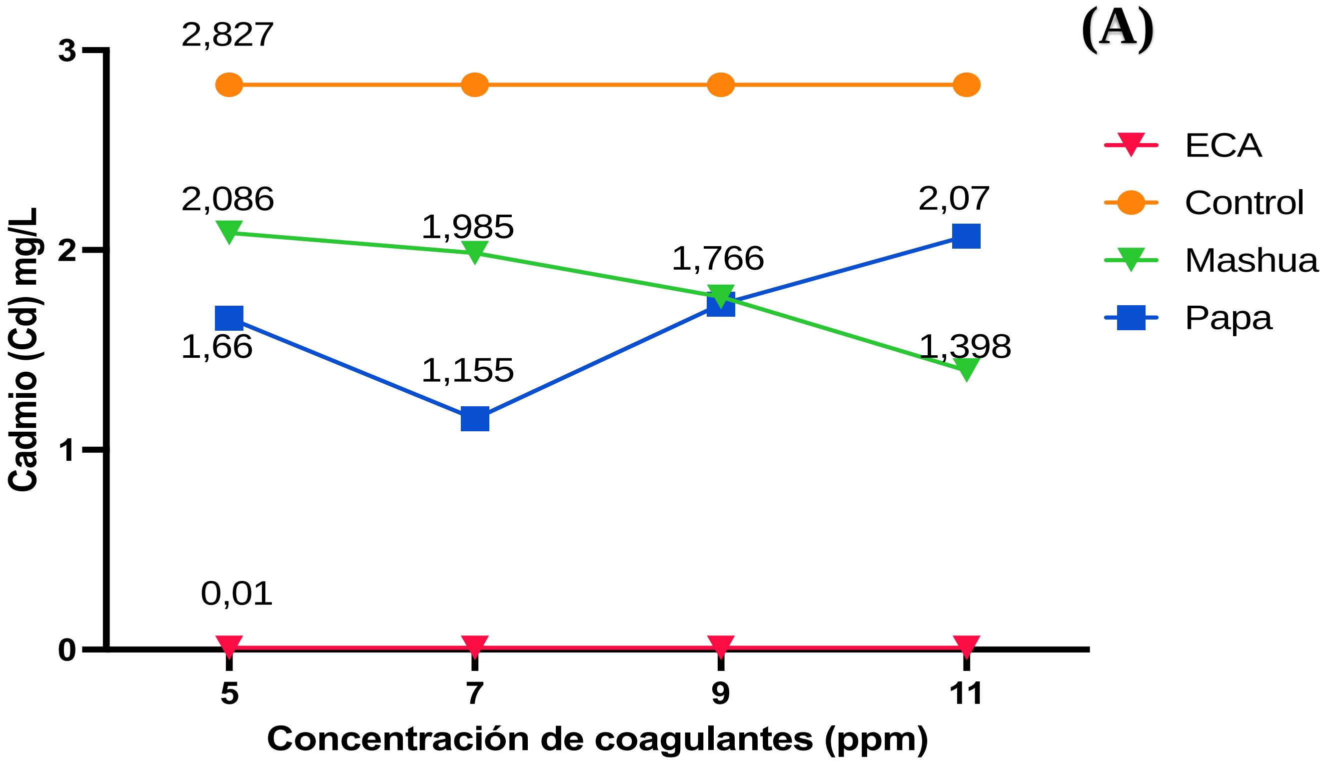


Figure 3. Average concentration value of chromium (Cr) present in the water of the environmental liability in relation to the treatment with coagulants of *S. tuberosum* (potato) and *T. tuberosum* (mashua) in concentrations of 5, 7, 9 and 11 ppm.



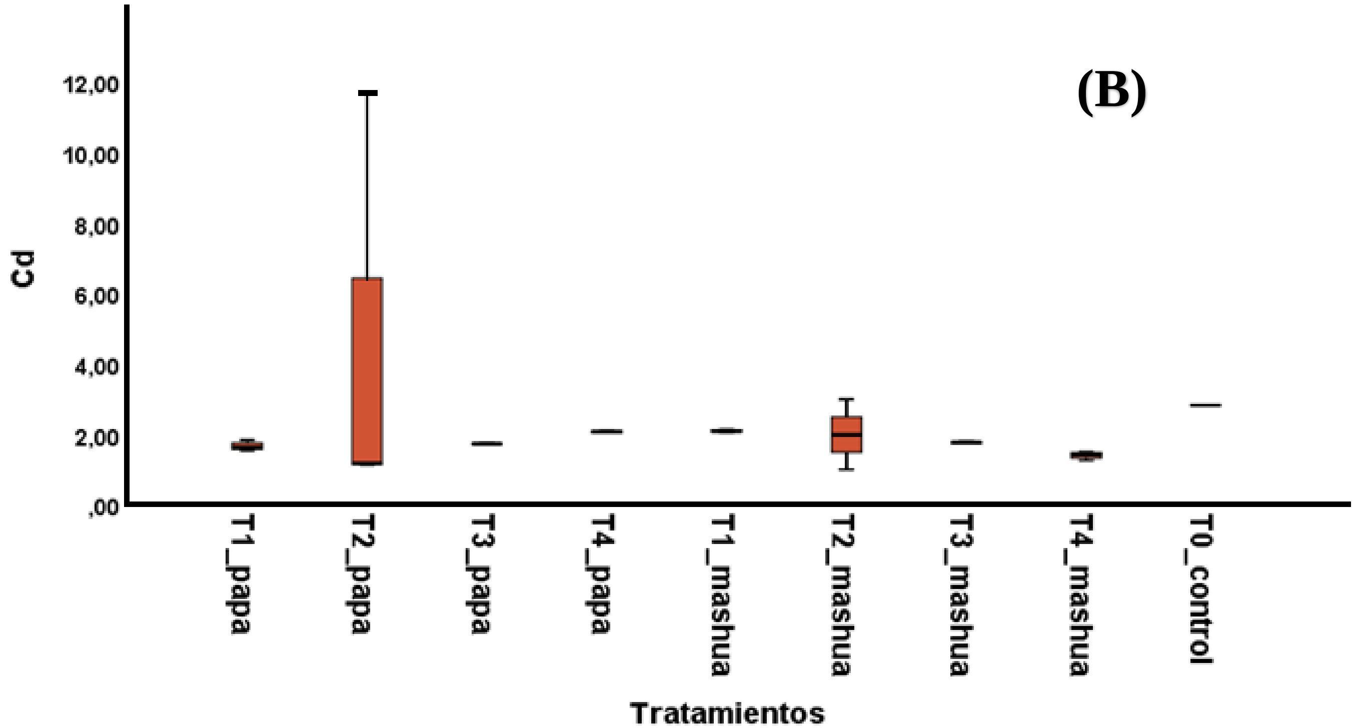
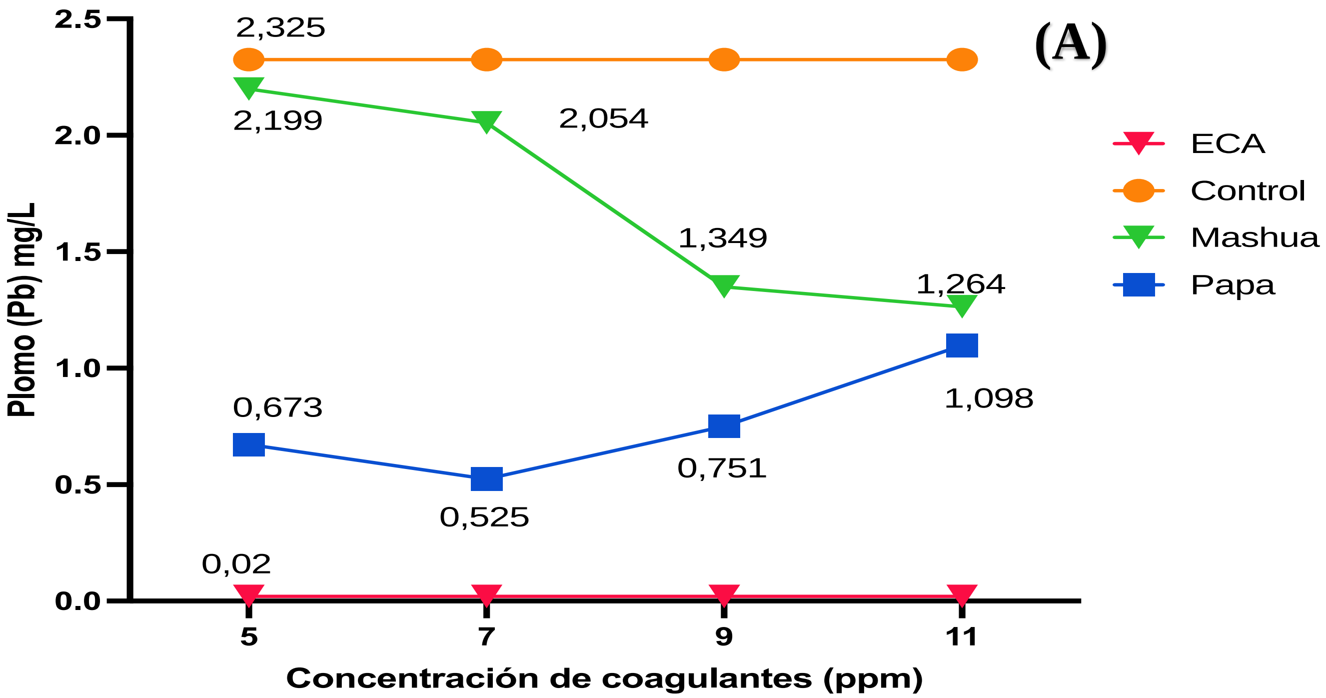


Figure 4. Average concentration value of Cadmium (Cd) in relation to the concentration and treatments with natural coagulants of *S. tuberosum* (potato) and *T. tuberosum* (Mashua) in concentrations of 5, 7, 9 and 11 ppm.



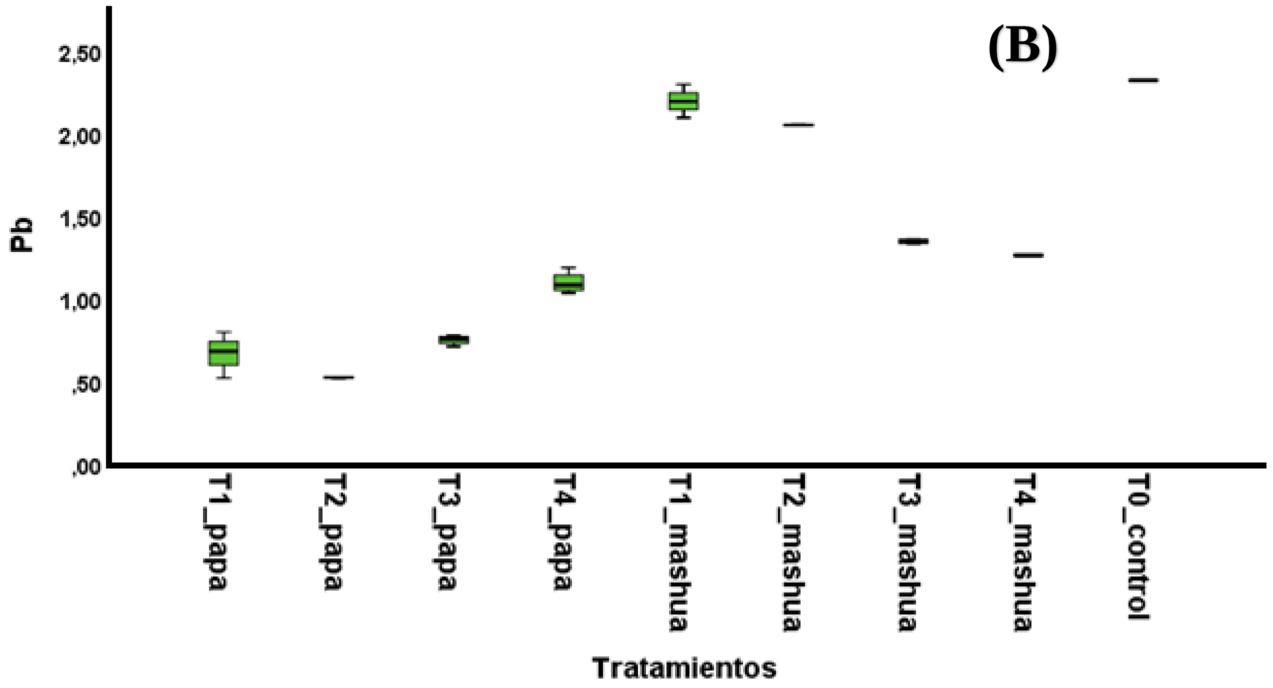


Figure 5. Average concentration value of lead (Pb) in the sample of water extracted from the environmental liability in relation to treatment with natural coagulants of *S. tuberosum* (potato) and *T. tuberosum* (Mashua) at concentrations of 5, 7,9 and 11ppm

Table 1. Characterization of water

Contaminant	Unit	Result
Cr	mg/L	0.328
Cd	mg/L	2.827
Pb	mg/L	2.325
pH	pH unit	6.46
Turbidity	NTU	416

chromium removal [49]. When comparing with the regulatory standards, it is observed that all treatments involving *T. tuberosum* meet the regulations. Furthermore, it is evident that the treatment using *S. tuberosum* at concentrations of 5, 7, and 9 ppm also complies with the regulations, as depicted in Figure 3-A. Moreover, there exists a significant difference among the means of the treatments, as illustrated in Figure. 3-B.

3.4. Cadmium

The initial result of the cadmium analysis conducted on the water sampled from the environmental liability indicated a concentration of 2.827 mg/L. Subsequent to the utilization of the natural coagulant extracted from *S. tuberosum*, the lowest recorded value was achieved, measuring 1.155 mg/L. This result was attained using a dose of 7 ppm. In contrast, when employing *T. tuberosum* as the coagulant, an observed value of 1.398 mg/L was registered, employing an 11 ppm dosage of the primary solution. Both natural coagulants derived from *S. tuberosum* and *T. tuberosum* peels exhibited a capability to mitigate the cadmium concentration within the water sourced from the environmental liability. However, this reduction was notably less pronounced in comparison to the initial cadmium concentration. This phenomenon can be attributed to the adsorption process of these natural coagulants, where ions adhere to the surface of the coagulant, leading to a decrease in their presence within the contaminated water, as described by Duany et al. [50]. These identified final values are consistent with the outcomes reported by Oyewo et al. [51]. In their study, they utilized cellulose particles as a natural coagulant, effectively showcasing an experimental absorption rate of 956.6 mg. This further substantiates the role of such coagulants in reducing the cadmium concentration in wastewater. In conclusion, both natural coagulants demonstrated the ability to lower the cadmium concentration, albeit not meeting regulatory standards, as depicted in Figure 4-A. Additionally, statistical analysis illustrated that there was no substantial distinction among the means of the treatments, as depicted in Figure 4-B.

3.5. Lead

The original concentration of lead present in the water sourced from the environmental liability was measured at 2.325 mg/L. Once treated with *S. tuberosum*, the lowest concentration achieved was 0.525 mg/L, observed at a dosage of 7 ppm. In contrast, the treatment conducted using *T. tuberosum* exhibited greater effectiveness, necessitating a higher coagulant dosage, and resulting in a concentration of 1.264 mg/L at an 11 ppm dosage. These coagulants' application facilitates a reduction in lead concentration, albeit to a moderate extent. This decrease in lead levels is attributed to the process of biosorption, a physicochemical phenomenon involving the uptake of contaminants, referred to as adsorbates or solutes, from an aqueous phase by a biologically derived solid adsorbent known as a biosorbent. Numerous factors influence this process, including the chemical composition of the solute and biosorbent in the aqueous medium, their functional groups, solubility, particle dimensions, and porosity. Through sustained interaction under specific conditions of concentration, pH, temperature, agitation, and duration, this process is initiated and can be characterized using appropriate parameters and mathematical models [52]. These findings closely resemble those of Gautama et al., who utilized natural coagulants derived from *M. oleifera*, Prosopis juliflora, and peanuts, achieving removal rates of 86%, 78%, and 72% respectively [53]. Similarly, this aligns with the work of Shan et al., who employed *M. oleifera* as a natural coagulant in heavy metal removal and demonstrated lead reduction from 1.304 to 0.417 mg/L in treated water [54]. Ultimately, it is evident that the use of these coagulants for environmental liability water treatment falls short of regulatory standards, as illustrated in Figure 5-A. Moreover, discernible distinctions among the various treatments are evident, as depicted in Figure 5-B.

3.6. Removal Efficiency S. tuberosum y T. Tuberosum

Utilizing the natural coagulant derived from the peel of *S. tuberosum* (commonly known as potato), the following results were obtained: a removal efficacy of 87.1% was accomplished for the reduction of turbidity by implementing a dose of 7 ppm. Similarly, the efficacy in reducing cadmium content was noted at 59.14% with a dosage of 7 ppm. Moreover, the reduction efficiency for chromium was notably high at 99.81% using a dosage of 9 ppm. In addition, the reduction efficiency for lead stood at 77.42% with a dose of 7 ppm. This substantiates the assertion that an optimal dosage of this coagulant for the examined water samples cannot be determined, thereby necessitating the application of higher concentrations. When employing the natural coagulant sourced from the peel of *T. tuberosum*, the achieved efficiencies were as follows, the efficiency in diminishing turbidity was recorded at 76.61% utilizing a dosage of 11 ppm. Similarly, the efficacy in removing cadmium content stood at 50.55% with a dose of 11 ppm. Moreover, the effectiveness in chromium removal was notably remarkable, reaching 99.94% at a dosage of 11 ppm. Lastly, the reduction in lead content was 45.63% at a dose of 11 ppm. Thus, it can be confidently stated that the optimal dosage for *T. tuberosum* is 11 ppm. It's important to highlight that both *T. tuberosum* and *S. tuberosum* demonstrated superior efficiency in chromium removal. This outcome corresponds with the findings of Camacho et al., who utilized *S. tuberosum* peel and attained an efficacy of 81.32% in turbidity reduction using a 10 mL dosage [23].

3.7. Analysis of Variance

When comparing the average values of the control group and the treatment groups, utilizing natural coagulants derived from *S. tuberosum* and *T. tuberosum*, a notable and statistically significant distinction was identified with a high level of confidence at 95%. The associated p-value, calculated at 0.007, further supports this observation. In essence, it can be deduced that the employment of these natural coagulants demonstrates efficacy in the removal of turbidity, chromium, and lead from the samples.

4. Conclusions

With regard to the removal of turbidity, Cd, and Pb parameters, it was noted that the most effective dosages utilizing *S. tuberosum* and *T. tuberosum* were 7 ppm and 11 ppm of the concentrated solution, respectively. Similarly, in the case of Cr, the optimal dosages were determined to be 9 ppm (*S. tuberosum*) and 11 ppm (*T. tuberosum*). In terms of the efficacy of pollutant removal when employing the concentrated solution of *S. tuberosum*, the recorded values were 87.1% for turbidity, 59.14% for cadmium, 99.81% for chromium, and 77.42% for lead. Conversely, when utilizing the concentrated solution of *T. tuberosum*, the observed removal rates were 76.61% for turbidity, 50.55% for cadmium, 99.94% for chromium, and 45.63% for lead. Ultimately, upon juxtaposing the outcomes of the treatment using the previously mentioned natural coagulants, it was discerned that solely the chromium parameter adheres to the stipulated Environmental Quality Standards (ECA).

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