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ORIGINAL

Morphology, Germination, and Early Growth of Albizia lebbeck and Albizia procera for Urban Afforestation

Morfología, germinación y crecimiento temprano de Albizia lebbeck y Albizia procera para la forestación urbana

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ABSTRACT

Introduction: Albizia lebbeck L. and Albizia procera (Roxb.) Benth. are exotic multipurpose tree species with high potential for urban and rural afforestation in Sudan. Understanding their pod and seed characteristics, as well as factors influencing germination and early growth, is essential for effective propagation and plantation success.
Objective: this study, conducted during 2019-2020, aimed to evaluate the morphology of pods and seeds, germination behavior, and early seedling growth of A. lebbeck and A. procera under different pre-sowing treatments.
Method: mature pods were collected from both species in the Blue Nile and Khartoum States. Pod and seed traits were measured for size, weight, and seed count. For germination tests, a total of 400 seeds per species were subjected to four pre-sowing treatments (100 seeds each): immersion in hot water (100 °C, cooled overnight), cold water (4 °C, 24 h), concentrated sulphuric acid (5 min) followed by soaking, and untreated control. Seeds were sown under controlled nursery conditions, and germination percentage, germination rate index (GRI), mean germination time (MGT), and early seedling growth (stem, leaves, roots) were recorded. Data were analyzed using ANOVA (GLM, SAS v9.0).
Results: significant differences (p = 0,0001) were observed between species in pod and seed morphology. Pre-sowing treatments significantly enhanced germination compared with the controls. The highest germination success (82,07 %) was achieved with hot water treatment at 80 °C for 10 min, followed by 79,00 % at 100 °C for 1 min. Germination started 4-6 days after sowing and was completed within 22-25 days. Although seed source had limited influence, significant interactions occurred between source and treatment.
Conclusions: hot water treatment (100 °C for 1 min) is recommended to improve seed germination of Albizia procera, especially under rural conditions such as those in Bangladesh. These findings contribute to the propagation and management strategies of Albizia species for afforestation programs.

Keywords: Pods; Seeds; Morphology; Albizia Species; Pre-Sowing Treatments; Sudan.

RESUMEN

Introducción: Albizia lebbeck L. y Albizia procera (Roxb.) Benth. son especies arbóreas exóticas multipropósito con gran potencial para la forestación urbana y rural en Sudán. Comprender las características de sus vainas y semillas, así como los factores que influyen en la germinación y el crecimiento temprano, es esencial para una propagación eficaz y el éxito de la plantación.
Objetivo: este estudio, realizado durante 2019-2020, tuvo como objetivo evaluar la morfología de las vainas y semillas, el comportamiento germinativo y el crecimiento temprano de las semillas de A. lebbeck y A. procera bajo diferentes tratamientos presiembra.
Método: se recolectaron vainas maduras de ambas especies en los estados de Nilo Azul y Jartum. Se midieron las características de las vainas y semillas: tamaño, peso y número de semillas. Para las pruebas de germinación, se sometieron un total de 400 semillas de cada especie a cuatro tratamientos previos a la siembra (100 semillas cada uno): inmersión en agua caliente (100 °C, enfriada durante la noche), agua fría (4 °C, 24 h), ácido sulfúrico concentrado (5 min) seguido de remojo, y un control sin tratamiento. Las semillas se sembraron en condiciones controladas de vivero, y se registraron el porcentaje de germinación, el índice de tasa de germinación (IRG), el tiempo medio de germinación (TMG) y el crecimiento inicial de las plántulas (tallo, hojas y raíces). Los datos se analizaron mediante ANOVA (GLM, SAS v9.0).
Resultados: se observaron diferencias significativas ($p = 0,0001$) entre especies en la morfología de las vainas y las semillas. Los tratamientos previos a la siembra mejoraron significativamente la germinación en comparación con los controles. El mayor éxito de germinación (82,07 %) se logró con el tratamiento con agua caliente a 80 °C durante 10 min, seguido del 79,00 % con 100 °C durante 1 min. La germinación comenzó entre 4 y 6 días después de la siembra y se completó en un plazo de 22 a 25 días. Si bien la fuente de la semilla tuvo una influencia limitada, se observaron interacciones significativas entre la fuente y el tratamiento.
Conclusiones: se recomienda el tratamiento con agua caliente (100 °C durante 1 min) para mejorar la germinación de las semillas de Albizia procera, especialmente en condiciones rurales como las de Bangladesh. Estos hallazgos contribuyen a las estrategias de propagación y manejo de las especies de Albizia para los programas de forestación.

Palabras clave: Vainas; Semillas; Morfología; Especies de Albizia; Tratamientos previos a la siembra; Sudán.

INTRODUCTION

The seeds of any plant species is a link between the evolutionary processes of the past and the potential for future adaptation.[1] Destitute seed germination and delayed nursery establishment restricted the intensive plantation practices in agroforestry, social forestry and home garden worldwide.[2,3,4,5,6,7] Seeds of many native and exotic species are challenging to germinate.[8] However, many pre-sowing techniques to overcome seeds dormancy and increase or enhance its germination percentage have been developed, studied and adopted for a diversity of seed types.[2,3,4,5,6,7,9,10,11,12]

Tropical seeds were classified into four categorizes based on their longevity and ability to storage,[8,13,14] these are viviparous seeds (germinate when attached to the mother plant); recalcitrant seeds (germinate soon after maturation and losing viability with drying); intermediate seeds (germinate immediately when mature with ability to survive partial without losing viability with drying), and orthodox seeds (that can be dried without losing viability). One important thing a grower can do is to learn as much as possible about the life history, ecology and habitat of the species he (or she) wishes to grow, in order to understand the processes seeds from each target species go through in nature. Furthermore, dormancy either external (physical, physical-physiological, chemical, or mechanical) or internal (morphological, physiological, or both), is an adaptation that ensures seeds germination and survival only when environmental conditions are favorable.[15,16] These conditions are necessary to allow seeds to break dormancy and germinate, and are highly variable among species, within a species, or among seed sources of the same species.[16] This degree of variability is advantageous because seeds will germinate at different times over a period of days, weeks, months, or even years, ensuring that some offspring will be exposed to favorable environmental conditions for survival. Environmental factors (i.e. light, water, oxygen and temperature) influencing germination since all plants have specific germination requirements based on ecological adaptations and the environmental cues that trigger germination for that species.[8]

Physical dormancy is the most common seed dormancy type seen in the tropics and species with external dormancy, include many of the legumes (Fabaceae), mallows (Malvaceae), and other tropical species that are adapted to fire, or inhabit arid to semiarid island habitats, or areas with pronounced wet-dry seasonal cycles.[8] The seeds with hard, solid, inflexible seed coat have an ability to recover germination with pre-sowing treatments.[17]

Various trees are fast growing and producing better producers of biomass, while the majority of the species have seeds, which have difficulties of germinating by presenting certain impermeability to water preventing their germination in normal conditions.[18,19] This problem of the imbibition phase is the important problem of the establishment of the forestry leguminous species.[20] Consequently, seeds require pretreatments to obtain a fast and a uniform germination with a considerable rate.[21]

The understanding of the aspects of seeds treatments is crucial for the regeneration and the successful integration in tree nurseries as well as for the direct plantation in arid and semi-arid lands.[22] More and above, it is important before attempting to grow a plant, to know the seed germination type because that helps determine the best seed treatments and sowing options for that seed. For orthodox seeds, knowing about the species helps you to provide the best conditions to dissipate, or "break," seed dormancy and achieve good rates of germination. Additionally, before beginning any reforestation, it is necessary to select which species and which origins are advisable to choose according to stations to be restored.[23]

In Sudan, there are many exotic species with high potential roles in urban forestry, horticulture and agroforestry, but few is known about their silviculture. In spite of the fact that, Albizia lebbeck and Albizia procera were introduced to Sudan from India and grown as avenue and roadside trees in some areas inside the country,[24] few is known about their silviculture, seeds technology and treatments as well as early growth development of seedling at nursery stage. Therefore, for better future utilization of these species, this study attempts to study the variability in pods and seeds morphological, quantify seeds production and determine the best possible pre-sowing treatment method that maximizes the germination characteristics (germination percentages, germination rate index and mean germination time) and seedlings growth performance of both species at the nursery condition.

METHOD

The study was carried out during 2019-2020, aiming to provide detailed data on pods and seeds morphology, seeds germination characteristics and early growth development of seedling among Albizia lebbeck and Albizia procera, a multipurpose and promising exotic tree species for utilization in urban afforestation programs in the Sudan.

Study sites description and tree identification

The study sites were selected within agro-ecological zone of the Sudan,[25,26,27] namely Khartoum State (15° 39' N, 32° 30' E; 15°35' N, 32° 30' E) in Semi-desert: Acacia tortilis – Maerua crassifolia Desert Scrub, where mean annual rainfalls is 75 - 300 mm/year; and Blue Nile State (12° 03' N, 34° 18' E; 12° 19' N, 34° 21' E) in Low rainfall woodland savanna on clay soils, where mean annual rainfalls is vary from isohyets 600-800 mm/year. A preliminary identification of Albizia lebbeck and Albizia procera made in the field based on published taxonomic key and written description.[24,28]

Tree sampling procedure and data collection

For each species, 10 mature trees (dbh 25-35 cm) were selected randomly (5 trees per site) not less than 100 m apart,[29,30] and located for position by using handle GPS (Model: Garmin Map 62) for further data collection. Then, 100 mature and healthy pods harvested from the crown (top, middle and bottom) of each single tree,[30] during fruiting season of both species (March-May) in the Sudan,[24] and measured for dimensions (length, width) in "cm" by using digital Vernier caliper (Model: GT-DC-01, Global tronics GmbH and Co. KG) and ruler. Also, number of seeds per pod was counted and weight of 100 pods and 100 seeds was determined in gram by using sensitive balance and used in calculation of the number of pods as well as seeds per kilogram ([1000*100/100-pods weight "g"] and [(1000*100/100-seeds weight "g"]). Further qualitative evaluation included pod color and surface texture, seed color and surface texture, as well as seed and areole shape. Fruits production (Kilogram/tree/year) was determined in two seasons 2019 and 2020 by harvesting and weighting in kilogram all pods (as possible) produced in the crown of 4 trees selected randomly for Albizia lebbeck and Albizia procera (2 trees per site).

Seeds germination experiment and early growth characterization of seedlings

Seeds extraction and purification process was carried out in the laboratory of the Department of Silviculture, Faculty of Forestry, University of Khartoum, Shambat, Sudan. The seeds extracted manually from 100 mature healthy pods selected randomly for each species from the harvested pods. Floating method was used to test viability,[12,31] discarding and eliminating damaged, insect infected and empty seeds. Pure seeds for each species were kept separately in clean polythene bags and stored for further uses at laboratory conditions at 2-5°C and 80 % of humidity.[12,32]

Effects of pre-sowing treatments on seeds germination

The germination experiment was carried out under controlled nursery condition,[12,33] at the nursery of Faculty of Forestry, University of Khartoum (15° 39' N, 32° 30' E) by using 400 seeds each species in completely randomized design with 4 pre-sowing treatments (100 seeds each treatment) and 4 replicates (25 seeds each replicate). The applied pretreatments were soaked in hot water (100°C) and kept to cool overnight, soaked in cold water (4°C) overnight, and soaked in concentrated sulphuric acid (98 % H2SO4) for two minutes followed by washing and soaking overnight in distilled water;(12,34) untreated seeds were used as control. Seeds for each species (400 seeds), each treatment (100 seeds) and each replicate (25 seeds) were sown in rate of one seed in 800 polythene bags (20x25 cm) prepared as sown unites by mixture of clay and sand (2:1) and kept at nursery condition under controlled irrigation. The number of germinated seeds (the emergence of cotyledon and 2 mm radicle through the seed coat) was counted on the 7th, 14th, 21st and 28th day after sowing,(12,22) and germination was expressed as percentages. Further calculations included the germination rate index (GRI) which reflects the percentage of germination on each day of the germination period (equation 1) and mean germination time (MGT) which represents the mean time a seed requires lot to initiate and end germination (equation 2).

$$GRI (\%) = \Sigma (n_i / D_i) \quad (1)$$
$$MGT (days) = (\Sigma n_i D_i) / (\Sigma n_i) \quad (2)$$

Where ni: number of seeds newly germinated at time Di; Di: days from the beginning of the germination test; Σni: total number of germinated seeds (final germination).

Morphological characterization of seedlings

Early evaluation of seedling morphological characters made after seeds germination and manifestation of cotyledons up to one week (7 days) using 35 germinates (seedlings) each species in seven destructive harvests (5 seedlings per harvest). Moreover, late morphological characterization of seedlings and growth development was made up to one month old (4 weeks) using 60 seedlings (germinates) each species in four destructive harvests (one destructive harvest a week) during the days: 7th, 14th, 21st and 28th after germination (15 seedlings per harvest).

One week old seedlings of Albizia lebbeck and Albizia procera described for variation in early morphological characters using the terminologies proposed by (35,36) and adopted by (12). The pattern of seedling development was treated as “phanerocotylar” when cotyledons emerge from the test and as “cryptocotylar” when they have not; cotyledon manifestation either food-storage (fleshy) or photosynthetic (paracotyledons); the term “epigeal” was applied for the cotyledons (Seed-leaves) when they raised above the soil surface and considered as “hypogeal” when they remain under the soil. Early (one week old) and late (one month old) morphological measurements of seedlings were made in “cm” using digital Vernier caliper (Model: GT-DC-01, Globaltronics GmbH and Co. KG) and ruler. These included cotyledons dimensions (length x width x thickness); shoot, root, hypocotyl and epicotyl length and diameter; compound leaf (mono- or bi-pinnate) length, width and petiole length; pinnae and leaflet length. The number of compound leaves (mono- or bi-pinnate) per seedling, number of pinnae pairs per leaf and number of leaflets pairs per pinnae were counted. Further description and evaluation was made for shape, color, surface texture and phyllotaxy of cotyledons; stem (hypocotyl and eipcotyl) bark color and texture; leaf type and phyllotaxy as well as leaflets shape, surface texture and color. Digital photographs were taken at different stages of seedlings development using digital camera (SAMSUNG 18x, WB200F) to complete seedling description.

Data arrangement and analysis

The data (pods and seeds morphology, seed germination and seedling morphology) was arranged in Excel sheets and the means were subjected to analysis of variance (one-way, two-way ANOVA) by using GLM procedure (Generalized Linear Model: GLM) calculated using SAS Version 9.0 (Statistical Analysis System) (2002) software. The mean separations were carried out using Duncan’s multiple range tests and significance was determined at $p < 0,05$.

RESULTS

The results of analysis of variance revealed significant variation ($p < 0,0001$) within and among the studied species of Albizia (A. Lebbeck and A. Procera). Regarding pods and seeds characteristics (table 1 and figures 1-2), seeds germination (table 2) and the morphological growth development of seedlings (tables 3-4 and figures 3-4).

Variation in germination and early growth morphology of seedlings: The treatments (H_2SO_4, Boiling water, Control) effect was highly significant ($p < 0,0001$) on the germination percentage, germination rate index and the mean time of germination (tables 1-2 and figure 2) within and among the studied species of A. Lebbeck and A. Procera. The seeds germination and early growth development of Albizia lebbeck (AL) and Albizia procera (AP) seedlings at 1st day after germination up to one week (7 days), indicated that, seedling of both species are epigeal, phanerocotylar type with reserve type cotyledon (figure 3-4).

Table 1. Results of Duncan's Multiple Range Test (DMRT) for pods and seeds morphological variation of Albizia lebbeck L. and Albizia procera (Roxb.) Benth., trees between Khartoum State and Blue Nile State in the Sudan

Parameters	**Species**	
	Albizia lebbeck L. (AL)	**Albizia procera (Roxb.) Benth. (AP)**
Number of pods per tree crown/Year	25920,66^{b} (±4129,01)	102332,23^{a} (±2087,66)
Pods production (Kg/tree/year)	94^{a} (±7,30)	84,00^{b} (±3,96)
Number of pods per Kilogram	276,38^{b} (±44,01)	31066,38^{a} (±499,21)
100-pods weight (g)	370,12^{a} (±56,27)	81,41^{b} (±1,67)
Pod length (cm)	24,65^{a} (±2,12)	14,19^{b} (±0,78)
Pod width (cm)	3,93^{a} (±0,20)	1,75^{b} (±0,14)
Pod constriction width (cm)	3,56^{a} (±0,37)	1,68^{b} (±0,32)
Number of seeds per pod	12,23^{a} (±2,09)	10,06^{b} (±0,72)
Number of seeds per tree crown/Year	314345,35^{b} (±64315,07)	1124958,11^{a} (±86577,18)
Seeds production (Kg/tree/year)	434,11^{a} (±138,77)	36,21^{b} (±2,70)
Number of seeds per Kilogram	748,86^{b} (±108,01)	31066,38^{a} (±499,21)
100-seeds weight (g)	136,15^{a} (±19,81)	3,27^{b} (±0,11)
Seed length (cm)	0,85^{a} (±0,06)	0,53^{b} (±0,03)
Seed width (cm)	0,65^{a} (±0,03)	0,44^{b} (±0,0.2)
Seed thickness (cm)	0,23^{a} (±0,01)	0,19^{b} (±0,06)
Pod color	Greenish-Yellow; Straw-colored	Dark brown
Pod surface texture	Smooth, glossy	Smooth, glossy
Seed color	Grayish-greenish	Grayish-greenish
Seed surface texture	Smooth, glossy	Smooth, glossy
Seed shape	Ovate-elliptic	Ovate-elliptic

Note: Means sharing the same letter (a or b) in the same row do not differ significantly at ($p \leq 0,05$) according to Duncan's Multiple Range Test; Means ± Standard deviation.

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Table 2. Results of analysis of variance (ANOVA) for the variation in seeds germination characteristics (Germination percentage, GRI and MGT) as affected by different pre-sowing treatments within and among Albizia lebbeck (L.) Benth., and Albizia procera (Roxb.) Benth., during days: 7th, 14th, 21st, and 28th after seeds sowing

Pre-sowing Treatments	Germination Parameters	Albizia lebbeck L. (AL) Day 7th	Day 14th	Day 21st	Day 28th	Total Average	Albizia procera (Roxb.) Benth. (AP) Day 7th	Day 14th	Day 21st	Day 28th	Total Average
Control	Germination (%)	0,00 (±0,00)	0,00 (±0,00)	52,5 (±12,58)	67,5 (±9,57)	30 (±5,54)	0,00 (±0,00)	15 (±12,91)	37,5 (±9,57)	57,5 (±9,57)	27,5 (±8,01)
	GRI (seed/day)	0,00 (±0,00)	0,00 (±0,00)	0,25 (±0,06)	0,24 (±0,03)	0,12 (±0,02)	0,00 (±0,00)	0,11 (±0,09)	0,18 (±0,05)	0,21 (±0,03)	0,13 (±0,04)
	MGT (days)	0,00 (±0,00)	0,00 (±0,00)	11,03 (±2,64)	18,9 (±2,68)	7,48 (±3,06)	0,00 (±0,00)	2,1 (±1,81)	7,88 (±2,01)	16,1 (±2,68)	6,52 (±9,57)
H2SO4 (5 min)	Germination (%)	77,5 (±17,08)	95 (±5,77)	100 (±0,00)	100 (±0,00)	93,13 (±5,71)	75 (±12,91)	80 (±16,33)	80 (±16,33)	82,5 (±12,58)	79,38 (±14,54)
	GRI (seed/day)	1,11 (±0,24)	0,68 (±0,04)	0,48 (±0,00)	0,35 (±0,00)	0,66 (±0,07)	1,07 (±0,18)	0,57 (±0,12)	0,38 (±0,08)	0,29 (±0,04)	0,58 (±0,11)
	MGT (days)	5,43 (±1,20)	13,3 (±0,81)	21 (±0,00)	28 (±0,00)	16,93 (±0,50)	5,25 (±0,9)	11,2 (±2,29)	16,8 (±3,43)	23,1 (±3,52)	14,09 (±4,93)
Hot water (100 0C)	Germination (%)	37,5 (±9,57)	60 (±8,16)	82,5 (±9,57)	100 (±0,00)	70 (±6,83)	97,5 (±5,00)	100 (±0,00)	100 (±0,00)	100 (±0,00)	99,38 (±1,25)
	GRI (seed/day)	0,54 (±0,14)	0,43 (±0,06)	0,39 (±0,05)	0,36 (±0,00)	0,43 (±0,05)	1,39 (±0,07)	0,71 (±0,00)	0,48 (±0,00)	0,36 (±0,00)	0,74 (±0,02)
	MGT (days)	2,63 (±0,67)	8,4 (±1,14)	17,33 (±2,01)	28 (±0,00)	14,09 (±0,96)	6,83 (±0,35)	14 (±0,00)	21 (±0,00)	28 (±0,00)	17,46 (±0,09)
Cold water (37 0C)	Germination (%)	0,00 (±0,00)	15 (±5,77)	35 (±5,77)	60 (±8,16)	27,5 (±4,93)	0,00 (±0,00)	32,25 (±12,58)	50 (±8,16)	70 (±8,16)	38,06 (±7,22)
	GRI (seed/day)	0,00 (±0,00)	0,11 (±0,04)	0,17 (±0,03)	0,21 (±0,03)	0,12 (±0,03)	0,00 (±0,00)	0,23 (±0,09)	0,24 (±0,04)	0,25 (±0,03)	0,24 (±0,04)
	MGT (days)	0,00 (±0,00)	2,1 (±0,80)	7,35 (±1,21)	16,8 (±2,29)	6,56 (±1,08)	0,00 (±0,00)	4,55 (±1,76)	10,5 (±1,71)	19,6 (±2,29)	8,66 (±1,44

Note: GRI: Germination Rate Index; MGT: Mean Germination Time (days)

Table 3. Variation in early seedlings growth development between Albizia lebbeck L. (AL) and Albizia procera (Roxb.) Benth. (AP) during 1st, 2nd, 3rd, 4th, 5th, 6th and 7th days after seeds germination and cotyledons manifestation

Traits	Species and days of seedlings measurements: Albizia lebbeck L. (AL) Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Albizia procera (Roxb.) Benth. (AP) Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
RotL (cm)	0,74	1,47	2,21	2,95	3,69	4,42	5,16	0,42	0,84	1,26	1,68	2,10	2,52	2,95
ShtL (cm)	1,28	2,57	3,85	5,13	6,41	7,70	8,98	0,58	1,16	1,74	2,32	2,90	3,49	4,07
HypCotL (cm)	0,77	1,55	2,32	3,09	3,86	4,63	5,41	0,29	0,58	0,87	1,16	1,45	1,74	2,03
HypCotD (cm)	0,03	0,06	0,10	0,13	0,16	0,19	0,22	0,02	0,04	0,05	0,07	0,09	0,11	0,12
EipCotL (cm)	0,51	1,02	1,53	2,04	2,55	3,06	3,57	0,22	0,44	0,66	0,88	1,10	1,32	1,54
EipCotD (cm)	0,02	0,03	0,05	0,06	0,08	0,09	0,11	0,01	0,01	0,02	0,03	0,03	0,04	0,05
CotyBdL (cm)	0,02	0,03	0,05	0,06	0,08	0,09	0,11	0,13	0,26	0,39	0,52	0,65	0,78	0,91

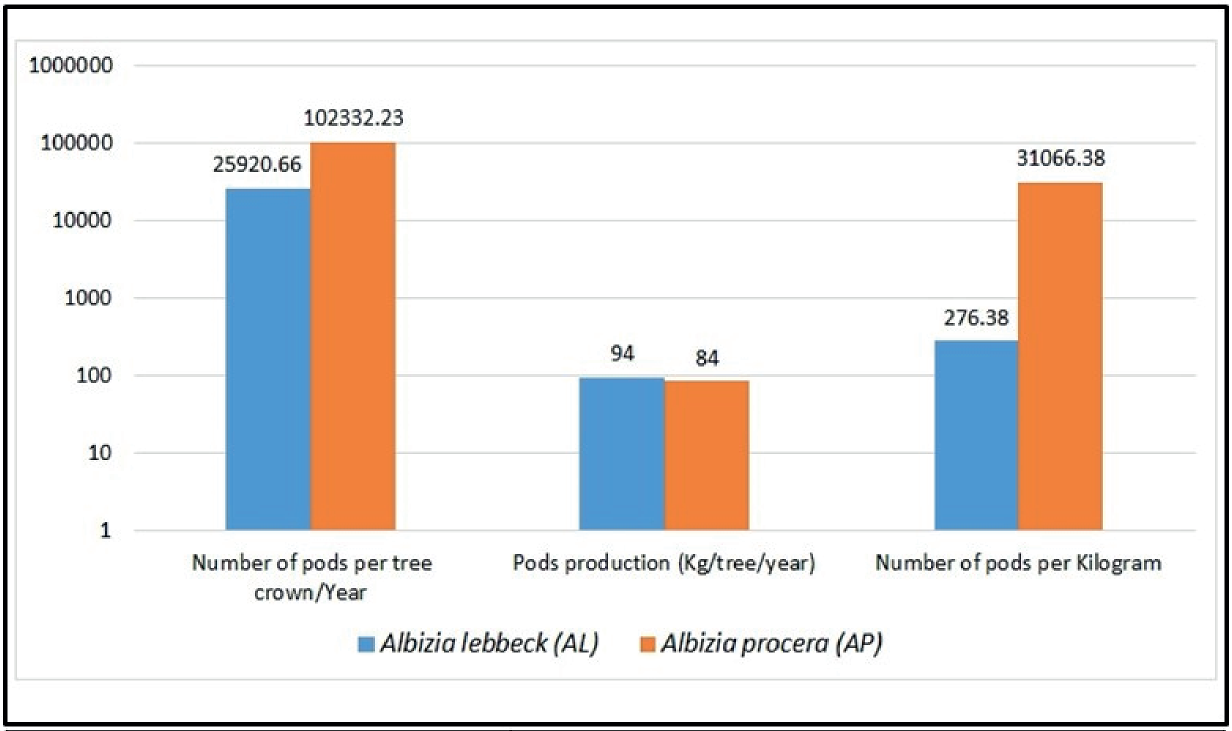
CotyBdW (cm)	0,10	0,20	0,31	0,41	0,51	0,61	0,72	0,09	0,17	0,26	0,34	0,43	0,52	0,60
CotyBdT (cm)	0,01	0,03	0,04	0,05	0,07	0,08	0,09	0,02	0,03	0,05	0,06	0,08	0,09	0,11
CotyPetL (cm)	Sessile	Sessile	Sessile	Sessile	Sessile	Sessile	Sessile	Sessile	Sessile	Sessile	sessile	sessile	sessile	sessile
EmLfNo/Sdlg	1	1	1	1	1	1	1	1	1	1	1	1	1	1
EmLfL (cm)	0,51	1,01	1,52	2,02	2,53	3,03	3,54	0,09	0,18	0,26	0,35	0,44	0,52	0,61
EmLfW (cm)	0,42	0,83	1,25	1,67	2,08	2,50	2,91	0,05	0,09	0,14	0,19	0,23	0,28	0,32
EmpLfPetL (cm)	0,11	0,22	0,34	0,45	0,56	0,67	0,79	0,03	0,06	0,09	0,12	0,14	0,17	0,20
NoLft/EmLf (Ps)	4	4	4	4	4	4	4	3	3	3	3	3	3	3
LftL (cm)	0,2619	0,5238	0,7857	1,0477	1,3096	1,5715	1,8334	0,0276	0,0552	0,0828	0,1104	0,1381	0,1656	0,1932
LftW (cm)	0,0621	0,1241	0,1862	0,2483	0,3104	0,3724	0,4345	0,0207	0,0415	0,0622	0,0829	0,1036	0,1244	0,1451
NoCBiPinLf/Sdlg	2	2	2	2	2	2	2	0,00	0,00	0,00	0,00	0,00	0,00	0,00
CBiPinLfL (cm)	0,55	1,10	1,65	2,21	2,76	3,31	3,86	0,00	0,00	0,00	0,00	0,00	0,00	0,00
CBiPinLfW (cm)	0,63	1,25	1,88	2,50	3,13	3,75	4,38	0,00	0,00	0,00	0,00	0,00	0,00	0,00
CBiPinLfPetL (cm)	0,20	0,41	0,61	0,82	1,02	1,23	1,43	0,00	0,00	0,00	0,00	0,00	0,00	0,00
PinNo/CBiPinLf (Ps)	1	1	1	1	1	1	1	0,00	0,00	0,00	0,00	0,00	0,00	0,00
PinL (cm)	0,46	0,92	1,38	1,84	2,30	2,76	3,22	0,00	0,00	0,00	0,00	0,00	0,00	0,00
PinW (cm)	0,26	0,53	0,79	1,05	1,31	1,58	1,84	0,00	0,00	0,00	0,00	0,00	0,00	0,00
PinPetL (cm)	0,02	0,03	0,05	0,06	0,08	0,09	0,11	0,00	0,00	0,00	0,00	0,00	0,00	0,00
NoLft/Pin (Ps)	5 (_1)	5 (_1)	5 (_1)	5 (_1)	5 (_1)	5 (_1)	5 (_1)	0,00	0,00	0,00	0,00	0,00	0,00	0,00
LfLtL (cm)	0,21	0,42	0,63	0,83	1,04	1,25	1,46	0,00	0,00	0,00	0,00	0,00	0,00	0,00
LfLtW (cm)	0,05	0,11	0,16	0,21	0,26	0,32	0,37	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Note: RotL (cm): root length (cm); ShtL (cm): shoot length (cm); HypCotL (cm): hypocotyl length (cm); HypCotD (cm): hypocotyl diameter (cm); EipCotL (cm): epicotyl length (cm); EipCotD (cm): epicotyl diameter (cm); CotyBdL (cm): cotyledon blade length (cm); CotyBdW (cm): cotyledon blade width (cm); CotyBdT (cm): cotyledon blade thickness (cm); CotyPetL (cm): cotyledon petiole length (cm); EmLfNo/Sdlg: number of embryonic leaf per seedling; EmLfL (cm): embryonic leaf length (cm); EmLfW (cm): embryonic leaf width (cm); EmpLfPetL (cm): embryonic leaf petiole length (cm); NoLflt/EmLf (Ps): number of leaflets per embryonic leaf (pairs); LftL (cm): leaflet length (cm); LftW (cm): leaflet width (cm); NoCBiPinLf/Sdlg: number of compound bi-pinnate leaves per seedling; CBiPinLfL (cm): compound bi-pinnate leaf length (cm); CBiPinLfW (cm): compound bi-pinnate leaf width (cm); CBiPinLfPetL (cm): compound bi-pinnate leaf petiole length (cm); PinNo/CBiPinLf (Ps): number of pinnae's per compound bi-pinnate leaf (pairs); PinL (cm): pinnae length (cm); PinW (cm): pinnae width (cm); PinPetL (cm): pinnae petiole length (cm); NoLft/Pin (Ps): number of leaflets per pinnae (pairs)

Table 4. Variation in early seedlings growth development between Albizia lebbeck L. (AL) and Albizia procera (Roxb.) Benth. (AP) during week 1 (W1), week 2 (W2), week 3 (W3) and week 4 (W4) after seeds germination and cotyledons manifestation

Traits	Species and days of seedlings measurements							
	Albizia lebbeck L. (AL)				Albizia procera (Roxb.) Benth. (AP)			
	W1	W2	W3	W4	W1	W2	W3	W4
RotL (cm)	5,16	6,07	6,52	8,10	2,95	3,34	4,71	5,91
ShtL (cm)	8,98	10,56	11,34	14,09	4,07	5,81	8,19	10,28
HypCotL (cm)	5,41	5,65	5,76	5,86	2,03	2,52	3,16	3,80
HypCotD (cm)	0,22	0,23	0,23	0,23	0,12	0,17	0,17	0,17
EipCotL (cm)	3,57	4,91	5,58	8,24	1,54	2,82	5,03	6,48
EipCotD (cm)	0,11	0,12	0,14	0,15	0,05	0,09	0,10	0,10
CotyBdL (cm)	0,11	0,00	0,00	0,00	0,91	0,71	0,68	0,00
CotyBdW (cm)	0,72	0,00	0,00	0,00	0,60	0,25	0,25	0,00
CotyBdT (cm)	0,09	0,00	0,00	0,00	0,11	0,11	0,11	0,00
CotyPetL (cm)	Sessile	Sessile	Sessile	Sessile	Sessile	Sessile	Sessile	sessile
EmLfNo/Sdlg	1	1	1	1	1	1	1	1
EmLfL (cm)	3,54	3,44	3,48	3,49	0,61	2,21	2,53	2,55
EmLfW (cm)	2,91	2,97	2,98	3,25	0,32	3,42	1,93	1,99
EmpLfPetL (cm)	0,79	0,91	0,92	0,94	0,20	0,43	0,66	0,71
NoLft/EmLf (Ps)	4	4	4	4	3	3	3	3
LftL (cm)	1,83	1,84	1,84	1,87	0,19	0,85	1,02	1,03
LftW (cm)	0,43	0,44	0,44	0,45	0,15	0,43	0,45	0,47
NoCBiPinLf/Sdlg	2	4	5	6	0,00	1	2	5
CBiPinLfL (cm)	3,86	4,84	5,82	6,35	0,00	2,01	2,23	3,12
CBiPinLfW (cm)	4,38	4,63	5,35	6,43	0,00	3,76	3,08	3,94
CBiPinLfPetL (cm)	1,43	1,43	2,39	3,24	0,00	1,00	1,08	1,73
PinNo/CBiPinLf (Ps)	1	1	1	1	0,00	1	1	1
PinL (cm)	3,22	3,35	3,49	4,48	0,00	1,35	1,47	2,17
PinW (cm)	1,84	2,09	2,35	3,03	0,00	0,86	1,01	1,59
PinPetL (cm)	0,11	0,11	0,12	0,15	0,00	0,79	1,00	0,14
NoLft/Pin (Ps)	5	5	6	7	0,00	3	3	3
LfLtL (cm)	1,46	1,52	1,61	1,91	0,00	0,54	0,65	0,99
LfLtW (cm)	0,37	0,40	0,43	0,45	0,00	0,33	0,39	0,45

Note: RotL (cm): root length (cm); ShtL (cm): shoot length (cm); HypCotL (cm): hypocotyl length (cm); HypCotD (cm): hypocotyl diameter (cm); EipCotL (cm): epicotyl length (cm); EipCotD (cm): epicotyl diameter (cm); CotyBdL (cm): cotyledon blade length (cm); CotyBdW (cm): cotyledon blade width (cm); CotyBdT (cm): cotyledon blade thickness (cm); CotyPetL (cm): cotyledon petiole length (cm); EmLfNo/Sdlg: number of embryonic leaf per seedling; EmLfL (cm): embryonic leaf length (cm); EmLfW (cm): embryonic leaf width (cm); EmpLfPetL (cm): embryonic leaf petiole length (cm); NoLflt/EmLf (Ps): number of leaflets per embryonic leaf (pairs); LftL (cm): leaflet length (cm); LftW (cm): leaflet width (cm); NoCBiPinLf/Sdlg: number of compound bi-pinnate leaves per seedling; CBiPinLfL (cm): compound bi-pinnate leaf length (cm); CBiPinLfW (cm): compound bi-pinnate leaf width (cm); CBiPinLfPetL (cm): compound bi-pinnate leaf petiole length (cm); PinNo/CBiPinLf (Ps): number of pinnae's per compound bi-pinnate leaf (pairs); PinL (cm): pinnae length (cm); PinW (cm): pinnae width (cm); PinPetL (cm): pinnae petiole length (cm); NoLft/Pin (Ps): number of leaflets per pinnae (pairs)



Parameters	Species	
	Albizia lebbeck (AL)	*Albizia procera* (AP)
Number of pods per tree crown/Year	25920.66b (±4129.01)	102332.23a (±2087.66)
Pods production (Kg/tree/year)	94a (±7.30)	84.00b (±3.96)
Number of pods per Kilogram	276.38b (±44.01)	31066.38a (±499.21)

Figure 1. Shows the variation in number of pods per tree crown, pods production (Kg/tree/year) and number of pods per Kilogram among Albizia lebbeck (AL) and Albizia procera (AP) exotic species growing in the Sudan

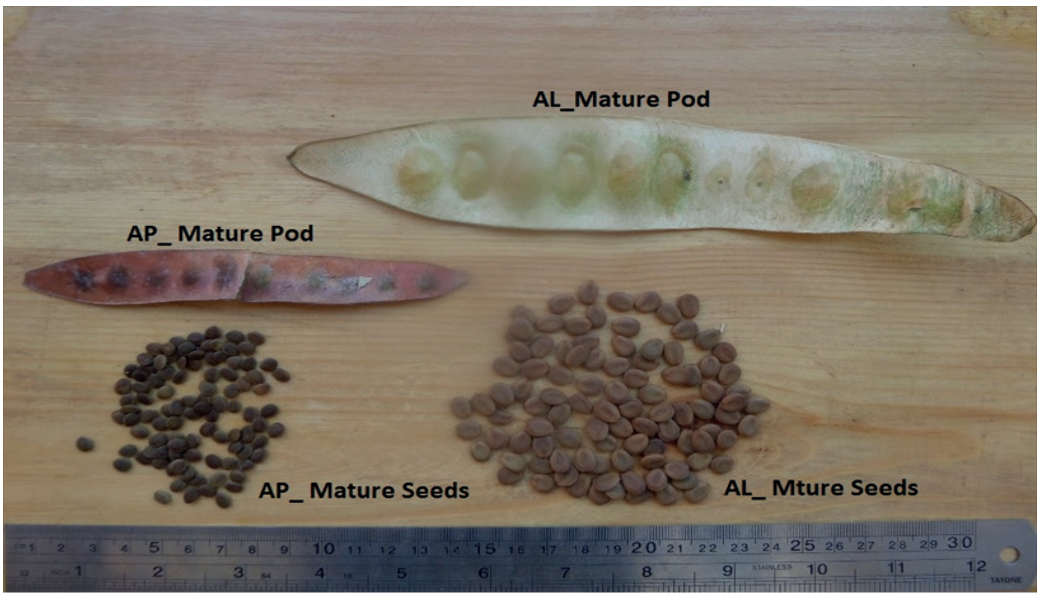


Figure 2. Mature pod and mature seeds variation among Albizia lebbeck (AL) and Albizia procera (AP) trees growing in Sudan

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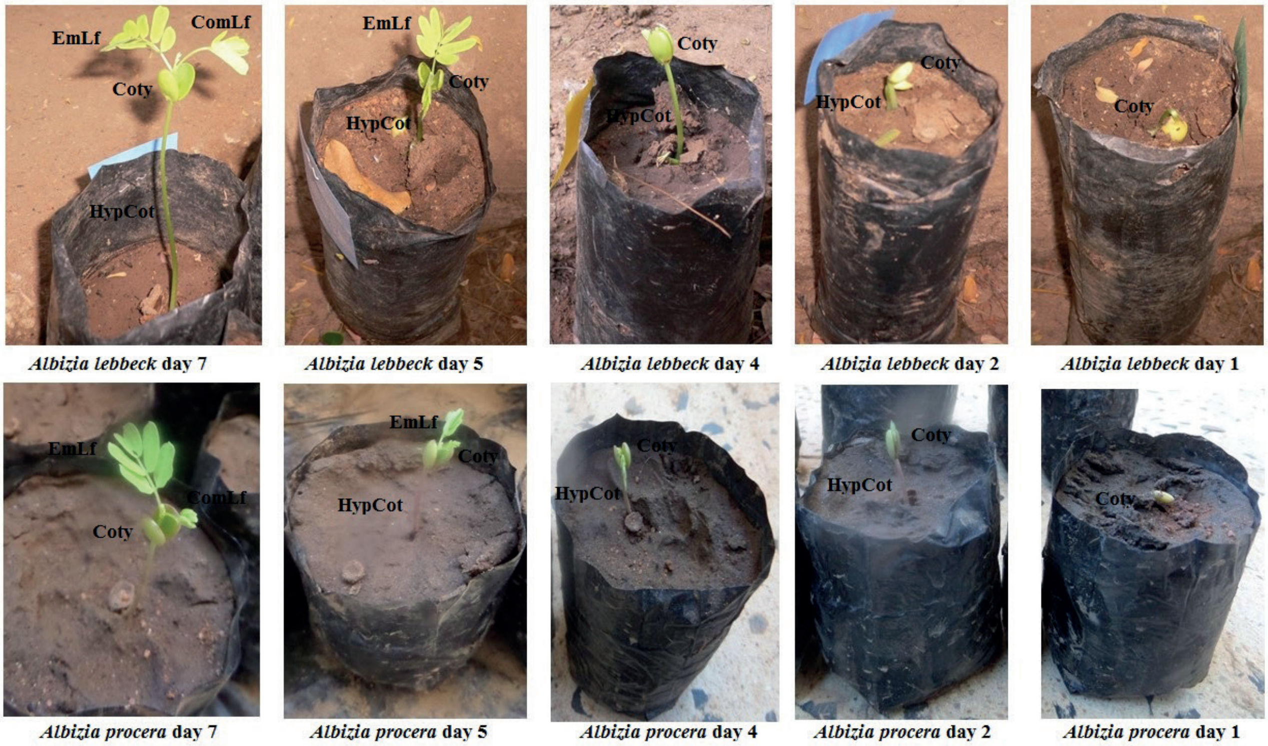

Figure 3. Seeds germination and early growth development of Albizia lebbeck (AL) and Albizia procera (AP) seedlings at 1st day after germination up to one week (7days)

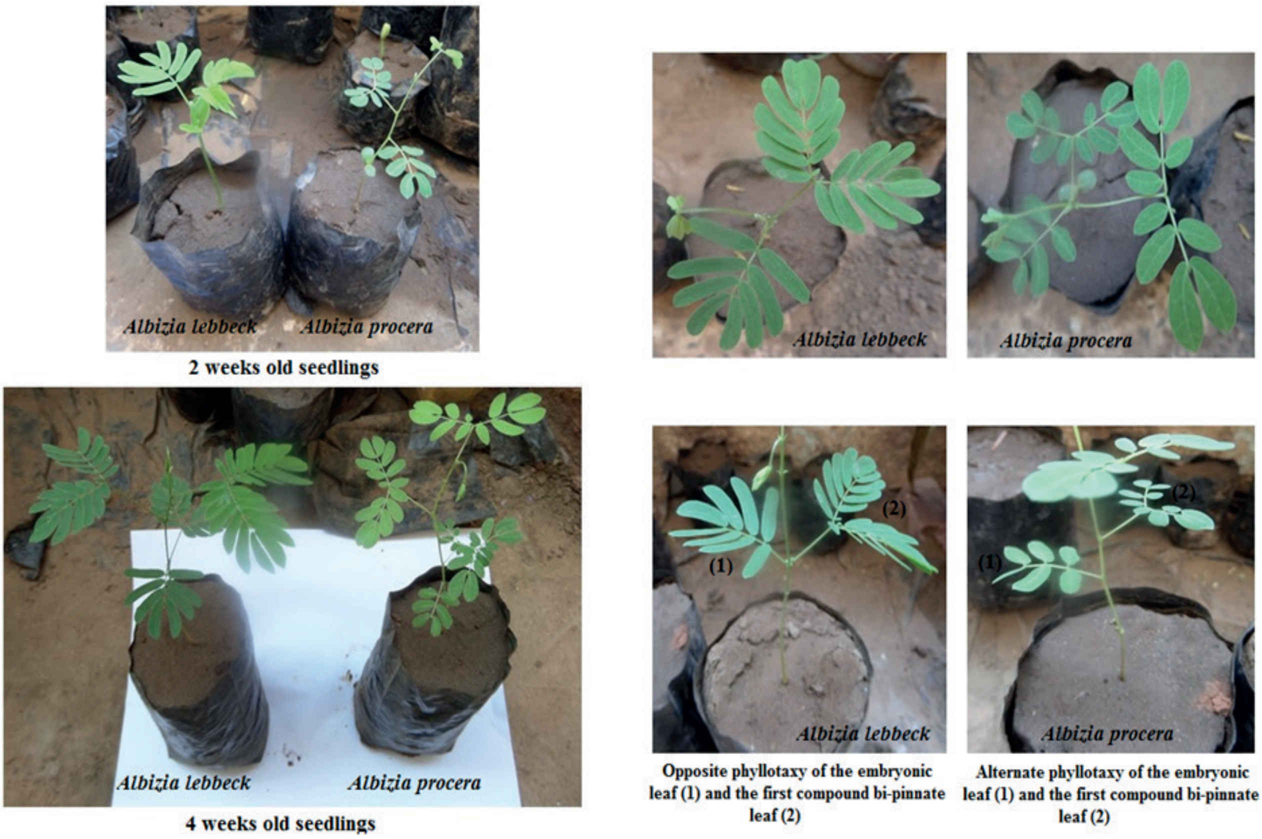

Figure 4. Seedlings morphological variation between Albizia lebbeck (AL) and Albizia procera (AP) at early growth development after germination up 2 and 4 weeks

DISCUSSION

In this study, both Albizia lebbeck L. and Albizia procera (Roxb.) Benth., potential tree for urban afforestation, were investigated on morphological characteristics of pods and seeds, and also the effect of pre-treatments on seeds germination characteristics and early growth development of seedling. The results, showed significant ($p \leq 0,001$) variation in pods and seeds quantitative morphological characteristics, as well as qualitative one between the two species. However, most of the pods morphological values (pods production (Kg/tree/year); 100-pods weight (g); pods length, width and constriction width (cm); number of seeds per pod and tree's crown), as well as seeds (seeds production (Kg/tree/year); 100-seeds weight (g); seed length, width, thickness (cm)), were of the highest for A. lebbeck L. than A. procera (Roxb.) Benth., trees. For qualitative morphological characteristics, the species showed similarity in pod surface texture, seed color, seed surface texture and seed shape, and were different in pod color. Elrod[37] stated that, the natural variation that occurs among organisms is generally controlled by genetic make-up and/or environmental influence. In fact, the phenotype of members of the same species may vary continuously while their genotype is relatively stable throughout the life of the organisms.[38] According to Akinyele[39], the variation in genetic make-up among organisms is of more taxonomic reliability than environmentally induced one. More and above, the evolutionary changes in the longer term, occur due to environment that may affect the genetic constitution of a population by the pressure of selection it exercises on the population.[40] Tiwari[41] studied the variability of pod and seed characteristics of Albizia procera. Albizia lebbeck pods were described as legume 13-24 x 34 cm, flattened, straw-colored, the margins thickened, straight or depressed between seeds (9-10 mm, long, elliptic, flattened, light brown), dehiscent along one suture.[42] As stated by Liu et al.[18] and Vargas et al.[19], various trees are fast growing and producing better of biomass, while the majority of the species have seeds dormancy, which exhibits difficulties in germination by presenting certain impermeability to water preventing their germination in normal condition. It is clear that, the important problem of the establishment of the forestry leguminous species is resulting from the problem of the imbibition phase of seeds.[20] Therefore, a fast and a uniform germination of these seeds with a considerable rate, can be obtained with suitable requirements of pretreatments.[21] The regeneration and the successful integration in tree nurseries, as well as for the direct plantation in arid and semi-arid lands, requires the understanding of the aspects of seeds treatments.[22] Seed problems related to seed dormancy often limit the use of particular species in nurseries for the production of seedlings; it is because seed dormancy can vary from species to species, stage of maturity of seed and degree of drought and consequently pretreatments should be adjusted accordingly.[43] According to Azad et al.[44,45], seed treatment can ensure both success in seed germination and germination speed and guarantee germination procedures to be quick and homogeneous. On the other hand in natural conditions, fire, extreme temperatures and digestive acids in animals' stomachs or the abrasion of blowing sand as factors that break hard seed coats and enhance germination.[12,46] Albizia species seeds have a coat dormancy that acts primarily as mechanical barrier limiting water and oxygen entrance.[43,47] Several ancient documents,[48,49,50,51,52] and recent documents,[5,7,43,53] showed that without pre-treatment and germination, success is very poor in Albizia species. However, there is little documentation available on the effects of pre-sowing treatment of Albizzia procera.[43] The effect of pre-sowing treatments on seeds germination characteristics, studied by applying four pre-sowing treatments within and among Albizia lebbeck (L.) Benth., and Albizia procera (Roxb.) Benth., over one month with intervals of 7th days of data record being 7th, 14th, 21st, and 28th after seeds sowing, under controlled nursery condition. These pre-treatments, were immersion in hot water (100 °C, cooled overnight), cold water (4 °C, 24 h), and concentrated sulphuric acid (5 min) followed by soaking, in addition to untreated as control. The germination indicators were, germination percentage, germination rate index (GRI), mean germination time (MGT), and early seedling growth (stem, leaves and roots). Pre-sowing treatments significantly improved germination compared with controls, with the highest germination percentage (100 %) obtained from H_2SO_4 in both of A. lebbeck and A. procera, and hot water treatment at 80 °C for 10 min in A. procera at the 28th day after germination.

As compared with control and cold water treatment, the germination success (%) in total average was the highest 93,13 (±5,71) for A. lebbeck in H_2SO_4 (5 min), than in A. procera 79,38 (±14,54); while for hot water (100 °C) treatment, the total germination average (%) A. procera showed the highest value 99,38 (±1,25) than A. lebbeck 70 (±6,83). This may be due to the hard seed coat of A. lebbek and the slightly soft one in A. procera. However, the hard seed coat cause physical seed dormancy and low germination rate in A. lebbeck to overcome this physical dormancy of seeds need pretreated with different external effects.[47] The application of manual scarification, sulphuric acid, hot water and dry heat treatments showed potentiality to break down the coat inhibition.[12,54,55] The results indicated by Azad et al.[43] revealed that, pre-sowing treatments affected the rate of germination of seeds, which significantly increased the germination percentages of seeds in hot water treatments compared with those in control (60,6 %) and the cold water treatment (4°C for 24 h, 63,53 %). The highest germination success was 82,07 % in the treatment of immersion in hot water (80°C) for 10 min, followed by 79 % in immersion in hot water (100°C) for 1 min. Germination started 4 to 6 days after seed sowing and completed in a period of 22 to 25 days in all treatments. Furthermore, the breaking of seed dormancy of A. lebbeck has been found successful with the use of acid scarification,[56] the use of hot water,[57] and mechanical scarification,[58] but all these methods have their limitations. This results agreed with Neelam

Tomar and Narendra Babu Shakya[47] who stated that, the hard seed coat cause physical seed dormancy and low germination rate in A. lebbeck (L.) to overcome this physical dormancy of seeds were pretreated with different external effects. On the other hand, several artificial methods are used in laboratory and nursery conditions to break seed dormancy exhibited by hard seed coat. The germination began 4–6 days after sowing and completed within 22–25 days for both species indicating fast growth performance of both species. It is clear from the findings, seed source had little effect, but significant effects were found between applied pre-treatments. Hot water treatment (100 °C for 1 min) is recommended in this study for enhancing germination of A. procera, and this agreed with Azad[43]. Furthermore, to facilitate germination of A. procera, the seed must be placed in favorable environmental conditions, like adequate moisture supply, appropriate gaseous balance and optimum light. For the sake of production of seedlings in mass and to get better germination, pre-sowing seed treatments are required.[59] In the present study, similar findings of description of early growth morphology and development of A. lebbeck and A. procera seedlings stated by Khan[60], who described the seedlings of both species in early growth as epigeal, phanerocotylar type with reserve type cotyledon.

Despite the valuable findings of this study, certain limitations should be acknowledged. The experiments were conducted under controlled nursery conditions, which may not fully represent the variable environmental conditions of natural field settings. Additionally, the study was limited to two exotic Albizia species and did not include genetic or biochemical analyses that could provide deeper insight into dormancy mechanisms. The relatively short observation period focused on early seedling growth, and long-term field trials are still needed to assess the survival, adaptability, and ecological impact of these species under different climatic and soil conditions in Sudan. Future research should therefore include broader environmental trials and molecular analyses to validate and expand upon these findings.

CONCLUSIONS

This study demonstrated clear differences between Albizia lebbeck and Albizia procera in seed germination behavior and early seedling growth, confirming their distinct physiological and morphological characteristics. The application of pre-sowing treatments proved effective in overcoming physical dormancy, which is typical of the genus Albizia. Among the tested methods, hot-water treatment (100 °C followed by soaking in normal water) is recommended as a practical and low-cost alternative to concentrated sulphuric acid for improving germination performance in both species. The morphological traits observed during early growth, including cotyledon shape, phyllotaxy, and leaf features, provide reliable diagnostic criteria for distinguishing between A. lebbeck and A. procera at the seedling stage. These findings offer useful guidance for nursery management and afforestation practices, particularly in arid and semi-arid regions of Sudan. Overall, both A. lebbeck and A. procera show strong potential for urban afforestation and reforestation initiatives, provided that their adaptation, ecological compatibility, and non-invasive behavior are carefully evaluated. Further studies on wood properties, ecological restoration potential, and medicinal applications are recommended to support their sustainable utilization in forestry and horticultural programs in Sudan.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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