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NaCl Accumulation in Leaves of Two Salt-Secreting Mangrove Species in Sarudu Village, Pasangkayu Regency, Indonesia

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Abstract

Mangroves are coastal vegetation with a high capacity to adapt to their environment, characterized by distinctive and unique root systems. This study aimed to determine the accumulation of salt (NaCl) in the leaves of two salt-secreting mangrove species in Sarudu Village, Pasangkayu Regency. The research employed a quantitative descriptive approach, with samples collected through a survey. Salt accumulation data were obtained through argentometric titration using the Mohr method. Environmental measurements in the mangrove forest of Sarudu Village showed an average air temperature of 30°C, salinity ranging from 29 to 30 ppt, and pH values between 7.0 and 7.1. The results indicated that the highest average salt accumulation in the leaves of Aegiceras corniculatum was recorded at Station 3 (6.08%), while the lowest was found at Station 1 (3.07%). Similarly, in Avicennia lanata, the highest NaCl accumulation was observed at Station 3 (5.33%), whereas the lowest occurred at Station 1 (2.92%). Station 3 exhibited the highest percentage of salt accumulation among all sampling stations, likely because it was located in a coastal area that was frequently inundated by seawater to a depth of approximately 20 cm.

Keywords: NaCl accumulation; *Aegiceras corniculatum*; *Avicennia lanata*; Mangrove.

INTRODUCTION

Mangroves are highly adaptive plants that can survive in environments with varying levels of salt accumulation, muddy or sandy soils, and tidal zones. To cope with high salinity, mangroves have developed unique root, stem, and leaf structures that enable them to absorb excess salt and subsequently remove it from their tissues (Syah et al., 2017). Mangroves are classified as halophytic plants, capable of growing and thriving in coastal areas characterized by high salinity and dynamic environmental conditions driven by tidal fluctuations. This capability is supported by various morphological and physiological adaptation mechanisms, including salt exclusion at the root level, ion accumulation in specific tissues, and salt secretion through specialized salt glands in the leaves. These adaptive mechanisms allow mangroves to maintain osmotic balance and sustain metabolic activities despite living in environments with high salt concentrations (Sinyo et al., 2022). Mangrove forests are tropical and subtropical coastal vegetation communities that are able to grow and develop in muddy intertidal environments. These vegetation communities typically occur in intertidal zones that experience regular seawater inundation and strong tidal currents. Consequently, mangroves are commonly found along shallow bays, estuaries, river deltas, and protected coastal areas (Apriliayni et al., 2018).

Mangroves are vegetation with a remarkable ability to adapt to environmental conditions and are characterized by distinctive and unique root systems (Saputra et al., 2024). To maintain water balance, mangroves employ several mechanisms, including stomatal regulation, osmotic adjustment, and salt secretion. These plants exhibit relatively low transpiration rates while continuously absorbing saline water through their roots. As a result, salt accumulates in the leaves. To overcome this condition, some mangrove species possess specialized salt glands that excrete excess salt. In mangroves that are frequently inundated by seawater, the absorption of salt ions occurs through the roots, particularly at the outer root surface (Utami et al., 2017). The influence of seawater increases the salt concentration, or salinity, of the surrounding water. Mangrove growth responses to salinity vary considerably among species; some mangrove species do not grow well under low-salinity conditions, whereas others can survive and develop successfully in freshwater environments (Darwati et al., 2022). Water quality within mangrove ecosystems also plays an important role in determining mangrove health and growth. Although mangroves are highly adaptable to fluctuations in salinity, they remain sensitive to changes in other water quality parameters, including temperature, pH, and dissolved oxygen (DO) levels (Radja et al., 2023).

Salt accumulation in mangroves refers to the buildup of salt within mangrove tissues, including the roots, stems, and leaves, which is subsequently removed either through specialized salt glands, the shedding of senescent leaves, or the exfoliation of old bark. This mechanism eliminates excess salt that could otherwise interfere with mangrove growth and development. High salinity can affect plant growth and physiology by increasing osmotic pressure and causing an ionic imbalance within cells. In mangroves, sodium (Na^+) and chloride (Cl^-) ions absorbed from the surrounding environment tend to accumulate in specific tissues, particularly in the leaves. Excessive salt accumulation may lead to physiological disturbances such as reduced photosynthetic efficiency, accelerated leaf senescence, and increased leaf abscission. Therefore, the ability of each mangrove species to regulate and accumulate salt is considered an important indicator for understanding its adaptive strategies in saline environments (Irvan, 2017). In addition to salinity, ecological factors such as temperature, pH, and water characteristics also play significant roles in determining mangrove growth and distribution. These environmental factors interact with one another and influence mangroves' ability to adapt to dynamic coastal habitats (Zakia & Lestari, 2022). Furthermore, the environmental physical and chemical properties may vary among mangrove growth zones. Species composition and vegetation density are strongly influenced by soil texture and salinity conditions, which affect the establishment and distribution of mangrove communities (Bachtiar, 2023).

Studies on salt accumulation in mangroves have been conducted on various species and in different locations. Sinyo et al. (2022) reported that the salt content in the roots and leaves of the salt-secreting mangrove *Avicennia* sp. differed between tidal and non-tidal conditions, indicating that environmental factors influence the level of salt accumulation. Irvan (2017) found that salt accumulation in *Avicennia alba* and *Sonneratia alba* was greater in the roots than in the leaves, with a relatively low proportion of salt being translocated to the leaves. Similarly, Oktavia (2016) reported that *Avicennia marina* and *Rhizophora mucronata* exhibited different capacities for salt accumulation, as reflected by their respective Bioconcentration Factor (BCF) and Translocation Factor (TF) values. Furthermore, Ayyaz et al. (2023) demonstrated that *Aegiceras corniculatum* possesses a high level of salinity tolerance through physiological adaptation mechanisms that support its survival in coastal environments. A similar study conducted by Enjella et al. (2024) analyzed the salt content in the leaves of *Rhizophora stylosa* and *Rhizophora mucronata*. Their findings indicated that mangrove leaves function as one of the primary organs involved in salt accumulation and excretion, making them useful indicators for evaluating mangrove adaptation to saline environmental conditions.

Mangrove habitat conditions are influenced not only by salinity but also by tidal dynamics and the characteristics of the substrate in which they grow. Hudoyo et al. (2021) explained that tidal fluctuations, the distribution of brackish water, and sediment composition play important roles in shaping mangrove distribution patterns in coastal areas. In addition, Saharani et al. (2025) reported that sediment texture is closely associated with mangrove vegetation distribution because it affects water availability, organic matter content, and nutrient availability within the substrate. Although numerous studies have investigated salt accumulation in mangroves across various species and locations, information regarding salt accumulation in *Aegiceras corniculatum* and *Avicennia lanata* within the mangrove ecosystem of Sarudu Village, Pasangkayu Regency, remains limited. Previous studies have primarily focused on other mangrove species, such as *Avicennia alba*, *Avicennia marina*, *Sonneratia alba*, and *Rhizophora mucronata*, and have generally examined salt accumulation in both roots and leaves simultaneously. To date, no quantitative data are available describing the level of salt accumulation in the leaves of *Aegiceras corniculatum* and *Avicennia lanata* growing under different inundation conditions in the mangrove forests of Sarudu Village.

Sarudu Village is one of the coastal areas in Pasangkayu Regency that supports a mangrove ecosystem inhabited by *Aegiceras corniculatum* and *Avicennia lanata*. Preliminary observations revealed relatively rapid leaf senescence and increased leaf abscission in both species. These conditions are suspected to be associated with the process of salt accumulation within leaf tissues. The novelty of this study lies in the analysis of salt (NaCl) accumulation in the leaves of two salt-secreting mangrove species, *Aegiceras corniculatum* and *Avicennia lanata*, growing under three different inundation conditions in the mangrove ecosystem of Sarudu Village, Pasangkayu Regency, using the Mohr argentometric titration method. This approach provides quantitative information on salt accumulation patterns in mangrove leaves under varying environmental conditions, thereby contributing to a better understanding of species-specific adaptive responses to salinity stress. Therefore, this study aimed to determine the level of salt (NaCl) accumulation in the leaves of *Aegiceras corniculatum* and *Avicennia lanata* in Sarudu Village, Pasangkayu Regency. Specifically, the study sought to analyze and compare NaCl accumulation levels in the leaves of these two species across three sampling stations characterized by different inundation levels within the mangrove ecosystem of Sarudu Village, Pasangkayu Regency.

MATERIALS AND METHODS

Study area

This study was conducted in July 2025. Leaf samples of *Aegiceras corniculatum* and *Avicennia lanata* were collected from the mangrove ecosystem of Sarudu Village, Sarudu District, Pasangkayu Regency. This location was selected because it supports mangrove species that possess salt-secretion (salt-secreting) mechanisms and exhibits signs of relatively rapid leaf senescence and increased leaf abscission in both species. These conditions are presumed to be associated with the accumulation of salt within leaf tissues as an adaptive response to the high-salinity conditions characteristic of coastal environments. In addition, no previous studies have specifically investigated the physiological characteristics of these two mangrove species in the study area. Consequently, scientific information regarding the condition and adaptive responses of mangroves in Sarudu Village remains limited. This study is expected to provide baseline data on the relationship between salt accumulation, leaf senescence, and leaf abscission in mangroves. Furthermore, the findings may serve as a valuable source of information for future mangrove management, conservation, and research development efforts in the Sarudu Village area.

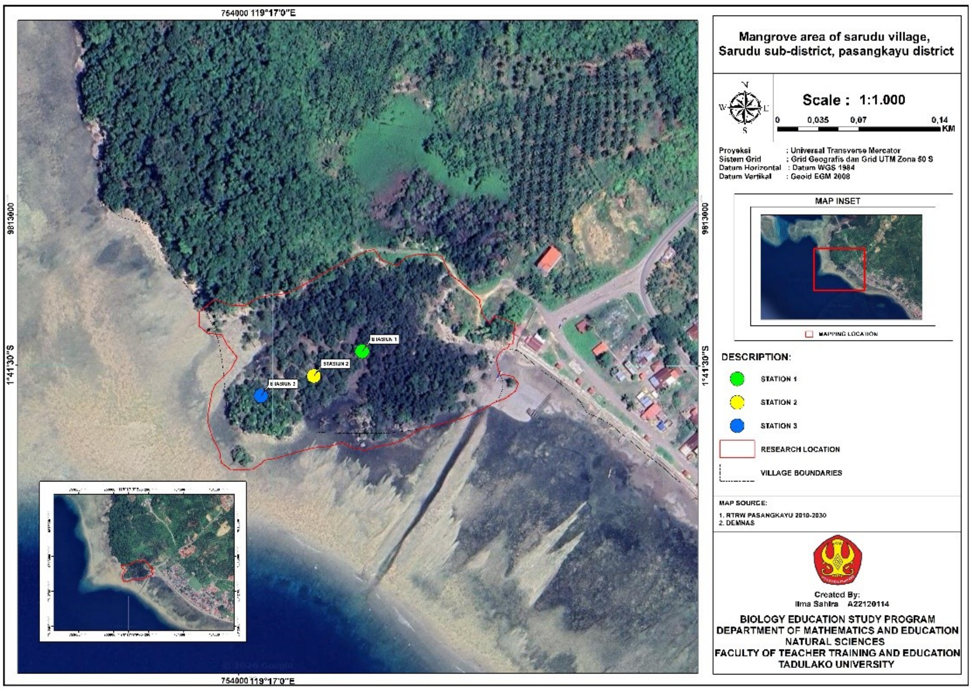

Figure 1. Map of the research location in Sarudu Village, Pasangkayu Regency, Indonesia (Arcgis 10.4).

Procedures

Leaf samples of Aegiceras corniculatum and Avicennia lanata were cleaned of any adhering debris and then sun-dried for three days until completely dry. The dried leaf samples were ground using a blender and sieved to obtain a homogeneous powder. A total of 0.5 g of the powdered sample was weighed and dissolved in 10 mL of distilled water. The solution was then filtered using filter paper to obtain a clear filtrate. The resulting filtrate was added with K_2CrO_4 indicator and subsequently titrated with a 0.1 N $AgNO_3$ standard solution until a brick-red color appeared indicating the endpoint of the titration. The volume of $AgNO_3$ used was recorded and employed to calculate the NaCl content in the leaf samples. NaCl concentration was calculated using the following equation. The analysis was performed in three replications for each sample to improve the precision and accuracy of the results. The obtained data were then averaged and presented in tabular form. The calculated NaCl values were subsequently used to compare the salt content between the two mangrove leaf species studied. NaCl content was determined using the following equation (Rahem & Kartika, 2020):

$$NaCl\ content\ (\%) = \frac{V \times N \times 58{,}5}{W}\ x\ 100$$

Explanation:
V = volume of $AgNO_3$ used in titration (mL)
N = normality of $AgNO_3$ 0.1 mol/L
58.5 = molar mass of NaCl (g/mol)
W = sample weight, 0.5 g converted to 500 mg

RESULTS AND DISCUSSION

Environmental Condition Measurement

Salt accumulation in the leaves of salt-secreting mangroves is influenced by various environmental factors, including temperature, pH, and salinity. These factors play an important role in determining the level of salt accumulation. The observed environmental conditions are presented in Table 1. The results of environmental parameter measurements in the mangrove forest area of Sarudu Village showed that water temperature from 30°C, salinity from 29–30 ppt, and pH ranged from 7.0–7.1, all of which are still within the optimal conditions for mangrove growth. A temperature of 30°C falls within the ideal range of 28–31°C, is influenced by sunny weather, and plays an important role in regulating metabolic activity and the distribution of aquatic organisms. Salinity levels of 29–30 ppt are also considered suitable for brackish water zones (10–30 ppt), reflecting the strong influence of tidal seawater, which is a key factor controlling mangrove zonation. Areas closer to the sea tend to have higher salinity compared to inland zones. Meanwhile, a pH range of 7.0–7.1, which is neutral, indicates productive and stable water conditions. This stability results from the balance between the decomposition of mangrove litter, which tends to produce acidic conditions, and the buffering capacity of carbonate and bicarbonate salts from seawater, which are alkaline in nature. Overall, these environmental parameters support the optimal growth and sustainability of mangrove ecosystems (Badu et al., 2022).

Table 1. Environmental Condition Measurement.

Water quality	Station 1	Station 2	Station 3
Temperature (°C)	30°C	30°C	30°C
Salinity (ppt)	29	29	30
pH	7,0	7,1	7,1

NaCl Salt Accumulation Data Analysis in *Aegiceras corniculatum* and *Avicennia lanata*

Data analysis in this study was conducted using leaf samples of *Aegiceras corniculatum* and *Avicennia lanata* through argentometric titration using the Mohr method. The results of the NaCl salt accumulation analysis in the leaves of both mangrove species indicated that the average salt accumulation increased from Station 1 to Station 3. At all sampling stations, *Aegiceras corniculatum* exhibited higher salt accumulation values compared to *Avicennia lanata*. The greatest difference between the two species was observed at Station 2, where salt accumulation values were 5.07% for *Aegiceras corniculatum* and 3.89% for *Avicennia lanata*. Meanwhile, the highest values for both species were recorded at Station 3, reaching 6.08% for *Aegiceras corniculatum* and 5.34% for *Avicennia lanata*. The results of NaCl accumulation analysis in the leaves of both species are presented in Table 2. Based on the measurements, the mean NaCl accumulation in *Aegiceras corniculatum* was 3.08% at Station 1, 5.07% at Station 2, and 6.08% at Station 3. In contrast, the mean NaCl accumulation in *Avicennia lanata* was 2.92% at Station 1, 3.89% at Station 2, and 5.34% at Station 3. The highest salt accumulation value was recorded in *Aegiceras corniculatum* at Station 3 (6.08%), while the lowest value was found in *Avicennia lanata* at Station 1 (2.92%). The standard deviation values at each station ranged from 0.30 to 0.49, indicating relatively low variation among replicates. Overall, at all observation stations, *Aegiceras corniculatum* showed higher average salt accumulation compared to *Avicennia lanata*.

NaCl salt accumulation in both mangrove species showed an increasing pattern from Station 1 to Station 3. The highest mean salt accumulation was recorded at Station 3, with values of 6.08% in *Aegiceras corniculatum* and 5.34% in *Avicennia lanata*. This increase in salt accumulation at sites with higher inundation is presumed to be associated with greater exposure to seawater and elevated environmental salinity, which influence the processes of salt ion uptake and regulation in mangroves. The results also showed that *Aegiceras corniculatum* consistently exhibited higher salt accumulation than *Avicennia lanata* across all observation stations. This difference is presumed to be related to species-specific differences in salt management mechanisms. As salt-secreting mangroves, both species possess leaf-based salt excretion mechanisms; however, the variation in accumulation levels indicates differences in physiological adaptive capacity between species. Antika et al. (2025) reported that *Avicennia lanata* possesses leaf anatomical structures and salt glands that function in regulating and excreting salt, enabling this species to survive in high-salinity environments. The relatively high salt accumulation observed in both species in this study indicates active salt regulation processes as an adaptive response to saline coastal conditions. The results of the analysis are presented in Table 2.

Table 2. NaCl Salt Accumulation Analysis in Mangroves of *Aegiceras corniculatum* and *Avicennia lanata.*

Samples	Station	Repetition	Sample Weight	Salt Accumulation	Average
Aegiceras corniculatum	1	I_a	0.5	3.39%	3.07%
		I_b		2.69%	
		I_c		3.15%	
	2	II_a	0.5	4.79%	5.06%
		II_b		5.38%	
		II_c		5.03%	
	3	III_a	0.5	5.85%	6.08%
		III_b		6.43%	
		III_C		5.96%	

Samples	Station	Repetition	Sample Weight	Salt Accumulation	Average
	1	I_a	0.5	3.27%	2.92%
		I_b		3.04%	
		I_c		2.45%	
	2	II_a	0.5	4.32%	3.89%
		II_b		3.74%	
		II_c		3.62%	
	3	III_a	0.5	5.73%	5.33%
		III_b		4.79%	
		III_C		5.49%	

Discussion

The results showed that NaCl salt accumulation in the leaves of *Aegiceras corniculatum* and *Avicennia lanata* increased from Station 1 to Station 3. Although the salinity levels among stations were relatively similar, ranging from 29–30 ppt, differences in salt accumulation were still observed in both species. This indicates that variations in salt accumulation are not solely influenced by water salinity but are also presumed to be related to the specific habitat characteristics of each station, including inundation frequency and the location's proximity to the coastline. Tobaru et al. (2024) explained that salinity, tidal dynamics, and aquatic environmental characteristics are site factors that influence physiological conditions and mangrove distribution in coastal ecosystems. Matatula et al. (2019) reported that salinity variation in mangrove environments is affected by water conditions and tidal fluctuations, while Hudoyo et al. (2021) emphasized that coastal hydrological characteristics play an important role in shaping mangrove habitat conditions. The observed increase is also presumed to be associated with environmental conditions characterized by higher inundation frequency and closer proximity to the coastline compared to the other stations. Rahman et al. (2025) stated that aquatic environmental factors, particularly salinity and tidal dynamics, significantly influence mangrove physiological conditions and distribution in coastal areas. This is further supported by Prayogo et al. (2025), who highlighted that environmental parameters are important indicators in determining mangrove ecosystem health and vegetation responses to habitat changes.

Differences in salt accumulation between the two species indicate that *Aegiceras corniculatum* exhibits a higher capacity for NaCl accumulation compared to *Avicennia lanata* across all observation stations. This difference is presumed to be related to variations in the physiological abilities of each species in absorbing, translocating, and excreting salt ions. The findings of this study are consistent with Ayyaz et al. (2023), who reported that *Aegiceras corniculatum* possesses high salinity tolerance through physiological adaptation mechanisms that support its survival in coastal environments. Saharani et al. (2025) also stated that each mangrove species has different adaptive strategies to coastal environmental conditions, resulting in variations in distribution patterns and salinity tolerance capacity. Variation in mangrove growth and adaptation across different coastal habitats has also been reported by Purnomo et al. (2025), who emphasized that species characteristics are a key factor in determining responses to varying environmental conditions. In addition, Sinyo et al. (2022) stated that salt accumulation levels in salt-secreting mangroves may differ among species due to differences in their ability to regulate salt absorbed from the environment.

The increase in salt accumulation at Station 3 is presumed to be associated with site conditions characterized by a higher inundation level compared to the other stations. Station 3 has an inundation depth of approximately 20 cm and is located closer to the coastline, allowing more intensive contact with seawater than Station 1 and Station 2. However, this study did not directly measure inundation frequency or duration; therefore, the relationship between inundation level and salt accumulation cannot be quantified in detail. Accordingly, further studies are required to assess tidal dynamics and inundation duration to obtain more comprehensive information. This pattern is consistent with the findings of Worabai et al. (2025), who reported that mangrove zonation and distribution are strongly influenced by habitat conditions, particularly salinity, substrate type, and tidal regimes. Differences in inundation conditions among stations in this study are presumed to be one of the factors affecting variations in salt accumulation in both mangrove species observed. Hudoyo et al. (2021) also stated that tidal processes and coastal hydrological conditions significantly influence mangrove habitat characteristics. The increase in salt accumulation in environments with higher salinity indicates that mangroves possess adaptive capabilities to saline conditions through mechanisms that regulate absorbed salt. This ability allows mangroves to maintain physiological balance despite growing in coastal habitats influenced by seawater (Khoiriyah & Widiyanti, 2023). Furthermore, Moha et al. (2025) explained that mangrove community structure in coastal areas is strongly affected by hydrological conditions and environmental salinity levels.

Mangroves possess distinctive root systems and are typically exposed to high environmental temperatures. Water and ion absorption in mangroves primarily occurs through root tips or root hairs, which have a large surface area. Ions are absorbed at the root epidermis and subsequently transported to the xylem via the symplastic pathway, passing through the epidermis, exodermis, cortex, endodermis, and pericycle, while still crossing selective living cell membranes. Soil water, which is less concentrated than cell sap, enters the roots via osmosis and is then transported through the xylem vessels to the leaves. This movement is driven by root pressure, stem capillarity, and leaf transpiration pull (Rudianti, 2018). As salt-secreting mangrove species, *Aegiceras corniculatum* and *Avicennia lanata* have the ability to excrete excess salt through salt glands located on their leaves. Apriliyani (2015) reported that increasing salinity affects various growth parameters of *Avicennia officinalis* seedlings, such as plant height, number of leaves, leaf area, as well as root and shoot biomass. These findings indicate that salinity stress induces complex physiological responses as an adaptive strategy to maintain osmotic balance and sustain growth in saline coastal environments. The presence of such structures represents an important physiological adaptation that enables mangroves to survive in high-salinity habitats. Antika et al. (2025) reported that *Avicennia lanata* possesses leaf anatomical structures that support salt regulation and excretion processes, allowing it to thrive in saline coastal environments. Similarly, Wang et al. (2025) demonstrated that mangrove species have cellular-level water and salt regulation mechanisms that play a crucial role in maintaining ionic balance under high-salinity conditions. The relatively high salt accumulation observed in both species in this study indicates the presence of salt management mechanisms as an adaptive response to coastal environments influenced by seawater inundation.

CONCLUSIONS

The results of environmental condition measurements in the mangrove forest area of Sarudu Village showed that the air temperature reached 30°C, with salinity levels ranging from 29–30 ppt and pH values between 7.0–7.1. These environmental conditions indicate that the mangrove area is still within a range that supports the growth and development of mangrove vegetation. Based on the results of the study, the highest average salt (NaCl) accumulation in the leaves of *Aegiceras corniculatum* was recorded at Station 3, with a value of 6.08%, while the lowest value was observed at Station 1, with 3.07%. Similarly, in *Avicennia lanata*, the highest NaCl accumulation was at Station 3 (5.33%), and the lowest at Station 1 (2.92%). The higher salt accumulation at Station 3 compared to the other stations is presumed to be influenced by its location in a coastal area that experiences more frequent seawater inundation, with water depth of approximately 20 cm. Higher inundation frequency facilitates greater salt input into the substrate, thereby increasing salt uptake by mangrove plants. In addition, the proximity of the site to the seawater source also contributes to higher salt concentrations accumulated in the leaf tissues of both species.

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