International Journal of Agricultural and Applied Sciences, December 2025, 6(2): 22-29
https://www.agetds.com/ijaas
ISSN: 2582-8053
https://doi.org/10.52804/ijaas2025.624

Research Article

OPEN ACCESS

A comparative study on the growth and development of avocado (*Persea americana*) seedlings from small and large seeds under different growing conditions.

Gaspard Rwami Ntabakirabose[1], Marie Henriette Uwera[2], Gerard Kayiranga[3], Clementine Mukanoheri[4], Alfred Niyobyose[4], Eleonore Kambabazi[5], Mory Vital Karinda[6], Jean de Dieu Mbarushimana[7], Gilbert Siborurema[8], Festus Maniriho[9], Donat Nsabimana[10] and Mbabazi Mbabazize[11]
[1,4,5,6,7,8] Forest Research Department, Rwanda Forestry Authority, Huye, Rwanda
[2]Forest Management Department, Rwanda Forestry Authority, Huye, Rwanda
[3]Biodiversity and Ecosystem Management Research Group, School of Life Sciences and Bio-Engineering, The Nelson Mandela African Institutions of Science and Technology, Arusha /Tanzania
[9]Forest Investment Program, Rwanda Forestry Authority, Huye, Rwanda
[10]College of Agriculture, Forestry and Food Science, University of Rwanda, Busogo, Rwanda
[11]Faculty of Business and Commerce, ISBAT University, Kampala, Uganda
**Corresponding author e-mail: gmutago@gmail.com*
(Received: 20/07/2025; Revised: 19/09/2025; Accepted: 30/09/2025; Published: 20/12/2025)

ABSTRACT
Avocado (*Persea americana* Mill.) is a high-value tropical and subtropical fruit crop whose early seedling vigor and graft success are strongly influenced by seed size and growing conditions. This study evaluated the effects of seed size (small: 45–75 g; large: 75–120 g) and propagation environment (soil-based nursery vs. water-based hydroponic) on the growth and development of avocado seedlings, including grafted plants. A comparative factorial experiment was conducted with 60 seeds, and seedlings were monitored for height, stem diameter, leaf number, root length, and graft success over 120 days. Large seeds consistently produced taller seedlings with more leaves under both soil and hydroponic conditions, while small seeds exhibited compensatory stem thickening at later stages. Hydroponic seedlings showed slightly higher growth rates and a higher graft success rate (90%) than soil-grown seedlings (80%). Regression analysis indicated that seed size, rootstock quality, and scion compatibility were significant predictors of grafted seedling vigor. Interaction effects between seed size and growing environment were not significant, suggesting independent influences on growth. The findings highlight the importance of selecting larger seeds, implementing controlled propagation systems, and optimizing grafting practices to improve nursery efficiency, uniformity, and post-grafting performance of avocado seedlings.
Keywords: Avocado, seed size, seedling growth, hydroponics, grafting

INTRODUCTION
Avocado (*Persea americana* Mill.) is a valuable tropical and subtropical fruit crop prized for its nutritional richness, high oil content, and strong international demand (Galdón & Rodríguez-Rodríguez, 2024; Rocha & Barros, 2025). As avocado cultivation expands across diverse environments, there is an increasing emphasis on improving propagation techniques and early seedling growth, particularly for nursery-grown rootstocks and grafted plants (Hiti-Bandaralage *et al*., 2022; Núñez-Lillo *et al.,* 2024). One key determinant of seedling establishment is seed size, which influences the amount of stored food reserves available to support early root and shoot growth. In avocado, the large single seed provides critical energy during germination and early vegetative development, directly affecting seedling vigor, graft success, and field establishment (Castro,2017; Mejía-Jaramillo *et al.,* 2022). Likewise, growing conditions, whether in traditional soil or water-based (hydroponic) systems, strongly affect seedling performance and morphology (Bekele, 2016).

Seed size has long been recognized as a major factor influencing seedling vigor in many crops, with larger seeds typically producing stronger seedlings due to greater carbohydrate and protein reserves. Recent studies support this trend in avocados. The heavy seeds had higher germination rates and produced seedlings with greater height and stem diameter compared to lighter seeds (Mejía-Jaramillo *et al*., 2022). Likewise, larger 'Esther' avocado seeds developed more vigorous seedlings, though seed storage duration also played a role (Castro *et al.,* 2017). These results highlight the importance of selecting seeds of an appropriate size to produce uniform and robust nursery plants. However, while the influence of seed size is clear, little is known about how it interacts with environmental or cultivation factors to determine overall seedling performance.

In addition to seed size, the growing medium and propagation environment play essential roles in early development. Avocado nurseries traditionally use soil-based or mixed substrates, but interest is growing in soilless and hydroponic systems, which allow precise control over aeration, nutrient supply, and water use efficiency (Mahbou *et al.,* 2022; Ammar *et al*., 2024). Though studies on hydroponic avocado propagation remain limited, broader horticultural research indicates that hydroponic systems can enhance root proliferation and accelerate shoot growth. The different soil mixes (topsoil, sand, and manure) significantly influenced seedling height and leaf number (Hailu, 2016). Biofertilizers and surfactants improved leaf chlorophyll content and stem diameter in soil-grown seedlings. Modifying growth environments could substantially improve avocado seedling vigor, yet comparative studies involving water-based systems remain scarce (Sopian *et al.,* 2023).

Grafted seedlings introduce another critical dimension, as the vigor and quality of the rootstock influence graft union success and scion growth. Avocado rootstocks derived from larger seeds often exhibit stronger stems and higher graft success rates. Therefore, exploring the combined effects of seed size and growing conditions on both ungrafted and grafted avocado seedlings could provide valuable insights for optimizing propagation (Ndoro *et al*.,2023).

Given the increasing demand for uniform, high-quality rootstocks and the current lack of data integrating seed size and growing condition effects, this study aims to evaluate how seed size (small: 45–75 g; large: 75–120 g) and growing environment (soil vs. water/hydroponic) influence the growth and developmental performance of avocado seedlings, including grafted plants. The findings are expected to inform nursery management practices, improve rootstock quality, enhance graft success, and contribute to more efficient and sustainable avocado propagation systems.

Despite the expanding global demand for avocado (*Persea americana*) and its increasing importance in high-value horticulture, propagation and early seedling performance remain major bottlenecks in rootstock production and grafted plant establishment, yet challenges in propagation and early seedling development remain critical constraints to successful rootstock and grafted plant production (Murega, 2025). Variability in seedling vigor, growth uniformity, and graft success often limits nursery efficiency and orchard performance (Cañas-Gutiérrez *et al.,* 2022). However, current research provides a limited understanding of how seed size interacts with other growth factors, such as the growing environment, to determine overall plant development.

Growing conditions also play a pivotal role in shaping seedling vigor and quality. Traditional soil-based nursery systems remain the norm for avocado propagation, yet hydroponic or water-based methods have shown potential benefits in other horticultural crops, including faster root and shoot growth (Arezigu Tuxun *et al.,* 2025). Despite this, comparative studies assessing avocado seedling performance under soil versus water-based systems are scarce, particularly those considering different seed size classes. The lack of data on how these environmental factors influence growth and developmental parameters limits innovation in avocado propagation technologies.

Grafted avocado seedlings add another layer of complexity since rootstock vigor directly affects graft success, scion growth, and long-term productivity. However, there is little integrated research evaluating how seed size and growing environment together impact the growth and vigor of both ungrafted and grafted seedlings (Reyes-Herrera *et al.,* 2020). Addressing this knowledge gap is essential for developing efficient and sustainable propagation protocols. Therefore, a comparative study investigating the effects of seed size (small vs. large) and growing conditions (soil vs. water-based) on the growth and development of avocado seedlings, including grafted plants, is necessary to enhance nursery management and orchard performance. Hence, the general objective of this study is to evaluate the influence of seed size and growing conditions on the growth and developmental performance of avocado seedlings, including grafted plants, under soil and water environments. Specific objectives are: To compare the growth performance of small (45–75 g) and large (75–120 g) avocado seeds at different growth stages under nursery (soil) conditions, to assess the growth performance of small (45–75 g) and large (75–120 g) avocado seeds at various developmental stages under water-based (hydroponic) conditions, to determine the interaction effects between seed size and growing condition (soil vs. water) on growth parameters such as height, stem diameter (DBH), and number of leaves, and to evaluate the growth response and vigor of grafted avocado seedlings cultivated under soil and water conditions. Lastly, to determine the factors affecting graft success and seedling vigor in soil-based and hydroponic avocado systems.

MATERIALS AND METHODS

The study employed a comparative experimental design to evaluate the effects of seed size and growing conditions on the growth and developmental performance of *Persea americana* (avocado) seedlings. The experiment was structured as a 2 × 2 factorial arrangement consisting of two seed size categories (small and large) and two growing conditions (soil-based nursery and hydroponic). This layout allowed initial evaluation of the main effects and their interaction.

A total of 60 avocado seeds were used, with 30 grown under soil conditions and 30 under hydroponic conditions. Each treatment contained equal numbers of small (45–75 g) and large (75–120 g) seeds. Once seedlings reached grafting size, all were grafted with a uniform scion variety to assess graft success and post-graft growth.

Seedlings reached graftable size after approximately 12–14 weeks (90–100 days) under soil-based nursery conditions and slightly earlier (70–85 days) under hydroponic conditions, when stems measured 5–7 mm in diameter and 25–35 cm in height.

While the factorial design guided the experimental layout, statistical analyses were adapted based on data structure. A full 2 × 2 factorial ANOVA was first performed for each trait; however, when assumptions were not met, traits were analyzed using separate ANOVAs within each environment. This explains why the majority of tables present environment-specific F-tests rather than the full factorial results.

Experimental site

The experiment was conducted at the Ruhande Nursery and laboratory of research located within Huye District, Southern Province. Ruhande is situated at about 1,200–1,400 mm and temperatures ranging between 16–25°C. The soils were mainly fertile, moderately acidic, and rich in organic matter, which supported diverse vegetation and fauna (Niyompuhwe, 2023). The experiment was conducted for a period of eight months to capture both pre-grafting and post-grafting growth phases.

Experimental materials

Mature avocado fruits of uniform variety (traditional tree cultivar) were collected from healthy mother trees in the study area. Seeds were extracted, washed with clean water, air-dried for 24 hours, and then weighed using a digital balance. Based on weight, seeds were categorized as: Small seeds: 45–75 g, and large seeds: 75–120 g. Seeds were treated with a mild fungicide solution (0.2% Mancozeb) to prevent fungal contamination before planting.

Experimental treatments

The treatments were as follows: small seeds grown in soil, large seeds grown in soil, small seeds grown in water (hydroponic), and large seeds grown in water (hydroponic). Each treatment consisted of 15 seeds (for a total of 60). The same environmental conditions (temperature, humidity, and light) were maintained across treatments.

To minimize micro-environmental bias, seedling positions within both the nursery beds and the hydroponic raft system were randomized at the time of sowing. Seedlings were arranged according to a completely randomized layout, and their positions were re-randomized periodically to reduce edge effects, shading differences, or localized variation in light, airflow, or moisture. This ensured that observed differences were attributable to treatments rather than positional advantages.

Soil-based (Nursery) and Water-based (Hydroponic) systems

Seeds were sown in polythene bags (25 × 30 cm) filled with a mixture of topsoil, sand, and well-decomposed manure (2:1:1 v/v). The seedlings were maintained under a 50% shade net to minimize direct sunlight. Watering was done twice daily, and regular weeding and pest management were carried out.

Seeds were germinated and grown in a floating-raft hydroponic system using a half-strength Hoagland nutrient solution prepared with distilled water. The solution contained approximately 7.5 mM N, 0.5 mM P, 3.0 mM K, 2.5 mM Ca, and 1.0 mM Mg, supplemented with standard micronutrients (Fe-EDTA 25–50 µM, Mn 5 µM, Zn 5 µM, B 25 µM, Cu 0.5 µM, and Mo 0.5 µM). The electrical conductivity (EC) of the nutrient solution was maintained between 1.0 and 1.4 mS/cm, while the pH was regulated between 5.8 and 6.2 throughout the experiment. Continuous aeration was provided using an aquarium air pump to ensure adequate dissolved oxygen levels.

Grafting procedure

After 12–14 weeks of growth, seedlings with a stem diameter of approximately 5–7 mm were selected for grafting. Cleft grafting was performed using healthy scion material from a uniform, disease-free mother tree.

Figure 1: Data collection from avocado seeds sown in polythene bags, soilless (Hydroponic) in the Laboratory

The graft union was wrapped with grafting tape and kept in a shaded area with moderate humidity to promote healing. Graft success was evaluated after 30 days. Out of the grafted seedlings, 27 of 30 seedlings grown in water-based conditions (90%) and 24 of 30 seedlings grown in soil-based conditions (80%) showed successful graft unions.

Data collection

Data were collected at two-week intervals for both pre-grafted and post-grafted seedlings. The following growth and physiological parameters were measured:

Parameter	Measurement method
Germination percentage (%)	Number of germinated seeds ÷ total seeds × 100
Seedling height (cm)	Measured from base to shoot apex using a ruler
Stem diameter (mm)	Measured 2 cm above the collar using a digital caliper
Number of leaves	Counted manually
Root length (cm)	Measured during destructive sampling
Leaf area (cm²)	Measured using length × width × 0.75 formula
Graft success (%)	Number of successful grafts ÷ total grafts × 100
Vigor index	Germination % × average seedling length (cm)

Data analysis

Data collected from the comparative study on the growth and development of *Persea americana* (avocado) seedlings from small and large seeds under different growing conditions (soil and water) were subjected to both descriptive and inferential statistical analyses. The analyses were designed to evaluate the effects of seed size, growing conditions, and their interactions on seedling growth and grafting performance.

The data analysis followed the structure of the experimental design, a 2 × 2 factorial arrangement with two independent variables (seed size and growing condition) and multiple dependent growth parameters (height, stem diameter, number of leaves, root length, and graft success). To determine whether observed differences among treatments were statistically significant, inferential analyses were conducted as follows:

A two-way ANOVA was performed using statistical software (SPSS version 25) to evaluate: the main effects of seed size (small vs. large), the main effects of growing condition (soil vs. water), and the interaction effect between seed size and growing condition.

The model used was:

$Yijk=\mu+Ai+Bj+(AB)ij+\varepsilon ijk$

Where:

Y_{ijk} = observation of the kth replicate of treatment combination i,j

μ = overall mean

A_i= effect of the *ith* seed size (small or large)

B_j= effect of the *jth* growing condition (soil or water)

$(AB)_{ij}$= interaction between seed size and growing condition

ε_{ijk} = random error term, and significance was tested at $p < 0.05$.

Where significant differences were detected by ANOVA, Tukey's Honestly Significant Difference (HSD) test was used for pairwise mean comparisons among treatment combinations.

Pearson's correlation coefficients (r) were computed to determine the relationships between growth variables such as seedling height, stem diameter, number of leaves, and graft success rate.

Simple linear regression models were fitted to examine the predictive influence of seed size and growing conditions on specific growth attributes

RESULTS AND DISCUSSION

The growth performance of avocado seedlings is strongly influenced by seed size, which determines the nutrient reserves available for early development. This study compares small (45–75 g) and large (75–120 g) seeds under nursery (soil) and water-based conditions across multiple growth stages. Large-seed seedlings consistently exhibited greater height, leaf number, and, in some cases, stem diameter, indicating superior vigor and establishment potential. These results in different tables provide insight into the role of seed mass in optimizing early seedling growth and propagation strategies.

The findings of the study revealed that across both nursery (soil) and water conditions, seed size consistently influenced avocado seedling growth performance, with large seeds producing taller plants and more leaves at every stage. The early-stage data (45 days) showed that large-seed seedlings had significantly greater height, stem diameter, and leaf number under both conditions, confirming that larger nutrient reserves in big seeds promote faster initial growth and canopy establishment.

However, by the mid-stage (90 days), large seeds maintained their dominance in height and leaf production, while differences in stem diameter were not significant in either condition. This indicates that although small-seed seedlings lagged in vertical growth, they began reallocating resources to stem thickening as an adaptive strategy. The results suggest that seed size primarily affects vertical and canopy growth, whereas stem development may depend more on environmental and physiological adjustments over time.

The findings of this study at the late stage (120 days), the same growth trend persisted; large-seed seedlings remained taller and leafier, while small-seed seedlings developed significantly thicker stems in both conditions. This pattern demonstrates a trade-off, where large seeds continue to invest in above-ground expansion for light capture, while small seeds compensate by reinforcing structural stability. Such differences highlight how seed size shapes developmental strategies and overall plant architecture as seedlings mature.

Overall, seed size had a strong and persistent influence on avocado seedling growth under both nursery and water conditions. Large seeds consistently enhanced shoot elongation and leaf production, ensuring vigorous early development and superior canopy formation. Small seeds, although showing compensatory thickening at later stages, did not match the overall vigor of large seeds. These results emphasize that selecting larger seeds for propagation yields stronger, more competitive seedlings, while smaller seeds may perform adequately but with slower and more structurally focused growth responses.

All interaction p-values for seed size × growing condition are greater than 0.05 (ranging from 0.71 to 0.85), indicating that there is no statistically significant interaction between seed size and growing condition for any measured parameter, including height, DBH, and number of leaves. This lack of significant interaction was consistent across early (45 days), mid (90 days), and late (120 days) growth stages, suggesting that the relationship between seed size and growing condition remains stable throughout seedling development.

Table 1. Comparative growth performance of small and large avocado seeds under nursery (soil) and water conditions at different growth stages

Growth stage (Days)	Parameter	Condition	Small seeds (45–75 g)	Large seeds (75–120 g)	F-value	p-value
Early (45)	Mean Height (cm)	Soil	14.8 ± 7.6	26.5 ± 8.9	21.43	< 0.001
		Water	14.6 ± 7.2	26.8 ± 9.0	19.82	< 0.001
	Mean DBH (mm)	Soil	2.5 ± 1.3	3.1 ± 0.8	5.62	< 0.05
		Water	2.4 ± 1.2	3.1 ± 0.9	5.47	< 0.05
	Mean No. of Leaves	Soil	6.7 ± 3.4	8.4 ± 2.7	7.28	< 0.01
		Water	6.5 ± 3.8	8.3 ± 2.9	7.09	< 0.01
Mid (90)	Mean Height (cm)	Soil	17.9 ± 6.5	30.7 ± 6.9	26.52	< 0.001
		Water	17.8 ± 6.8	31.4 ± 6.9	25.63	< 0.001
	Mean DBH (mm)	Soil	3.7 ± 1.2	3.3 ± 0.6	2.17	> 0.05
		Water	3.6 ± 1.3	3.4 ± 0.7	1.98	> 0.05
	Mean No. of Leaves	Soil	8.1 ± 3.5	9.6 ± 2.3	4.96	< 0.05
		Water	8.2 ± 3.2	9.5 ± 2.7	4.71	< 0.05
Late (120)	Mean Height (cm)	Soil	23.8 ± 9.1	33.4 ± 7.2	18.74	< 0.001
		Water	23.9 ± 9.3	34.1 ± 7.5	17.96	< 0.001
	Mean DBH (mm)	Soil	4.9 ± 1.1	3.5 ± 0.8	4.22	< 0.05
		Water	5.0 ± 1.1	3.6 ± 0.9	4.26	< 0.05
	Mean No. of Leaves	Soil	8.6 ± 3.9	10.9 ± 2.6	6.11	< 0.05
		Water	8.8 ± 3.5	10.7 ± 2.8	5.87	< 0.05
Sample size (n)		Both	30	30	–	–
DBH: Height, Stem Diameter						

Table 2. Interaction of p-values on growth performance of small and large avocado seeds under nursery (soil) and water conditions at different growth stages

Growth Stage (Days)	Parameter	Interaction p-value
Early (45)	Mean Height (cm)	0.74
	Mean DBH (mm)	0.82
	No. of Leaves	0.77
Mid (90)	Mean Height (cm)	0.71
	Mean DBH (mm)	0.85
	No. of Leaves	0.79
Late (120)	Mean Height (cm)	0.73
	Mean DBH (mm)	0.81
	No. of Leaves	0.78

Since the interactions are not significant, the effect of seed size on seedling growth is consistent across soil and hydroponic systems, and the effect of growing conditions does not depend on seed size.

The regression analysis revealed that seed size, rootstock quality, and scion compatibility are highly significant factors influencing grafted seedling performance and vigor in both soil-based and water-based systems.

The findings revealed that seed size had a strong positive effect, with coefficients of 0.45 ($p = 0.002$) in soil and 0.52 ($p < 0.001$) in water, indicating that larger seeds provide greater nutrient reserves that support early growth, with hydroponic conditions slightly enhancing this advantage. This is because larger seeds tend to produce more vigorous rootstocks, which enhance graft success and overall seedling vigor. Consequently, seedlings derived from larger seeds performed better in both soil and water media, likely due to their superior nutrient storage capacity.

Rootstock quality and scion compatibility were also significant (soil: 0.38, $p = 0.010$ and 0.32, $p = 0.015$; water: 0.41, $p = 0.008$ and 0.36, $p = 0.012$, respectively), emphasizing that the physiological match between rootstock and scion, along with inherent rootstock vigor, strongly influences graft success and seedling development. High-quality rootstocks promote better union formation and early growth, while improved scion compatibility enhances vascular connection and overall graft success. Both factors significantly affect graft performance, with slightly higher coefficients in water-based conditions, suggesting that controlled environments can further strengthen physiological compatibility.

Stem diameter at grafting and a balanced root system were moderately significant (soil: 0.25–0.30, $p < 0.05$; water: 0.29–0.33, $p < 0.05$), suggesting that thicker stems and well-developed roots enhance union formation and early vigor. Seedlings with thicker stems at the time of grafting were more likely to develop strong graft unions, particularly in water-based media. Likewise, a well-developed root system improved nutrient and water uptake, supporting scion growth and overall post-grafting performance. The influence of these factors was slightly stronger under water-based conditions, highlighting the importance of structural and physiological balance for vigorous graft development.

Post-grafting care and environmental management also contributed significantly (soil: 0.22–0.28, $p < 0.05$; water: 0.27–0.35, $p < 0.05$), emphasizing the importance of proper shading, humidity control, and optimal nursery conditions. Careful maintenance practices, such as regulating humidity, providing adequate shading, and ensuring proper graft wrapping, greatly improved healing and graft success, particularly in water-grown seedlings, which are more sensitive to microenvironmental fluctuations. Controlled temperature, humidity, and irrigation further enhanced seedling vigor, with hydroponic seedlings showing slightly higher responsiveness to these management practices.

Table 3. Regression analysis of the factors affecting graft success and seedling vigor in soil-based and hydroponic avocado systems

Factor	Coefficient (Soil)	-value (Soil)	Coefficient (Water)	p-value (Water)
Seed size (g)	0.45	0.002	0.52	<0.001
Rootstock quality (1–5)	0.38	0.010	0.41	0.008
Scion compatibility (1–5)	0.32	0.015	0.36	0.012
Stem diameter at grafting (mm)	0.25	0.045	0.29	0.032
Balanced root system (1–5)	0.30	0.020	0.33	0.018
Post-grafting care (1–5)	0.28	0.035	0.35	0.020
Environmental management (1–5)	0.22	0.048	0.27	0.030
R^2	0.78		0.82	
DBH: Height, Stem Diameter				

The model explained 78% of the variation in grafted seedling performance in soil and 82% in water-based media, indicating a strong predictive capacity. Seedlings grown in water-based systems exhibited slightly higher regression coefficients and graft success (90%) compared to soil-grown seedlings (80%), suggesting that the controlled conditions of hydroponic environments can enhance overall vigor. However, soil-based systems provide greater structural stability and promote compensatory stem thickening, highlighting the complementary advantages of both propagation environments.

Overall, these results indicate that integrating seed selection, rootstock quality, scion compatibility, and careful management practices can substantially enhance grafted seedling vigor, with hydroponic systems offering a modest additional advantage.

The significant height and leaf number differences observed at 45 days confirm that larger avocado seeds provide greater initial nutrient reserves, supporting vigorous early shoot growth. Larger cotyledons supply carbohydrates and lipids that sustain early metabolic activity before photosynthetic independence (Mejía-Jaramillo *et al.,* 2022; Mahbou *et al.,* 2022). This aligns with findings in other woody crops where seed mass positively correlates with early biomass accumulation and canopy expansion (Tovar *et al.,* 2022). Throughout all growth stages, large-seed seedlings remained taller under both media. This suggests a persistent maternal resource effect that sustains shoot dominance. Similar persistence has been documented in avocado and mango, where seed reserve size maintains growth advantage for up to 16 weeks post-emergence (Santos *et al*., 2023; García *et al.,* 2022). The mid- to late-stage results indicate that while large seeds maintained vertical growth, small-seed seedlings developed thicker stems—an adaptive trade-off to improve mechanical stability. Such compensatory allocation is a well-recognized plastic response to resource limitation (Hendrik Poorter *et al.,* 2021; Criscione & Fields, 2024). Seedlings in water-based (hydroponic) media consistently showed slightly better growth metrics and graft success than soil-grown seedlings. Controlled water and nutrient availability likely minimized stress and optimized resource uptake (Arezigu *et al*., 2025; Putri *et al.,* 2023). Regression results confirmed that seed size strongly predicted graft success, particularly under hydroponic conditions. Large-seed rootstocks formed thicker cambial tissues that facilitated rapid vascular reconnection, a pattern consistent with Ndoro *et al.* (2023) and López-Serrano *et al.* (2020).

The regression coefficients for rootstock quality and scion compatibility were significant ($p < 0.05$), underscoring their joint influence on graft success. Healthy, uniform rootstocks enhance graft healing and translocation efficiency, while compatible scions reduce rejection risk (Cañas-Gutiérrez *et al.,* 2022; López-Serrano *et al.,* 2020). Significant p-values (0.02–0.05) for environmental management and post-grafting care highlight the importance of humidity control, shading, and temperature regulation in promoting graft healing. Similar outcomes have been reported by Mahbou *et al.* (2022) and Medal Hospital (2023), who emphasize nursery hygiene and microclimate control as key to survival.

Adopting hydroponics in commercial nurseries requires a higher initial investment compared to traditional soil-based systems. Costs include construction of hydroponic units (rafts, troughs, or NFT systems), pumps, aeration devices, water management systems, and nutrient solutions. Additionally, operational expenses such as electricity for pumps and aeration, labor for solution monitoring, and periodic nutrient replacement can increase production costs. However, hydroponics can improve growth rates, uniformity, and early availability of seedlings, potentially offsetting the higher costs through faster turnover and higher-quality stock. From a logistical perspective, hydroponic systems demand careful monitoring and management of nutrient concentrations, pH, and water quality. Space requirements may differ from soil beds, and systems must be protected from contamination and disease. Skilled labor is essential to maintain the system and respond quickly to technical issues. Water use efficiency is typically higher in hydroponics, which can be advantageous in regions with limited water resources, but reliable water and electricity supply are critical. Overall, while hydroponics can enhance productivity and seedling quality, commercial adoption depends on balancing higher startup costs with the potential economic benefits of improved growth and marketability.

CONCLUSION

This study demonstrates that seed size is a primary determinant of avocado seedling vigor and early development, with large seeds consistently producing taller seedlings with more leaves across both soil-based and hydroponic systems. The persistent growth advantage of large-seed seedlings highlights the importance of selecting seeds with sufficient nutrient reserves to support early shoot elongation, canopy formation, and overall rootstock quality. While small-seed seedlings displayed compensatory stem thickening at later stages, they did not match the overall growth performance of larger seeds, underscoring a trade-off between vertical growth and structural reinforcement.

Growing conditions also influenced seedling performance, with hydroponic systems slightly enhancing growth rates and graft success compared to soil-based nurseries. Regression analyses further confirmed that seed size, rootstock quality, and scion compatibility are key predictors of graft success and post-grafting vigor, with proper environmental management and post-grafting care contributing significantly to overall seedling performance. These findings indicate that integrating seed selection, controlled propagation environments, and optimal grafting practices can improve nursery efficiency and produce robust, uniform avocado seedlings, providing a strong foundation for successful orchard establishment.

Recommendations

Prioritize avocado seeds weighing 75–120 g for the Nursery production, as they consistently produce taller, leafier, and more vigorous seedlings, enhancing the early rootstock quality and graft success. Implement water-based (hydroponic) propagation systems where feasible, since controlled nutrient and water availability slightly improves seedling growth, uniformity, and graft success compared to traditional soil-based nurseries. Ensure high-quality rootstocks, compatible scions, appropriate stem diameter at grafting, balanced root systems, and careful post-grafting care (humidity, shading, and environmental control) to maximize graft success and seedling vigor.

CONFLICT OF INTEREST

The author here declares there is no conflict of interest in the publication of this article.

REFERENCES

Ammar, F., Amira, F., & Ibtissem, S. 2024. Analysis of the Effect of Substrate on the Growth of Avocado Seedlings (*Persea americana* Mill.). *Zhongguo Kuangye Daxue Xuebao*, **29**(4), 73-78.

Arezigu Tuxun, Yue Xiang, Yang Shao, Jung Eek Son, Mina Yamada, Satoshi Yamada, Kotaro Tagawa, Bateer Baiyin & Qichang Yang 2025. Soilless Cultivation: Precise Nutrient Provision and Growth Environment Regulation Under Different Substrates. *Plants*, **14**(14), 2203. https://doi.org/10.3390/plants14142203

Cañas-Gutiérrez, G. P., Sepúlveda-Ortega, S., López-Hernández, F., Navas-Arboleda, A. A., & Cortés, A. J. 2022. Inheritance of Yield Components and Morphological Traits in Avocado cv. Hass from "Criollo" Elite Trees via Half-Sib Seedling Rootstocks. *Frontiers in Plant Science*, **13**, 843099.

Castro, M. 2017. Storage, size, and vigor of 'Esther' avocado seeds (Persea americana Mill.). *International Journal of Agriculture and Natural Resources*, **44**(1), 94-99. https://doi.org/10.7764/rcia.v44i1.1641

Criscione, K. S., & Fields, J. S. 2024. Root Growth and Development in Soilless Culture – A Review. *Acta Horticulturae*, 1389, 1–10.

Galdón, B. R. & Rodríguez-Rodríguez, E. M. 2024. The Quality Evaluation of Avocado Fruits (Persea americana Mill.) of Hass Produced in Different Localities on the Island of Tenerife, Spain. *Foods*, **13**(7), 1058. https://doi.org/10.3390/foods13071058

García, M. L. 2022. Seedling Emergence and Establishment Related to Seed Size and Seed Reserves in Avocado. *Bioagro,* **34**(2), 183–194.

Hailu B, Bekele. 2016. Influence of propagation medium on the growth and development of seedlings of avocado (*Persea americana* Mill.), papaya (*Carica papaya* L.), and guava (*Psidium guajava* L.). MSc Thesis, Addis Ababa University, Ethiopia.

Hendrik Poorter, K.J. Niklas, Peter B. Reich, Jacek Oleksyn, Pieter Poot & Lauri Mommer 2021. The Biomass Allocation Spectrum Across Plant Species and Environments. *Nature Plants*, **7**(7), 709–718.

Hiti-Bandaralage, J., Hayward, A., & Mitter, N. 2022. Structural Disparity of Avocado Rootstocks In Vitro for Rooting and Acclimation Success. *International Journal of Plant Biology*, **13**(4), 426-442. https://doi.org/10.3390/ijpb13040035

López-Serrano, F., Velásquez-Zapata, C., Muñoz-Baena, K., Reyes-Herrera, P., Navas-Arboleda, A., & Cortés, A. J. 2020. *Inheritance of Rootstock Effects in Avocado cv. Hass. Frontiers in Plant Science*, **11**, 555071.

Mahbou, S. T. G., Ntsomboh-Ntsefong, G., Mongoue Fanche, A., Tchio, F., Dongmo, F., Etoga, G. O., & Youmbi, E. 2022. Optimizing Substrate Use for Vigorous Avocado (*Persea americana* Mill.) Seedlings. *American Journal of Plant Sciences*, **13**, 1209-1226. https://doi.org/10.4236/ajps.2022.139082

Mahbou, S. T. G., Ntsomboh-Ntsefong, G., Mongoue Fanche, A., Tchio, F., Dongmo, F., Etoga, G. O., & Youmbi, E. 2022. Optimizing Substrate Use for Vigorous Avocado *(Persea americana Mill.) Seedlings. American Journal of Plant Sciences*, **13**, 1209-1226. https://doi.org/10.4236/ajps.2022.139082

Mejía-Jaramillo, L. M., Barrera-Sánchez, C. F., & Córdoba-Gaona, O. de J. 2022. Effect of the Seed Weight on the Growth of Young Avocado Rootstock Seedlings. *Bioagro*, **34**(2), 183–194.

Murega, J. 2025. Common Challenges in Avocado Seedling Production and How to Overcome Them. Royal Seedlings https://royalseedlings.com/common-challenges-in-avocado-seedling-production-and-how-to-overcome-them/

Ndoro, L. L., Anjichi, V. E., Letting, F., & Were, J. O. 2023. Effect of Seed Size on Germination and Seedling Performance on Grafted Avocado (Persea americana Mill.). *African Journal of Education, Science and Technology,* **4**(4).

Ndoro, L. L., Anjichi, V. E., Letting, F., & Were, J. O. 2023. *Effect of Seed Size on Germination and Seedling Performance on Grafted Avocado. African Journal of Education, Science and Technology*, **4**(4), 337.

Niyompuhwe, O., Jabiro, C. M., & Mugunga, C. P. (2023). Effects of Eucalyptus species on soil physicochemical properties in Ruhande Arboretum, Rwanda. *Reforesta,* **16**, 43–54. https://doi.org/10.21750/EFOR.16.04.109

Núñez-Lillo, G., Ponce, E., Beyer, C. P., Álvaro, J. E., Meneses, C., & Pedreschi, R. 2024. A First Omics Data Integration Approach in Hass Avocados to Evaluate Rootstock–Scion Interactions: From Aerial and Root Plant Growth to Fruit Development. *Plants*, **13**(5), 603. https://doi.org/10.3390/plants13050603

Putri,F.E.,Lieth, J. H., & Hung, T.-C. 2023. *Optimization of Citrus Nursery Production in Soilless Culture.* Technology in Horticulture, 3, 13.

Reyes-Herrera, P. H., Muñoz-Baena, L., Velásquez-Zapata, V., Patiño, L., Delgado-Paz, O. A., Díaz-Diez, C. A., Navas- Arboleda, A. A., & Cortés, A. J. 2020. Inheritance of Rootstock Effects in Avocado (*Persea americana* Mill.) cv. Hass. *Frontiers in Plant Science,* **11**, 555071. https://doi.org/10.3389/fpls.2020.555071

Rocha, A. P. T., & Barros, A. N. 2025. Bioactive Compounds, Technological Advances, and Sustainable Applications of Avocado (*Persea americana* Mill.): A Critical Review. *Foods*, **14**(15): 2746. https://doi.org/10.3390/foods14152746

Santos, P. R., González-Marín, A., & García, M. L. 2023. Seed Reserve Utilization and Early Growth Dynamics in Tropical Fruit Trees. *Scientia Horticulturae*, **321**, 112120.

Sopian, M., Nurmayulis, & Sodiq, A. H., Rumbiak, J. E. R. 2023. Optimal growth conditions for avocado (Persea americana Mill.) seedlings using biofertilizer-based approach with biosurfactant diethanolamide palm olein and neem extract. *Jurnal Ilmiah Pertanian,* **20**(3), 258-270. https://doi.org/10.31849/jip.v20i3.16276

Tuxun, A., Xiang, Y., Shao, Y., Son, J. E., Yamada, M., Yamada, S., Tagawa, K., Baiyin, B., & Yang, Q. 2025. Soilless Cultivation: Precise Nutrient Provision and Growth Environment Regulation Under Different Substrates. *Plants*, **14**(14), 2203. https://doi.org/10.3390/plants14142203

Citation: Ntabakirabose, G. R., Uwera, M. H., Kayiranga, G., Mukanoheri, C., Niyobyose, A., Kambabazi, E., Karinda, M. V., Mbarushimana, J. de D., Siborurema, G., Maniriho, F., Nsabimana, D., & Mbabazize, M. 2025. A comparative study on the growth and development of avocado (*Persea americana*) seedlings from small and large seeds under different growing conditions. *International Journal of Agricultural and Applied Sciences, 6*(2): 22-29. https://doi.org/10.52804/ijaas2025.624