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# Seed Morphology and Dispersal Trade-offs in Three Tropical Trees of Semi-Arid Northern Nigeria

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## ABSTRACT

Seed morphology and dispersal mechanisms critically influence plant population dynamics, regeneration, and spatial distribution in semi-arid tropical ecosystems. This study examined relationships between seed traits and dispersal patterns of three ecologically and economically important tree species—Albizia lebbeck, Delonix regia, and Azadirachta indica—at the Take-Up Site of the Federal University Dutsin-Ma, Katsina State, Nigeria. A total of 90 seeds per species were collected using systematic quadrat sampling. Seed weight, length, and structural characteristics were measured, while dispersal distances were recorded. Trait–dispersal relationships were analyzed using one-way ANOVA and Pearson correlation. Significant interspecific variation was observed ($p < 0.05$). Albizia lebbeck produced the smallest and lightest seeds (0.10 ± 0.02 g; 0.91 ± 0.05 cm) and exhibited the greatest dispersal distance (3.19 ± 0.30 m). Delonix regia had the largest seeds (0.44 ± 0.08 g; 1.98 ± 0.15 cm) with shorter dispersal (2.75 ± 0.25 m), while Azadirachta indica showed intermediate traits (0.36 ± 0.07 g; 1.48 ± 0.12 cm) and dispersal distance (2.77 ± 0.28 m). Seed weight and length were strongly negatively correlated with dispersal distance ($r = -0.983$ and $-0.902$, $p < 0.01$). These patterns illustrate the ecological trade-off between dispersal and establishment, where lighter seeds enhance colonization potential while heavier seeds favor seedling survival. Albizia lebbeck is suited for colonizing degraded landscapes, Delonix regia for managed plantings, and Azadirachta indica for adaptive, heterogeneous systems. However, potential limitations related to seed–parent association and unmeasured environmental dispersal drivers should be considered when interpreting these findings. Understanding these trait–dispersal relationships supports evidence-based species selection, propagation strategies, and restoration planning in semi-arid ecosystems

**Keywords:** seed morphology, dispersal, Albizia lebbeck, Delonix regia, Azadirachta indica, semi-arid ecosystems, restoration, agroforestry

## INTRODUCTION

Seed morphology and dispersal mechanisms play a fundamental role in plant population dynamics, regeneration, and spatial distribution, influencing both species persistence and ecosystem resilience (Fenner and Thompson, 2005; Saatkamp et al., 2019). In tropical ecosystems, variations in seed size, mass, and structural adaptations significantly affect dispersal efficiency, seed fate, and seedling establishment success (Howe and Smallwood, 1982; Willson, 1993; Beckman and Rogers, 2013). The trade-off between seed size and dispersal distance is a well-established ecological principle, where smaller seeds are typically dispersed over longer distances, enhancing colonization potential, while larger seeds allocate more resources to improve seedling survival and competitive ability (Moles and Westoby, 2004; Westoby et al., 2014). Recent studies further emphasize that this trade-off is shaped by dispersal vectors (wind, water, and animals) and environmental heterogeneity, which jointly determine regeneration patterns and species distribution (Thomson et al., 2018; Snell et al., 2019). In semi-arid and savanna ecosystems, such as northern Nigeria, seed dispersal strategies are particularly critical due to environmental stressors including limited rainfall, high temperatures, and soil degradation. These conditions necessitate adaptive dispersal mechanisms that enhance both seed survival and spatial spread (Nathan et al., 2011; Saatkamp et al., 2019). Wind dispersal (anemochory), animal-mediated dispersal (zoochory), and mechanical dispersal (autochory) each play distinct roles in shaping vegetation structure and regeneration dynamics in such environments (Corlett, 2017).

Despite the ecological and economic importance of Albizia lebbeck lebbeck, Delonix regia , and Azadirachta indica in agroforestry, urban greening, and land restoration, there remains a scarcity of site-specific studies on their seed morphological traits and dispersal mechanisms in northern Nigeria. This knowledge gap limits the effectiveness of nursery practices, reduces germination efficiency, and constrains large-scale reforestation and ecosystem restoration initiatives (Choudhury et al., 2016; Sacande and Berrahmouni, 2018). Therefore, understanding the relationships between seed morphology, dispersal strategies, and propagation potential is essential for developing evidence-based silvicultural practices and enhancing sustainable land management in semi-arid tropical regions.

## MATERIALS AND METHODS

### Study Area

The study was conducted at the Take-Up Site of the Federal University Dutsin-Ma (FUDMA), Katsina State, Nigeria (Latitude: 12.4810°N, Longitude: 7.3520°E), located in the Sudan savanna ecological zone. The area is semi-arid, with annual rainfall of 500–1000 mm, pronounced wet and dry seasons, sparse vegetation, and scattered drought-tolerant grasses and trees (Saatkamp et al., 2019; Nathan et al., 2011).

### Study Species Selection

Three ecologically important tree species viz Albizia lebbeck lebbeck (wind-dispersed), Delonix regia (mechanically dispersed), and Azadirachta indica (biotically dispersed) were selected for their role in afforestation and urban greening and for comparative analysis of morphology–dispersal relationships (Moles and Westoby, 2004; Thomson et al., 2018).

### Sampling Design and Field Procedure

A systematic quadrat sampling method was employed to ensure spatial representation and minimize sampling bias (Kent, 2012), using 1 m × 1 m quadrats randomly placed beneath and around mature parent trees within each species' concentration area. Seeds were collected from natural dispersal zones surrounding each tree to capture realistic dispersal patterns, following established field-based seed ecology protocols (Nathan et al., 2011). Seed–parent association was inferred based on proximity to the nearest mature tree, species dominance within the sampling area, and the absence of overlapping canopies.

This approach is commonly applied in field-based dispersal studies where direct tracking of seed origin is not feasible. However, while practical, this assumption may introduce some uncertainty in situations where multiple conspecific individuals occur in close proximity. A total of 90 seeds per species were collected, providing an adequate sample size for statistical analysis and ecological interpretation.

### Measurement of Seed Morphological Traits

Seed traits were measured using standardized laboratory procedures. Seed weight (g) was determined with a digital analytical balance (±0.01 g precision), a key functional trait influencing dispersal ability and seedling establishment (Moles and Westoby, 2004). Seed length (cm) was measured with a calibrated ruler, as seed size is directly linked to dispersal potential and resource allocation strategies (Westoby et al., 2014). Seed shape and structure were visually observed and categorized by form (oblong, oval, or elongated) and testa characteristics (hard/soft, smooth/rough), traits that affect resistance to environmental stress and dispersal efficiency (Beckman and Rogers, 2013).

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### Measurement of Dispersal Distance

Dispersal distance was measured as the linear distance (m) between the parent tree and the location of each seed using a measuring tape, considering only naturally dispersed seeds. This approach captures field-based estimates of dispersal patterns and provides a practical representation of seed distribution around parent trees (Nathan et al., 2011; Thomson et al., 2018). However, the measurements represent ground-projected distances and may underestimate the actual dispersal trajectories, which can be influenced by factors such as wind turbulence, seed release height, and animal movement.

### Data Analysis

Descriptive statistics, expressed as mean ± standard deviation, were calculated for all variables, while one-way ANOVA was used to test differences among species. Pearson correlation analysis was employed to examine relationships between seed weight and dispersal distance, as well as seed length and dispersal distance, following common practices in ecological trait-based studies (Snell et al., 2019).

## THEORETICAL FRAMEWORK

The study is grounded in seed ecology theory, drawing on the seed size–dispersal trade-off, dispersal kernel, and plant functional trait frameworks, which explain how morphological traits influence dispersal strategies and regeneration patterns in semi-arid ecosystems (Moles and Westoby, 2004; Nathan et al., 2011; Saatkamp et al., 2019).

## RESULTS

### Seed Traits and Dispersal Patterns

The study revealed significant interspecific variation in seed morphology and dispersal characteristics ($p < 0.05$), indicating differences among the three species (Table 1). Albizia lebbeck produced the smallest and lightest seeds (0.10 ± 0.02 g; 0.91 ± 0.05 cm) and recorded the greatest dispersal distance (3.19 ± 0.30 m). Delonix regia produced significantly larger and heavier seeds (0.44 ± 0.08 g; 1.98 ± 0.15 cm), with a shorter dispersal distance (2.75 ± 0.25 m). Azadirachta indica exhibited intermediate seed traits (0.36 ± 0.07 g; 1.48 ± 0.12 cm) and dispersal distance (2.77 ± 0.28 m).

**Table 1. Seed Traits and Dispersal Characteristics of Selected Tree Species**

| Species | Weight (g) | Length (cm) | Dispersal Distance (m) |
|---|---|---|---|
| **Albizia lebbeck** | 0.10 ± 0.02 | 0.91 ± 0.05 | 3.19 ± 0.30 |
| **Delonix regia** | 0.44 ± 0.08 | 1.98 ± 0.15 | 2.75 ± 0.25 |
| **Azadirachta indica** | 0.36 ± 0.07 | 1.48 ± 0.12 | 2.77 ± 0.28 |

Values are mean ± standard deviation (n = 30 seeds per species)

Different superscripts indicate significant differences ($p < 0.05$, Tukey HSD)

### Trait–Dispersal Relationships

Pearson correlation analysis revealed strong relationships between seed morphological traits and dispersal distance (Table 2). Seed weight and seed length were highly positively correlated ($r = 0.967$, $p < 0.01$). In contrast, both seed weight and seed length were strongly negatively correlated with dispersal distance ($r = -0.983$ and $r = -0.902$, respectively; $p < 0.01$).

**Table 2. Pearson Correlation Matrix of Seed Morphological Traits and Dispersal Distance**

| Trait | Weight (g) | Length (cm) | Dispersal (m) |
|---|---|---|---|
| **Weight (g)** | 1 | 0.967 | -0.983 |
| **Length (cm)** | 0.967 | 1 | -0.902 |
| **Dispersal (m)** | -0.983 | -0.902 | 1 |

Values represent Pearson correlation coefficients (n = 30 seeds per species). $p < 0.01$ for all correlations

## DISCUSSION

### Seed Traits and Dispersal Patterns

The results confirm the inverse relationship between seed size and dispersal distance. Smaller seeds of Albizia lebbeck enhance wind dispersal efficiency, while larger seeds of Delonix regia prioritize seedling establishment. Azadirachta indica demonstrates adaptive flexibility through mixed dispersal strategies. The observed variation in seed morphology and dispersal distance reflects distinct ecological strategies among the studied species. The small and lightweight seeds of Albizia lebbeck are well adapted for wind-mediated dispersal (anemochory), where reduced mass enhances aerodynamic transport and facilitates wider spatial distribution (Nathan et al., 2011; Thomson et al., 2018). This supports the widely reported inverse relationship between seed size and dispersal distance (Moles and Westoby, 2004; Fenner and Thompson, 2005).

In contrast, the larger and heavier seeds of Delonix regia are associated with limited dispersal, likely resulting from mechanisms such as explosive dehiscence and occasional water movement. These mechanisms typically result in localized seed deposition (Howe and Smallwood, 1982; Corlett, 2017). However, the larger seed size provides greater nutrient reserves, which enhances seedling establishment and early growth, illustrating the trade-off between dispersal capacity and establishment success (Westoby et al., 2014; Moles et al., 2005).

Azadirachta indica exhibited intermediate characteristics, suggesting a mixed dispersal strategy involving both abiotic (wind) and biotic (animal-mediated) vectors. This flexibility allows the species to colonize heterogeneous environments and adapt to variable conditions typical of semi-arid ecosystems (Willson, 1993; Beckman and Rogers, 2013). These findings highlight species-specific adaptive strategies in response to environmental pressures. Albizia lebbeck is suited for long-distance colonization, Delonix regia for localized establishment, and Azadirachta indica for balanced dispersal and survival. These differences have important implications for reforestation, agroforestry, and urban greening programs.

### Trait–Dispersal Relationships

The strong positive correlation between seed weight and seed length indicates coordinated seed development, where larger seeds tend to have greater structural dimensions. This relationship reflects inherent allometric growth patterns in seed formation.

The negative correlations between seed size (weight and length) and dispersal distance confirm the widely recognized inverse relationship between seed size and dispersal range (Moles and Westoby, 2004; Nathan et al., 2011). Smaller and lighter seeds are more effectively transported by wind, enabling greater dispersal distances, whereas larger seeds tend to fall closer to the parent plant due to increased mass and reduced aerodynamic efficiency.

These findings provide quantitative support for the species-specific dispersal strategies observed in Albizia lebbeck, Delonix regia, and Azadirachta indica. The results reinforce the ecological trade-off between dispersal capacity and establishment potential, where species optimize either spatial spread or seedling survival depending on their adaptive strategy.

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**Ecological and Silvicultural Implications**

The observed differences in seed morphology and dispersal patterns have important ecological and practical implications. The lightweight, wind-dispersed seeds of Albizia lebbeck make it highly suitable for colonizing degraded or open landscapes, supporting large-scale restoration efforts. In contrast, the larger and heavier seeds of Delonix regia favor localized establishment, making the species appropriate for urban greening and controlled planting systems where seedling survival is prioritized over dispersal distance.

Azadirachta indica, with its intermediate seed traits and likely mixed dispersal mechanisms, demonstrates adaptive flexibility and is well suited for agroforestry systems and heterogeneous environments. In general, functional diversity in dispersal strategies enhances ecosystem resilience and provides a scientific basis for species selection in semi-arid afforestation and restoration programs (Saatkamp et al., 2019; Sacande and Berrahmouni, 2018).

**Additional Ecological Factors**

Dispersal outcomes in plant populations are shaped not only by intrinsic seed traits but also by a suite of environmental drivers that influence the movement and ultimate deposition of diaspores. Wind dynamics—including speed, direction, and turbulence—can dramatically alter dispersal kernels, particularly for lightweight seeds (Bullock et al., 2017; Soons et al., 2018). For example, high wind speeds can augment dispersal distances beyond what is predicted by simple linear measures, while variable wind directions can create anisotropic dispersal patterns that affect spatial genetic structure (Nathan et al., 2012; Seidler and Plotkin, 2024). In the semi-arid context of northern Nigeria, seasonal wind patterns during the onset and cessation of the rainy season could enhance or restrict seed movement, but these dynamics were not captured in this study.

Seed release height is another important factor. Taller parent trees can disperse seeds over greater horizontal distances due to increased fall time and interaction with wind shear profiles, a phenomenon well documented in both wind-dispersed and mixed-mode species (Matlack, 2016; Hogan and Callaway, 2020). In our study, variation in crown height among Albizia lebbeck, Delonix regia, and Azadirachta indica could have contributed to observed dispersal differences independent of seed mass and morphology.

Canopy structure also mediates dispersal by altering local airflow and creating boundary layer effects that either impede or facilitate seed escape (Nathan et al., 2011; Tackenberg et al., 2021). Denser canopies can trap seeds close to parent trees, while more open spatial arrangements enhance the likelihood of seeds entering wind streams capable of long-distance dispersal.

Finally, animal vectors play a critical role for species with biotic or mixed dispersal strategies. Small mammals, birds, and insects can move seeds far beyond their point of release, either externally (epizoochory) or internally (endozoochory) (Couvreur et al., 2020; Schleuning et al., 2024). Azadirachta indica seeds, for instance, may be transported by frugivores or granivores, leading to complex dispersal patterns not captured by linear, ground-based measurements.

Although these ecological drivers were not directly quantified in our sampling design, their effects are supported by recent empirical and modeling studies and should be incorporated in future research to fully understand the spatial dynamics of seed dispersal in semi-arid ecosystems.

## LIMITATIONS OF THE STUDY

While this study provides valuable insights into seed morphology and dispersal trade-offs, several limitations must be acknowledged to contextualize the findings.

First, the assumption of seed–parent association based on proximity to the nearest mature tree may introduce uncertainty. In heterogeneous or multi-stem stands, seeds from adjacent conspecific individuals may be mistaken for those originating from the focal parent tree (Fortuna et al., 2023). Molecular parentage analysis (e.g., microsatellites or SNP genotyping) can reduce this uncertainty in future studies, but such approaches were beyond the scope of the present work.

Second, dispersal distance was measured as ground-projected linear distance, which likely underestimates true dispersal trajectories. Seeds released above ground level enter complex three-dimensional wind fields, and actual dispersal distances can be greater than ground projections alone suggest, especially in wind-dominated systems (Tackenberg et al., 2021; Nathan et al., 2023). Incorporating vertical release height and using wind tunnel experiments or Lagrangian stochastic models would improve dispersal estimates in future research.

Third, environmental variables that influence dispersal (e.g., wind speed and direction, atmospheric stability, animal vector activity) were not directly measured. Recent work has shown that diurnal and seasonal variation in wind patterns can strongly modulate seed dispersal potential (Soons et al., 2018; Seidler and Plotkin, 2024), and that animal behavior, habitat use, and foraging patterns can introduce non-random long-distance dispersal events (Couvreur et al., 2020; Schleuning et al., 2024). Without these data, it is not possible to fully partition the relative contributions of intrinsic seed traits versus extrinsic dispersal forces.

Finally, the relatively small sample size (90 seeds per species) limits statistical power for detecting fine-scale dispersal differences, although the strong correlations and significant ANOVA results indicate robust patterns. Increasing sample sizes and incorporating temporal replication across seasons would further validate and generalize the findings.

## CONCLUSION

Seed morphology significantly influences dispersal and regeneration strategies in semi-arid ecosystems. Albizia lebbeck is adapted for long-distance dispersal, Delonix regia prioritizes establishment, and Azadirachta indica balances both strategies. These findings validate the seed size–dispersal trade-off and provide a scientific basis for restoration planning.

## RECOMMENDATIONS

Based on the observed seed traits and dispersal patterns, the following recommendations are proposed for ecological restoration and silvicultural planning in semi-arid regions:

1. Utilize Albizia lebbeck for large-scale restoration of degraded lands due to its high dispersal capacity.
2. Implement manual propagation techniques for Delonix regia to overcome limited natural dispersal.
3. Promote Azadirachta indica for its adaptability and wide ecological tolerance.
4. Incorporate seed trait–dispersal relationships into afforestation and land restoration strategies.
5. Investigate seed germination rates, seedling survival, and long-term establishment patterns in relation to dispersal mechanisms.

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