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Microclonal success of avocado using different scions and clonal rootstock varieties

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Abstract

This study explored the microclonal compatibility of various avocado clonal rootstocks and scion varieties, assessing their influence on growth parameters such as leaf production, chlorophyll content, stem length, and stem diameter. The study employed a randomized complete block design (RCBD) with split plots, focusing on different clonal rootstock and scion combinations. The results demonstrated significant interactions between the clonal stock and scion varieties, influencing key growth metrics. 'Hass' scions microcloned onto 'Purple' and 'Evergreen' clonal rootstocks produced 5.60 leaves each, showing superior growth. In terms of leaf area, 'Hass' scions microcloned onto 'Purple' clonal rootstocks had the largest leaf area of 36.11 cm², significantly higher than other combinations. The chlorophyll content (Soil Plant Analysis Development [SPAD] values) was highest when 'Hass' scions were microcloned onto 'Purple' clonal rootstocks, yielding a 35.82 SPAD values. The highest stem length (6.02 cm) was observed in ‘Hass’ scion microcloned on ‘Evergreen’ clonal rootstock, while the biggest stem diameter (0.300 cm) was observed in ‘Evergreen’ scion microcloned onto ‘Purple’ clonal rootstock. These findings suggest that the pairing of 'Hass' microclone on 'Purple' clonal rootstock, can optimize early plant growth, leaf production, and plant health, and significantly impacts plant vigor. Further research may be conducted to monitor long-term plant health and refine microcloning techniques for improved avocado cultivation.

Keywords: Avocado microclones, Clonal rootstock-scion compatibility, Scion-clonal rootstock interaction, Microcloning success

1. Introduction

Avocado (*Persea americana* Mill.) cultivation has gained significant global attention due to its rising demand, driven by its nutritional value, culinary versatility, and economic potential [1,2]. It provides essential nutrients and have high economic value, supporting rural livelihoods and driving economic growth. As a result, maximizing the efficiency and productivity of avocado farming has become a key focus for agricultural researchers [3,4]. Among the various techniques to enhance avocado production, grafting stands out as a highly effective method [5,6]. Grafting combines different varieties of rootstocks and scions to produce plants with improved growth characteristics, such as increased fruit yield, better resistance to diseases, and enhanced stress tolerance [7,8]. However, the success of grafting largely depends on the compatibility between the selected rootstock and scion varieties, making it crucial for growers to understand the physiological interactions between these two components [9, 10].

In the context of avocado cultivation, the compatibility between rootstocks and scions is particularly significant for optimizing key growth parameters such as leaf area, chlorophyll content, stem length, and overall plant vigor. While various studies have explored grafting techniques for other fruit crops, avocado-specific research on scion-rootstock interactions remains limited. Previous research in fruit crops has shown that selecting compatible scion-rootstock combinations can greatly improve plant health and growth, leading to higher yields and better-quality fruits [11,12]. Despite this, the specific combinations that are most effective for avocado grafting, particularly in tropical regions like the Philippines, are still underexplored.

This study seeks to address this gap by exploring the microclonal compatibility between various avocado clonal rootstocks and scion varieties. The focus is on understanding the effects of various clonal rootstocks such as 'Purple', 'Evergreen', and 'Hass' when grafted with different scion varieties. Key growth parameters such as leaf production, chlorophyll content, stem length, and stem diameter were evaluated to determine the most effective microcloning combinations. By analyzing these parameters, this research may provide essential data on how different clonal rootstock-scion pairings influence the early growth and development of avocado plants, offering insights into the most successful combinations for optimal growth.

In this study, the terms *"microcloning"*, *"microclonal"*, or *"microclones"* are related to a specialized form of vegetative propagation. The process begins by grafting clonal rootstocks onto nurse seedlings. Once established, selected scions are grafted onto these clonal rootstocks. Subsequently, the clonal rootstocks can be induced to form roots using appropriate rooting devices. The resulting plant, which is composed of the clonal rootstock and the grafted scion, is termed a *"microclone."* Compared with conventionally grafted avocado seedlings, microclones are lighter, free from disease, and easier to transport, offering clear practical advantages for large-scale propagation and distribution. This research is crucial for improving avocado cultivation in tropical and subtropical regions, where challenges like heat stress, water scarcity, and soil degradation prevail. By identifying compatible scion-clonal rootstock pairings that enhance plant health and resilience, it could boost productivity and promote sustainable farming practices, reducing chemical reliance and improving ecological balance.

This study contributes to the United Nations' Sustainable Development Goals (SDGs), 2 (Zero Hunger) and 12 (Responsible Consumption and Production). By identifying microcloning combinations that boost plant health and yield, it can improve food security and nutrition through increased avocado production. Furthermore, promoting sustainable farming practices aligns with responsible agriculture, addressing resource use and environmental concerns. Ultimately, this research aids in achieving SDGs focused on sustainable agriculture, food security, and economic development.

2. Materials and methods

2.1 Experimental design and treatments (open-field nursery)

The study on microclonal compatibility of avocado clonal rootstocks and scion varieties was conducted at Central Mindanao University from April 2024 to March 2025. Climatic data from DOST-PAGASA (2025) indicates ideal conditions for avocado growth from November 2024 to March 2025. However, during the hotter months (April to June), high temperatures could stress the trees, especially with limited water availability, requiring careful manual irrigation management to mitigate heat stress.

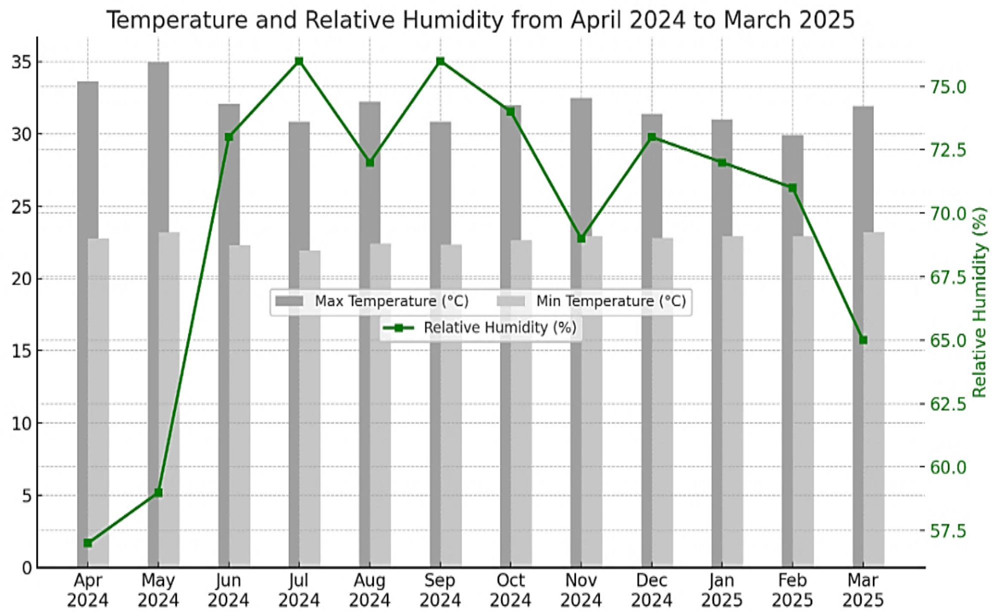

Figure 1 April 2024 – March 2025 RH (%) and min. & max. temp. (ºC) in the experimental area. Source: [9] DOST-PAGASA (2025).

2.2 Materials, Equipment, and Experimental Design

The following planting materials were used: 189 ‘Evergreen’ rootstock seedlings that served as nurse seedlings; 63 each of ‘Purple’, ‘Evergreen’, and ‘Hass’ avocado clonal rootstocks; 63 each of ‘Purple’, ‘Evergreen’, and ‘Hass’ avocado microclones; nursery supplies (cocopeat, garden soil, vermicompost, rice hull); tools (ruler, SPAD meter, Vernier caliper, Easy Leaf® App, MunCell® App); and other materials (sprinklers, polyethylene bags, etiolation boxes, and working tools such as bolo, spade, scissors, and cutters). Data were analyzed using STAR software.

Figure 2 Clonal rootstock x scion combinations of avocado varieties.

	Scion: ‘Purple’	Scion: ‘Evergreen	Scion: ‘Hass’
Clonal Rootstock: ‘Purple’	Purple’ clonal rootstock x ‘Purple’ scion	‘Purple’ clonal rootstock x ‘Evergreen’ scion	‘Purple’ clonal rootstock x ‘Hass’ scion
Clonal Rootstock: ‘Evergreen’	‘Evergreen’ clonal rootstock x ‘Purple’ scion	‘Evergreen’ clonal rootstock x ‘Evergreen’ scion	‘Evergreen’ clonal rootstock x ‘Hass’ scion
Clonal Rootstock: ‘Hass’	‘Hass’ clonal rootstock x ‘Purple’ scion	‘Hass’ clonal rootstock x ‘Evergreen’ scion	‘Hasss’ clonal rootstock x ‘Hass’ scion

The experiment was laid out as a Split Plot within a Randomized Complete Block Design (RCBD), with three clonal rootstock varieties (‘Purple’, ‘Evergreen’, and ‘Hass’) as the main plots and three microclone scion varieties (‘Purple’, ‘Evergreen’, and ‘Hass’) as the subplots (Figure 2). Each treatment had five sample plants used for data collection, replicated three times, giving a total of 135 experimental plants. In addition, two buffer plants were included for each treatment as replacements in case of mortality, ensuring that data collection would not be disrupted by plant loss. Randomization and plot layout were carried out using STAR 2.0.1.

2.3 Nursery Management, Grafting, and Care

‘Evergreen’ avocado seeds, along with ‘Purple’ and ‘Evergreen’ clonal rootstocks, were sourced locally, while ‘Hass’ clonal rootstocks were purchased (Figure 3(A)). Nurse seedlings were pre-germinated in cocopeat and transferred to polyethylene bags with a growing mix (Figure 3(B)). Once the nurse seedlings reached a 6 mm stem diameter, they were grafted with ‘Purple’, ‘Evergreen’, and ‘Hass’ clonal rootstocks (Figure 3(C)). Grafts were monitored 21 days post-grafting for success, and once at least 50% of clonal rootstocks produced buds, etiolation began. The grafts were placed in ventilated etiolation boxes for two weeks, promoting bud development in darkness (Figure 3(D)). Six months later, when shoots of clonal rootstocks reached the desired diameter, scions of ‘Hass’, ‘Purple’, and ‘Evergreen’ were microcloned onto the clonal rootstocks (Figure 3(E)). The microclones were kept under ambient conditions with shading, and manual watering was done via sprinklers and misting, with temperature and humidity monitored.

2.4 Statistical data analysis:

After tabulating the collected data (Figure 3(F)), analysis of variance (ANOVA) was performed using the Statistical Tool for Agricultural Research (STAR ver.2.0.1) software. Furthermore, the parameters that were determined to be significant as indicated by the F calculated value, the comparison of means was carried out using Tukeys’ Honest Significant Difference (HSD) for the post hoc analysis. While ANOVA assumes normality of residuals, agricultural experiments with balanced designs and replications are generally robust to moderate deviations. This study followed these principles.

Figure 3 The researchers performed the following: (A) gathered and collected planting materials. (B) pre-germinated and grew nurse seedlings. (C) grafted the clonal stocks. (D) etiolated the clonal rootstocks. (E) microcloned the scion onto the clonal rootstock. (F) gathered important data.

3. Results

The analysis of variance (ANOVA) results summarized in Table 2 indicate that both the clonal rootstock variety (A) and the scion variety (B), as well as their interaction (AxB), have a highly significant effect on all measured parameters of avocado microclones 60 days after microcloning. The "highly significant" results (1% probability) show that the choice of clonal rootstock variety significantly influences the leaf number and area, leaf chlorophyll, stem length and diameter. Similarly, the scion variety also plays a significant role in these parameters. Furthermore, the interaction between the clonal rootstock and scion variety is highly significant, suggesting that the impact of one factor on these parameters depends on the level of the other. This means that both the clonal rootstock and scion variety, as well as their combination, are critical in determining the growth and development of avocado microclones.

Table 1 ANOVA summary of the different factors and interactions on different parameters 60 days after microcloning of avocado.

Factors	Leaf Parameters			Stem Parameters	
	Number	Area (cm^2)	Chlorophyll (Soil Plant Analysis Dev't [SPAD] Value)	Length (cm)	Diameter (cm)
Clonal Rootstock Variety (A)	**	**	**	**	**
Scion Variety (B)	**	**	**	**	**
Clonal Rootstock Variety x Scion Variety (AxB)	**	**	**	**	**

** - highly significant (1%, Probability)

Table 2 Interaction of clonal rootstock variety and scion variety on the different parameters of avocado microclones 60 days after grafting.

Clonal Rootstock Variety (A)	Scion Variety (B)	Leaf Parameters			Stem Parameters	
		Number	Area (cm^2)	Chlorophyll (Soil Plant Analysis Dev't [SPAD] Value)	Length (cm)	Diameter (cm)
'Purple'	'Purple'	$4.73^{a,AB}$	$10.56^{a,C}$	$29.06^{a,B}$	$2.12^{a,B}$	$0.297^{a,A}$
	'Evergreen'	$4.07^{a,B}$	$17.17^{a,B}$	$33.25^{a,AB}$	$3.17^{a,B}$	$0.300^{a,A}$
	'Hass'	$5.60^{a,A}$	$36.11^{a,A}$	$35.82^{a,A}$	$5.07^{a,A}$	$0.247^{a,B}$
'Evergreen'	'Purple'	$4.33^{a,B}$	$7.57^{a,A}$	$17.09^{b,B}$	$1.96^{a,B}$	$0.263^{b,A}$
	'Evergreen'	$0.600^{b,C}$	$0.056^{b,B}$	$0.600^{c,C}$	$1.74^{b,B}$	$0.060^{b,C}$
	'Hass'	$5.60^{a,A}$	$12.97^{b,A}$	$26.36^{b,A}$	$6.02^{a,A}$	$0.223^{a,B}$
'Hass'	'Purple'	$2.67^{b,A}$	$7.83^{a,A}$	$18.72^{b,A}$	$1.87^{a,A}$	$0.290^{ab,A}$
	'Evergreen'	$1.00^{b,B}$	$4.07^{b,AB}$	$8.90^{b,B}$	$2.50^{ab,A}$	$0.060^{b,B}$
	'Hass'	$1.80^{b,AB}$	$2.04^{c,B}$	$5.80^{c,B}$	$1.62^{b,A}$	$0.050^{b,B}$
c.v. %		a=19.69 b=14.39	a=13.56 b=13.39	a=12.25 b=10.39	a=15.37 b=12.05	a=5.30 b=7.62

Note: Letters in lowercase indicate highly significant differences among clonal rootstock varieties (Factor A) at each level of scion variety (Factor B), while UPPERCASE LETTERS represent highly significant differences among scion variety (Factor B) at each level of clonal rootstock variety (Factor A), based on Tukey's HSD at the 1% level.

3.1 Number of leaves at 60 days after grafting

At 60 days after microcloning, the number of leaves from five randomly selected microclones showed a significant interaction between clonal rootstock and scion variety. 'Purple' scion microcloned onto 'Purple' clonal rootstock had the most leaves, followed by 'Purple' on 'Evergreen', while 'Purple' on 'Hass' had the least. 'Evergreen' scion microcloned onto 'Purple' clonal rootstock produced the most number of leaves, outperforming 'Evergreen' scion microcloned onto 'Hass' and 'Evergreen' clonal rootstocks. 'Hass' scion microcloned onto 'Purple' and 'Evergreen' clonal rootstocks each produced more leaves than 'Hass' microcloned onto 'Hass' clonal rootstock.

3.2 Leaf Area (cm^2)

Leaf area was measured using the "Easy Leaf Area" App 60 days after microcloning, with the fourth youngest leaf sampled for consistency. The results showed a significant interaction between clonal rootstock and scion variety. The leaf area of the clonal rootstocks ('Purple', 'Hass', and 'Evergreen') had similar superior values. The highest leaf area was observed in 'Purple' clonal rootstock and 'Evergreen' scion. In contrast, 'Hass' and 'Evergreen' clonal rootstocks with 'Evergreen' scion had smaller leaf areas. Furthermore, 'Purple' clonal rootstock with 'Hass' scion produced the largest leaf area, surpassing 'Evergreen' and 'Hass' clonal rootstocks with 'Hass' scions.

3.3 Leaf Chlorophyll Content (Soil and Plant Analysis Development [SPAD] units)

Leaf chlorophyll content, measured using the SPAD Chlorophyll Meter, showed a significant interaction between clonal rootstock and scion variety. The highest chlorophyll content was observed when 'Purple' scion was microcloned onto 'Purple' clonal rootstock, followed by 'Hass' and 'Evergreen' clonal rootstocks. For 'Evergreen' scion, the highest chlorophyll content was with 'Purple' clonal rootstock, while 'Hass' and 'Evergreen' rootstocks attained the lowest SPAD values. When 'Hass' scion was microcloned onto 'Purple' clonal rootstock, the chlorophyll content was highest, followed by 'Evergreen' clonal rootstock. The lowest value found in 'Hass' clonal rootstock.

3.4 Stem Length (cm)

Stem length was measured from the microcloning union to the node of the youngest leaf. A significant interaction between clonal rootstock and scion variety was observed. 'Purple' scion microcloned onto 'Purple' clonal rootstock resulted in the longest stem length, followed by 'Evergreen', and by 'Hass' clonal rootstocks. For 'Evergreen' scion, the longest stem length occurred when microcloned onto 'Purple' clonal rootstock, followed by 'Hass' clonal rootstock, and lastly by 'Evergreen' clonal rootstock. 'Hass' scion microcloned onto 'Evergreen' clonal rootstock had the longest stem length, with a similar value when microcloned onto 'Purple' clonal rootstock. 'Hass' scion microcloned onto 'Hass' clonal rootstock had the shortest stem length.

3.5 Stem Diameter (cm)

Sixty days after microcloning, stem diameter was measured at the middle of the stem using an electronic caliper. A significant interaction between clonal rootstock and scion variety was observed. ‘Purple’ clonal rootstock with ‘Purple’ scion had the largest stem diameter, followed by ‘Hass’ clonal rootstock with ‘Purple’ scion. ‘Evergreen’ clonal rootstock with ‘Purple’ scion had the smallest diameter. In contrast, ‘Evergreen’ and ‘Hass’ clonal rootstocks with ‘Evergreen’ scion had the smallest diameters. ‘Purple’ clonal rootstock with ‘Hass’ scion had a stem diameter that is similar to ‘Evergreen’ clonal rootstock with ‘Hass’ scion. The smallest diameter was observed when ‘Hass’ clonal rootstock was microcloned with ‘Hass’ scion.

Table 3 provides an analysis of leaf and stem color 60 days after microcloning, based on different combinations of clonal rootstock and scion varieties. The color ratings are derived from a scale that measures hue, value, and chroma, ranging from yellow to greenish hues. The results show that the leaf and stem color ratings across most combinations are relatively consistent, with values hovering around 5.00, indicating a moderate yellow-green hue.

Table 3 Leaf and stem color at 60 days after microcloning the clonal rootstocks and scions.

Clonal Rootstock Varieties X Scion Varieties	Leaf	Stem
A1B1 (‘Purple’ Clonal Rootstock x ‘Purple’ Scion)	5.00	5.00
A1B2 (‘Purple’ Clonal Rootstock x ‘Evergreen’ Scion)	5.47	5.00
A1B3 (‘Purple’ Clonal Rootstock x ‘Hass’ Scion)	5.33	5.00
A2B1 (‘Evergreen’ Clonal Rootstock x ‘Purple’ Scion)	5.00	5.00
A2B2 (‘Evergreen’ Clonal Rootstock x ‘Evergreen’ Scion)	6.00	6.00
A2B3 (‘Evergreen’ Clonal Rootstock x ‘Hass’ Scion)	5.47	5.33
A3B1 (‘Hass’ Clonal Rootstock x ‘Purple’ Scion)	5.87	5.13
A3B2 (‘Hass’ Clonal Rootstock x ‘Evergreen’ Scion)	5.00	5.00
A3B3 (‘Hass’ Clonal Rootstock x ‘Hass’ Scion)	5.00	5.00

Scale (Leaf and Stem Color) adapted from Esgrina and Tan (2025).

3.6 Leaf Color

Leaf color was measured 60 days after microcloning using the Muncell Color Chart ® digital application. The leaf color of ‘Evergreen’ scion microcloned onto ‘Evergreen’ clonal rootstock was a vibrant green-yellow. Whereas, the color of ‘Purple’ scion on ‘Hass’ clonal rootstock was a vibrant green-yellow. The ‘Hass’ scion microcloned onto ‘Hass’ clonal rootstock displayed a duller leaf color.

3.7 Stem Color

For ‘Purple’ clonal rootstock, all scion varieties achieved a moderate stem color with balanced lightness and vibrancy. Similarly, ‘Purple’, ‘Evergreen’, and ‘Hass’ scions microcloned onto ‘Purple’ clonal rootstock showed no noticeable differences. With ‘Evergreen’ clonal rootstock + ‘Purple’ scion, and ‘Evergreen’ scion + ‘Evergreen’ clonal rootstock attained a brighter, more vibrant color. ‘Hass’ scion microcloned on ‘Evergreen’ clonal rootstock, and ‘Hass’ clonal rootstock + ‘Purple’ scion showed a rich color.

4. Discussions

The study's findings have both practical and theoretical implications for avocado microcloning techniques. Practically, microcloning 'Hass' scions onto 'Purple' or ‘Evergreen’ clonal rootstocks produced the highest number of leaves, indicating that this combination maximizes leaf production. This result can guide growers on the best clonal rootstock-scion pairings for enhanced early growth and potentially higher yields. On the other hand, combinations like 'Hass' clonal rootstock microcloned with 'Hass' scions and 'Evergreen' clonal rootstock microcloned with 'Evergreen' scions performed poorly, emphasizing the importance of selecting the right pairings. The differences in clonal rootstock–scion compatibility may be linked to biological factors. Successful grafting requires good vascular tissue alignment and callus formation, which support water and nutrient flow. Compatibility also depends on hormonal balance between the scion and clonal rootstock, as well as efficient nutrient and water transport. Finally, genetic relatedness influences whether tissues fuse successfully, which may explain why some combinations grew better than others.

Theoretically, this study shows that microcloning success depends on the genetic compatibility between scion and clonal rootstock varieties. Compatible pairs, such as ‘Hass’ on ‘Purple’, performed better in growth and chlorophyll content. These outcomes suggest that closer genetic affinity supports better vascular alignment, hormone exchange, and nutrient flow, thereby advancing our understanding of how genetics influence graft success. The findings contribute to the development of more precise grafting theories and shed light on the role of genetics in graft success. Previous research [16,17,18] showed that the compatibility of clonal stock and scion varieties significantly impacts plant growth, promoting higher leaf production and overall vigor. This study aligns with these findings, reinforcing the idea that certain combinations, such as microcloning 'Hass' scions onto 'Purple' clonal rootstocks, result in optimal plant performance.

Furthermore, the results emphasize the relationship between clonal rootstock and scion in terms of leaf chlorophyll content, a key indicator of plant health and photosynthetic efficiency. Microcloning 'Purple' clonal rootstock with 'Purple' or 'Hass' scions resulted in significantly higher chlorophyll content, which may contribute to improved growth and yield in avocado cultivation. In contrast, poor performance was noted with combinations like 'Evergreen' scion microcloned onto 'Evergreen' clonal rootstock, stressing the importance of optimizing microclone combinations for better agronomic outcomes. The findings align with studies [19,20,21] which highlighted the importance of chlorophyll content in photosynthetic efficiency and plant growth.

The study also emphasizes the role of graft compatibility in stem growth. For instance, microcloning 'Evergreen' scions onto 'Purple' clonal rootstocks resulted in the longest stem length, which could improve plant development and future yield. In contrast, combinations such as 'Hass' scion microcloned onto 'Hass' clonal rootstock resulted in shorter stems. These results are consistent with other findings [22,23,24], which explored the impact of scion and clonal rootstock combinations on plant growth, particularly stem elongation.

Additionally, the study's results suggest that selecting compatible combinations of clonal rootstock and scion is crucial for optimizing stem diameter. The best growth in terms of stem diameter was observed when 'Purple' clonal rootstock was microcloned with 'Purple' scions, while 'Hass' clonal rootstock microcloned with 'Hass' scions resulted in the smallest stem diameter, which underscores the importance of considering both scion and clonal rootstock variety for optimal plant development. This study's results align with other works [25] that also observed significant interactions between scion and rootstock combinations in avocado.

From a visual quality perspective, the study found that the combination of 'Evergreen' scions microcloned onto 'Evergreen' rootstocks produced leaf color that is potentially enhancing the marketability of the plants. On the contrary, 'Hass' scion microcloned onto 'Hass' clonal rootstock resulted in duller leaf color, suggesting this combination might not be ideal for growers aiming to optimize aesthetic appeal. These results align with previous research [26,27,28,29] which found that scion-clonal rootstock compatibility influences not only plant vigor but also visual attributes like leaf color, contributing to the plant’s commercial value.

The study highlights the importance of selecting the right scion-clonal rootstock combinations for optimal growth, photosynthetic efficiency, and aesthetic quality of avocado. The findings provide actionable insights for avocado growers, suggesting that combinations like 'Hass' scion on 'Purple' clonal rootstock may offer optimum results in terms of growth and leaf production. Conversely, mismatched combinations like 'Hass' scion microcloned onto 'Hass' clonal rootstock may be avoided. These results highlight the critical role of selecting compatible pairings for successful propagation, contributing to SDG 2 (Zero Hunger) through improved productivity and SDG 12 (Responsible Consumption and Production) by supporting more sustainable nursery practices. As this study was limited to 60 days of vegetative growth of avocado microclones, the findings should be considered preliminary. Long-term evaluations of yield, survival, and stress tolerance are necessary before making firm recommendations for growers. Further research into genetic mechanisms underlying graft compatibility could refine grafting techniques and optimize avocado cultivation.

5. Conclusions

The study concludes that the 'Hass' scion microcloned onto 'Purple' clonal rootstock yielded the best results, demonstrating superior chlorophyll content, leaf area, and stem length, making it the optimal combination for promoting growth. The 'Purple' clonal rootstock showed consistent success across various scion varieties, particularly with 'Hass' and 'Purple', while 'Evergreen' scion microcloned onto 'Evergreen' clonal rootstock resulted in poor growth. These findings highlight the importance of selecting compatible scion–clonal rootstock pairings to maximize microcloning success and plant vigor.

In addition to their agronomic significance, these results support the United Nations Sustainable Development Goals, particularly SDG 2 (Zero Hunger) by enhancing avocado productivity and nutritional availability, and SDG 12 (Responsible Consumption and Production) by promoting sustainable nursery practices and efficient propagation systems. Future research focusing on long-term growth, yield, and stress tolerance will further strengthen the role of microclonal techniques in advancing sustainable avocado production. Since this study was limited to 60 days of vegetative growth, it is but proper to continue monitoring long-term growth and disease resistance. Additionally, future research may focus on improving microcloning techniques and exploring genetic compatibility to optimize avocado cultivation.

6. Conflicts of interest

The authors declare no conflict of interest. The supporting entities had no involvement in the study's design, data collection, analysis, or interpretation, nor in the writing of the manuscript or the decision to publish the results.

7. Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work the author(s) used ChatGPT in order to paraphrase ideas, improve grammar, linguistic consistency, clarity, and cohesion of the paper. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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9. Author Contributions

The following are the contributions of the authors: FOEsgrina (lead/corresponding author, conduct of research, data gathering, and writing of results); RJTan, NBBaldo, SMTDargantes, CDAmper, and MMMarin (technical and academic support); MJMAbello (research logistics); MLPedroso and ALCAlagos (statistical design, analyses, and interpretation of data).

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