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Research Paper

Ion Chromatographic Analysis of Major Electrolyte Cations in Sappan Wood Extract (*Caesalpinia sappan* L.)

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Abstract
Using ion chromatography, a convenient method for analyzing major electrolyte cations (lithium, sodium, ammonium, potassium, magnesium, calcium, strontium, and barium) was presented and applied to Sappan wood samples. The analysis used a Metrohm C4-150/4.0 column with nitric acid (HNO_3) as the eluent. Optimal separation was achieved with an eluent flow rate of 0.8 mL/min, resulting in excellent peak resolution and complete separation within 20 min. Calibration curves for all targeted cations were established within the 0.5 to 20.0 mg/L concentration range, demonstrating strong linearity with correlation coefficients (R^2) greater than 0.999, ensuring accurate and reliable analysis. The Sappan wood samples were obtained from Ternate City, North Maluku, where cation concentrations were varied based on the extraction method. Boiling the sappan wood samples, as compared to soaking in hot purified water, significantly increased the release of electrolyte cations, resulting in higher concentrations and a greater variety of cations. Calcium was the most abundant cations in each extraction method, with a concentration of 37.80 mg/kg (5 min soaking), 43.92 mg/kg (10 min soaking), and 83.73 mg/kg (10 min boiling). In contrast, the concentration of three electrolyte cations: lithium, strontium, and barium, was below the instrument's detection limit in all the samples.

Keywords
Ion Chromatography, Electrolyte Cations, Sappan Wood

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1. INTRODUCTION

Sappan wood (*Caesalpinia sappan* L.) is widely recognized in Southeast Asia for its traditional medicine applications. It is known for its diverse therapeutic properties, including antioxidant, antimicrobial, and anti-inflammatory (Safitri et al., 2022; Syamsunarno et al., 2021; Vij et al., 2023). The plant's extensive use in traditional medicine has sparked scientific investigation to elucidate its chemical composition, mainly focusing on bioactive compounds that may contribute to its health benefits (Bhattacharya et al., 2024; Riaz et al., 2023).

In addition to its medicinal uses, Sappan wood is notable for its rich red pigment, Brazilian, which has been utilized historically as a natural dye for textiles and artworks (Dapson and Bain, 2015; Sasongko et al., 2024; Vij et al., 2023). This pigment and other compounds found in the wood have attracted interest due to their potential applications beyond traditional medicine, including their use in modern pharmacology and natural product chemistry (Bhardwaj et al., 2021; Yuan et al., 2016). Understanding Sappan wood's chemical constituents, including its essential electrolyte cations, is crucial for exploring its traditional and contemporary applications.

Electrolyte cations such as sodium, potassium, magnesium, and calcium are essential for the physiological functions of plants and are often linked to health benefits when used in therapeutic contexts (Alrashidi et al., 2022; Price et al., 2012; Schiefermeier-Mach et al., 2020). However, although naturally occurring, cations like lithium and ammonium are generally toxic at higher concentrations. Strontium, beneficial in small amounts for bone health, may cause adverse effects in larger quantities (Kolodziejska et al., 2021). Barium, particularly in its soluble form, is known to be toxic to humans and is generally unsafe for therapeutic use (Kravchenko et al., 2014; Krishna et al., 2020). Therefore, certain cations offer health benefits, however, it must be carefully managed due to their potential toxicity.

Historically, the analysis of these cations has relied on conventional methods such as gravimetric analysis (Paredes et al.,

2023), titration (Shyichuk et al., 2023), and atomic absorption spectroscopy (AAS) (Alva, 2021). Gravimetric analysis, a technique based on mass measurement, is often used to analyze the concertation of specific ions by precipitating them as insoluble compounds. This method has been traditionally applied to the analysis of calcium in plant tissues by converting it into calcium oxalate, which is then weighed. On the other hand, titration is a volumetric method commonly used to determine the concertation of cations such as magnesium and calcium in water samples via complexometric titration with EDTA. Although these methods are effective in specific cases, they often need more sensitivity and selectivity when dealing with complex biological matrices, such as plant extracts or food samples, where multiple ions may be present in varying concentrations.

The AAS method offers greater sensitivity than gravimetric and titration methods. It has been widely employed in detecting trace metals like magnesium, potassium, and calcium in environmental and biological samples. For instance, AAS is frequently used to quantify the levels of calcium and magnesium in soil and water samples for agricultural purposes (Bisergaeva and Sirieva, 2020). Despite its higher sensitivity, AAS can still be limited when multiple cations coexist in a single one, as the technique typically requires separate analyses for each ion, which can complicate the analytical workflow and increase the time needed for analysis.

Moreover, these conventional methods often involve laborious sample preparation. They may struggle with interference from other components in biological matrices, making them less suited for analyzing complex samples, such as plant-based therapeutic extracts, where multiple cations must be quantified simultaneously. As a result, more advanced techniques should be increasingly sought that offer higher sensitivity, specificity, and the ability to analyze various cations in a single run, reducing the complexity and time required for accurate analysis.

Advanced analytical techniques, such as inductively coupled plasma mass spectrometry (ICP-MS) (Marie et al., 2011; Nadeau et al., 2018) and capillary electrophoresis (Chen et al., 2016; Rathore, 2017), have been introduced to overcome these challenges. These methods provide higher accuracy and sensitivity in detecting cations, although they are often associated with higher costs, complex sample preparation, and limitations in applicability across different sample types.

Ion chromatography (IC) has emerged as a superior analytical method, particularly suited for separating and analyzing multiple cations in complex matrices (Amin et al., 2008, 2023; Small, 1989). IC is favored for its high sensitivity, precision, and relatively straightforward sample preparation process, making it an invaluable tool for analyzing diverse biological samples.

Applying IC to analyze plant extracts, including Sappan wood, has proven effective in analyzing cations with minimal interference from other sample components. Numerous studies have validated the reliability of this method across a broad range of biological materials, further cementing its significance in cation analysis.

Despite the extensive research on Sappan wood, most studies have concentrated on its phenolic compounds and flavonoids, with limited attention given to its electrolyte cations. This research addresses this gap by presenting a detailed analysis of eight essential electrolyte cations in Sappan wood using IC.

The selection of these specific cations is predicated on their established physiological roles and importance in medicinal plants. For instance, lithium is associated with neurological health, calcium and magnesium are essential for bone and muscle function, and potassium and sodium are critical for maintaining cellular homeostasis. This unique focus on electrolyte cations in Sappan wood sets this study apart and promises to provide valuable insights.

The methodology employed in this study involves the extraction of cations from Sappan wood, followed by their separation and analysis using IC. The extraction has been optimized to ensure maximum recovery of the target cations while minimizing potential interference from other compounds in the wood. IC offers distinct advantages because it can effectively separate cations with similar properties, such as sodium and ammonium, which might present analytical challenges when using other methods. Furthermore, using a conductivity detector in IC allows for the sensitive detection of these cations, even at low concentrations.

The findings of this study are expected to provide a comprehensive cation profile of Sappan wood, offering novel insight into its chemical composition and potential medicinal properties. This profile will advance the understanding of Sappan wood's therapeutic potential and contribute valuable data to the broader field of medicinal plant research. By employing IC, this research highlights the method's efficacy in analyzing cations within complex plant matrices, establishing a methodological foundation for future studies on other medicinal plants. This study aims to expand the current knowledge of Sappan wood's chemical profile and underscore the importance of electrolyte cations in its traditional and potential therapeutic applications. This research could stimulate studies into the medicinal properties of Sappan wood and other related plants. IC in this study provides precise quantitative data on the electrolyte cations in Sappan wood. It establishes a robust framework for future investigation into the cationic content of other medicinal plants. This research contributes significantly to ongoing efforts to fully understand the spectrum of bioactive compounds in traditional herbal medicines.

2. EXPERIMENTAL SECTION

2.1 IC Instrument

A Metrohm Eco IC ion chromatograph, manufactured in Switz erland, was utilized to precisely analyze major electrolyte cations in Sappan wood. The instrument is known for its compact design and ability to perform non-suppressed and suppressed ion detection. The system has a sequential double-piston IC pimp, a 10-μL sample loop, an IC detector, and Metrohm's IC Microdata software, which controls data acquisition and instrument operation on a Windows platform. The analysis

was carried out using a Metrosep C4-150/4.0 cation-exchange column and a Metrosep C guard/4 guard column to ensure accurate separation and analysis of the electrolyte cations under investigation.

2.2 Preparation of Solutions and Eluent

The chemicals utilized in this study were obtained from Merck, Germany, and were of analytical-grade quality. Stock solutions with a concentration of 1000 mg/L for multi-element IC were prepared and diluted to match the concentration ratios typical of the actual samples. Standard solutions for the major electrolyte cations were created before calibration, with concentrations ranging from 0.1 to 20 mg/L. These solutions included a mixture of lithium, sodium, ammonium, potassium, magnesium, calcium, strontium and barium.

All solutions were carefully prepared using pure water and filtered through a 0.22-μm membrane filter to ensure purity before being injected into the IC system. A 3.5 mM nitric acid (HNO_3) solution was used as the eluent for electrolyte cations analysis and was filtered through a 0.22-μm membrane filter before use.

2.3 Collection of Sappan Wood Samples

Sappan wood samples were carefully collected from Ternate City, North Maluku, with only mature trees selected to ensure consistency and quality. The harvested twigs were transported to the laboratory for further processing (Figure 1). The twigs were then thinly sliced and weighed in preparation for extracting Sappan wood samples.

Figure 1. Sappan Wood Stick Samples Were Obtained from Ternate City, North Maluku

2.4 Preparation of Sappan Wood Extract

Two different methods were used to prepare Sappan wood extract. First, 20 g of Sappan wood was immersed in 100 mL of hot purified water, following the hot water soaking technique. This immersion was performed for two durations: 5 min and 10 min. This soaking process aimed to extract major electrolyte cations by allowing them to dissolve into the hot water, offering an efficient extraction method. For the second approach, the boiling method, another 20 g of Sappan wood was heated directly in 100 mL of purified water for 10 min. This boiling process, a crucial step, releases cation electrolytes from the wood into the water. As expected, some water evaporated during boiling, which reduced the volume. To compensate, purified water was added until the final volume reached 100 mL, ensuring consistent extract volumes across samples to compare cation electrolytes accurately. Figure 2 shows the different Sappan wood extracts obtained in varying preparation conditions: (a) soaking in hot purified water for 5 min, resulting in a lighter-colored extract. (b) soaking in hot purified water for 10 min, yielding a medium-colored extract, and (c) boiling in purified water for 10 min, which produced the darkest extract, demonstrating how different extraction times and methods affect the concentration and appearance of the extracts.

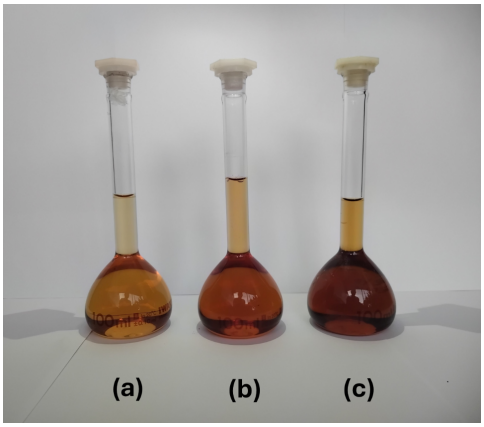

Figure 2. Sappan Wood Extracts Were Prepared under Varying Conditions: (a) Soaking in Hot Purified Water for 5 Min, (b) Soaking in Hot Purified Water for 10 Min, and (c) Boiling in Purified Water for 10 Min

Once these preparations were completed, the extracts were passed through a 0.22-μm membrane filter (Merck) to remove any particulates that might interfere with further analysis. This filtration process was vital for ensuring accurate and reliable results. By standardizing the final volume at 100 mL post-boiling, the concentration of major electrolyte cations could be reliably analyzed and compared across the various extraction methods. Careful handling and preparation of the Sappan wood extract samples were crucial for obtaining accurate and dependable data on the presence and concentration of major electrolyte cations in the extracts.

3. RESULT AND DISCUSSION

3.1 Effect of HNO_3 Concentration as the Eluent

Various studies have demonstrated that HNO_3 is commonly used as an eluent for separating and analyzing cationic electrolytes, including monovalent cations like lithium, sodium, potassium, and ammonium, as well as divalent cation such as magnesium, calcium, strontium, and barium. The eluent must exhibit a strong affinity for the ion exchange resin to improve the efficiency of separating major electrolyte cations. HNO_3 is typically employed in low concentrations to create optimal acidic conditions for the elution of these electrolyte cations. Achieving the correct acidity level is crucial for promoting the movement of major electrolyte cations through the separation

column. One key reason HNO_3 was selected as the eluent is its high compatibility with the separation column. It is known to be non-reactive with column materials, particularly ion exchange resins or other acid-resistant materials, ensuring that the eluent remains uncontaminated and does not cause any unwanted reactions that could interfere with the accuracy of the analysis.

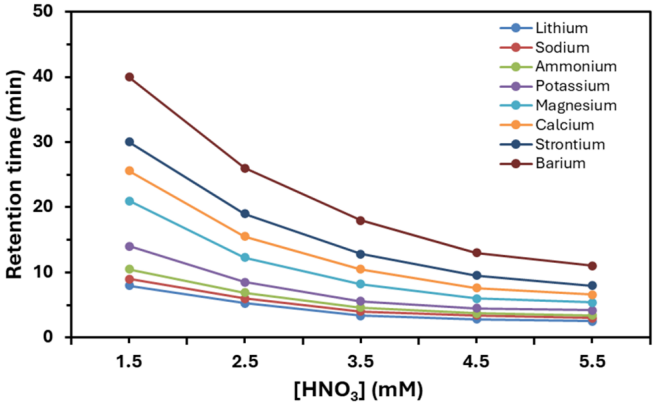

Figure 3. Effects of Varying Eluent Concentrations on Retention Time. Eluent: 1.5 – 5.5 mM HNO_3. Separation Column: Metrosep C4-150/4.0. Eluent Flow Rate: 0.8 mL/min

This study examined the effect of varying HNO_3 concentrations on the retention time of each cation, using concentrations ranging from 1.5 to 5.5 mM. As shown in Figure 3, increasing the concentration of HNO_3 resulted in decreased retention times for the electrolyte cations. At eluent concentrations above 3.5 mM, peak overlaps occurred, particularly affecting the resolution of sodium and ammonium. In contrast, these overlapping issues were not observed for the other major cations (potassium, magnesium, calcium, strontium, and barium). When the eluent concentration was below 3.5 mM, the retention times for divalent cations increased, while the retention times for monovalent cations remained relatively stable. Based on the retention times and peak resolution, it was recommended that the optimal eluent concentration for separating all major electrolyte cations was 3.5 mM.

3.2 Determination of Major Electrolyte Cations Using a Standard Sample

Figure 4 illustrates the ion chromatogram of major monovalent and divalent electrolyte cations, obtained by injecting 10-μL of a standard sample containing a mixture of eight cations: lithium, sodium, ammonium, magnesium, calcium, strontium, and barium. Under the specified chromatographic conditions, all electrolyte cations were successfully separated within 20 min, demonstrating the method's efficiency in analyzing these electrolytes.

In this chromatogram, the peaks of all electrolyte cations are oriented upwards. This phenomenon occurs due to the

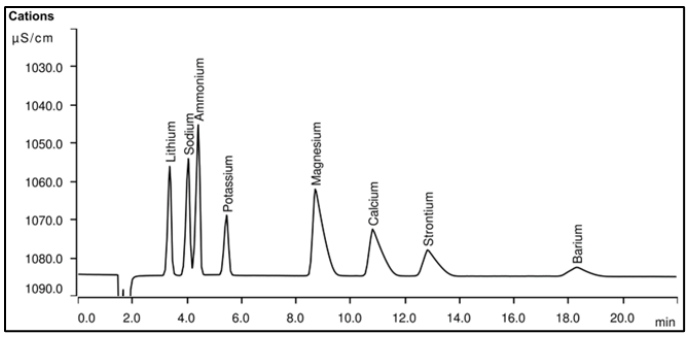

Figure 4. Ion Chromatographic Profile of Monovalent and Divalent Major Electrolyte Cations Using a Standard Sample. Eluent: 3.5 mM HNO_3. Separation Column: Metrosep C4-150/4.0. Eluent Flow Rate: 0.8 mL/min. Volume of Sample: 10-μL. Concentration of Major Electrolyte Cations (in mg/L): Lithium (10), Sodium (10), Ammonium (20), Potassium (20), Magnesium (20), Calcium (20), Strontium (20), and Barium (20). Column Temperature: 35°C

hydronium ion (H^+) from the HNO_3 eluent acting as a carrier for the cation analytes during the ion exchange process in the separation column. When the conductance of the analyte cations exceeds that of the hydronium ion, the resulting peaks appear upward. Conversely, a peak directed downwards at the chromatogram's start is observed. This downward peak, known as the system peak, provides a reference point for the conductance of the analyte cations, as it represents ions that exhibit lower conductance than hydronium ions, marking the initial stage of the separation process.

This setup effectively demonstrates the apparent resolution of cationic electrolytes under optimal conditions, ensuring accurate identification and quantification of each analyte present in the sample. The distinct behavior of the peaks-either upward or downward-corresponds directly to the ionic conductance differences between the analytes and the eluent, providing a reliable basis for interpreting chromatographic results.

3.3 Validation of the Method

Calibration curves were established by plotting each major electrolyte cation's peak height signals against their respective concentrations. Linearity was confirmed using standard solutions for lithium and sodium with concentrations of 0.1, 0.5, 2, 4, and 10 mg/L. Meanwhile, the concentrations for ammonium, potassium, magnesium, calcium, strontium, and barium were set at 0.2, 1, 4, 10, and 20 mg/L, as illustrated in Figure 5. The least square method was applied to derive the regression line equation for the calibration curves, demonstrating the linear correlation between concentration and detector response.

The method's reproducibility for all electrolyte cations was considered satisfactory under the conditions outlined in Table 1. Precision was evaluated by performing five injections of a standard mixture containing the eight major electrolyte cations. The relative standard deviation (RSD) of these cation's con-

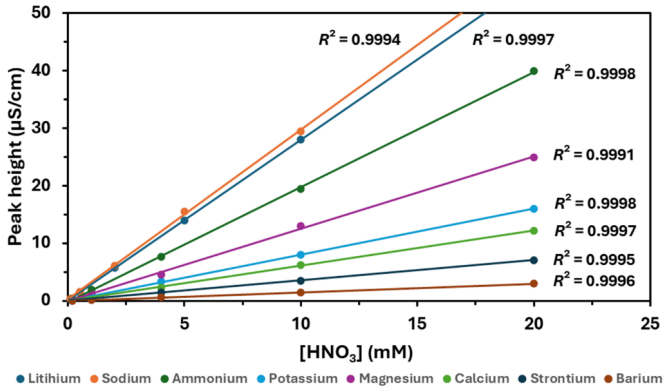

Figure 5. Calibration Curve Plotting the Ion Concentration of the Standard Sample Containing Major Electrolyte Cations Against the Peak Height of the Detector Signals

ductivity response peak heights ranged from 1.89% to 3.49%, indicating good precision.

The effectiveness of the current method in detecting low concentrations of substances was assessed by injecting a 10-μL volume of standard solution. The limit of detection (LOD) was calculated by comparing the signal generated by the analytical instrument to the background noise, with a signal-to-noise ratio of 3. A lower LOD indicates a higher sensitivity of the method to the substance being analyzed. The results are shown in Table 1. This technique identifies the eight major electrolyte cations in Sappan wood at sub-ppm detection level.

Table 1 also compares the LOD values achieved in this study with those reported in other studies. The results indicate that the LOD in this study in superior, suggesting that the method applied here may offer greater accuracy and efficiency in detecting low concentrations of electrolyte cations compared to previous methods.

3.4 Application for the Analysis of Electrolyte Cations in Sappan Wood Extract

The main goal of this study was to evaluate the major electrolyte cations present in Sappan wood extract samples typically found in Ternate City, North Maluku. The samples underwent extraction under three distinct conditions:

- 5 min of soaking in hot purified water
- 10 min of soaking in hot purified water
- 10 min of boiling in purified water

To ensure precision in the analysis, the Sappan wood extracts were prepared using these methods and then filtered through a 0.22-μm membrane filter before injection into the IC instrument. The separation and analysis results for these major electrolyte cations are shown in Figure 6. Before delving into the findings on the detection or absence of individual electrolyte cations, it is crucial first to acknowledge that the behavior of these cations under the different extraction methods provides valuable insights into their solubility, their interactions with the wood matrix, and their presence in the samples. The

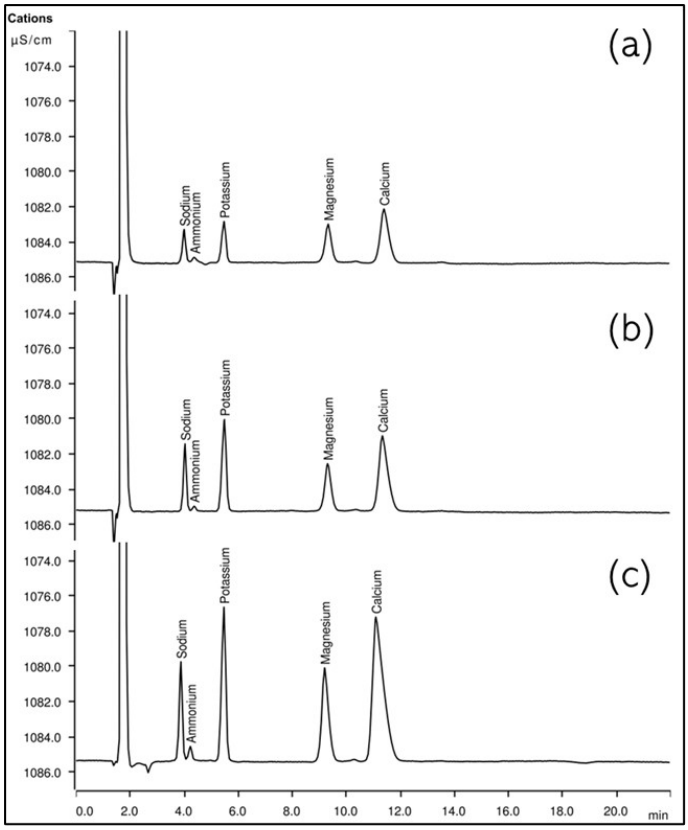

Figure 6. Ion Chromatograms Profile of Electrolyte Cations Extracted from Sappan Wood under Three Different Conditions: (a) Soaking in Hot Purified Water for 5 Min, (b) Soaking in Hot Purified Water for 10 Min, and (C) Boiling in Purified Water for 10 Min, under the Chromatographic Conditions in Figure 4

concentrations and detectability of these cations reveal not only the chemical compositions of Sappan wood but also the effectiveness of the extraction techniques used. Table 2 summarizes the analysis data of Sappan wood from three different extraction methods. Below, we explain how each method evaluates each major electrolyte cation concentration.

Lithium, Strontium, and Barium (Below the LOD) The absence of lithium, strontium, and barium in the Sappan wood extract suggests that these electrolyte cations are present in extremely low concentrations, below the LOD of the employed method, or not in significant quantities in this plant species. This result aligns with findings from other studies on the mineral composition of plants, where certain cations like lithium, strontium, and barium are either minimally present or absent in many plant tissues, depending on the species and the environmental conditions.

For instance, on the metal content in medicinal plants, it was found that certain plants accumulate specific metals based on their growing environment and the soil's mineral content. Plants growing in soils with low lithium, strontium, or bar-

Table 1. Data on the Detection Limit (LOD), Relative Standard Deviation (RSD) of Peak Height, and Retention Time (TR) under the Chromatographic Conditions Shown in Figure 4

Electrolyte Cations	LOD (mg/L) Present Study	LOD (mg/L) Previous Study[a]	RSD (%) of Peak Height (n=5)	Regression Equation	Retention Time, TR (min)
Lithium	0.045	-	2.09	$y = 2.9533x + 0.2145$	3.37
Sodium	0.053	0.1	2.67	$y = 2.7955x + 0.0559$	4.04
Ammonium	0.057	-	2.96	$y = 2.0004x + 0.1948$	4.42
Potassium	0.059	0.3	3.24	$y = 0.7977x + 0.0559$	5.46
Magnesium	0.064	0.2	3.35	$y = 1.2614x + 0.0722$	8.71
Calcium	0.083	0.3	2.91	$y = 0.6126x + 0.0268$	10.81
Strontium	0.096	-	3.12	$y = 0.3545x + 0.0055$	12.83
Barium	0.098	-	3.49	$y = 0.1502x + 0.0056$	18.29

[a](Wen et al., 2022)

Table 2. Summary of Data for Major Electrolyte Cations Using the Soaking Hot Purified Water and Boiling Methods, Analyzed under the Chromatographic Conditions Shown in Figure 4

Electrolyte Cations	Concentration (mg/kg) Hot Purified Water Soaking Method (a) 5 min	(b) 10 min	Purified Water Boiling Method (c) 10 min
Lithium	n.d.	n.d.	n.d.
Sodium	7.65	15.65	24.51
Ammonium	0.81	1.05	2.75
Potassium	18.62	41.45	69.85
Magnesium	11.95	14.85	29.53
Calcium	37.80	43.92	83.75
Strontium	n.d.	n.d.	n.d.
Barium	n.d.	n.d.	n.d.

n.d.= not detected (below the LOD)

ium levels tend to show minimal or no accumulation of these elements in their tissues (Nagaraju and Karimulla, 2002).

Similarly, research by Kabata-Pendias (2010) highlights the complex nature of lithium and strontium accumulation in plants. These elements are often found in trace amounts, but the accumulation varies widely depending on the soil composition. For example, plants growing in regions rich in lithium-bearing minerals may accumulate detectable amounts of lithium. At the same time, those in lithium-poor soils may not show any presence of the element.

Thus, the absence of lithium, strontium, and barium in the Sappan wood samples is consistent with other research on plat mineral content, where these electrolyte cations are negligible or require more sensitive techniques to be accurately quantified.

3.4.1 Sodium

The significant increase in sodium concentration with longer extraction times and the boiling method suggests sodium is readily extractable from the Sappan wood matrix, especially under higher temperatures. Sodium, a highly soluble alkali metal, leaches quickly into aqueous solutions, consistent with findings from other studies on plant materials. For example, a study by Blumwald et al. (2000) demonstrated that sodium is easily extracted from plant tissues, particularly when prolonged water or heat exposure is present. Their research showed that sodium concentrations in plant extracts increased significantly when the samples were boiled, as boiling enhances the mobility of sodium ions, allowing them to diffuse more effectively from the plant cell matrix into the surrounding solution.

Sodium concentration increased significantly across the three methods, from 7.65 mg/kg (5 min soaking) to 15.65 mg/kg (10 min soaking) and 24.51 mg/kg in the boiling method. This trend suggests that sodium, a highly soluble and mobile ion, is readily extracted into the water, with longer soaking times leading to greater sodium release. However, the boiling method proved even more efficient, extracting the highest sodium concentration. Boiling likely accelerates the breakdown of the plant cell structure, facilitating faster and more complete leaching of sodium into the water. These observations underscore the importance of method selection in sodium extraction from plant materials. Higher temperatures and longer extraction times can significantly enhance sodium leaching, which may be for studies focusing on sodium's nutritional or pharmacological properties in medicinal plants like Sappan wood.

3.4.2 Ammonium

Ammonium concentrations increased across the methods, from 0.81 mg/kg (5 min soaking) to 1.05 mg/kg (10 min soaking) and 2.75 mg/kg in the boiling method. Although ammonium shows lower overall concentrations than sodium, the trend highlights that longer soaking times and higher temperatures enhance ammonium extraction. The boiling method yielded the highest ammonium concentration, which can be attributed to the improved solubilization and diffusion of ammonium ions at higher temperatures. Ma et al. (2023) also observed that ammonium extraction improves with increased heat and time, as thermal processes promote the breakdown of plant tissues, releasing more ammonium into the solvent.

This observation is supported by research from Li et al. (2017) who studied ammonium extraction from plant materials and demonstrated that ammonium ions are highly soluble and tend to leach into aqueous solutions more efficiently with increased temperature and time. They noted that heat facilitates the breakdown of plant cell structures, allowing ammonium ions to diffuse more readily into the extraction medium. This is similar to the findings in the Sappan wood extraction, where ammonium concentrations increase substantially with longer soaking and boiling.

The rising concentration of ammonium with increased times and higher temperatures in the boiling method suggests that the ammonium ions in Sappan wood are present in easily liberated forms by heat. This indicates that ammonium may be more accessible within the plant matrix under such conditions.

3.4.3 Magnesium

Magnesium concentration followed a similar upward trend, increasing from 11.95 mg/kg (5 min soaking) to 14.85 mg/kg (10 min soaking) and reaching 29.53 mg/kg with boiling. Magnesium, a divalent ion, is less mobile than sodium but significantly increases extraction efficiency with extended soaking time and boiling. The higher temperature in the boiling method facilitates the release of magnesium ions from the plant matrix, likely due to the breakdown of magnesium-bound complexes within plant tissues. This is consistent with findings that magnesium extraction is more effective when higher temperatures are applied, as heat enhances the release of ions from cellular structures. Research has also shown magnesium is one of the more easily extractable divalent cations in plant tissues due to its solubility and relatively weak binding within the plant matrix. Higher temperatures help break down cell walls and membranes, further facilitating the release of magnesium into the extraction medium.

Thus, the increase in magnesium concentration in the Sappan wood extract with prolonged heating and soaking times is consistent with existing literature, emphasizing that magnesium is efficiently extracted through heat-intensive methods. This suggests that boiling or extended hot water extraction methods would be the most effective for applications requiring high magnesium yield.

3.4.4 Calcium

Calcium, the most abundant of the detected cations, substantially increased across the three methods. The concentration rose from 37.80 mg/kg (5 min soaking) to 43.92 mg/kg (10 min soaking) and dramatically to 83.75 mg/kg in boiling. Calcium is typically bound within the cell walls of plants, and the increase in extraction efficiency with longer soaking times and higher temperatures suggests that thermal processes are especially effective in breaking down calcium-bound structures, such as pectin. White and Broadley (2003), explain that calcium is tightly bound in the plant matrix, and high temperatures are necessary to release it effectively, which aligns with the increased calcium concentration observed with boiling.

Furthermore, a study on mineral extraction from plant materials supports this observation, showing that calcium concentrations in extracts increase significantly when subjected to higher temperatures and extended extraction periods. They noted that heat accelerates the degradation of pectin and other cell wall components, enhancing calcium ion release into the surrounding solution.

The data from the Sappan wood extraction, where calcium concentrations more than double from 5 min of soaking to the boiling method, underscore the effectiveness of heat in facilitating the release of calcium ions. This suggests that calcium is highly abundant in Sappan wood and highly mobile under heat and water conditions, making boiling the most effective method for extracting calcium. These findings are essential for research focused on calcium extraction from plant materials. They demonstrate that prolonged heat treatment, such as boiling, is particularly effective for maximizing calcium yield, which could benefit nutritional or pharmacological applications.

4. CONCLUSIONS

This study successfully applied an IC method to analyze major electrolyte cations in Sappan wood extract sample from Ternate City, North Maluku. The method achieved optimal separation with excellent peak resolution, and the calibration curves showed strong linearity for all analyzed cations. The results demonstrated that boiling method was more effective than soaking method in hot water in enhancing the release of electrolyte cations, with calcium being the most abundant cation. In contrast, the lithium, strontium, and barium concentrations were below the LOD in all samples.

5. ACKNOWLEDGMENT

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