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A comparative anatomical and taxonomic study of three aquatic species: *Typha domingensis, Eichhornia crassipes,* and *Nasturtium officinale*

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Abstract

This study was conducted at three stations along the Tigris River in Salah al-Din Governorate (Al-Dhuluiya, Al-Alam, and Baiji) to compare the leaves of three aquatic and semi-aquatic species *Typha domingensis, Eichhornia crassipes, and Nasturtium officinale* from both morphological and anatomical perspectives.

The anatomical examination of transverse leaf sections revealed distinct structural variations reflecting ecological adaptations. *Eichhornia crassipes* exhibited the most extensive development of aerenchyma, with large intercellular air spaces occupying the majority of the mesophyll, a clear adaptation to its free-floating aquatic lifestyle. *Typha domingensis* showed well-developed but comparatively smaller aerenchyma, consistent with its emergent growth in swampy habitats. *Nasturtium officinale*, in contrast, possessed a mesophyll with moderately developed intercellular spaces and limited aerenchyma, corresponding to its semi-aquatic habitat.

Morphological observations further supported these adaptations. *Typha domingensis* bears long, linear, ribbon-like leaves (1–3 m in length) with parallel venation, providing mechanical support and efficient emergent growth. *Eichhornia crassipes* is characterized by broad, ovate to orbicular floating leaves with inflated, spongy petioles that enhance buoyancy. *Nasturtium officinale* has pinnately compound leaves with fleshy, ovate leaflets and long, flexible petioles, adaptations that facilitate survival in partially submerged and humid environments.

Keywords: Parenchyma Differentiation; Leaf Anatomical Adaptation; Hydrophytic Features; Parenchyma Differentiation; Aerenchyma Tissue; Stomatal Distribution

1. Introduction

Also referred to as hydrophytes or macrophytes, represent a diverse group of plant species that have undergone morphological (1), anatomical, and physiological adaptations enabling them to survive in saturated soils or in conditions where they are partially or fully submerged in water (2). These plants are essential to freshwater environments and estuarine ecosystems, which play a major role in nutrient cycling, primary productivity, and offering a variety of aquatic organism's structural habitats (3). highlights the essential role that aquatic plants play in aquatic food webs. assisting detritus-based systems by allowing their organic matter to break down and providing herbivores with a direct food source. (4) emphasize their ecological importance, pointing out how they help stabilize sediments, lessen shoreline erosion, and enhancing the quality of water by serving as bio filters to eliminate contaminants and enhancing the quality of water by serving as bio filters to eliminate contaminants and absorb surplus nutrients (5). Different morphological and anatomical adaptations are present in aquatic plants. that enable them to flourish in anoxic and wet conditions. Among them are thin cuticles, diminished or nonexistent stomata on submerged leaves, and aerenchyma development

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tissue that aids in gas exchange and buoyancy, as well as specific reproductive techniques. (6) through Anatomical studies revealed that these modifications are evolutionary reactions to anoxic or hypoxic environments, guaranteeing effective oxygen transfer to tissues that are submerged. Some species, including *Eichhornia crassipes* and *Pistia stratiotes* have exceptional vegetative propagation skills that allow for quick colonization have exceptional vegetative propagation skills that allow for quick colonization. of aquatic habitats, which can occasionally lead to invasive behavior (7). Beyond Aquatic plants play important ecological roles and have significant economic and medicinal Aquatic plants play important ecological roles and have significant economic and medicinal significance (8).

2. Biology of the species under study

2.1. First: Eichhornia crassipes

This species belongs to the Pontidryaceae family (9). It is native to the Amazon basin of South America, but due to its exceptional versatility, it has been widely introduced to tropical and subtropical regions for its ornamental value (10). Morphologically, this species is characterized by a thick, fibrous root system, often connected by fine biofilms, as well as thick, glossy, oval leaves with swollen, spongy petioles that provide buoyancy (11). Its inflorescences consist of flower spikes ranging in color from lavender to violet, each with a noticeable yellow spot on the upper petal, an essential feature for attracting pollinators (12). *E. crassipes* poses ecological risks, but it has also demonstrated possible environmental and financial gains when appropriately mastered (13). It is very effective in eliminating heavy metals like lead, cadmium, and arsenic through phytoremediation, as well as wastewater's excess nutrients and organic pollutants (14). Its substantial biomass, abundant in for bioenergy, nitrogen, potassium, calcium, and magnesium have all been investigated. production, biochar synthesis, composting, and as a source of animal manure and green manure feed (15).

2.2. Second: Typha domingensis

Often called southern bulrush or southern cattail, *Typha domingensis* (16). is a perennial emergent macrophyte that is a member of the Typhaceae family (17). It flourishes in It is extensively found in wetlands, marshes, lakeshores, and slowly flowing rivers. Africa, Asia, Europe, and the Americas' tropical and subtropical zones (18). The plant, distinguished by its characteristic cylindrical inflorescences and long, narrow leaves made up of distinct flower spikes for the male (upper) and female (lower), usually grows in It can grow to a height of 2–4 m in shallow water or saturated soils (19). *T. domingensis* is a significant ecological element in wetland ecosystems. It's a vast rhizomatous root network is essential for preventing shoreline erosion and sediment stabilization (20). Furthermore, it offers habitat and food for a variety of fauna, such as birds, fish, and invertebrates (21). *T. domingensis* is noteworthy for its high phytoremediation efficiency (22). The Significant levels of heavy metals, including lead (Pb), can be accumulated by plants (23). mercury (Hg), cadmium (Cd), and chromium (Cr) in its roots and aerial tissues, making it appropriate for artificial wetlands and wastewater treatment systems. Research has claimed that it could eliminate 70–80% of specific pollutants from contaminated water (24).

2.3. Third: Nasturtium officinale

Watercress, or *Nasturtium officinale*, is a perennial aquatic plant. plant that is a member of the Brassicaceae family (25). It can be found all over the temperate areas and is regarded as one of the first leafy vegetables that people ate (26). It has historically been valued as a medicinal herb as well as a nutrient-dense food. demonstrating its use as a therapeutic food with functional qualities (27). *N. officinale* contains a variety of phencompounds in addition to glucosinolates. comprising phenolic acids like caffeic acid and flavonoids like quercetin and kaempferol and chlorogenic acids, all of which greatly enhance its potent antioxidant properties (28). According to experimental research, PEITC reduces oxidative stress and DNA damage by blocking phase I enzymes involved in carcinogenesis and triggering apoptosis Phase II detoxification enzymes are activated and modulated (29). Additionally, this plant's phenolic-richch extracts have shown neuroprotective and hepatoprotective properties (30).

3. Material and methods

3.1. Preparing transverse sections

Eichhornia crassipes, Typha domingensis, and Nasturtium officinale fresh leaves were cut into thin, consistent slices by hand using a sharp razor blade to section transversely. appropriate for microscopic inspection. The sections were cleaned right away using distilled water to get rid of any adhering debris and any remaining cell sap (31).

3.2. Double Staining Technique

A common double staining procedure was applied to the transverse sections using Fast Green and Safranin. The sections were initially submerged in a 1% Safranin solution. for roughly two to five minutes, enabling the stain to permeate and color tissues with thick walls and lignification. Distillation water was used to gently rinse away any excess stain. in order to avoid overstaining. After that, the sections were counterstained using 0.5% Fast Green for 30 to 60 seconds to distinguish between tissues with thin walls, such as parenchyma and cells of the collenchyma. Finally, the stained sections were briefly rinsed, mounted in 50% glycerin, and prepared for microscopic observation. Safranin imparted a distinct red coloration to lignified cell walls and xylem vessels, whereas Fast Green-stained non-lignified tissues green, providing clear contrast between different tissue types.

4. Results and discussion

4.1. The Anatomical study

4.1.1. The species Eichhornia crassipe

The transverse section of the leaf of *Eichhornia crassipes*, commonly known as water hyacinth, exhibits the typical anatomical traits of a free-floating hydrophytic monocotyledonous plant. Its structure reflects several specialized adaptations to an aquatic environment. The section reveals the following components figure 1:

Epidermis

The epidermis is single-layered, composed of large, polygonal, thin-walled cells, externally covered by a very thin cuticle, indicating minimal adaptation for water conservation.

The lack of significant lignification contributes to the flexibility of the leaves, which is advantageous in an aquatic habitat.

Numerous stomata are present on both surfaces (amphistomatic condition). The stomata are oval in shape, formed by two kidney-shaped guard cells, and facilitate efficient gaseous exchange in a water-rich environment.

Mesophyll

As is typical of hydrophytes, the mesophyll is undifferentiated into palisade and spongy parenchyma and consists of two main tissues

- Chlorenchyma: Located directly beneath the epidermis, composed of compact parenchymatous cells rich in chloroplasts, serving as the primary site of photosynthesis.
- Aerenchyma: Constituting the majority of the mesophyll, formed by large intercellular air spaces (air lacunae) separated by thin-walled parenchymatous cells. These air cavities are essential hydromorphic adaptations that enhance buoyancy and facilitate internal aeration under hypoxic aquatic conditions.

Vascular System

The vascular bundles are collateral and closed, scattered throughout the mesophyll, and surrounded by a parenchymatous bundle sheath.

- Xylem: Poorly developed and oriented towards the adaxial side, reflecting the minimal need for water conduction in an aquatic habitat.
- Phloem: Well-developed and oriented towards the abaxial side, ensuring the active translocation of photosynthates.

Additional Hydromorphic Features

The presence of soft parenchymatous tissues, a very thin cuticle, and reduced sclerenchyma indicates low mechanical stress and minimal structural support requirements.

Large air lacunae within the aerenchyma provide buoyancy, keeping the leaves afloat on the water surface.

Chloroplast-rich epidermal and mesophyll cells enhance photosynthesis in environments with high light availability.

4.1.2. The species Typha domingensis

According to the provided microscopic image figure 1, the transverse section of the Typha domingensis leaf exhibits the typical anatomical features of a hydrophytic monocotyledonous plant, well adapted to its aquatic or semi-aquatic environment.

Epidermis

Due to its aquatic habitat, where excessive water loss is not a concern, the epidermis consists of a single layer of polygonal cells externally covered by a very thin cuticle. The epidermal cells are relatively large, thin-walled, and lack significant lignification. A key distinguishing characteristic of the epidermis is the presence of stomata, which are elliptical structures formed by two kidney-shaped guard cells.

In the water-rich environment, numerous stomata distributed on both leaf surfaces facilitate efficient gaseous exchange.

Mesophyll

Beneath the epidermis, the mesophyll differentiates into aerenchyma and chlorenchyma.

- **Chlorenchyma**: Located directly under the epidermis, it is composed of compact parenchymatous cells rich in chloroplasts, actively participating in photosynthesis.
- **Aerenchyma**: Typha domingensis possesses a highly developed aerenchyma, which constitutes the majority of the mesophyll. This tissue consists of large intercellular air spaces separated by thin parenchymatous cell walls. These extensive air lacunae, clearly visible in transverse sections, represent an essential adaptation for buoyancy and internal aeration, enabling the plant to survive in hypoxic aquatic environments.

Vascular System

The vascular bundles are scattered throughout the mesophyll and are enclosed by a parenchymatous bundle sheath. Consistent with typical monocot anatomy, each vascular bundle is collateral and closed, with xylem oriented toward the adaxial side and phloem toward the abaxial side.

Since the plant is hydrophytic and water conduction is not limiting, the xylem vessels are comparatively small. Conversely, the well-developed phloem indicates active translocation of photosynthates.

General Adaptations

Overall, the leaf structure clearly exhibits hydrophytic adaptations, including a prominent aerenchyma, a thin epidermis with numerous stomata to facilitate rapid gaseous exchange, and a poorly developed cuticle.

4.1.3. The Species Nasturtium officinale

The transverse section of the leaf of *Nasturtium officinale*, a semi-aquatic dicotyledonous plant belonging to the family Brassicaceae, exhibits distinct xeromorphic and hydromorphic anatomical features that reflect its adaptation to a semi-aquatic habitat. The stained section reveals the following structural details figure 1:

Epidermis

The upper epidermis consists of a single layer of polygonal cells with thin cell walls, externally covered by a relatively thin cuticle. This structure reflects adaptation to a humid or aquatic environment, where water loss is minimal.

The lower epidermis is similar in structure to the upper epidermis but contains a higher density of stomata, making the leaf amphistomatic. The stomata are of the cruciferous type, a characteristic feature of the Brassicaceae family, facilitating efficient gaseous exchange in moist conditions.

Mesophyll

The mesophyll is dorsiventral and differentiated into two distinct regions

- **Palisade Parenchyma**: Located beneath the upper epidermis, it consists of one to two layers of elongated columnar cells tightly packed with chloroplasts, serving as the primary site of photosynthesis. The relatively reduced thickness, compared with terrestrial dicot leaves, reflects its adaptation to an aquatic or semi-aquatic habitat.

- **Spongy Parenchyma**: Occupying the lower mesophyll region, it is composed of loosely arranged, irregularly shaped cells with conspicuous intercellular air spaces (aerenchyma). These air cavities are essential hydromorphic adaptations, enhancing buoyancy and facilitating internal aeration.

Vascular System

The vascular bundles are collateral and closed, surrounded by a parenchymatous bundle sheath.

- **Xylem**: Reduced in amount and oriented towards the adaxial (upper) side, consistent with the plant's low requirement for water conduction in a water-abundant environment.
- **Phloem**: Well-developed and located towards the abaxial (lower) side, ensuring efficient translocation of photosynthates.

The vascular bundles are relatively small and scattered within the mesophyll, a typical feature of delicate aquatic leaves.

- Additional Hydromorphic Features

The spongy mesophyll contains large intercellular air spaces (aerenchyma), which improve aeration and increase buoyancy. The thin cuticle and reduced sclerenchyma indicate low mechanical stress and minimal need for water conservation. In addition, some epidermal cells may contain chloroplasts, contributing to photosynthesis, especially in thin leaves exposed to abundant light and water.

The three aquatic and semi-aquatic plant species under study (*Typha domingensis, Eichhornia crassipes, and Nasturtium officinale*) exhibit both common hydrophytic adaptations and species-specific structural variations reflecting their ecological niches. The comparison is summarized as follows:

- Epidermis

- *Typha domingensis* The epidermis is single-layered, composed of thin-walled polygonal cells covered by an extremely thin cuticle.
- Stomata are amphistomatic, elliptical in shape, and consist of kidney-shaped guard cells distributed on both surfaces, enabling effective gaseous exchange in an aquatic environment.
- *Eichhornia crassipes* The epidermis is single-layered, consisting of large polygonal thin-walled cells with a very thin cuticle and little lignification, providing flexibility and buoyancy for floating leaves.
- The leaf surface is amphistomatic with numerous oval stomata, each formed by two kidney-shaped guard cells, adapted to a free-floating aquatic lifestyle.
- *Nasturtium officinale* The epidermis is single-layered, with thin-walled polygonal cells and a relatively thin cuticle compared to terrestrial plants.
- Amphistomatic leaves possess Brassicaceae-typical cruciferous-type stomata, allowing efficient gaseous exchange in humid or semi-submerged conditions.
- Mesophyll

- *Typha domingensis* The mesophyll is differentiated into chlorenchyma beneath the epidermis and extensive aerenchyma occupying the majority of the mesophyll.
- Large intercellular air spaces enhance internal aeration and provide buoyancy.
- *Eichhornia crassipes* The mesophyll is undifferentiated, with chlorenchyma located directly beneath the epidermis for photosynthesis.
- Highly developed aerenchyma with large air lacunae ensures excellent buoyancy, characteristic of floating hydrophytes.
- *Nasturtium officinale* The mesophyll is dorsiventral, with 1–2 layers of palisade parenchyma rich in chloroplasts beneath the upper epidermis, and spongy parenchyma with moderate intercellular air spaces.
- The aerenchyma is less developed than in the other two species, reflecting adaptation to semi-aquatic conditions.

Vascular System

- *Typha domingensis* The vascular bundles are collateral and closed, scattered within the mesophyll, with reduced xylem and well-developed phloem, indicating hydrophytic adaptation.
- *Eichhornia crassipes* Similar to Typha, the vascular bundles are collateral and closed, dispersed throughout the mesophyll, with poorly developed xylem and well-developed phloem.
- *Nasturtium officinale* The vascular bundles are collateral and closed, surrounded by a parenchymatous sheath.
- Xylem is reduced, while phloem is well-developed. The bundles are comparatively small and scattered, typical of delicate aquatic or semi-aquatic dicot leaves.

Hydromorphic Adaptations

- *Typha domingensis* Prominent aerenchyma, amphistomatic leaves, thin cuticle, and reduced sclerenchyma reflect strong adaptation to completely aquatic or marshy habitats.
- *Eichhornia crassipes* Highly developed aerenchyma with large air lacunae for buoyancy, thin epidermis, numerous stomata, and reduced supporting tissues indicate adaptation to a free-floating aquatic lifestyle.
- *Nasturtium officinale* Moderate aerenchyma, dorsiventral mesophyll, thin cuticle, and amphistomatic condition suggest semi-aquatic adaptations, more suited to humid or partially submerged environments than to fully aquatic habitats.

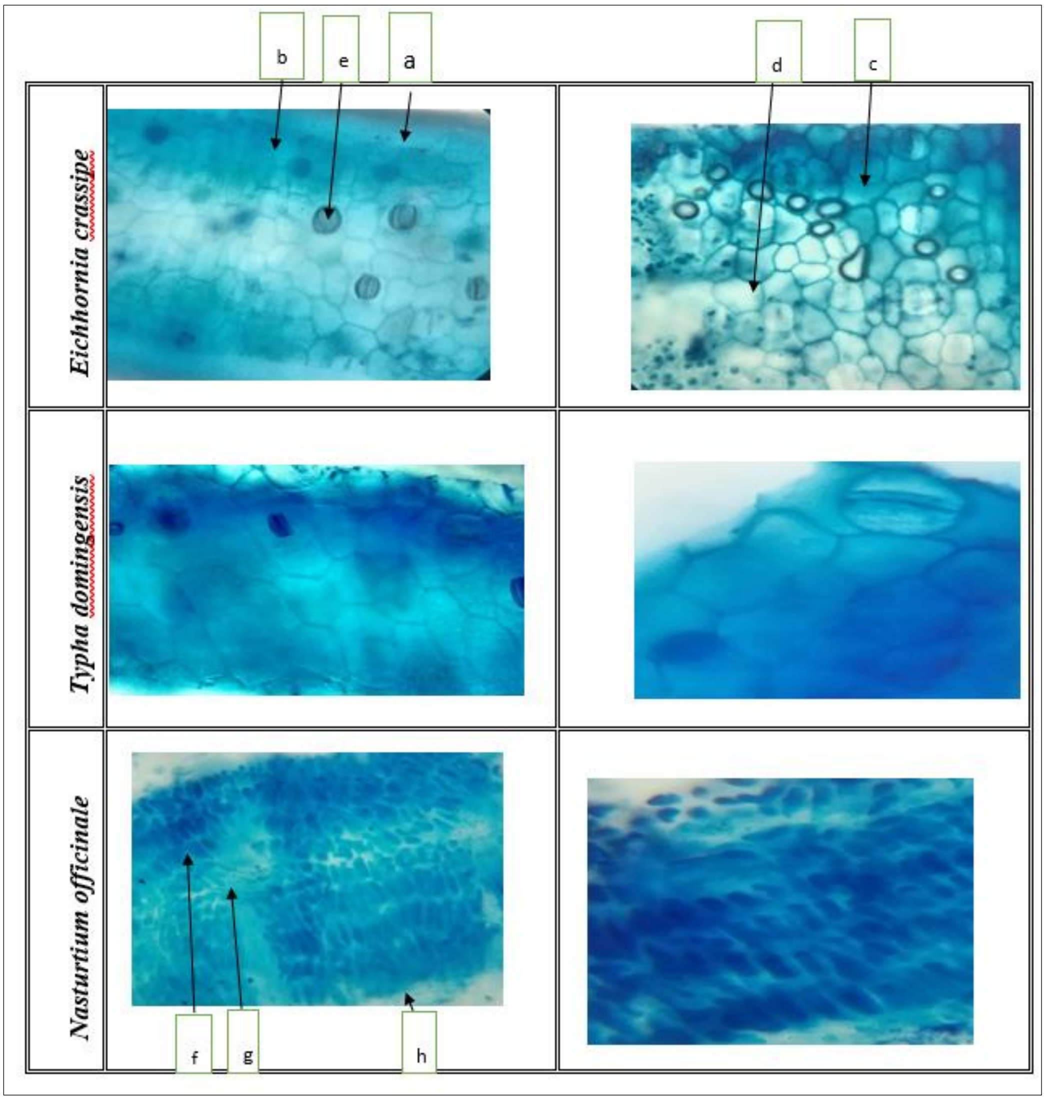

Figure 1 Cross sections of the leaf 1-a: Epidermis upper 2-b: Collenchyma 3-c: Paranchyma 4-d: Aerenchyma 5-e: Stomata 6-f: Palisade cell.7-g: Spongy cell 8-h: Lower epidermis

4.2. Anatomical study

4.2.1. The species Eichhornia crassipe

Eichhornia crassipes leaves have unique morphological adaptations that allow the plant to flourish as an aquatic hydrophyte that floats freely figure 2.

- Arrangement of Leaves
  - The leaves grow from a short, thickenstem and are simple and alternately arranged. They It is called a compressed rhizome. Every leaf is joined to the enlarged stem. spongy petiole that gives the water's surface stability and buoyancy.
- Size and Shape of the Leaf
  - The lamina ranges in shape from ovate to orbicular and is smooth, glossy, and broad. The leaf's heart-shaped, cordate base ensures a secure attachment to the petiole. Thiele the apex is somewhat obtuse and rounded. Environmental factors influence the size of leaves. Circumstances, with diameters usually between 10 and 20 cm, providing ta leaves with a relatively thick and large in appearance.
- Leaf Texture and Margin
  - The leaf margin is entire, smooth, and free of serrations. The lamina is thick, fleshy, and coriaceous, which enhances buoyancy and provides mechanical resistance to water currents.
- Venation Pattern
  - The venation is reticulate (net-like), which is characteristic of modified hydrophytic monocots. The midrib is prominent and slightly raised on the abaxial (lower) surface, contributing to mechanical support.
- Petiole Structure
  - The petiole is long, spongy, and prominently inflated, forming a bulbous structure filled with aerenchyma tissue that facilitates buoyancy. Its smooth, green surface also contributes to photosynthesis.
- Leaf Coloration
  - The leaves are bright green and glossy, reflecting a high chlorophyll content, which supports efficient photosynthesis under high light intensity in open aquatic habitats.
- Adaptive Significance
  - The thick, waxy cuticle of the lamina and the inflated petiole play crucial roles in maintaining buoyancy and preventing waterlogging. The broad lamina maximizes light interception, enhancing photosynthetic efficiency in floating aquatic

4.2.2. The species Typha domingensis

The leaves of *Typha domingensis* exhibit distinct morphological features that are highly adapted to its emergent hydrophytic lifestyle in marshy and wetland habitats.

- Leaf Arrangement
  - The leaves are simple, long, and linear, arranged in a basal rosette pattern. They emerge alternately from the stem base, forming dense clusters that encircle and protect the basal portion of the stem.
- Leaf Size and Shape
  - The lamina is narrow and linear-ensiform (sword-shaped), with a strap-like appearance. Leaf length varies between 1 and 3 meters, depending on water depth and surrounding environmental conditions. The leaves are grass-like due to their relatively small width, which ranges from 0.5 to 2 cm.
- Leaf Base and Apex
  - The leaf apex is acute and tapering, facilitating efficient water shedding. The leaf base partially sheaths the stem, providing mechanical support and stability in marshy or aquatic environments.
- Leaf Texture and Margin
  - The leaf margin is entire and smooth, lacking serrations. It's coriaceous, thick, and The leaf's somewhat stiff texture allows it to resist water currents and stay upright. Place above the water's surface.
- Pattern of Vendors
  - Being a species that is monocotyledonous, Parallel venation is seen in *Typha domingensis.* Along the lamina, numerous tiny veins run longitudinally, providing both mechanical flexibility and strength.
- Color of the Leaf
  - The dull, waxy surface of the green to grayish-green leaves reduces water absorption. loss and provides defense against fungal infections that are prevalent in marshy environments.

- Adaptive Significance
    - Above the water's surface, light interception is improved by the long, narrow, and upright leaves. Their thin, strap-like shape lessens resistance to wind and water currents, and their parallel venation and rigid texture offer structural support, guaranteeing stability in aquatic conditions that are emerging.

4.2.3. The Species Nasturtium officinale

Nasturtium officinale leaves have unique morphological adaptations that sustain its semi-aquatic way of life in habitats that are humid and partially submerged.

- Arrangement of Leaves
    - Along the succulent, creeping stem, the leaves are arranged alternately. They create dense clusters close to the water's surface, enhancing photosynthetic stability and efficiency in conditions of partial submersion.
- Type and Composition of Leaves
    - The leaves are pinnately compound, with multiple leaflets arranged oppositely. sitely. ositely along the middle rachis. In general, the terminal leaflet is rounder and larger than the lateral ones, giving light interception a larger surface area.
- Leaf Size and Shape
    - The leaflets have entire or slightly crenate (wavy) margins and are ovate to obovate in shape. Depending on the surroundings, their length varies from 2 to 5 cm, making in contrast to other aquatic macrophytes, they are comparatively small.
- Apex and Leaf Base
    - Each leaflet has a rounded, obtuse apex and a base that tapers toward the petiolule. form that reduces mechanical damage and promotes effective water shedding in water that is flowing.
- Leaf Texture and Margin
    - Because of its high-water content, the lamina has a smooth, succulent texture. Adjustment to moist conditions. The leaflets' full or slightly lobed margin provides somewhat wavy look, which could lessen drag in gentle water flows.
- Structure of Petioles
    - The long, thin, and meaty petiole helps to keep the leaflets at or close to the water's surface and permits flexibility in water currents. It ranges in length from 2 to 10cm, depending on the conditions of growth.
- Leaf Coloration
    - A high concentration of chlorophyll is indicated by the leaves' bright to dark green color.
    - providing low- to moderate-light conditions that are typical of shaded or
    - habitats that are partially submerged.

4.3. Significance in Adaptation

The leaves' complex structure improves flexibility and lowers water resistance. avoiding mechanical stress by preventing currents. Water is stored by the succulent texture. Orage adaptability and could make gas exchange easier in moist or submerged conditions. Furthermore, the leaflets can float or stay upright in shallow water thanks to the long petioles. water, maximizing the absorption of light. Comparative analysis of the three leaves' morphological traits Significant structural variations were found in the studied species, indicating their ecological modifications to various aquatic environments.

4.3.1. Morphological Comparison

Typha domingensis exhibits morphological traits typical of emergent hydrophytes. Its leaves are long, strap-like, and linear, arranged alternately in a basal rosette. The lamina is stiff, coriaceous, and grayish-green with a dull, waxy surface. Leaves range from 1 to 3 meters in length and 0.5 to 2 cm in width. The long, sheathing petiole provides strong mechanical support, while the parallel venation (a monocot characteristic) enhances structural rigidity and resistance to water currents, enabling the plant to remain erect above the water surface.

Eichhornia crassipes, in contrast, shows highly specialized morphological adaptations for a free-floating lifestyle. It's simple, broad, ovate to orbicular leaves have smooth, entire, fleshy margins and a glossy, bright green surface. The lamina averages 10 to 20 cm in diameter, supported by swollen, inflated, spongy petioles filled with aerenchyma tissue, which ensures excellent buoyancy.

Nasturtium officinale possesses intermediate morphological adaptations characteristic of semi-aquatic plants. Its compound pinnate leaves consist of multiple ovate to obovate fleshy leaflets arranged alternately along a creeping stem. The terminal leaflet is typically larger with entire to slightly crenate margins. Long, slender, and flexible petioles enable the plant to partially float or withstand mild water currents. The bright to dark green coloration reflects a high chlorophyll content, allowing efficient photosynthesis in humid, partially submerged conditions.

4.3.2. Ecological Interpretation

The comparative findings reveal a clear relationship between leaf structure and ecological adaptation:

The most sophisticated hydrophytic specializations are displayed by *Eichhornia crassipes*, which is ideal for suitable for a free-floating way of life, with a focus on buoyancy, high photosynthetic, and adjustment to aquatic hypoxic conditions. Strongly suited to emergent swampy environments, *Typha domingensis* has structural reduced hydrophytic specializations and stiffness, which allow it to grow upright above the surface of the water.

Office *Nasturtium officinale* exhibits intermediate characteristics, fusing mesophytic and Its semi-aquatic, humid, and partially submerged habitat is reflected in its hydrophytic characteristics. Together, these anatomical and morphological changes show how strVariation Aquatic plant variation is strongly linked to ecological tactics and habitat-specific necessities for survival.

Figure 2 A- *Eichhornia crassipes* B- *Typha domingensis* C- *Nasturtium officinale*

5. Conclusion

Typha domingensis's comparative morphological and anatomical analysis, *Nasturtium officinale* and *Eichhornia crassipes* demonstrate the close relationship between aquatic plants' ecological niches and structural modifications. *Escherichia crassipes* possesses the most specialized hydrophytic characteristics, such as extensive aerenchyma, undifferentiated mesophyll, and inflated petioles, which guarantee buoyancy and effective photosynthesis when floating freely. The adaptations of *Typha domingensis* appropriate for emergent swampy environments, including stripes of strap-like leaves, moderate development of the aerenchyma and strong mechanical support. In the connasturtium *Nasturtium officinale* exhibits intermediate characteristics, fusing hydrophytic and mesophytic characteristics that allow for survival in humid and semi-aquatic conditions. These results highlight the evolutionary importance of structural diversity as a crucial component of aquatic aerophyte habitat specialization, utilization, and ecological success.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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