RESEARCH ARTICLE

Intra and Interspecific Relation of Tree Species Aspects of Seed Biometry, Phenology, Seed Dispersion, and Germination

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Abstract

Bangladesh, with its dense population and diverse ecological landscape, embodies a unique environmental tapestry. This study explores the intricate interplay between tree phenology, seed dispersal seed germination, and biometric characteristics within the context of Bangladesh's rich biodiversity. Through field research conducted from 2020 to 2023 in the Chittagong division, we investigated species such as *Artocarpus chama*, *Avicennia officinalis*, *Terminalia arjuna*, *Terminalia bellirica*, and *Terminalia chebula*. The findings reveal significant variations in seed morphology, phenology, germination, and ecological roles among these species. Furthermore, through dendrogram analysis and principal component analysis (PCA), we elucidate the underlying patterns and relationships governing biometric variability. These insights provide valuable contributions to our understanding of ecological processes and inform conservation strategies aimed at preserving Bangladesh's forest tree biodiversity.

Keywords: Seed biometry; Phenology; Seed dispersion; Seed quality; Germination

Introduction

Bangladesh, a country marked by its dense population and rich biodiversity, presents a unique environmental canvas. With an astounding density of 1,119 people per square kilometer (Miah et al., 2023), it covers approximately 11% of its total land area with forests, comprising three distinct types: evergreen, mixed evergreen, and deciduous. This diversity in forest types contributes to the nation's extensive biodiversity, boasting around 500 timber species among its flora (Reza & Kamrul, 2012; Uddin et al., 2020). Such ecological richness plays a pivotal role in the global effort to combat warming, offering a natural buffer against climate change (Islam et al., 2022). However, this biodiversity is under threat, with an increasing number of species becoming critically endangered (Rahman et al., 2018). The causes of species degradation in Bangladesh are multifaceted, involving both abiotic and biotic factors that influence species distribution. These factors are intertwined with the ecological processes (Crouzeilles et al., 2016) that sustain the country's rich biodiversity. For instance, phenology, the study of periodic plant and animal life cycle events, seed size, types, and dispersal rates are crucial for understanding seed germination and the natural regeneration of species (Lima et al., 2020). These elements are essential for the maintenance and restoration of ecological balance within the forests (Islam et al., 2022).

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The challenge of preserving Bangladesh's biodiversity is significant, given the pressures of human population density and the consequent habitat destruction (Roy et al., 2015). Conservation efforts must prioritize the understanding of ecological interactions, such as the relationships between species and their physical environment, and how these are affected by human activity. Protecting the natural habitats, promoting sustainable land use practices, and fostering a deeper understanding of the ecological importance of biodiversity are critical steps toward mitigating the effects of global warming and ensuring the survival of critically endangered species (Hossain et al., 2020). The path forward involves a comprehensive approach that integrates conservation, education, and sustainable development to safeguard the natural heritage of Bangladesh for future generations (Islam et al., 2022).

Artocarpus chama, a species within the genus Artocarpus, is a remarkable deciduous tree known for its straight bole and significant stature (Krupa et al., 2022), reaching heights of 30-40 meters with a diameter at breast height (DBH) of 1-1.5 meters (Roy et al., 2015). This tree exemplifies the diversity and utility found within its family, contributing not only to the ecological framework of its native habitats but also offering benefits to wildlife, particularly birds that find its fruits edible (Kumar et al., 2017).

Preferring shaded environments, *Artocarpus chama* thrives in moist conditions, indicative of its adaptation to specific ecological niches that favor moisture and reduced direct sunlight. This preference suggests that the tree plays a crucial role in its ecosystem, likely contributing to the structure and function of the forest layers by providing canopy coverage or acting as an understory component in more densely forested areas (Jagtap & Bapat, 2010). The fruit of *Artocarpus chama* serves as a food source for a variety of bird species, facilitating seed dispersal through ornithochory (seed dispersal by birds) (Lima et al., 2020). This ecological interaction highlights the tree's role in its ecosystem, promoting biodiversity through its contribution to the diet of birds and the subsequent dispersal of its seeds, which is crucial for the regeneration of forests and the maintenance of healthy ecological systems (Getzner & Islam, 2020). Conservation of *Artocarpus chama* and its habitat is essential for preserving the biodiversity of the regions it inhabits (Islam et al., 2022). Understanding the ecological requirements and the role of this tree species in its natural environment helps inform conservation strategies (Mengist & Soromessa, 2019). Protecting the moist and shaded habitats preferred by *Artocarpus chama* ensures not only the survival of this species but also the myriad forms of life that depend on it, directly or indirectly, for sustenance and habitat (Ashrafuzzaman et al., 2021).

Avicennia officinalis, a vital mangrove species, typically reaches a height of 10-13 meters with a diameter at breast height (DBH) of 18-25 cm. This light-demanding tree thrives in the unique intertidal zones of mangrove forests (Mehta et al., 2021), requiring regular inundation by tidal waters to sustain its growth and physiological processes. The species is adapted to saline environments, showcasing remarkable resilience to the challenging conditions characteristic of mangrove ecosystems. Its roots are equipped with specialized pneumatophores, which facilitate oxygen intake in waterlogged soils, demonstrating a fascinating adaptation to its habitat. The presence of *Avicennia officinalis* is crucial for maintaining the ecological balance of mangrove forests, providing essential services such as coastline stabilization, carbon sequestration, and serving as a nursery for various marine species (Mitra et al., 2023). Conservation efforts for these mangrove habitats are essential to ensure the survival of *Avicennia officinalis* and the myriad of life forms that depend on this ecosystem for their survival (Sultana et al., 2021).

Terminalia arjuna, a member of the Combretaceae family, is an evergreen tree distinguished by its extensive use in traditional medicine and it's ecological significance (Getzner and Islam, 2020). Noted for its shade-bearing capacity(Hasnat et al.,2016), it thrives in various environmental conditions (Amalraj & Gopi, 2017; Basha et al., 2017;Crouzeilles et al.,2016), contributing to the biodiversity of the areas it inhabits. Its broad, dense canopy provides essential habitat and protection for numerous species, while its striking appearance and robust stature add aesthetic value to landscapes (Roy et al., 2015). *Terminalia arjuna* plays a pivotal role in ecological balance, supporting a range of organisms and processes within its ecosystem, making it a valuable component of its native habitats.

Terminalia bellirica, a deciduous and light-demanding tree, holds significant value beyond its ecological role known for its large stature and distinctive fruit (Saxena et al., 2013; Das et al.,2020), it is widely utilized in traditional practices, particularly in the production of dyes and inks. This usage stems from the rich tannins and pigments found within its fruit and bark, offering a natural source for these substances. The tree's contributions to local ecosystems (Islam et al., 2022), combined with its utility in crafts and traditional industries, underscore its importance in both natural and human-made environments. Its cultivation and sustainable harvesting are key to preserving the balance between its ecological importance and cultural uses. *Terminalia chebula*, a member of the Combretaceae family, reaches an impressive height of up to 30 meters with a diameter at breast height (DBH) of around 130 cm. This substantial tree is renowned for its medicinal properties and slow seedling growth (Basha et al., 2017; Das et al., 2020; Sairkar et al., 2017; Saxena et al., 2013), which underscores its need for conservation and mindful cultivation. The slow development from seedling to mature tree highlights the importance of patience and long-term planning in the conservation of this species. *Terminalia chebula*'s significant ecological and medicinal values make it a key species within its native habitats, contributing to biodiversity and offering benefits ranging from healthcare to ecosystem stability (Hossain et al., 2020; Islam et al., 2022). The purpose of this study is to develop an understanding of the processes governing tree phenology, seed dispersal, and seed biometry. Investigating seed traits such as length, width, thickness, and volume offers insights into how these characteristics influence seed dispersal, germination rates, and seedling survival (Hasnat et al., 2016; Lima et al., 2020; Matin et al., 2006; Nguyen et al., 2019). This study aims to examine the phenological diversity and biometric variations of selected tree species. By analyzing critical phases like seed dispersal, flowering, and fruiting times, and using statistical methods including t-tests, Euclidean distance in Ward's method, and Principal Component Analysis (PCA), the research seeks to identify significant differences and similarities among the species, enhancing our understanding of their biological and ecological diversity.

Methods and materials

The study, conducted from 2020 to 2023, took place in the Chittagong division of Bangladesh, a region known for its diverse geological and biological habitats. This area is particularly rich in species such as *Artocarpus chama*, *Terminalia arjuna*, *Terminalia bellirrica*, and *Terminalia chebula*, all found within the geographical boundaries of Chittagong (22° 22' 0.001" N, 91° 47' 60" E) at an altitude of 29 meters (Roy et al., 2015). The average temperature and rainfall in this area are 26°C and 3000mm respectively. *Avicennia officinalis* specimens were collected from the Sundarbans.

Biometric analysis of the selected species was conducted at the IFESCU seed laboratory at the University of Chittagong. The university campus features both natural and artificial forest habitats that provide an ideal environment for seed storage and germination practices. In April 2022, the area experienced its highest recorded temperature of 39°C and a maximum rainfall of 3200mm (Alam et al., 2023; Roy et al., 2015). The selected species—*A. chama*, *T. arjuna*, *T. bellirrica*, and *T. chebula* - are widely found and distributed across the Chattogram, Bandarban, and Rangamati districts. These areas are characterized by hilly tertiary mountain ranges and contain virgin forests and seed orchards. To ensure effective seed harvesting, monitoring was conducted across 10 representative reproductive stages up to the year 2022. The species were classified into groups based on germination % (high, mid, low), leaf deciduousness (deciduous, evergreen, and semi-evergreen) and seed dispersal syndromes, including zoochoric and barochoric dispersal mechanisms, as detailed in Table 1.

Table 1: List of five forest tree species included in this study with Phenology and Dispersion Syndrome.

Species	Family	Phenology	Seed dispersal	Germination%	Flowering	Fruiting
Artocarpaus chama	Moracceae	DT	Z	L	March	July
Avicennia officinalis	Avicenniaceae	EG	Z	M	February	August
Terminalia arjuna	Combretaceae	EG	B	H	April	February
Terminalia bellirrica	Combretaceae	DT	B	H	March	November
Terminalia chebula	Combretaceae	DT	B	H	April	November

Note: Leaf phenology is represented as Deciduous Tree (DT) and Evergreen (EG), while seed dispersal is categorized as Zoochronic (Z) and Barochoric (gravity) (B), germination% also categories into high=H(+80%), mid=M(+50%), low=L(+20%).

Among the selected plus trees, three individuals were chosen from the 10 monitored, in a randomized manner for seed collection. Ripe seeds were harvested manually from these selected representative plus trees. The seeds were then extracted from the fruits in the seed lab and dried for one day in sunlight. Following this, biometric variables were measured for ten seeds from each species. Seed matrix measurements were taken from base to apex for length (cm), width (cm), and thickness (cm), measured at the seed's midline. These measurements were made using a digital caliper with a precision of 0.01 cm. Data analysis was conducted in two main ways: firstly, a simple arithmetic mean was calculated for each parameter (length, width, thickness, and calculated volume in cubic centimeters (L×W×T)) (Pereira & Alberto, 2017). Additionally, a univariate statistical analysis was performed to ascertain the biometric variable (bioV) from the seed matrix, including the minimum, maximum, mean, standard error, and coefficient of variance (CV%) (Do Nascimento et al., 2019).

Statistical Analysis

The similarity of biometric variables measured among and between the species was assessed using t-tests, with the results visualized in box plot graphs. To standardize the averages of biometric variables for each seed matrix, data were analyzed to understand cluster formation using Euclidean distance in Ward's method (Ukpatu et al., 2015), determining if the species were grouped accordingly. Furthermore, Principal Component Analysis (PCA) was conducted to identify the biometric variables that contributed to species grouping (Janekovi & Novak, 2012; Udoinyang, 2015). Data management was performed using Excel, while all statistical analyses were executed using R version 4.2.2. These analyses enabled the identification of significant differences and similarities in biometric variables, providing insights into the grouping patterns and relationships among the species. By using robust statistical methods, the study ensured accurate classification and understanding of the species' biometric characteristics, contributing to a deeper knowledge of their biological and ecological diversity.

Results

A univariate analysis statistical analysis of species

Phenological diversity, as detailed in Table 1, provides insights into the timings of seed dispersal, flowering, and fruiting across months. Initial standard errors are also presented, indicating data reliability, where lower values suggest greater accuracy. Elucidates that seeds from species such as *A. officinalis*, *T. arjuna*, and *T. chebula* have unique shapes, leading to significantly larger standard errors, as revealed in Table 2. These species demonstrate low coefficients of variance in length, width, and thickness, whereas *A. chama*'s seed volume shows a higher coefficient of variance at 106.07%. Relationship between parameters (length, width, thickness, and volume) are assessed, with Figure 1 displaying the results of t-tests. These tests reveal statistical significance (P<0.05) for length and width in *A. officinalis*, *T. arjuna*, *T. bellirrica*, and *T. chebula*, indicating noteworthy differences in these dimensions. Despite belonging to the same family, *A. officinalis* and *T. arjuna* exhibit different seed dispersal syndromes, namely zoochoric and barochoric, respectively. Figure 1 and Table 2 highlight the variations in seed volumes among species. *A. officinalis*, *T. arjuna*, *T. bellirrica*, and *T. chebula* all show higher volumes, with *T. arjuna* standing out for its superior germination percentages (60-70%) in both forest and conventional soils.

Table 2: A univariate analysis statistics of biometric parameters evaluated, verifying differences within and between species.

Species	BioV	N	Min	Max	Mean	SE	CV (%)
Artocarpaus chama Buch.-Ham ex Wall.	L	10	1.32	1.54	1.43	0.16	10.88
	W	10	0.57	0.9	0.74	0.23	31.75
	T	10	0.07	0.49	0.28	0.30	106.07
	V	10	0.06	0.27	0.17	0.15	88.28
Avicennia officinalis L.	L	10	2.8	3.71	3.26	0.64	19.77
	W	10	2.6	2.92	2.76	0.23	8.20
	T	10	0.52	1.88	1.20	0.96	80.14
	V	10	4.51	10.57	7.54	4.29	56.84
Terminalia arjuna (Roxbo.ex DC)	L	10	3.51	5.99	4.75	1.75	36.92
	W	10	2.1	2.9	2.50	0.57	22.63
	T	10	1.53	2.38	1.96	0.60	30.74
	V	10	12.81	23.35	18.08	7.46	41.23
Terminalia bellirrica (Gaertn.) Roxb.	L	10	2.33	3.43	2.88	0.78	27.01
	W	10	2.02	2.38	2.20	0.25	11.57
	T	10	1.53	1.69	1.61	0.11	7.03
	V	10	8.06	10.21	9.14	1.52	16.61
Terminalia chebula Retz	L	10	3.3	4.77	4.04	1.04	25.76
	W	10	1.95	2.31	2.13	0.25	11.95
	T	10	1.12	1.84	1.48	0.51	34.40
	V	10	7.97	12.12	10.05	2.93	29.14

Note: Biometric Variables (BioV) include Length (L), Width (W), Thickness (T), and Volume (V). Number of Seeds (N), Minimum (Min), Maximum (Max), Standard Error (SE), and Coefficient of Variation (CV %) are recorded for Length (cm), Width (cm), Thickness (cm), and Volume (cm^3).

The smaller dimensions of A. chama seeds have been found to affect both the percentage and timing of germination. A higher mass or volume generally correlates with higher germination percentages but inversely affects the germination time. Furthermore, A. chama's smaller seed size facilitates a higher rate of dispersal compared to T. arjuna, despite their distinct phonologies. Within the Combretaceae family, T. arjuna is notable

for its unique flowering and fruiting periods, spanning from March-April and November to February, respectively. Research indicates that the thickness of A. chama's seed coating layers plays a crucial role in nutrient and water permeability. These findings underscore the interconnectedness of biometric characteristics, demonstrating that larger seed volumes not only contribute to higher germination percentages but also enhance nutrient and water absorption.
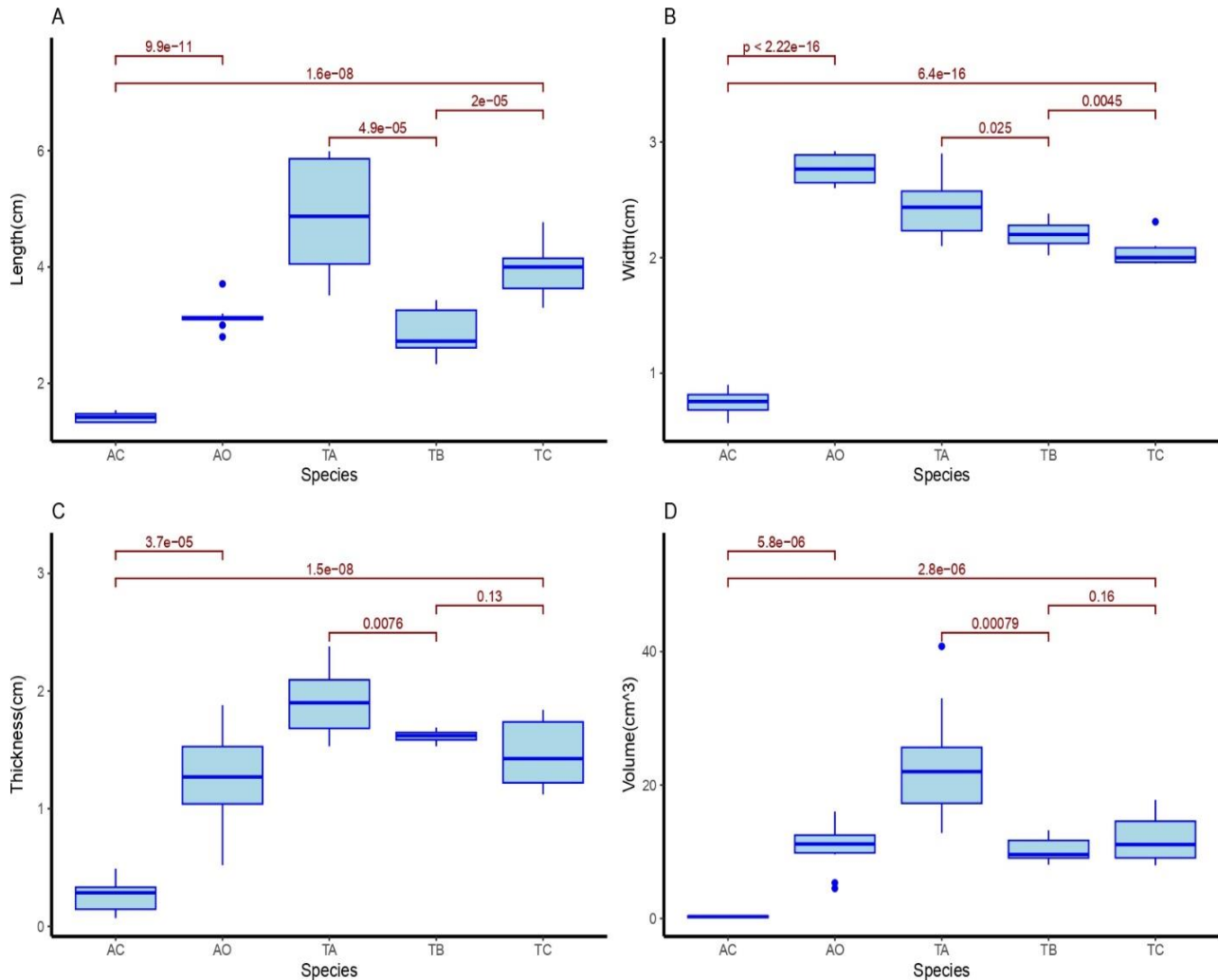

Figure 1: Box plot (t-test) displaying the values of length, width, thickness (cm), and volume (cm^3) for five tree species: *Artocarpus chama* (AC), *Avicennia officinalis* (AO), *Terminalia arjuna* (TA), *Terminalia bellirica* (TB), and *Terminalia chebula* (TC).

Similarity of biometric Variable in species Intra and interspecific analysis

Constructed using Euclidean-agglomerative-complete clustering, the dendrogram, featuring 50 observations for each biometric variable, is meticulously annotated with phenology and seed dispersal color information (Figure 2). This dendrogram divides into two main branches, encompassing a total of 50 members, and reaches a height of 7.66. Its distinctive structure uncovers specific patterns, notably that leaves numbered 1, 3, 6, 7, 8, and 9 distinctly

represent the Combretaceae family. Conversely, leaves numbered 41, 42, 44, 46, 47, and 49, alongside leaves 43, 45, 48, and 50, are indicative of the Moraceae family. This hierarchical arrangement effectively unveils the inherent relationships among the biometric variables, highlighting the distinctive characteristics of these plant families. The dendrogram's visual representation is instrumental in discerning these patterns, thereby facilitating a comprehensive understanding of the complex interplay between phenology, seed dispersal color, and the biometric variables across the diverse plant specimens. This enhanced insight aids significantly in advancing the study of plant biology by illuminating the connections between physical traits and their evolutionary and ecological implications.
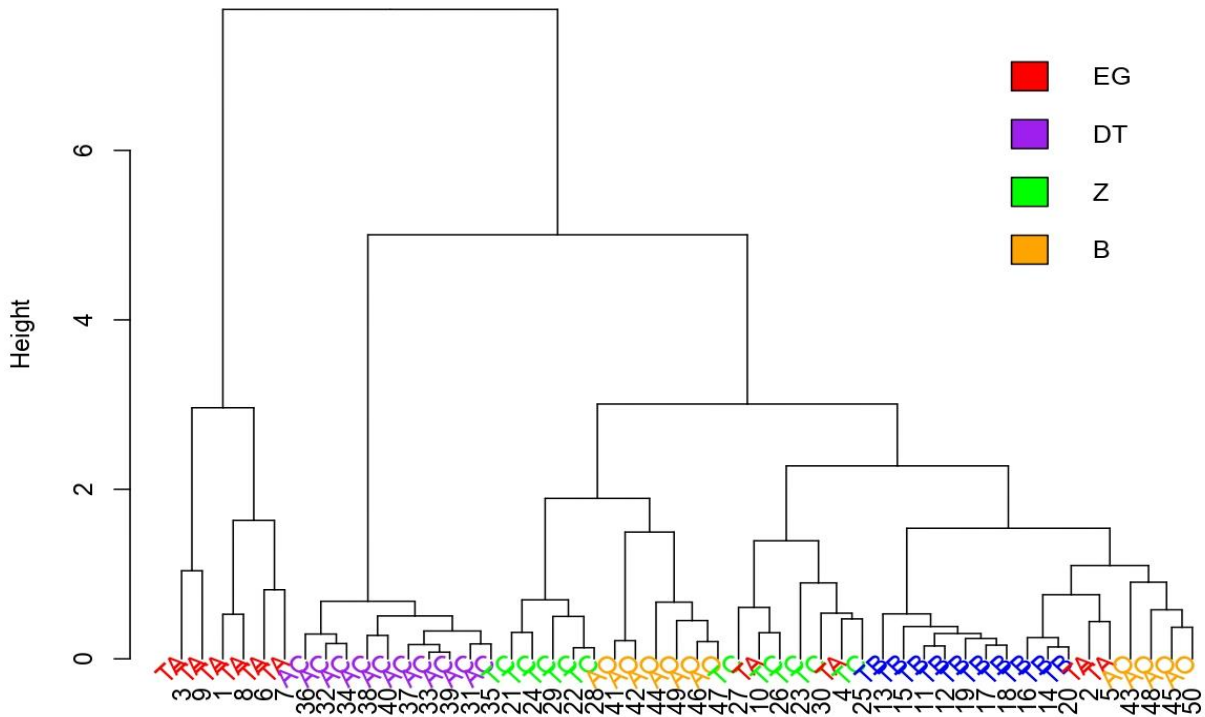

Figure 2: Dendrogram depicting intra- and interspecific similarity based on biometric variables (length, width, thickness, volume) of forest species seeds, with n=10 for each species, totaling N=50 for each biometric variable. Species include *Artocarpus chama* (AC), *Avicennia officinalis* (AO), *Terminalia arjuna* (TA), *Terminalia bellirica* (TB), and *Terminalia chebula* (TC). Cophenetic coefficient = 0.7541.

PCA of Biometric variable

Within the framework of dimension reduction, the principal components exhibit a progressive decline from PCA1 through PCA4, highlighting the essence of data simplification in complex analysis. Remarkably, PCA1 and PCA2 cumulatively account for a significant 92.5% of the variance among components, illustrating the primary axes potency in capturing the bulk of the data's variability. The PCA plot offers a lucid illustration of how PCA1, contributing 82.84%, and PCA2, adding another 10.17%, delineate the intricacies of seed dispersion and phenology within the cluster groups (Figure 3). It's within this graphical representation that the distinction of *A. chama*'s data

from others becomes markedly apparent, underscoring the unique characteristics of this specimen in comparison to its counterparts. Delving into the specifics, the standard deviations associated with PCA1 through PCA4 (n=4) stand at 1.82, 0.63, 0.45, and 0.27, respectively. These figures reflect the decreasing influence of each successive principal component on the dataset's variance. Furthermore, the contributions to PCA1, characterized by values of -0.5 for length, -0.4 for width, -0.5 for thickness, and -0.5 for volume, underscore the uniform influence of these biometric parameters in shaping the primary component. Conversely, the contributions to PCA2 are more varied, with -0.4 from length, +0.8 from width, +0.04 from thickness, and -0.3 from volume, indicating differential impacts on this secondary axis. This meticulous analysis sheds light on the pivotal elements steering the principal components and elucidates their consequential effects on the overarching biometric traits of the specimens. Such insights are instrumental in comprehending the multidimensional aspects of biometric variability, thereby enhancing our understanding of the intrinsic and extrinsic factors that define the biological and ecological identities of these plant species. Through this lens, the principal component analysis not only simplifies complex data but also reveals the meaningful patterns and relationships hidden within, offering a rich narrative on the dynamics of seed dispersal, germination and phenology in relation to biometric characteristics.
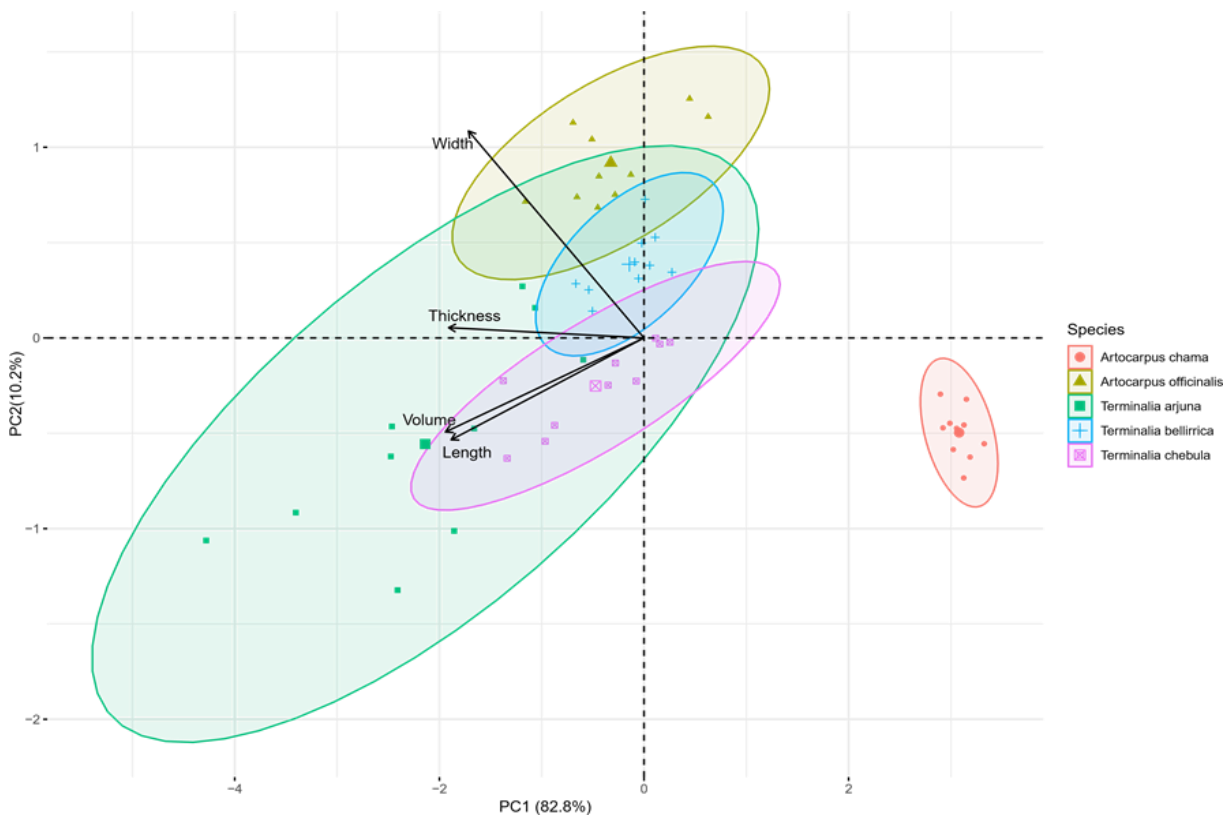

Figure 3: Principal Component Analysis depicting the distances between biometric variable matrices based on characteristics of *Artocarpus chama* (AC), *Avicennia officinalis* (AO), *Terminalia arjuna* (TA), *Terminalia bellirica* (TB), and *Terminalia chebula* (TC). The left figure illustrates the variation explained by each component, presented as percentages, while the right figure focuses on PCA1 and PCA2, detailing their contributions.

Discussion and implementation

The influence of seed size on germination, seed dispersal, and seedling growth in *T. bellirica*, *T. chebula*, *A. officinalis*, and *A. chama* is profound and multifaceted. In *T. bellirica*, larger seeds significantly enhance seed dispersal and afforestation efforts (Chowdhury et al., 2024; Wright et al., 2007). Seeds averaging 2.77 cm in length exhibit a 45% germination rate, underscoring the vital correlation between seed size and germination success (Hossain et al., 2013,2020; Khan & Shankar, 2014). This finding sets the stage for further observations across different species. Similarly, *T. chebula* demonstrates a direct relationship between seed size and germination rates, seed dispersal efficiency, and seedling growth robustness (Westoby, 1998). This pattern highlights the critical role of seed dimensions in species survival and expansion, suggesting that larger seeds tend to have advantageous outcomes in terms of germination and establishment (Chowdhury et al., 2024).In mangrove ecosystems, the seed sizes of *A. officinalis* are markedly influenced by pollinators, plant diversity, and seed establishment efficacy (Mehta et al., 2021). This interplay emphasizes the ecological significance of seed size in mangrove forests, where larger seeds generally exhibit greater success in rooting and proliferating (Westoby et al., 2002; Yang et al., 2018).

For *A. chama*, seed mass emerges as a pivotal factor for germination success. Seeds weighing between 300-350 mg achieve over 90% germination rates, fostering extensive seed dispersal and enhancing plant resilience (Khan & Shankar, 2014). Seedlings from larger and heavier seeds display superior resilience, crucial for the continued growth and spread of these species in their natural habitats (Hossain et al., 2014; Ashrafuzzaman et al.,2021). The broader implications of this study suggest that seed size not only affects immediate germination and seedling viability but also has long-term impacts on the ecological success and sustainability of these species. For instance, larger seeds often contain more resources, which support the initial stages of seedling development, giving them a competitive edge in nutrient-poor environments. This advantage can lead to higher survival rates and greater ability to withstand environmental stresses, such as drought or poor soil conditions (Hasnat et al., 2016).Furthermore, understanding the relationship between seed size and plant performance can inform conservation strategies(Zuffo et al., 2017). For endangered or threatened species, selecting larger seeds for propagation could improve the chances of successful restoration efforts. In managed forests and plantations, utilizing seeds with optimal size characteristics can enhance overall forest health and productivity.

However, the study also points out the limitations, such as the need for larger sample sizes and more extensive field surveys to validate the findings. Future research could explore the genetic basis of seed size variation and its ecological implications across a broader range of species and environments. Integrating molecular techniques with traditional biometric analyses could offer deeper insights into how seed size influences plant fitness and ecosystem dynamics. In conclusion, this research underscores the multifaceted role of seed size in plant ecology, providing crucial insights that can enhance both theoretical understanding and practical applications in forestry, conservation, and ecological restoration.

Conclusion

This study explores phenological diversity by examining key phrases such as seed dispersal, flowering, and fruiting times. Standard errors in Table 2 highlight species-specific variations, with *A. officinalis*, *T. arjuna*, and *T. chebula* distinguished by their unique seed shapes, underscoring nature's complexity. While biometric measurements show low variance in length, width, and thickness, *A. chama* stands out with significant seed volume variation, suggesting diverse adaptability and dispersal strategies compared to *T. arjuna* (Khan & Shankar, 2014). A dendrogram visually separates the Combretaceae and Moraceae families, revealing their hierarchical relationships. Principal component analysis (PCA) further clarifies species differentiation, particularly for *A. chama*. This comprehensive study offers

deep insights into plant phenology, seed dispersal, and the intricate interplay between genetic and environmental factors, enriching our understanding of biological diversity and adaptability.

Statement of Conflict of Interest: The authors declare that there are no conflicts of interest regarding the publication of this paper. Any potential conflicts have been disclosed to the journal and are detailed within the manuscript as required.

Authors' Contribution: Detail the contributions of each author to the manuscript, e.g., "Author 1: *Mohd Imran Hossain Chowdhury*, designed the study, wrote the initial draft and analyzed the data. Author 2*: Mehedi Hasan Rakib*, conducted the experiments and analysis. Author 3: *Chinmoy Das*, contributed to the final version of the manuscript."

Data Availability Statement: The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request, included within the article and its supplementary materials, etc. This statement ensures transparency and reproducibility of the research findings.

Manuscript Originality: I confirm that this manuscript is original, has not been published before, and is not currently under consideration for publication by any other journal. All the authors have approved the manuscript and agree with its submission to Journal of Agriculture Sustainability and Environment.

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