

Effects of Seed Pretreatment, Substrate Types and Water Stress on Germination and Growth of *Dalbergia melanoxylon* (Guill. & Perr.)

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Abstract

Dalbergia melanoxylon (Guill. & Perr.) is an important species providing significant socio-economic and ecological services. Despite its importance, *D. melanoxylon* is facing increasing anthropogenic pressure and climate change. This study aimed to evaluate the effects of seed pretreatment, substrate and water stress on germination and seedling growth of *D. melanoxylon*. A split-plot experimental design with three factors (seed pretreatment, substrate and water stress) and three replications was established. Pretreatment (dehulled “D” and non-dehulled seeds “ND”), substrate (3/3 sand “SB1”; 2/3 sand + 1/3 potting soil “SB2”; 1/3 sand + 2/3 potting soil “SB3”) and water stress (Watering every day “ST0”, every three days “ST3”, every seven days “ST7” and every ten days “ST10”) were the factors and modalities considered in this study. Results showed that dehulled seeds (25.86 ± 9.99%) significantly improved germination rate compared to non-dehulled seeds (11.16 ± 2.41%). The pure sand substrate (3/3 sand) gave the highest germination rate, and the combination of dehulling with pure sand achieved the best performance (41.96 ± 8.36%). For growth and biomass parameters, substrate SB2 recorded the highest values for diameter (0.21 ± 0.08 cm), height (10.65 ± 2.75 cm), leaf number (12.21 ± 2.56), aerial dry biomass (4 ± 1.75 g) and root dry biomass (9 ± 2 g). For the response to stress, the ST10 recorded the lowest values of diameter (0.16 ± 0.03 cm), height (7.02 ± 0.87 cm), leaf number (5.97 ± 3.26), aerial (2.5 ± 1.49 g) and root (7.5 ± 2.5 g) dry biomass. ST7, ST10 and SB1

produced the lowest growth values across all parameters (diameter, height, and leaf number). Overall, these findings provide essential insights to guide conservation and reforestation strategies by identifying optimal germination, growth, and adaptation conditions for *D. melanoxyton*.

Keywords

D. melanoxyton, Pretreatment, Substrate, Water Stress

1. Introduction

Dalbergia melanoxyton (Guill. & Perr.), a species native to Africa [1], is naturally distributed across many African countries, particularly within the Sahelian zone [2]. In Senegal, it was first reported in 1828 in the Walo region of the north by Perrottet [3]. This multipurpose species is renowned for its socioeconomic and ecological significance [4]. Its heartwood, dense and ebony-like in color, is highly durable and internationally valued [5]-[8]. It is considered among the most expensive timbers in the world, with prices reaching up to 18,000 USD per cubic meter [9]. This precious wood is primarily used in the manufacture of musical instruments, sculptures and fine furniture [10]. In Senegal, *D. melanoxyton* provides numerous ecosystem goods and services to local populations, particularly in the Ferlo, one of its main distribution zones [11] [12]. In this region, ecosystems supply fuelwood, construction material, medicinal plants and various non-timber forest products [13]. The Ferlo, sylvopastoral zone, is naturally characterized by extensive livestock farming as the dominant activity [14] [15]. Within this context, *D. melanoxyton* contributes significantly by providing nutritious fodder appreciated by livestock, along with energy and construction wood, as well as products used in traditional medicine [5] [16]-[18]. Beyond its socio-economic uses, the species also fulfills important ecological functions. As a legume, it contributes to atmospheric nitrogen fixation [19] [20]. It is often retained within farming systems to enhance nitrogen availability, preserve soil fertility, and help stabilize soils [10] [19] [21]. In the Ferlo, for example, studies by [11] reported that farmers deliberately leave *D. melanoxyton* standing in short-cycle cultivated fields during land clearing. More broadly, the species contributes to the ecological integrity of the forests where it occurs, supporting habitat diversity.

Despite its socio-economic and ecological importance, *D. melanoxyton* is currently subjected to both anthropogenic and natural pressures. The high demand for its valued heartwood has led to overexploitation, while in the Ferlo, populations are further impacted by climatic deterioration, particularly recurrent drought [22]. Moreover, the species faces biological constraints, including low seed viability, poor germination rates (20% - 50% within 8 - 20 days) and slow plant growth, which limit its natural regeneration [23]-[25]. These combined factors have contributed to the regression of its natural populations, leading to its classification as Near Threatened on the IUCN Red List [26].

In the face of the degradation of *D. melanoxylon* stands, ex situ regeneration practices may offer an alternative for reforesting degraded areas and enhancing the conservation of the species. Within this framework, the present study aimed to contribute to the development of long-term management and conservation strategies for Sahelian woody species facing both natural and anthropogenic pressures. More specifically, it aimed to evaluate the effects of seed pretreatments on the germination of *D. melanoxylon* and to assess the influence of substrates and water stress on *D. melanoxylon* seedling growth.

2. Material and Methods

2.1. Study Area

The study was conducted at the experimental farm of the Department of Agroforestry, Assane Seck University of Ziguinchor (UASZ) (**Figure 1**). The site, located within the municipality of Ziguinchor at 12°32'54.88" N and 16°16'40.89" W, covers an area of 1.3 ha. The region receives an average annual rainfall ranging from 1300 to 1500 mm [27]. The climate is tropical, belonging to the southern coastal Sudanian domain, with a long dry season (October to May) and a four-month rainy season [28].

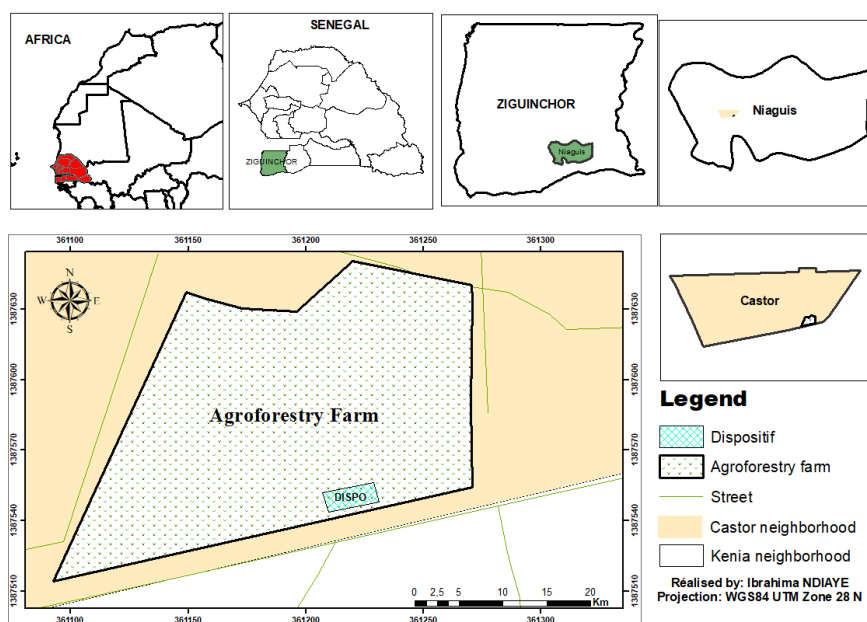


Figure 1. Location of the study site.

2.2. Collection and Preparation of Vegetal Material

Seeds of *D. melanoxylon* from the Ferlo were used as vegetal material in this study. They were collected from Labgar, Velingara Ferlo and Younoufere, located in the Ferlo zone (**Figure 2**), which exhibit no significant genetic differentiation [29]. The Ferlo zone is characterized by a long dry season lasting 7 - 9 months (October to May) and a rainy season of 3 - 5 months [30], with annual rainfall ranging from

100 mm to 600 mm. The mean annual temperature is 28.6°C, with monthly minimum and maximum averages of 24.4°C in January and 32.3°C in May [29] [31].

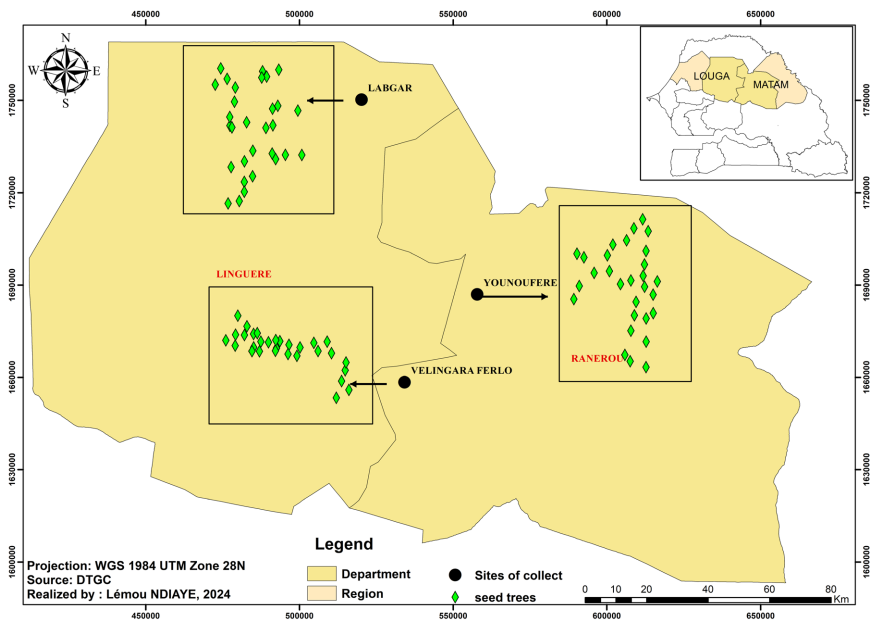


Figure 2. Location of seed collection.

The collection of *D. melanoxylon* seeds was carried out in December 2023 during the peak fruiting period. Ideal seed trees (ideotypes) were selected according to the criteria established by [32]. These were mature, healthy, and vigorous trees, but not too old. To define unrelated seed trees, a distance of 90 - 150 m, shorter than the 200 m, was used, considering the relic distribution of *D. melanoxylon* populations [32]. Collected seeds were sorted and stored in zippered bags for conservation. Seed viability was assessed using Petri dishes containing hydrophilic cotton moistened with water. The seeds were subjected to two treatments (dehulled and non-dehulled) (Figure 3). Manual dehulling was employed in order to avoid damaging the seed embryo.



Figure 3. Dehulled (A) and non-dehulled (B) *D. melanoxylon* seeds.

2.3. Experimental Design and Treatments

For this study, an experimental split-plot design (Figure 4) with three factors (pre-

treatment, substrate and water stress) and repetitions (blocks) was established over an area of 39.03 m² (7.55 × 5.17 m). The pretreatment (dehulled “D” and non-dehulled seeds “ND”), substrate (3/3 sand “SB1”; 2/3 sand + 1/3 potting soil “SB2”; 1/3 sand + 2/3 potting soil “SB3”) and water stress (Watering every day “ST0”, every three days “ST3”, every seven days “ST7” and every ten days “ST10”) were the factors and modalities considered in this study. Each block was subdivided into two (2) sub-blocks corresponding to the modalities of the pretreatment factor (dehulled and non-dehulled seeds). Each sub-block comprised 12 elementary plots, each representing a specific combination of the Substrate (3 levels) and Water stress (4 levels) factors, resulting in a total of 72 elementary plots for the entire experimental design. The allocation of treatment combinations within sub-blocks was performed using a completely randomized procedure. A spacing of 1 m was maintained between blocks, while the distance between elementary plots was 0.25 m. The elementary plots are square-shaped, measuring 40 cm on each side with a depth of 10 cm. The substrates consisted of potting soil and sand collected from roadside edges, mixed in different proportions (3/3 sand, 2/3 sand + 1/3 potting soil and 1/3 sand + 2/3 potting soil). Polyethylene seedling tubes measuring 14 cm in diameter and 25 cm in height, filled with 1.5 kg of substrate, were used as containers. A total of 13 seedling tubes were arranged in each elementary plot. The seedling tubes were pre-irrigated and subsequently sown with three seeds per tube. Germination was monitored per day for 30 days, after which thinning was performed to retain one seedling per tube.

To assess the adaptive response to water stress, four different irrigation frequencies (watering every day, every three days, every seven days and every ten days) were applied [33]. Seedlings were irrigated daily until the 150th day after sowing (DAS). Water stress induction was initiated at 150 DAS and maintained for a period of 60 days [33]. During this stress time, irrigation was applied at 100% of the field capacity of each substrate.

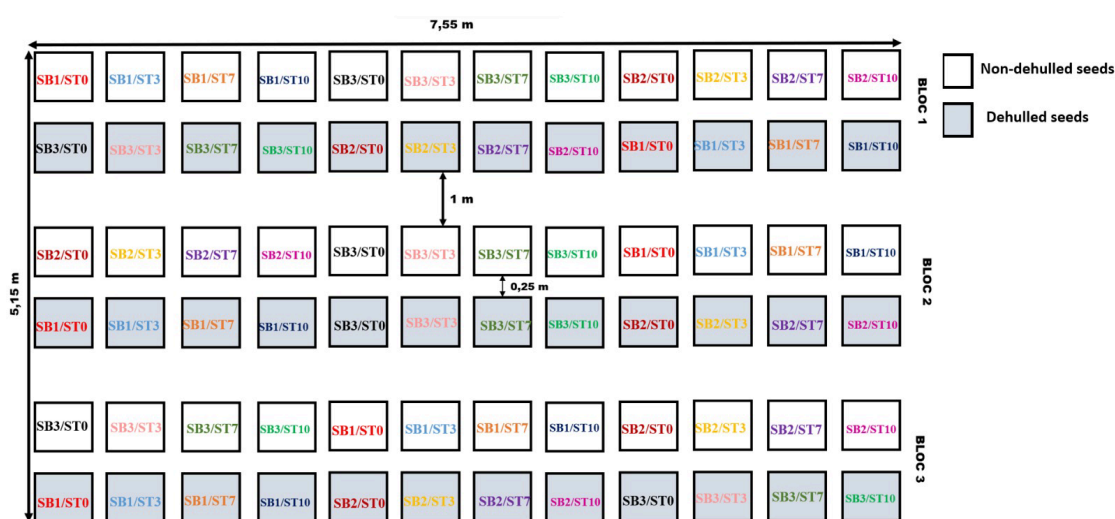


Figure 4. Experimental design of germination test and seedlings growth of *D. melanoxylon*.

2.4. Data Collection

2.4.1. Characterization of Substrates

Substrate samples were collected and analyzed at the Agroforestry Department laboratory of Assane SECK University of Ziguinchor. The analyses focused on particle-size distribution and field capacity for each substrate. Particle size was determined using a vibrating sieve with 500 g of soil per substrate for 10 minutes [34]. The proportions of sand, silt, and clay obtained from the sieves were then used to classify substrate texture using the textural triangle [35].

Field capacity was measured using the wetting-drainage method described by [36]. A 300 g sample of dry substrate was placed in perforated pots, allowing excess water to drain without substrate loss. The samples were gradually watered to saturation, indicated by water beginning to flow through the perforations. To minimize evaporation, the pots were covered with black plastic bags and kept in the shade for 24 hours, allowing gravitational water to drain while retaining moisture corresponding to field capacity. After this period, the final weight of each pot was measured and used to calculate field capacity using the following formula:

$$\text{Field Capacity (\%)} = \frac{\text{final weight} - \text{initial weight}}{\text{initial weight}} \times 100$$

2.4.2. Germination

Germination of seeds was recorded daily over 30 DAS. A seed is considered germinated once the radicle emerges through the seed coat. The number of emerged seeds was counted and the radicle emergence was considered to determine the germination rate and duration (daily germination and germination time) and germination quality (germination index and germination vigour index). The germination rate was calculated per pretreatment and substrate using the following formula:

$$\text{Germination rate (\%)} = \frac{\text{Number of germinated seeds}}{\text{Total number of seeds sown}} \times 100$$

The daily germination was to determine the mean daily germination (MDG). It was calculated using the following formula [37]:

$$\text{MDG} = \frac{\%Gf}{X^{\text{th}} \text{ day of the test}}$$

where %Gf is the germination rate on the X^{th} day of the test, determined by the number of germinations obtained at the end of the experiment, expressed as a percentage of the total number of seeds tested.

The germination time in terms of days after sowing (DAS) was recorded to determine the mean germination time (GT). GT is a measure used to assess the speed at which seeds germinate and represents the average time required for a seed to germinate based on the seeds that have actually germinated [38]. The mean germination time (MGT) was calculated using the following formula:

$$\text{GT} = \frac{\sum NiTi}{\sum Ni}$$

where N_i is the number of seeds newly germinated at time T_i .

The germination index (GI) is a measure used to assess the speed and distribution of seed germination. It was calculated using the following formula [39]:

$$GI = \frac{\sum(N_i T_i)}{S}$$

where N_i is the number of newly germinated seeds on day i (otherwise, it is the number of germinations recorded at T_i minus the number of seeds germinated at $T_i - 1$); T_i is the number of days after sowing; and S is the total number of seeds sown.

The germination vigour index (GVI) is a measure that evaluates the speed and uniformity of seed germination. GVI is useful for determining the overall vigour of the seeds and allows for the comparison of germination performance among different treatments [40] and was calculated using the following formula:

$$GVI = \frac{\left[\left(\frac{a}{1} + \frac{b}{2} + \frac{c}{3} \dots + \frac{z}{n} \right) \right] \times 100}{S}$$

where a, b, c, \dots, z represent the number of seeds germinated each day; n is the number of days over which the experiment lasts (30 days); S is the total number of seeds sown.

2.4.3. Mortality

The daily mortality was recorded to determine the number of seedlings that fail to survive after germination. This calculation excludes the initial period before the first germination, when no seedlings are observable, providing a more accurate estimate of actual mortality. The mean daily mortality (MDM) was determined using the following formula:

$$MDM = \frac{\sum(M_i\%)}{\text{day } x \text{ of the experiment} - \text{Germination lag}}$$

where $M_i\%$ = daily mortality rate (%); x = day of the experiment (up to 30 days); Germination lag = time between sowing and the first germination.

2.5. Growth, Biomass and Survival Parameters

2.5.1. Growth and Biomass Parameters

Plant growth monitoring started at 60 days after sowing (DAS) and was conducted at 15-day intervals. Growth measurements were taken on the six central plants of each elementary plot. Measured or counted parameters included diameter, height, and leaf number. The diameter was measured using a caliper and the height by tape.

Aerial and root dry biomass were assessed at 210 DAS. Six plants per elementary plot were randomly sampled. Fresh material was dried at 65°C for 72 h and weighed with a precision balance (0.01 g).

2.5.2. Survival

The number of survival seedlings was counted up to 210 DAS to determine the

survival rate. The survival rate was calculated according to substrate type and watering frequency using the following formula:

$$SR(\%) = \frac{N_v}{N_0} \times 100$$

where N_0 is the number of plants at the beginning of the experiment and N_v is the number of living plant at the end of the experiment.

2.6. Data Analysis

The collected data were entered into Excel and analyzed using R software (version 4.2.2). Statistical analyses included Analysis of Variance (ANOVA) and multiple comparison tests, specifically Fisher's Least Significant Difference (LSD) and Student-Newman-Keuls (SNK), at a significance level of 5%. A Principal Component Analysis (PCA) was also performed.

3. Results

3.1. Substrates Characteristics

The granulometric analysis revealed a variation in texture and field capacity between substrates (Table 1). The substrate SB1 ($93 \pm 3.06\%$) contained a higher proportion of sand, followed by SB2 ($70 \pm 1\%$) and SB3 ($57 \pm 1.32\%$). For silt content, SB2 ($22.5 \pm 1\%$) recorded higher silt content. The clay content in the substrates varied between $4.8 \pm 1.58\%$ and $42 \pm 1.69\%$. In absolute terms, SB3 had the highest clay content ($42 \pm 1.69\%$), while SB1 had the lowest ($4.8 \pm 1.58\%$). The sandy substrate composed of $93 \pm 3.06\%$ sand had the lowest field capacity ($11 \pm 2\%$). The sandy-loamy substrate with $70 \pm 1\%$ sand, $22.5 \pm 1\%$ silt and $7.5 \pm 1\%$ clay recorded a medium field capacity value ($25.5 \pm 3.2\%$). In contrast, the sandy-clay substrate with $42 \pm 1.69\%$ clay content reached the highest field capacity ($35.33 \pm 1.5\%$).

Table 1. Texture and field capacity of the substrates.

	Sand (%)	Silt (%)	Clay (%)	Texture	Field Capacity (%)
SB1	93 ± 3.06 a	2.2 ± 0.26 b	4.8 ± 1.58 b	Sandy	11 ± 2 c
SB2	70 ± 1 b	22.5 ± 1 a	7.5 ± 1 b	Sandy-loam	25.5 ± 3.2 b
SB3	57 ± 1.32 c	1 ± 0.1 c	42 ± 1.69 a	Loamy-clay	35.33 ± 1.5 a

SB1 (3/3 Sand); SB2 (2/3 Sand + 1/3 potting soil); SB3 (1/3 Sand + 2/3 potting soil).

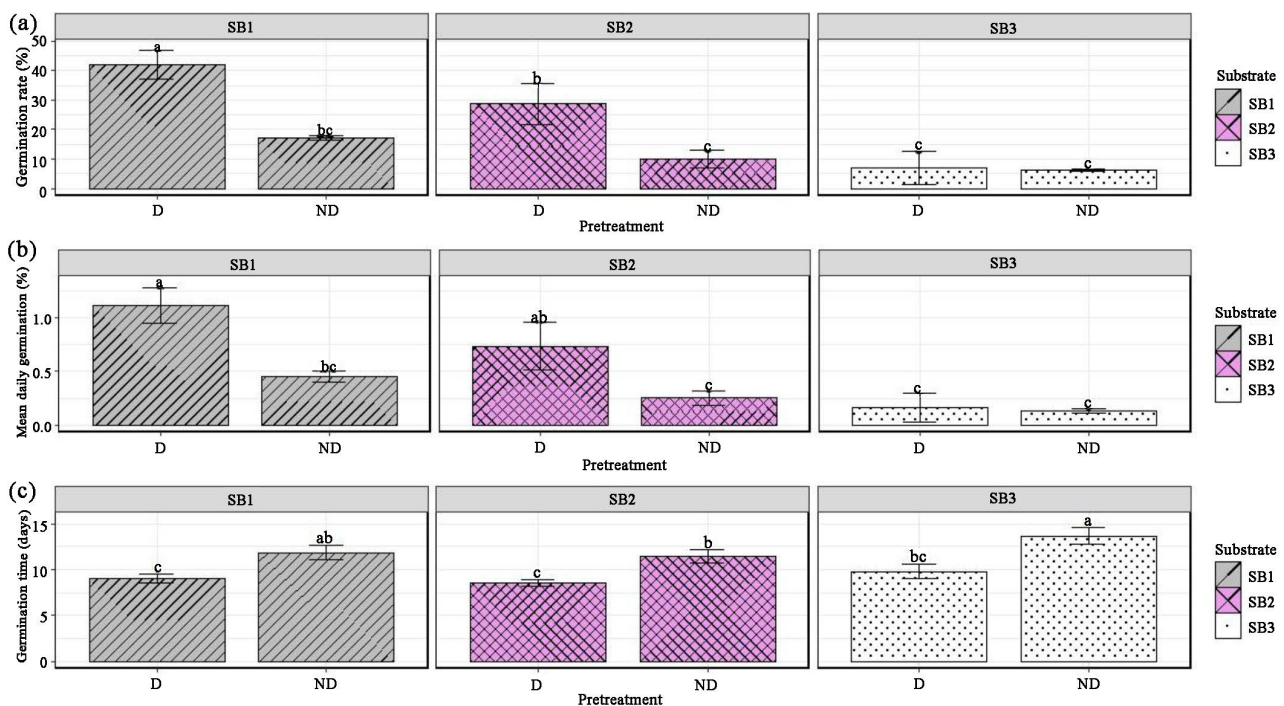
3.2. Germination

3.2.1. Germination Rate and Duration

The ANOVA revealed significant differences ($p < 0.05$) of germination parameters between pretreatments and substrates (Figure 5). Dehulled seeds exhibited the highest germination rate ($25.86 \pm 9.99\%$) compared to non-dehulled seeds ($11.16 \pm 2.41\%$). While, dehulled seeds exhibited higher daily germination (0.66

$\pm 0.3\%$) compared to non-dehulled seeds ($0.27 \pm 0.08\%$). For germination duration, non-dehulled seeds recorded the highest germination duration (12.33 ± 1.38 days) than dehulled seeds (9.12 ± 0.85 days). Among substrates, 3/3 sand recorded a higher germination rate ($29.57 \pm 4.8\%$), followed by 2/3 sand + 1/3 potting soil ($19.17 \pm 8.58\%$), while 1/3 sand + 2/3 potting soil produced the lowest germination rate ($6.7 \pm 5.15\%$). With regard to the daily germination, 3/3 sand ($1.11 \pm 0.29\%$) and 2/3 sand + 1/3 potting soil ($0.73 \pm 0.38\%$) produced the highest daily germination. The substrates did not significantly influence ($p > 0.05$) the germination duration.

The interaction pretreatment*substrate significantly ($p < 0.05$) affects the germination parameters (Figure 5). The combination of dehulled seeds with 100% sand achieved the highest germination rate ($41.96 \pm 8.36\%$), whereas the lowest ($6.41 \pm 0.68\%$) was observed with non-dehulled seeds in 1/3 sand + 2/3 potting soil. The dehulled seeds on substrates 1 (3/3 sand) and 2 (2/3 sand + 1/3 potting soil) recorded the highest daily germination averages ($1.11 \pm 0.29\%$ and $0.73 \pm 0.38\%$).



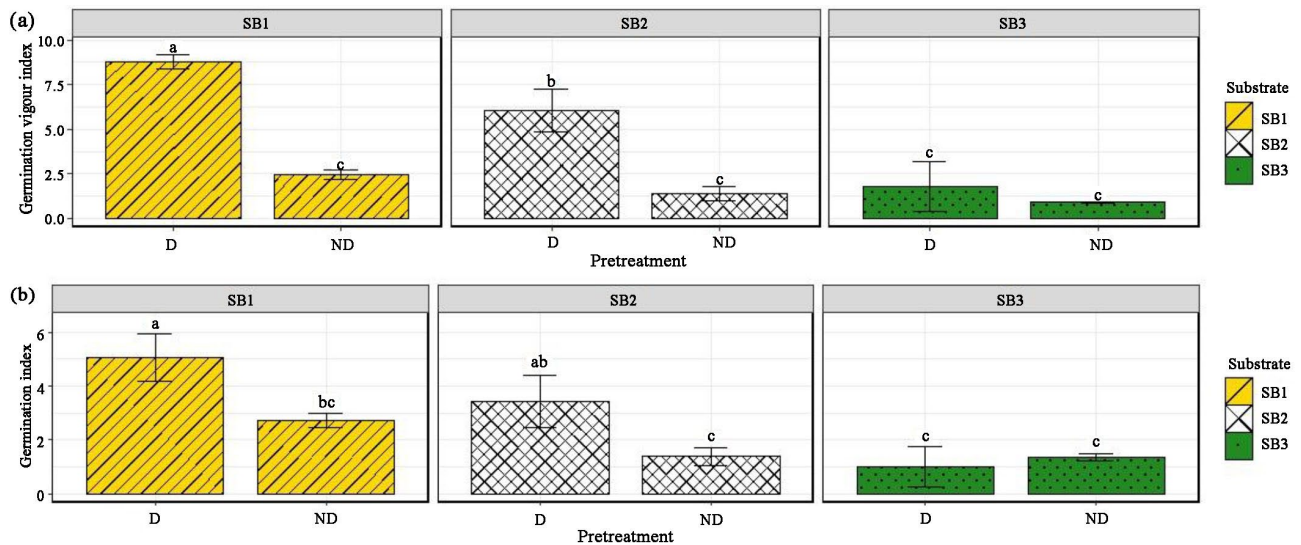
SB1 (3/3 Sand); SB2 (2/3 Sand + 1/3 potting soil); SB3 (1/3 Sand + 2/3 potting soil); D (dehulled seeds); ND (non-dehulled seeds).

Figure 5. Variation of Germination rate (a) and duration (b, c) between pretreatments and substrates.

3.2.2. Germination Quality

The ANOVA revealed significant differences ($p < 0.05$) between pretreatments, substrates, and their interaction on the germination vigor index and germination index (Figure 6). It showed that dehulled seeds produced the highest germination vigour index (5.54 ± 1.07) and germination index (3.158 ± 0.87) compared to non-dehulled seeds (1.57 ± 0.42 and 1.82 ± 0.24). Regarding substrates, the analysis showed that

substrates SB1 and SB2 yielded the best GVI (5.61 ± 0.33 and 3.71 ± 0.81) and GI (3.87 ± 0.57 and 2.41 ± 0.66) values, while SB3 consistently showed the lowest values. The highest GVI and GI values were obtained with dehulled seeds on SB1 (8.795 ± 0.714 and 5.04 ± 0.88) and SB2 (6.050 ± 2.085 and 3.43 ± 0.98).

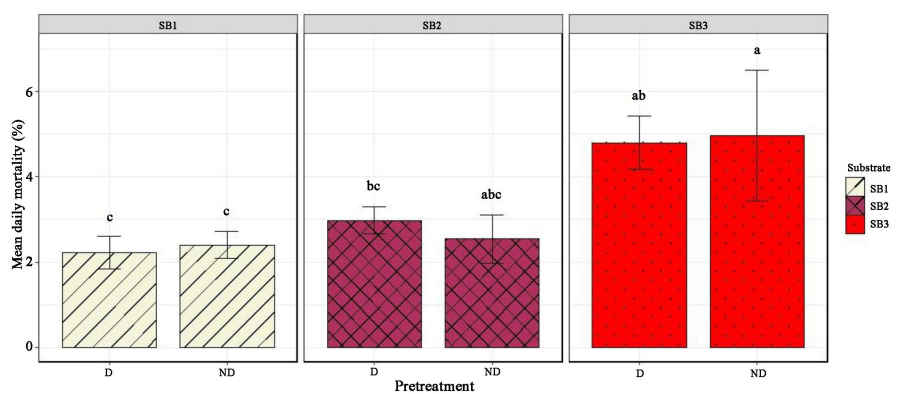


SB1 (3/3 Sand); SB2 (2/3 Sand + 1/3 potting soil); SB3 (1/3 Sand + 2/3 potting soil); D (dehulled seeds); ND (non-dehulled seeds).

Figure 6. Variation of germination quality according to pretreatment and substrate.

3.2.3. Mortality

ANOVA indicated that the interaction between pretreatment and substrate (**Figure 7**) had no significant effect ($p > 0.05$), nor did the pretreatment factor alone ($p > 0.05$). However, the substrate factor alone had a significant effect ($p < 0.05$) on seedling daily mortality. Fisher's test revealed that SB3 (1/3 sand + 2/3 potting soil) resulted in the highest mean daily mortality rate ($4.88 \pm 1.07\%$) compared to the other substrates, regardless of pretreatment. No statistically significant difference was observed between SB2 (2/3 sand + 1/3 potting soil) and SB1 (3/3 sand).



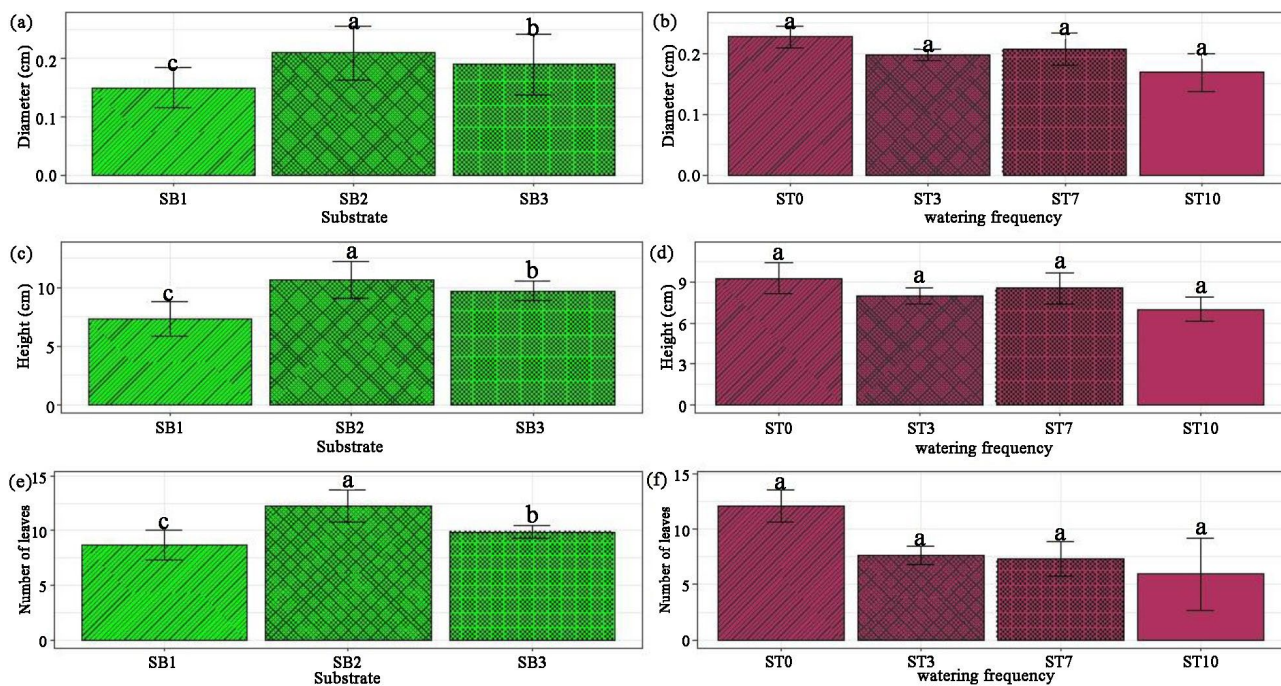
SB1 (3/3 Sand); SB2 (2/3 Sand + 1/3 potting soil); SB3 (1/3 Sand + 2/3 potting soil); D (dehulled seeds); ND (non-dehulled seeds).

Figure 7. Variation of mean daily mortality according to pretreatment and substrate.

3.3. Growth Parameters

Analysis of variance (ANOVA) revealed a significant effect of substrates on all measured parameters ($p < 0.05$). The Student-Newman-Keuls (SNK) test further indicated that SB2 (2/3 sand + 1/3 potting soil) produced the best performance (**Figure 8**), with the highest mean collar diameter (0.21 ± 0.08 cm), maximum mean height (10.65 ± 2.75 cm), and greatest mean leaf number (12.21 ± 2.56 leaves). This was followed by SB3 (1/3 sand + 2/3 potting soil), whereas SB1 (100% sand) recorded the lowest values, with a mean collar diameter of 0.15 ± 0.06 cm, a mean height of 7.31 ± 2.57 cm and an average of 8.68 ± 2.43 leaves.

Statistical analysis revealed that watering frequency did not have a significant effect on these parameters ($p > 0.05$). However, in absolute terms, the ST10 treatment recorded the lowest performance, with the smallest mean collar diameter (0.16 ± 0.03 cm), the shortest mean height (7.02 ± 0.87 cm) and the lowest mean number of leaves (5.97 ± 3.26 leaves).



SB1 (3/3 Sand); SB2 (2/3 Sand + 1/3 potting soil); SB3 (1/3 Sand + 2/3 potting soil); ST0 (Watered daily); ST3 (Watered every three days); ST7 (Watered every seven days); ST10 (Watered every ten days).

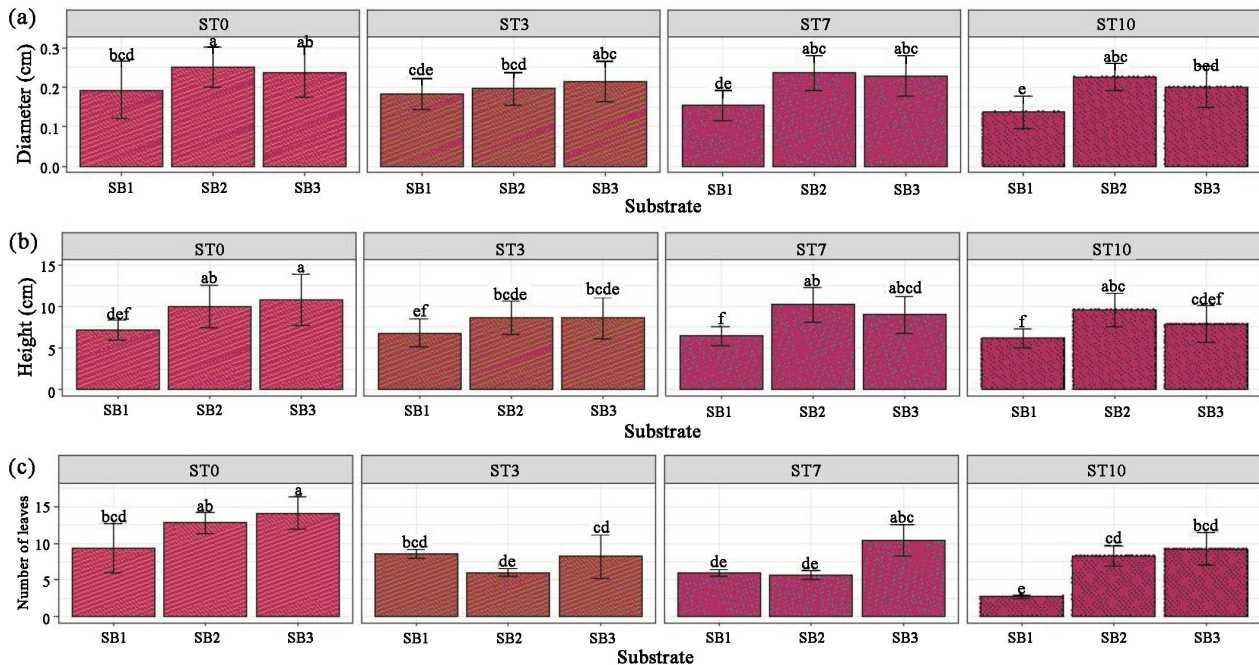
Figure 8. Effects of substrate and watering frequency on seedling growth Parameters.

The analysis shows a significant effect of the substrate and watering frequency interaction on growth parameters. The lowest mean diameter (0.13 ± 0.07 cm) was observed in SB1 (100% sand) under ST10, while the highest (0.25 ± 0.08 cm) was recorded in unstressed plants (ST0) of SB2. No significant difference was found between these and unstressed plants of SB3.

For height (**Figure 9(b)**), the tallest plants were observed in unstressed SB3 seedlings (10.77 ± 5.33 cm), while the shortest (6.15 ± 2.08 cm) were recorded in

SB1 under the ST10 treatment.

For leaf number (**Figure 9(c)**), unstressed plants of SB3 produced the highest mean leaf number (14.10 ± 2.87), followed by SB2 (12.77 ± 3.50). The lowest leaf number (2.69 ± 0.48) occurred in SB1 under ST10.



SB1 (3/3 Sand); SB2 (2/3 Sand + 1/3 potting soil); SB3 (1/3 Sand + 2/3 potting soil); ST0 (Watered daily); ST3 (Watered every three days); ST7 (Watered every seven days); ST10 (Watered every ten days); p (probability of the interaction between substrate and watering frequency).

Figure 9. Variation of diameter, height, and leaf number in response to the interaction between substrate and watering frequency.

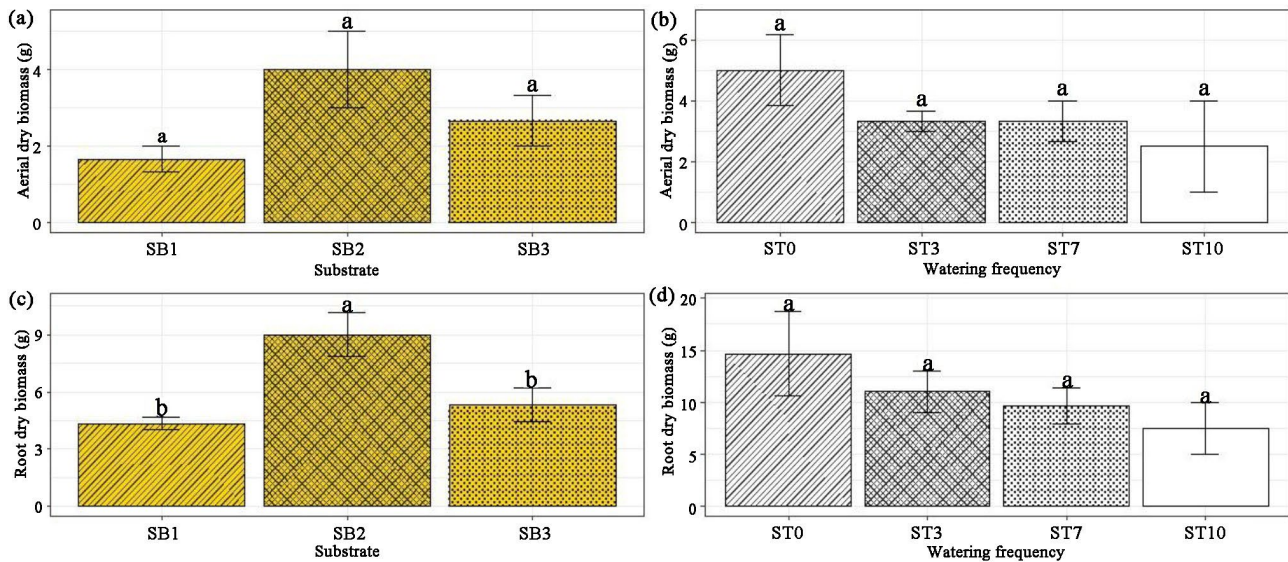
3.4. Biomass Parameters

Statistical analysis indicated that aerial dry biomass (**Figure 10**) was not significantly affected by substrate ($p > 0.05$). In contrast, a significant effect of substrate was observed on root dry biomass ($p < 0.05$). SB2 (2/3 sand + 1/3 potting soil) resulted in the highest mean root dry biomass (9.00 ± 2.00 g), followed by SB3 (1/3 sand + 2/3 potting soil). The sandy substrate (100% sand) produced the lowest mean value (4.33 ± 0.57 g).

Statistical analysis showed that watering frequency had no significant effect on these parameters. However, the absolute values indicate that the ST0, ST3 and ST7 treatments produced the highest dry biomass, both for the aerial (5 ± 1.15 g; 3.33 ± 0.33 g; and 3.33 ± 0.66 g) and the root components (14.66 ± 4 g; 11 ± 2 g; and 9.66 ± 1.76 g). In contrast, the ST10 treatment recorded the lowest biomass values, with only 2.5 ± 1.49 g for the aerial and 7.5 ± 2.5 g for the roots.

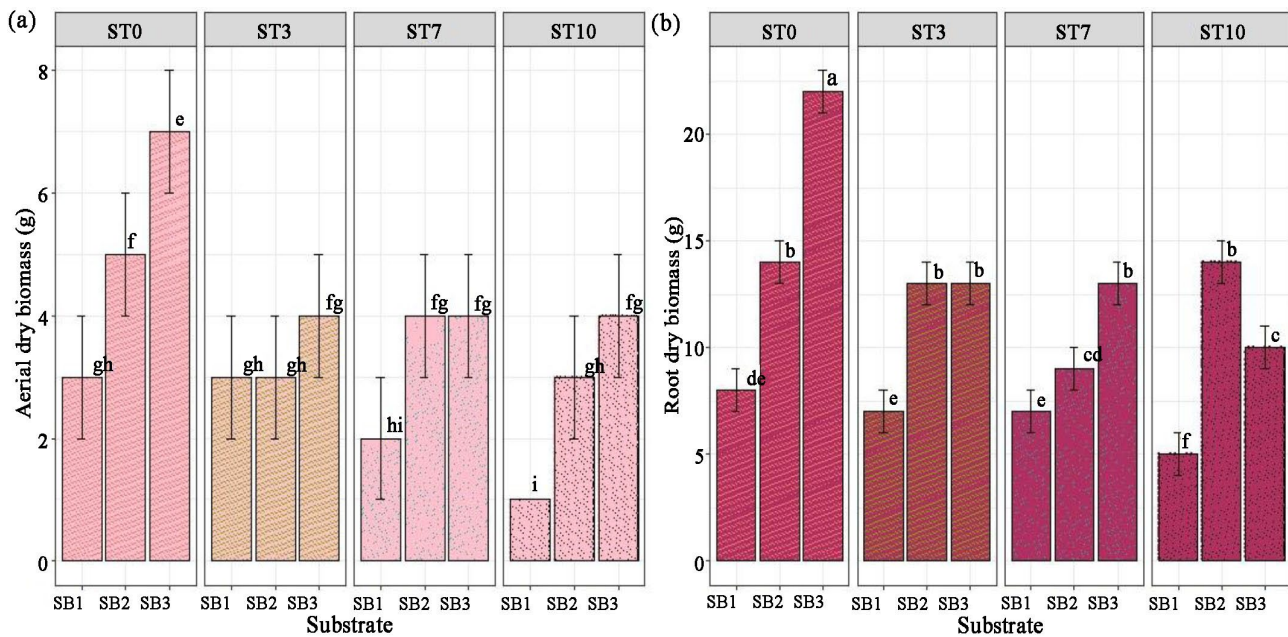
ANOVA revealed significant interactions between substrate and watering frequency for both aerial and root dry biomass (**Figure 11**). On average, root biomass (11.3 g) was greater than aerial biomass (3.58 g), regardless of substrate or watering frequency. Plants grown in SB3 had the highest aerial (4.75 g) and root (14.65

g) biomasses, followed by SB2 (3.75 g and 12.5 g). Watering frequency also had a significant effect, with unstressed plants (ST0) showing the largest values across substrates. The combination SB3 + ST0 produced the highest mean aerial and root biomasses (7 ± 1 g and 22 ± 1 g), whereas SB1 + ST10 yielded the lowest (1 ± 0 g and 5 ± 1 g).



SB1 (3/3 Sand); SB2 (2/3 Sand + 1/3 potting soil); SB3 (1/3 Sand + 2/3 potting soil); ST0 (Watered daily); ST3 (Watered every three days); ST7 (Watered every seven days); ST10 (Watered every ten days).

Figure 10. Variation in aerial and root dry biomass across the different substrates and watering frequency.

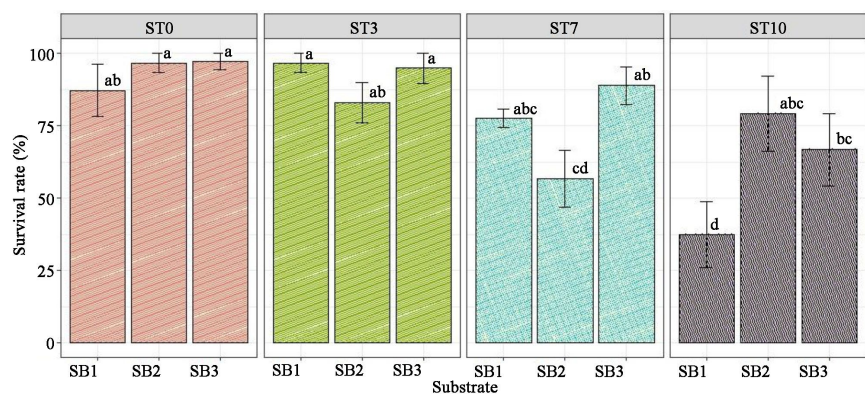


SB1 (3/3 Sand); SB2 (2/3 Sand + 1/3 potting soil); SB3 (1/3 Sand + 2/3 potting soil); ST0 (Watered daily); ST3 (Watered every three days); ST7 (Watered every seven days); ST10 (Watered every ten days).

Figure 11. Dry biomass in response to the interaction of substrate and watering frequency.

3.5. Survival Rate

The analysis of **Figure 12** revealed that the watering regime (watering frequency) alone had a significant influence ($p < 0.05$) on this parameter. Similarly, the interaction between the two factors (substrate and watering frequency) also had a significant effect ($p < 0.05$). The analysis showed that the ST10 frequency resulted in the lowest survival rate ($61.09 \pm 12.2\%$). Regarding the interaction, the analysis indicated that seedlings watered daily (ST0) and every three days (ST3) showed the highest mean survival rates ($93.07 \pm 5.01\%$ and $91.51 \pm 5.16\%$) compared to those watered at ST7 and ST10 frequencies. Seedlings grown on substrate SB1 and watered at ST10 frequency recorded the lowest mean survival rate ($37.42 \pm 1.9\%$), while the highest was obtained from seedlings on substrate SB3 watered at ST0 frequency ($97.22 \pm 4.81\%$).



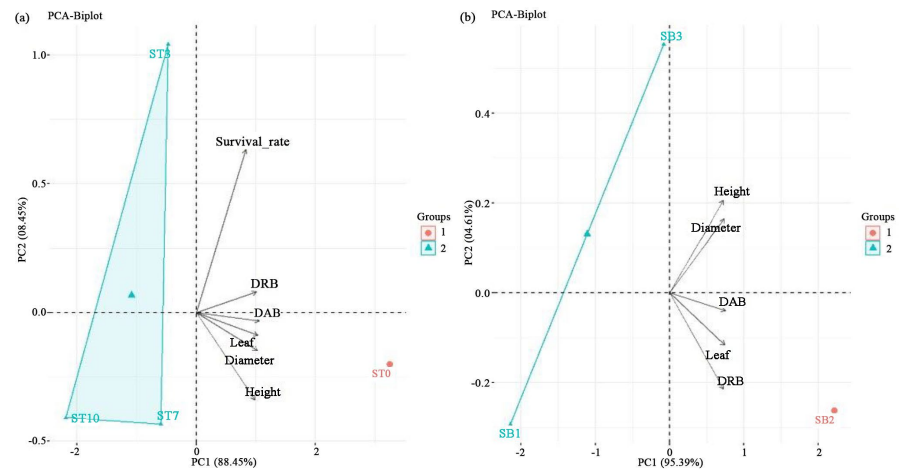
SB1 (3/3 Sand); SB2 (2/3 Sand + 1/3 potting soil); SB3 (1/3 Sand + 2/3 potting soil); ST0 (Watered daily); ST3 (Watered every three days); ST7 (Watered every seven days); ST10 (Watered every ten days).

Figure 12. Plant survival rate as a function of substrate and watering frequency.

3.6. Characteristics of Substrates and Watering Frequency

Principal component analysis (PCA) revealed that the first axis (PC1) accounted for 88.45% of the variance, while the second axis (PC2) explained 8.45%, yielding a cumulative variance of 96.9%. The PCA (**Figure 13(a)**) distinguished two groups. The first group, located on the positive side of the x-axis and corresponding to frequency ST0, exhibited the highest performance for the measured parameters. The second group, located on the negative side of the y-axis and composed of frequencies ST3, ST7, and ST10, showed the lowest performance.

The first axis (PC1) accounted for 95.39% of the total variance, while the second axis (PC2) explained 04.61%, representing a cumulative variance of 100% (**Figure 13(b)**). The PCA revealed two distinct groups. Group 1, located on the positive side of the x-axis and represented by SB2, was associated with superior performance across the measured parameters (plant height, leaf number, collar diameter, aerial and root dry biomass). In contrast, Group 2, composed of SB1 and SB3, was positioned on the opposite side of the axis and exhibited comparatively lower performance for the same parameters.



SB1 (3/3 Sand); SB2 (2/3 Sand + 1/3 potting soil); SB3 (1/3 Sand + 2/3 potting soil).

Figure 13. Principal component analysis (PCA) of parameters studied according to substrate (a) and watering frequency (b).

4. Discussion

4.1. Germination

The results highlight the importance of seed pretreatment (dehulling) and substrate on the germination capacity of *D. melanoxyton*. Dehulling significantly improved germination compared to non-dehulling seeds, in agreement with findings reported for *Argania spinosa* L. [41] and *Neocarya macrophylla*. Sabine [42] [43].

By removing the seed coat, dehulling enhances permeability, allowing faster water and air penetration and reducing both physical and chemical barriers [44]-[47]. This promotes imbibition, gas exchange and radicle emergence by limiting inhibitory compounds [48]-[50]. As a result, embryonic metabolism is triggered earlier, shortening the mean germination time compared to intact seeds, which must first overcome the resistance of the seed coat [51].

Substrate was also a critical factor for germination, with significant differences among the three tested substrates. SB1 (100% sand) and SB2 (2/3 sand + 1/3 potting soil) showed the best performance, likely due to their lighter texture and higher aeration. Such conditions reduce the risk of waterlogging, which can inhibit germination by creating hypoxic environments that disrupt metabolic activity in the endosperm and embryo, sometimes leading to seed death [52]. This result is consistent with [7], who reported better germination of *D. melanoxyton* seeds under low to medium moisture. In contrast, SB3 (1/3 sand + 2/3 potting soil), with higher water retention, may have created anoxic conditions unfavorable for germination [53]. Similar trends were observed in *Prosopis africana* (Guill. & Perr.) Taub, where seeds germinated optimally (100%) in erosion sand [45].

The maximum germination rate observed (41.96 %) for dehulled seeds on SB1 (100% sand) remained below 50%, consistent with previous reports of *D. melanoxyton* seed germination ranging from 20% to 50% [7] [23] [24]. Seedling mortality, however, was not significantly affected by pretreatment. Instead, it was

largely determined by post-germination factors such as substrate, water management and pathogens. While dehulling improved germination, it did not ensure seedling survival, which depends heavily on soil and climatic conditions [54]. SB3 (1/3 sand + 2/3 potting soil) recorded higher mortality rates regardless of pretreatment, likely due to its high-water retention and poor aeration, which restrict root development and increase susceptibility to abiotic stress and pathogens [55]. Similar results were reported by [56], who showed that poor substrate aeration often leads to root mortality, frequently preceded by fungal infections such as *Phytophthora*.

4.2. Growth and Biomass Parameters

The analysis of growth parameters in *D. melanoxylon* seedlings revealed a significant effect of substrate on plant development. SB2 and SB3 produced the best growth, mainly due to the addition of potting soil. This amendment improves soil physico-chemical properties by enhancing water retention and supplying essential nutrients such as exchangeable cations, organic matter and total nitrogen. Such conditions favor vigorous growth and healthy seedling establishment. Comparable effects were reported by [57] in *Artemisia annua* L., where nutrient-rich substrates similarly enhanced plant development.

SB1 (3/3 sand) exhibited the lowest performance, mainly due to its low organic matter and nutrient content, combined with poor water retention, which limits the resources available for seedling development. This agrees with [58], who reported that substrates dominated by coarse particles, such as sand, provide good aeration but poorly support plant nutrition and water availability. In contrast, SB2 (2/3 sand + 1/3 potting soil) performed well in growth parameters, despite containing less potting soil than SB3 (1/3 sand + 2/3 potting soil). This suggests that an optimal balance between aeration (from sand) and nutrient supply (from potting soil) is more important than simply maximizing organic content. Similar results were reported by [59], who showed that well-drained substrates enriched with organic matter promote better growth of *Azelia africana* Smith ex Pers. Overall, organic-rich substrates such as potting soil improve soil structure and nutrient availability, creating favorable conditions for the optimal growth of *D. melanoxylon* seedlings, which are naturally adapted to nutrient-poor soils.

However, regarding dry biomass, only root biomass was significantly influenced by the substrates. *D. melanoxylon* seedlings developed their root system more than the aerial parts. This preferential root growth at the expense of above-ground growth has been reported by several authors in other species [60]-[62]. According to [63], root system development is a key factor in the survival of young plants. Root hypertrophy represents an effective adaptive strategy for the persistence of woody species, as it allows the accumulation of essential nutrient reserves.

Moreover, optimal soil characteristics for root development in *D. melanoxylon* seedlings include soil textures such as silt, sandy loam and clay loam [25]. This could explain the marked root growth observed with SB2 (2/3 sand and 1/3 pot-

ting soil) and SB3 (1/3 sand and 2/3 potting soil). These soil types provide an ideal balance between drainage and moisture retention, thereby promoting rooting and seedling growth. The use of substrates rich in organic matter, such as potting soil, optimizes these conditions by improving soil structure and providing the necessary nutrients for the proper development of *D. melanoxyton* seedlings

The results of this study highlight the combined influence of water stress and substrate type on *D. melanoxyton*. Plants grown in SB3 (1/3 sand + 2/3 potting soil) performed best, followed by those in SB2 (2/3 sand + 1/3 potting soil). This trend can be explained by the higher organic matter content of potting soil, which enhances water retention and provides essential nutrients. Under water stress conditions, organic-rich substrates act as buffers by retaining moisture longer and supplying water to the roots, thereby mitigating drought effects. Similar findings were reported by [64] and [65], who showed that the wettability of organic matter improves plant tolerance to drought.

In contrast, the poor performance observed in SB1 (3/3 sand) can be attributed to its particle size. Coarse sand drains quickly, which under water deficit conditions becomes highly limiting. This observation is consistent with [58], who emphasized that sandy substrates provide good aeration but are unable to sustain adequate plant nutrition and water retention.

Regarding irrigation frequency, watering every ten days (ST10) was the most severe treatment, resulting in the lowest growth performance. Severe water stress reduces water and nutrient uptake, leading to mineral deficiencies (notably nitrogen and phosphorus) due to reduced element transport to the roots and consequently limiting seedling growth [66] [67]. Plants in SB1 under ST10 were the most affected because of the low water-holding capacity of sand. Under prolonged intervals, substrate moisture becomes critical and *D. melanoxyton* deprived of water experiences intense physiological stress that inhibits growth and survival. Water deficit also decreases photosynthetic activity [68] and alters both physiological processes regulating growth and biochemical pathways [69]-[72] and biochemical pathways [73] [74]. These results corroborate those of [75], who also observed reduced growth under water stress in two *Acacia* species.

Regarding aerial and root dry biomass, results revealed that *D. melanoxyton* prioritizes root system development over the aerial part under water stress. A well-developed root system capable of extracting water from the soil under deficit conditions is a key trait for drought tolerance [76]. This strategy reflects the species' adaptation to water-limited environments, as extensive roots enhance water uptake while reducing transpiring surface area. These findings align with observations on *Acacia tortilis* (Forssk) Hayne subsp. *raddiana* (Savi) [77] and on *Combretum micranthum* G. Don, *Faidherbia albida* (Del) A. Chev, and *Pterocarpus lucens* Lepr. ex Guill. & Perr [33].

5. Conclusion

This study underscores the critical role of seed pretreatment and substrate type on the germination and growth of *D. melanoxyton* seedlings, as well as the species

adaptive responses under water stress. Seed dehulling significantly enhanced germination, highlighting the importance of overcoming physical and chemical barriers. Light, sandy substrates optimized germination, whereas mixed substrates of sand and potting soil promoted the best seedling growth by balancing aeration, water retention and nutrient supply. Under water stress, *D. melanoxyton* displayed adaptive strategies such as prioritizing root development over aerial biomass and storing more water in aerial tissues, which enhances drought tolerance. These findings provide valuable insights for the sustainable management and conservation of the species, including optimal germination conditions, growth requirements and strategies to mitigate water deficit impacts on young seedlings.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Arbonier, M. (2008) Ligneux du Sahel V.1.0.
- [2] Orwa, C. (2009) Agroforestry Database: A Tree Reference and Selection Guide, Version 4.0. World Agroforestry.
- [3] Chevalier, A. (1934) Sur l'origine des Ebènes commerciaux de l'Antiquité, du XVIIe-XVIIIe siècle et de l'époque contemporaine. *Revue de botanique appliquée et d'agriculture coloniale*, **14**, 948-965. <https://doi.org/10.3406/jatba.1934.5436>
- [4] Kiondo, F., Feyissa, T., Ndakidemi, P.A. and Seth, M. (2014) *In Vitro* Propagation of *Dalbergia melanoxyton* Guill. & Perr.: A Multipurpose Tree. *American Journal of Research Communication*, **2**, 181-194.
- [5] Bryce, J.M. (1967) The Commercial Timbers of Tanzania. CABI.
- [6] Washa, W.B. (2014) A Review of the Literature of *Dalbergia melanoxyton*. *International Journal of Plant and Forestry Sciences*, **1**, 1-6.
- [7] Washa, W.B. and Nyomora, A.M.S. (2012) The Effect of Moisture and Seed Treatment on the *In-Situ* and *Ex-Situ* Regeneration of *Dalbergia melanoxyton* (African Blackwood) in Pugu Forest Reserve. *Huria: Journal of the Open University of Tanzania*, **10**, 54-67.
- [8] Nakai, K. (2020) Enhancing the Potential of African Blackwood, *Dalbergia melanoxyton*, through Sustainable Forest Utilization: A Valuable Tree Species in Tanzanian Miombo Forest.
- [9] Jenkins, M., Oldfield, S. and Aylett, T. (2002) International Trade in African Blackwood.

- [10] Bell, J. (2023) Mpingo: A Closer Look. International Clarinet Association.
- [11] Ndong, A.T., Ndiaye, O., Sagna, M.B., Diallo, A., Galop, D. and Guisse, A. (2016) Caractérisation de la végétation ligneuse sahélienne du Sénégal: Cas du Ferlo. *International Journal of Biological and Chemical Sciences*, **9**, 2582-2594. <https://doi.org/10.4314/ijbcs.v9i6.6>
- [12] Ngom, D., Fall, T., Sarr, O., Diatta, S. and Akpo, L.E. (2013) Caractéristiques écologiques du peuplement ligneux de la réserve de biosphère du Ferlo (Nord Sénégal). *Journal of Applied Biosciences*, **65**, 5008-5023. <https://doi.org/10.4314/jab.v65i0.89644>
- [13] Sambou, A. (2016) Vegetation Change, Tree Diversity and Food Security in the Sahel: A Case from the Salinity-Affected Fatick Province in Senegal.
- [14] Niang, K., Ndiaye, O., Diallo, A. and Guissé, A. (2014) Flore et structure de la végétation ligneuse le long de la Grande Muraille Verte au Ferlo, nord Sénégal. *Journal of Applied Biosciences*, **79**, 6938-6946. <https://doi.org/10.4314/jab.v79i1.15>
- [15] TACC (2014) Rapport d'analyse de la vulnérabilité aux changements climatiques de la zone du Ferlo. 224.
- [16] Chigora, P., Masocha, R. and Mutenheri, F. (2007) The Role of Indigenous Medicinal Knowledge (IMK) in the Treatment of Ailments in Rural Zimbabwe: The Case of Mutirikwi Communal Lands. *Journal of Sustainable Development in Africa*, **9**, 26-43.
- [17] Kerharo, J. and Adam, J.-G. (1974) La pharmacopée sénégalaise traditionnelle: Plantes médicinales et toxiques. FAO AGRIS, 805-869.
- [18] Kareru, P.G., Gachanja, A.N., Keriko, J.M. and Kenji, G.M. (2008) Antimicrobial Activity of Some Medicinal Plants Used by Herbalists in Eastern Province, Kenya. *African Journal of Traditional, Complementary and Alternative Medicines*, **5**, 51-55. <https://doi.org/10.4314/ajtcam.v5i1.31256>
- [19] Amri, E., Kanyeka, Z.L., Lyaruu, H.V.M. and Nyomora, A.S. (2009) Evaluation of Genetic Diversity in *Dalbergia melanoxylon* Populations Using Random Amplified Poly-Morphic DNA Markers. *Research Journal of Cell and Molecular Biology*, **3**, 71-79.
- [20] Högborg, P. (1986) Nitrogen-Fixation and Nutrient Relations in Savanna Woodland Trees (Tanzania). *The Journal of Applied Ecology*, **23**, 675-688. <https://doi.org/10.2307/2404045>
- [21] Albano, G. (2001) Indigenous Management Practices and Conservation of *Dalbergia melanoxylon* Guill. & Perr. in Mozambique: A Case Study Form Two Villages in Southern Cabo Delgado.
- [22] Cornet, A. and Poupon, H. (1977) Description des facteurs du milieu et de la végétation dans cinq parcelles situées le long d'un gradient climatique en zone sahélienne au Sénégal. *Bulletin de l'IFANT*, **39**, 241-302. https://www.researchgate.net/profile/Antoine-Cornet-3/publication/32993256_Description_des_facteurs_du_milieu_et_de_la_vegetation_dans_cinq_parcelles_situees_le_long_d'un_gradient_climatique_en_zone_sahelienne_au_Senegal/links/576aff2608aefcf135bd51e0/Description-des-facteurs-du-milieu-et-de-la-vegetation-dans-cinq-parcelles-situees-le-long-dun-gradient-climatique-en-zone-sahelienne-au-Senegal.pdf
- [23] Amri, E. (2002) Propagation Studies of Economically Important Plants: *Dalbergia melanoxylon*, *Swartzia madagascariensis* (Papilionaceae) and *Prunus africana* (Rosacea).
- [24] Mbuya, L.P., Msanga, H.P., Ruffo, C.K., Birnie, A. and Tengnäs, B.O. (1994) Useful Trees and Shrubs for Tanzania: Identification, Propagation and Management for Agricultural and Pastoral Communities.

- [25] Washa, W.B.A., Nyomora, A.M.S. and Lyaruu, H.M.V. (2012) Improving Propagation Success of *D. melanoxyton* (African Blackwood) in Tanzania (II): Rooting Ability of Stem and Root Cuttings of *Dalbergia melanoxyton* (African Blackwood) in Response to Rooting Media Sterilization in Tanzania. *Tanzania Journal of Science*, **38**, 43-53. <https://doi.org/10.65085/2507-7961.1877>
- [26] Schatz, G.E. (2009) Plants on the IUCN Red List: Setting Priorities to Inform Conservation. *Trends in Plant Science*, **14**, 638-642. <https://doi.org/10.1016/j.tplants.2009.08.012>
- [27] Ndiaye, O., Goudiaby, A.O.K. and Sambou, A. (2018) Effects of Substrate on Germination and Growth of *Moringa oleifera* Lam., *Acacia mellifera* (vahl) Benth. and *Zizyphus mauritiana* Lam. Seedlings. *Reforesta*, No. 6, 86-99. <https://doi.org/10.21750/refor.6.07.60>
- [28] Diatta, C.D., Gueye, M. and Akpo, L.E. (2013) Les plantes médicinales utilisées contre les dermatoses dans la pharmacopée Baïnouk de Djibonker, région de Ziguinchor (Sénégal). *Journal of Applied Biosciences*, **70**, 5599-5607. <https://doi.org/10.4314/jab.v70i1.98762>
- [29] Ndiaye, L., Diallo, A.M., Vu, T.H.G., Mueller, M., Ngom, D., Mbaye, T., *et al.* (2025) Genetic Diversity of *Dalbergia melanoxyton* Guill. & Perr. Populations in the Ferlo Zone (Senegal) Using Nuclear and Chloroplast Microsatellite Markers. *Genetic Resources and Crop Evolution*, **72**, 4901-4913. <https://doi.org/10.1007/s10722-024-02255-1>
- [30] Ngom, D. (2008) Définition d'indicateurs de gestion durable des ressources sylvo-pastorales au Ferlo (Nord-Sénégal).
- [31] Diallo, A., Faye, M., Ndiaye, O. and Guissé, A. (2011) Variations de la composition de la végétation herbacée des plantations de *Acacia senegal* (L.) Willd de la zone de Dahra (Ferlo). *International Journal of Biological and Chemical Sciences*, **5**, 1250-1264. <https://doi.org/10.4314/ijbcs.v5i3.72273>
- [32] Daïnou, K., Tosso, D.F., Bracke, C., Bourland, N., Forni, E., Hubert, D., Kankolongo, M., Loumeto, J.J., Louppe, D. and Ngomanda, A. (2021) Guide pratique des plantations d'arbres des forêts denses humides d'Afrique.
- [33] Kagambèga, F.W., Nana, R., Bayen, P., Thiombiano, A. and Boussim, J.I. (2019) Tolérance au déficit hydrique de cinq espèces prioritaires pour le reboisement au Burkina Faso. *Biotechnology, Agronomy, Society and Environment*, **23**, 245-256. <https://doi.org/10.25518/1780-4507.18199>
- [34] Camara, B., Dasylyva, M., Diouf, N.M., Kane, N.A., Diedhiou, M.A.A. and Ngom, D. (2023) Combined Effect of *Faidherbia albida* (Del) A. Chev Leaf Litter and Manure on Soil Physicochemical Composition, Growth and Yield of Rice (*Oryza sativa* L.) in Lower Casamance, Senegal. *Journal of Applied Biosciences*, **190**, Article No. 20050. <https://doi.org/10.35759/jabs.190.4>
- [35] Jamagne, M. (1967) Bases et Techniques d'une cartographie des sols. *Annales Agronomiques*, **18**, Article No. 142.
- [36] Cornet, A. (1971) Méthodes de détermination de la capacité de rétention en eau du sol. 36.
- [37] Osborne, J.M., Fox, J.E.D. and Mercer, S. (1993) Germination Response under Elevated Salinities of Six Semi-Arid Bluebush Species (Western Australia). In: Lieth, H. and Masoom, A.A., Eds., *Tasks for Vegetation Science*, Springer, 323-338. https://doi.org/10.1007/978-94-011-1858-3_35
- [38] Czabator, F.J. (1962) Germination Value: An Index Combining Speed and Complete-

- ness of Pine Seed Germination. *Forest Science*, **8**, 386-396.
<https://doi.org/10.1093/forestsience/8.4.386>
- [39] Scott, S.J., Jones, R.A. and Williams, W.A. (1984) Review of Data Analysis Methods for Seed Germination. *Crop Science*, **24**, 1192-1199.
<https://doi.org/10.2135/cropsci1984.0011183x002400060043x>
- [40] Jain, N.K. and Saha, J.R. (1971) Effect of Storage Length on Seed Germination in Jute (*Corchorus Spp.*). *Agronomy Journal*, **63**, 636-638.
<https://doi.org/10.2134/agronj1971.00021962006300040037x>
- [41] Mezghenni, H., Hamrouni, L., Hanana, M., Jamoussi, B., Bouzid, S. and Khouja, M.L. (2014) Multiplication de l'arganier *Argania spinosa* (L.) Skeels. *Journal of New Sciences*, **10**, 1-12.
- [42] Guimbo, I.D., Ambouta, K.J.M., Mahamane, A. and Larwanou, M. (2011) Germination et croissance initiale de *Neocarya macrophylla* (Sabine) Prance, une espèce oléagineuse du Niger. *Tropicultura*, **29**, 88-93.
- [43] Sambou, A., Diémé, J.S., Camara, B., Dione, F. and Baldé, B. (2024) Effects of Different Nut Pretreatments and Substrates on Germination and Seedlings Growth of *Neocarya macrophylla* Sabine in Basse Casamance, Senegal. *iForest-Biogeosciences and Forestry*, **17**, 346-352. <https://doi.org/10.3832/ifer4528-017>
- [44] Agboola, D.A., Idowu, W.F. and Kadiri, M. (2006) Seed Germination and Seedling Growth of the Mexican Sunflower *Tithonia diversifolia* (Compositae) in Nigeria, Africa. *Revista de Biología Tropical*, **54**, 395-402.
<https://doi.org/10.15517/rbt.v54i2.13881>
- [45] Ahoton, L.E., Adjakpa, J.B., M'po, I.M. and Akpo, E.L. (2009) Effet des prétraitements des semences sur la germination de *Prosopis africana* (Guill., Perrot. et Rich.) Taub., (Césalpiniacées). *Tropicultura*, **27**, 233-238.
- [46] Mbaye, N., Diop, A.T., Guèye, M., Diallo, A.T., Sall, C.E. and Samb, P.I. (2002) Etude du comportement germinatif et essais de levée de l'inhibition tégumentaire des graines de *Zornia glochidiata* Reichb. ex DC., légumineuse fourragère. *Revue d'élevage et de médecine vétérinaire des pays tropicaux*, **55**, 47-52.
<https://doi.org/10.19182/remvt.9845>
- [47] Hamidou, A., Iro, D.G., Boubé, M., Malick, T.S. and Ali, M. (2014) Potential Germination and Initial Growth of *Sclerocarya birrea* (A. Rich.) Hochst, in Niger. *Journal of Applied Biosciences*, **76**, 6433-6443. <https://doi.org/10.4314/jab.v76i1.12>
- [48] Bacchetta, G., Belletti, P., Brullo, S., Cagelli, L., Carasso, V., Casas, J.L., Cervelli, C., Escrib, M.C., Fenu, G., Gorian, F., et al. (2006) Manuel pour la récolte l'étude, la conservation et la gestion *ex Situ* du matériel végétal.
- [49] N'Dri, A.A., Vroh-Bi, I., Kouamé, P.L. and Bi, I.Z. (2011) Bases génétiques et biochimiques de la capacité germinative des graines: Implications pour les systèmes semenciers et la production alimentaire. *Sciences & Nature*, **8**, 119-137.
- [50] Baskin, C.C. and Baskin, J.M. (2000) Seeds: Ecology, Biogeography, and, Evolution of Dormancy and Germination.
- [51] Fenner, M. and Thompson, K. (2005) The Ecology of Seeds. Cambridge University Press. <https://doi.org/10.1017/cbo9780511614101>
- [52] Heuze, V., Tran, G. and Boval, M. (2011) Substrats de croissance et germination des espèces forestières. *Forêt Méditerranéenne*, **32**, 54-61.
- [53] Zhao, X., Ren, Y., Schmidhalter, U. and Zhang, F. (2020) Influence of Soil Texture and Composition on Plant Growth and Nutrient Uptake. *Plant and Soil*, **452**, 15-28.
- [54] Hartmann, H.T., Kester, D.E., Davies, F.T. and Geneve, R.L. (2017) Hartmann & Kes-

ter's Plant Propagation Principles and Practices.

- [55] Whitmore, T.C. (1998) An Introduction to Tropical Rain Forests.
- [56] Abourouh, M., Lamhamedi, M.S. and Fortin, J.A. (1995) Techniques de mycorrhization en pépinière des plants forestiers. Centre de la Recherche Forestière.
- [57] Müller, M. and Brandes, D. (1997) Growth and Development of *Artemisia annua* L. on Different Soil Types. *Verhandlungen-Gesellschaft Fur Okologie*, **27**, 453-460.
- [58] Marschner, P. (2012) Marschner's Mineral Nutrition of Higher Plants.
- [59] Ouedraogo, A., Thiombiano, A. and Bognounou, F. (2013) Influence des substrats sur la croissance de *Azadirachta africana* en pépinière. *Bois et Forêts des Tropiques*, **316**, 5-16.
- [60] Ouedraogo, A., Thiombiano, A., Hahn-Hadjali, K. and Guinko, S. (2006) Régénération sexuée de *Boswellia dalzielii* Hutch., un arbre médicinal de grande valeur au Burkina Faso. *Bois & Forêts des Tropiques*, **289**, 41-48.
- [61] Yélémo, B., Yaméogo, G., Millogo, J. and Hien, V. (2007) Germination sexuée et dynamique de développement de *Piliostigma reticulatum* (DC) Hochst, une espèce agroforestière du Burkina Faso. *Science et changements planétaires/Sécheresse*, **18**, 185-192.
- [62] Bationo, B.A., Some, N.A., Ouedraogo, S.J. and Kalinganire, A. (2010) Croissance comparée des plantules de cinq espèces ligneuses soudaniennes élevées en rhizotron. *Sécheresse*, **21**, 196-202. <https://doi.org/10.1684/sec.2010.0255>
- [63] Dauro, D., Mohamed-Saleem, M.A. and Gintzburger, G. (1997) Recruitment and Survival of Native Annual Trifolium Species in the Highlands of Ethiopia. *African Journal of Ecology*, **35**, 1-9. <https://doi.org/10.1111/j.1365-2028.1997.015-89015.x>
- [64] Flaig, W., Nagar, B.R., Söchtig, H. and Tietjen, C. (1976) Soil Organic Matter and Soil Productivity, Soils Bulletin.
- [65] Weil, R.R. and Brady, N. (2017) The Nature and Properties of Soils.
- [66] Dugo, M.-V.G. (2006) Effet du déficit hydrique sur l'état de nutrition azotée chez les graminées fourragères.
- [67] Gahoonia, T.S., Raza, S. and Nielsen, N.E. (1994) Phosphorus Depletion in the Rhizosphere as Influenced by Soil Moisture. *Plant and Soil*, **159**, 213-218. <https://doi.org/10.1007/bf00009283>
- [68] Jewell, M.C., Campbell, B.C. and Godwin, I.D. (2010) Transgenic Plants for Abiotic Stress Resistance. In: Kole, C., et al., Eds., *Transgenic Crop Plants*, Springer, 67-132. https://doi.org/10.1007/978-3-642-04812-8_2
- [69] Coners, H. and Leuschner, C. (2002) *In Situ* Water Absorption by Tree Fine Roots Measured in Real Time Using Miniature Sap-Flow Gauges. *Functional Ecology*, **16**, 696-703. <https://doi.org/10.1046/j.1365-2435.2002.00665.x>
- [70] Lassouane, N., Aid, F. and Lutts, S. (2016) Drought Inhibits Early Seedling Establishment of *Parkinsonia aculeata* L. under Low Light Intensity: A Physiological Approach. *Plant Growth Regulation*, **80**, 115-126. <https://doi.org/10.1007/s10725-016-0148-0>
- [71] Kebbas, S., Lutts, S. and Aid, F. (2015) Effect of Drought Stress on the Photosynthesis of *Acacia tortilis* Subsp. *Raddiana* at the Young Seedling Stage. *Photosynthetica*, **53**, 288-298. <https://doi.org/10.1007/s11099-015-0113-6>
- [72] Dehghanipoodeh, S., Ghobadi, C., Baninasab, B., Gheysari, M. and Shiranibidabadi, S. (2018) Effect of Silicon on Growth and Development of Strawberry under Water Deficit Conditions. *Horticultural Plant Journal*, **4**, 226-232.

<https://doi.org/10.1016/j.hpj.2018.09.004>

- [73] Dupuy, L., Drénou, C. and Fourcaud, T. (2003) Sols, racines et ancrage des arbres forestiers. *Forêt Entreprise*, **153**, 39-43.
- [74] Stewart, M. and Blomley, T. (1994) Use of *Melia volkensii* in a Semi-Arid Agroforestry System in Kenya. *The Commonwealth Forestry Review*, **73**, 128-131.
- [75] Otieno, D.O., Schmidt, M.W.T., Adiku, S. and Tenhunen, J. (2005) Physiological and Morphological Responses to Water Stress in Two Acacia Species from Contrasting Habitats. *Tree Physiology*, **25**, 361-371. <https://doi.org/10.1093/treephys/25.3.361>
- [76] Chloupek, O., Dostál, V., Středa, T., Psota, V. and Dvořáčková, O. (2010) Drought Tolerance of Barley Varieties in Relation to Their Root System Size. *Plant Breeding*, **129**, 630-636. <https://doi.org/10.1111/j.1439-0523.2010.01801.x>
- [77] Logbo, J., Bada, F., Gnancadja, L.S., Ameglio, T. and Akpo, L.E. (2011) Estimation de la biomasse racinaire en fonction de la teneur en eau du sol chez les espèces sahéliennes: Cas d'*Acacia tortilis* (Forsk.) Hayne ssp. *Raddiana* (Savi) Brenand et de *Balanites aegyptiaca* (L) Del, en station et en milieu naturel. *International Journal of Biological and Chemical Sciences*, **5**, 94-110. <https://doi.org/10.4314/ijbcs.v5i1.68090>