Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

# Effects of Grafting on the Growth Performance of Grape Scion-Rootstock Combinations

**Seri Kamila**
Nasional University
**Mohamad Ali Fulazzaky**
mohamad.ali.fulazzaky@uika-bogor.ac.id

Universitas Ibn Khaldun Bogor

**Research Article**

**Keywords:** Grape variety, Grafting system, Scion-rootstock combination, Planting material, Tropical climate

**Posted Date:** March 4th, 2026

**DOI:** https://doi.org/10.21203/rs.3.rs-8639323/v1

**License:** This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

**Additional Declarations:** No competing interests reported.

# Abstract

Meeting Indonesia's high demand for grapes necessitates improving local grape cultivation, which offers a profitable opportunity due to multiple harvests per year. However, selecting suitable grape varieties for Indonesia's climate poses a significant challenge. This study examined the impact of scion-rootstock combinations (Jupiter and Transfiguration scions grafted onto Isabella, Kober, and Tleki rootstocks) on growth parameters and grafting success in grapevines. Statistical analysis showed that the scion-rootstock combinations has significantly affect the shoot length, shoot diameter, and grafting success but not significantly affect the emergence time and leaf number. Statistical analysis revealed significant effects of scion-rootstock combinations on shoot length, shoot diameter, and grafting success, but no significant impact on emergence time or leaf number. The Transfiguration-Isabella combination outperformed others, yielding the highest grafting success rate (90%) and superior growth performance. This study's findings can inform grape variety selection for Indonesian cultivation, helping meet the high demand for grapes.


# 1. Introduction

Grapes (*Vitis vinifera L.*) are climbing plants native to the region between the Caspian and Black Seas, from where they spread to Europe, America, and Asia (Grassi and De Lorenzis, 2021). Grape cultivation in Indonesia commenced in the early 19th century, with initial plantings in several locations. Driven by rising demand and a 1982 policy aimed at reducing grape imports, grape cultivation expanded in Indonesia. Key grape-producing regions in Indonesia include East Java and Bali, while NTT and NTB show potential for future grape development (Riaz et al., 2018). Grape productivity differs significantly between tropical and subtropical regions, with the latter achieving yields of up to 20 tons/ha/year, whereas in Indonesia, yields average around 10 tons/ha/year (Khadatkar et al., 2025). In contrast to their native regions where grapes typically produce once a year in spring, tropical regions offer the potential for multiple harvests, with up to three crops per year, presenting a significant opportunity for grape cultivation. By assessing spatial variability and vigor levels, vineyard management can be optimized for enhanced sustainability and production efficiency (Ferro et al., 2023). Domestic grape demand exceeds local production, necessitating imports. According to BPS-Statistics Indonesia, Indonesian grape production declined by 7.39% from 11,763 tons in 2017 to 10,867 tons in 2018, amidst rising demand (Menezes et al., 2024). Successful grape cultivation requires quality planting material, suitable location selection, and optimal maintenance (Mokarram et al., 2023). Several grape varieties have been successfully cultivated in Indonesia, exhibiting desirable traits like drought resistance (Tan et al., 2025), yet further productivity enhancements are needed. Grape productivity can be enhanced through grafting, using suitable rootstock combined with high-quality scion. Grafting combines rootstock and scion, enabling reciprocal interactions between the stems (Migicovsky et al., 2021). High-quality grafted grapevines require both suitable rootstock and scions that produce high yields and good fruit quality, necessitating careful selection and compatibility testing. Grape yield and quality are significantly influenced by rootstock selection, as evidenced by recent studies (Maj et al., 2025; Migicovsky et al., 2019). Several introduced grape varieties, including Jupiter, Ninel, Dixon, and Pestrij, have been widely cultivated in Indonesia

(Pangestuti, R. et al. 2025). Selecting suitable rootstock is a critical strategy for vineyard development, particularly for large-scale commercial ventures, as it influences disease resistance, productivity, and ultimately, fruit quality (Oliveira et al., 2024).

Grape cultivation in Indonesia primarily relies on cuttings, with few farmers skilled in grafting using rootstock. However, research consistently shows that grafted grapevines outperform cuttings in terms of yield quantity and quality (Yin et al., 2025). In Indonesia, several grape varieties developed by the Citrus and Subtropical Fruit Research Institute have been released as superior varieties, boasting fruit quality comparable to imports. However, despite their quality, these varieties, including Probolinggo Biru-81, Bali, and Prabu Bestari, exhibit low productivity, likely due to climate and environmental factors, as well as limitations in seed type and cultivation practices (Schultz, 2016; Wang et al., 2023). High-quality grape seedling production depends on variety selection and production processes (Steiner et al., 2021). Introducing foreign grape varieties, particularly from regions with similar climates like Brazil or India, offers promising development opportunities in Indonesia. Introduced grape varieties have shown promise in Indonesia's climate, producing fruit of decent quality (Guerriero et al., 2024). However, further research is needed to fully assess their suitability and address knowledge gaps. Grafting is an effective vegetative propagation method for producing high-quality grape seedlings. This technique combines cutting and grafting, offering advantages like faster production times, as it utilizes trunk-derived rootstock rather than seeds. Farmers in Indonesia are increasingly familiar with cultivating *Vitis vinifera* and *Labrusca* species, with *Vitis labrusca* showing promise as a rootstock due to its adaptability in the local climate. Successful grapevine grafting relies on scion-rootstock compatibility and quality, as well as optimal growing media conditions, including porosity, aeration, nutrient content, and water-holding capacity (Daler et al., 2025). Further research is needed to explore the performance of introduced grapevine scions grafted onto diverse rootstocks.

This study advances scientific knowledge by exploring grafted grape adaptation, growth, and yield, shedding light on rootstock-scion interactions and the effects of altitude and season on tropical grape cultivation. Specific rootstock-scion combinations are expected to demonstrate optimal compatibility and growth, potentially leading to improved grape development outcomes. This study aims to: (1) evaluate the compatibility and growth suitability of grafted grape combinations using 2 scions and 3 rootstocks, and (2) assess the growth response of Jupiter and Transfiguration grape varieties on different rootstocks. A series of experiments were conducted to investigate the adaptation, growth, compatibility, yield, and fruit quality of introduced grapes subjected to grafting treatments. The findings will inform the development of compatible and adaptable grape cultivars, serving as a foundation for future research.

## 2. Materials and methods

# 2.1. Materials and tools

This experiment utilized 3 grape rootstock varieties (Isabella, Kober, and Tleki) and 2 scion cultivars (Jupiter and Transfiguration) to investigate grafting compatibility and performance. The planting medium comprised compost, rice husk charcoal, soil, sand, NPK fertilizer, and the fungicides Dithane and Amistar Top. Stem grafting was employed as the grafting method (Nisar et al., 2012). Tools included polybags (30 cm × 20 cm), gardening tools, buckets, raffia rope, bamboo, UV plastic, measuring instruments, cameras, and stationery.

## 2.2. Factorial design

The study employed a 2×3 factorial experiment in a completely randomized design (CRD) layout (Woodard, 2023). The 2×3 factorial design consisted of 18 experimental units, each with 3 plants, resulting in a total of 54 plants observed, with 3 replications per treatment combination. The two factors were: (1) scion variety (V): V1 (Jupiter), V2 (Transfiguration) and (2) rootstock variety (B): B1 (Isabella), B2 (Kober), B3 (Tleki). The six treatment combinations were: (1) V1B1 (Jupiter-Isabella), (2) V1B2 (Jupiter-Kober), (3) V1B3 (Jupiter-Tleki), (4) V2B1 (Transfiguration-Isabella), (5) V2B2 (Transfiguration-Kober), and (6) V2B3 (Transfiguration-Tleki).

## 2.3. Planting procedures

The planting medium consisted of a 1:1:1:1 (v/v) mixture of soil, rice husk charcoal, goat manure compost, and sand, thoroughly mixed and placed in polybags under a paranet shade to prevent sunburn (Gianluca et al., 2025). The grafted plants, consisting of connected scion and rootstock stems, were then planted in polybags filled with the prepared planting medium. Plants were randomly arranged in each block and labeled for identification. Maintenance included daily watering with 900 mL of water per polybag, administered using a measuring cup. NPK 15-15-15 fertilizer, containing balanced N-P-K, was applied every 2 weeks at 250 mL/polybag. Disease control involved applying Dithane (6 g/L water) as needed based on infestation severity, and Amistar Top (1 mL/L water) weekly for fungal diseases, adjusted according to severity. Plant maintenance followed the standard operating procedures of local grape farmers (Chibanda et al., 2020). This research was conducted in Serua Village, Bojong Sari District, Depok City, West Java, from January 2024 to July 2025.

## 2.4. Observation

Developmental observations of grafted grapevines as shown in Fig. 1 were conducted 7–60 days after planting (DAP), with 3 sample plants per treatment combination. Data from three replicate observations per combination were averaged. The observed parameters included days to sprouting (DAP) from planting to emergence of shoots with fully formed leaves, shoot length (cm) measured from base to tip at the end of the study, shoot diameter (mm) measured at the midpoint using a caliper, number of leaves counted weekly considering only fully opened leaves, and grafting success rate (%) calculated as the percentage of live plants per treatment combination. Plants were evaluated based on root and shoot growth criteria at the end of the study. The grafting success rate was determined using the formula: Grafting success rate (%) = (Number of successful grafts / Total number of grafts) x 100%.

## 2.5. Data analysis

Statistical analysis of emergence time, shoot length, shoot diameter, leaf number, and grafting success was conducted using Microsoft Excel, with triplicate combinations used to calculate average values. Observation data were analyzed using factorial ANOVA with a CRD (Andrade, 2024; Gerami, 2008). Statistical significance was determined using a two-way ANOVA with the CRD method, with $P \leq 0.05$ considered significant (Alibabaei et al., 2021). If a significant interaction between scion and rootstock factors was detected, Duncan's Multiple Range Test (DMRT) was used to identify the best scion-rootstock combination. DMRT is a post-hoc statistical test used to identify specific significant differences between group means following a significant one-way ANOVA (Agbangba et al., 2024). If no significant interaction was found, DMRT was applied to compare the main effects of each factor. The relationship between variables was examined using Pearson's correlation analysis (Miot, 2018). Data analysis was performed using the Statistical Package for Social Science (SPSS) version 22 and OriginPro (IBM Corp., Armonk, NY).

# 3. Results and discussion

## 3.1. ANOVA results

Grafting Jupiter and Transfiguration scions onto Isabella, Kober, and Tleki rootstocks enhances grape cultivation in Indonesia, with significant growth performance improvements observed in V1B1, V1B2, V1B3, V2B1, V2B2, and V2B3 graft combinations. ANOVA was used to compare the means of five dependent variables - emergence time, shoot length, shoot diameter, leaf number, and grafting success - to determine significant differences, as per Djenar et al. (2024. Table 1 presents between-subjects effects analysis for five dependent variables (emergence time, shoot length, shoot diameter, leaf number, and grafting success) across six graft combinations (V1B1 to V2B3), based on observations from 7 to 60 days. This analysis statistically explores differences between means of dependent variables (emergence time, shoot length, shoot diameter, leaf number, and grafting success) while controlling the family-wise error rate. These five dependent variables evaluated two aspects: (1) individual effects of scions and rootstocks, and (2) combined effects of grafting Jupiter and Transfiguration scions onto Isabella, Kober, and Tleki rootstocks. The F-value indicates whether the means of two (or more) variables differ significantly, evaluating the impact of different parameter inputs on multivariate data. The P-value evaluates the probability of obtaining results at least as extreme as the observed data, assuming the null hypothesis is true, thereby assessing the potential of scion-rootstock combinations in the new grape grafting system. ANOVA results, based on F-values and P-values (indicated in Table 1), confirm significant effects of parameter inputs on grape grafting outcomes. For significant impact on grape cultivation, parameter inputs that have an impact on the growth performance of scion-rootstock combinations into the grape cultivation should have the P-value of less than 0.05.

Table 1
Tests of between-subjects effects

| Source | Type III Sum of Squares | df | Mean square | F | Significance |
|---|---|---|---|---|---|
| Dependent Variable: shoot emergence | | | | | |
| Corrected Model | 17,778[r] | 5 | 3.556 | 2.462 | 0.093 |
| Scion | 3.556 | 1 | 3.556 | 2.462 | 0.143 |
| Rootstocks | 8.444 | 2 | 4.222 | 2.923 | 0.092 |
| Scion-Rootstocks | 5.778 | 2 | 2.889 | 2.000 | 0.178 |
| Error | 17.333 | 12 | 1.444 | | |
| Corrected Total | 35.111 | 17 | | | |
| Remarks that “r” represents *R* squared = 0.506 (Adjusted *R* squared = 0.301) | | | | | |
| Dependent Variable: shoot length | | | | | |
| Corrected Model | 85,778[r] | 5 | 17.156 | 5.719 | 0.006 |
| Scion | 18.000 | 1 | 18.000 | 6.000 | 0.031 |
| Rootstocks | 41.444 | 2 | 20.722 | 6.907 | 0.010 |
| Scion-Rootstocks | 26.333 | 2 | 13.167 | 4.389 | 0.037 |
| Error | 36.000 | 12 | 3.000 | | |
| Corrected Total | 121.778 | 17 | | | |
| Remarks that “r” represents *R* squared = 0.704 (Adjusted *R* squared = 0.581) | | | | | |
| Dependent Variable: shoot diameter | | | | | |
| Corrected Model | 1,325[r] | 5 | .265 | 6.913 | 0.003 |
| Scion | .534 | 1 | .534 | 13.928 | 0.003 |
| Rootstocks | .253 | 2 | .127 | 3.304 | 0.072 |
| Scion-Rootstocks | .538 | 2 | .269 | 7.014 | 0.010 |
| Error | .460 | 12 | .038 | | |
| Corrected Total | 1.785 | 17 | | | |
| Remarks that “r” represents *R* squared = 0.742 (Adjusted *R* squared = 0.635) | | | | | |
| Dependent Variable: leaf number | | | | | |
| Corrected Model | 65,111[r] | 5 | 13.022 | 5.581 | 0.007 |

| Source | Type III Sum of Squares | df | Mean square | F | Significance |
|---|---|---|---|---|---|
| Scion | 43.556 | 1 | 43.556 | 18.667 | 0.001 |
| Rootstocks | 6.778 | 2 | 3.389 | 1.452 | 0.272 |
| Scion-Rootstocks | 14.778 | 2 | 7.389 | 3.167 | 0.079 |
| Error | 28.000 | 12 | 2.333 | | |
| Corrected Total | 93.111 | 17 | | | |
| Remarks that "r" represents *R* squared = 0.699 (Adjusted *R* squared = 0.574) | | | | | |
| Dependent Variable: grafting success | | | | | |
| Corrected Model | 5133,333[r] | 5 | 1026.667 | 19.978 | 0.000 |
| Scion | 3755.556 | 1 | 3755.556 | 73.081 | 0.000 |
| Rootstocks | 508.333 | 2 | 254.167 | 4.946 | 0.027 |
| Scion-Rootstocks | 869.444 | 2 | 434.722 | 8.459 | 0.005 |
| Error | 616.667 | 12 | 51.389 | | |
| Corrected Total | 5750.000 | 17 | | | |
| Remarks that "r" represents *R* squared = 0.893 (Adjusted *R* squared = 0.848) | | | | | |

The ANOVA results in Table 1 revealed significant effects of Jupiter and Transfiguration scions grafted onto Isabella, Kober, and Tleki rootstocks on shoot length, shoot diameter, and grafting success, with P-values of 0.037, 0.010, and 0.005, respectively, all below the 0.05 threshold. However, the effects of Jupiter and Transfiguration scions grafted onto Isabella, Kober, and Tleki rootstocks on emergence time and leaf number were not significant (P > 0.05), with P-values of 0.178 and 0.079, respectively (see Table 1), indicating no substantial influence on grape grafting growth performance.

# 3.2. Performance of scion-rootstock combinations

This study evaluated the performance of scion-rootstock combinations in grape cultivation, focusing on key parameters such as shoot emergence time, shoot length, shoot diameter, leaf number, and grafting success, to inform effective grape production practices in Indonesia.

# 3.1. Shoot emergence

The time to shoot emergence for grafted grape plants is presented in Table 2. Letters ('a', 'b', 'c', 'p', 'q') following the mean values represent DMRT results. According to the DMRT test, same letters (e.g., 'a', 'b') indicate no significant difference. Since both scions (Jupiter and Transfiguration, marked 'p') and rootstocks (Isabella, Kober, Tleki, marked 'a') share the same letter within their respective groups, shoot emergence time is not significantly influenced by scion or rootstock type. According to Table 2, neither

scion nor rootstock alone significantly affected grape shoot emergence time. Shoot emergence times averaged 10.67 ± 1.32 d for Jupiter and 9.78 ± 1.48 d for Transfiguration, with no significant difference (P = 0.178). Shoot emergence times averaged 9.33 ± 1.63 d for Isabella, 11.00 ± 1.41 d for Kober, and 10.33 ± 0.82 d for Tleki rootstocks. Although Isabella rootstock tended to accelerate shoot emergence and Kober was slower, the differences between rootstocks were not statistically significant, as indicated by the same letter ‘a’ in column means. All scion-rootstock combinations promoted relatively uniform bud emergence, indicating that scion or rootstock selection did not significantly impact budbreak acceleration in grafted grapes. Shoot emergence timing is linked to physiological factors like hormones and nutrient reserves, which promote root and shoot growth, suggesting the importance of healthy, well-developed planting material for rootstock and scion (Feng et al., 2024). The compatibility between Isabella (*Vitis labrusca*) rootstock and Transfiguration grape scion (*Vitis vinifera*) likely facilitated faster shoot emergence (8.67 ± 2.08 d; see Table. 2), indicating quicker callus formation and subsequent shoot growth. A well-formed callus bridge enhances scion-rootstock compatibility, facilitating efficient nutrient and water translocation to support scion growth (Rasool et al. 2020). According to Pina and Errea (2009), scion-rootstock incompatibility can manifest weeks after grafting, characterized by poor vascular connections and phloem degeneration at the graft junction. Disrupted vascular fusion can impede water, nutrient, and assimilate transport, leading to further damage and compromising plant growth (Yang et al., 2025). The effect of scion-rootstock combinations on days to shoot emergence is illustrated in Fig. 2. Figure 2 presents the average shoot emergence times for Jupiter and Transfiguration scions grafted onto Isabella, Kober, and Teleki rootstocks, highlighting the effect of scion-rootstock combinations. Notably, Transfiguration scion on Isabella rootstock showed effective performance with shorter days to sprouting.

Table 2
Effects of scion and rootstock varieties on growth parameters and grafting performance of grapevines

| Scion variety | Unit | Rootstock variety | | | Average |
|---|---|---|---|---|---|
| | | Isabella | Kober | Tleki | |
| Shoot emergence | | | | | |
| Jupiter | d | 10.00 ± 1.00 | 12.00 ± 1.00 | 10.00 ± 1.00 | 10.67 ± 1.32$^{(p)}$ |
| Transfiguration | d | 8.67 ± 2.08 | 10.00 ± 1.00 | 10.67 ± 0.58 | 9.78 ± 1.48$^{(p)}$ |
| Average | d | 9.33 ± 1.63$^{(a)}$ | 11.00 ± 1.41$^{(a)}$ | 10.33 ± 0.82$^{(a)}$ | P = 0.178 |
| Length of grape shoots | | | | | |
| Jupiter | cm | 8.33 ± 1.53$^{(b)}$ | 7.00 ± 1.00$^{(b)}$ | 8.33 ± 1.53$^{(b)}$ | 7.89 ± 1.36 |
| Transfiguration | cm | 13.67 ± 3.21$^{(a)}$ | 8.00 ± 1.00$^{(b)}$ | 8.00 ± 1.00$^{(b)}$ | 9.89 ± 3.33 |
| Average | cm | 11.00 ± 3.69 | 7.50 ± 1.05 | 8.17 ± 1.17 | P = 0.037 |
| Diameter of grape shoots | | | | | |
| Jupiter | mm | 1.20 ± 0.10$^{(b)}$ | 1.33 ± 0.15$^{(b)}$ | 1.30 ± 0.20$^{(b)}$ | 1.28 ± 0.15 |
| Transfiguration | mm | 2.03 ± 0.21$^{(a)}$ | 1.43 ± 0.21$^{(b)}$ | 1.40 ± 0.26$^{(b)}$ | 1.62 ± 0.37 |
| Average | mm | 1.62 ± 0.48 | 1.38 ± 0.17 | 1.35 ± 0.22 | P = 0.010 |
| Number of grape leaves | | | | | |
| Jupiter | - | 7.67 ± 1.15 | 9.00 ± 2.00 | 8.00 ± 1.00 | 8.22 ± 1.39$^{(q)}$ |
| Transfiguration | - | 13.33 ± 2.08 | 10.67 ± 1.53 | 10.00 ± 1.00 | 11.33 ± 2.06$^{(p)}$ |
| Average | - | 10.50 ± 3.45$^{(a)}$ | 9.83 ± 1.83$^{(a)}$ | 9.00 ± 1.41$^{(a)}$ | P = 0.079 |
| Success of grape grafting | | | | | |
| Jupiter | % | 41.67 ± 7.64$^{(c)}$ | 43.33 ± 7.64$^{(c)}$ | 46.67 ± 5.77$^{(c)}$ | 43.89 ± 6.51 |
| Transfiguration | % | 90.00 ± 10.00$^{(a)}$ | 65.00 ± 5.00$^{(b)}$ | 63.33 ± 5.77$^{(b)}$ | 72.78 ± 14.39 |
| Average | % | 65.83 ± 27.64 | 54.17 ± 13.2 | 55.00 ± 10.49 | P = 0.005 |

Remarked that the numbers displayed are the mean ± standard deviation, the mean number followed by a different letter indicates a significant difference based on the DMRT at a 95% confidence level.

# 3.2. Length of grape shoots

Grape shoot length following grafting with various rootstocks is presented in Table 2. Different letters ('a', 'b') denote significant differences in shoot length. The Transfiguration-Isabella combination (marked with 'a') produced significantly longer shoots, while other combinations (marked with 'b') had shorter shoots with no significant differences among them. The results (Table 2) reveal a significant scion-rootstock interaction effect on grafted grape shoot length (Nicolosi et al., 2020). Transfiguration scions grafted onto Isabella rootstock produced the longest shoots (13.67 ± 3.21 cm), significantly outperforming other combinations, while Jupiter scions yielded shorter, more uniform shoots (7.00–8.33 cm) across all rootstocks. Isabella rootstock promoted longer shoots, particularly with Transfiguration scions, whereas Kober and Tleki rootstocks did not (see Fig. 3). This indicates that optimal shoot growth depends on the specific scion-rootstock combination (Carvalho et al., 2021), with Transfiguration-Isabella being the most effective. With a P value of 0.037, the differences in shoot length among grafting combinations are statistically significant at the 95% confidence level (He et al., 2025). This study highlights the genetic influence of rootstock on scion growth, provided compatibility is achieved (Shivran et al., 2022). Previous research by Karabulut and Çelik (2022) supports this, identifying promising rootstock varieties in Indonesia, such as Alphonso Lavalle (*Vitis vinifera*), Isabella (*Vitis labrusca*), and Red Master (*Vitis riparia*). Grape shoot length after grafting with different rootstocks is illustrated in Fig. 3. Figure 3 shows that Jupiter scion grafted onto Isabella and Tleki rootstocks had slightly longer average shoot lengths (8.33 cm) than Kober rootstock (7.00 cm). In contrast, Transfiguration scion on Isabella rootstock had a significantly longer average shoot length (13.67 cm) compared to Kober and Tleki rootstocks (8.00 cm). Notably, the Transfiguration scion on Isabella rootstock exhibited superior performance with significantly longer grape shoots.

# 3.3. Diameter of grape shoots

Grape shoot diameter following grafting with various rootstocks is presented in Table 2. Letter 'a' indicates the Transfiguration-Isabella combination had significantly larger shoot diameters, while letter 'b' denotes other combinations with smaller, statistically similar diameters, highlighting a significant interaction effect between Transfiguration scion and Isabella rootstock. Experimental evidence (Table 2) shows a significant scion-rootstock interaction effect on grafted grape shoot diameter (Nicolosi et al., 2020). Transfiguration scions on Isabella rootstock had the largest shoot diameters (2.03 ± 0.21 mm), significantly surpassing other combinations, while Jupiter scions produced smaller diameters (1.20–1.33 mm) with less variation across rootstocks (see Table 2). Isabella rootstock promoted larger shoot diameters, especially with Transfiguration scions, whereas Kober and Tleki rootstocks had less impact. This suggests that shoot diameter is determined by the specific scion-rootstock interaction rather than individual components (Warschefsky et al., 2016). A P-value of 0.010 indicates that the differences in shoot diameter among grafting combinations are statistically significant at the 95% confidence level. Earlier callus formation likely facilitated compatibility between Transfiguration scions and Isabella rootstocks, contributing to enhanced growth (Warschefsky et al., 2016). Compatibility between scion and rootstock facilitates nutrient and water translocation, supporting metabolic processes in grape plants (Chitarra et al., 2017). Shoot diameters for grafted grapevines with different rootstocks are shown in

Fig. 4. Kober rootstocks, with their large-diameter pith, facilitate the implantation of ultra-high frequency transponders in grapevines (Luvisi et al., 2012). Figure 4 reveals contrasting trends: Jupiter scion had narrower average shoot diameters on Isabella (1.20 mm) compared to Kober (1.33 mm) and Tleki (1.30 mm) rootstocks, whereas Transfiguration scion on Isabella rootstock had significantly larger diameters (2.03 mm) than on Kober (1.43 mm) and Tleki (1.40 mm) rootstocks. Transfiguration on Isabella rootstock excelled with significantly larger shoot diameters.

# 3.4. Number of grape leaves

Number of leaves on grapevines grafted with different rootstocks is presented in Table 2. Letters ‘p’ and ‘q’ denote significant differences in leaf number between scions, with Transfiguration producing more leaves than Jupiter. The rootstocks (Isabella, Kober, Tleki) showed no significant difference (same letter ‘a’), indicating scion type is the dominant factor influencing leaf number. Table 2 shows that neither scion nor rootstock significantly influenced the number of leaves in grafted grape plants. Transfiguration scions averaged more leaves (11.33 ± 2.06) than Jupiter scions (8.22 ± 1.39), but the difference was not statistically significant (P = 0.079). Rootstock comparison showed similar leaf numbers: Isabella (10.50 ± 3.45), Kober (9.83 ± 1.83), and Tleki (9.00 ± 1.41), with no significant differences (same letter notation). The tested scion and rootstock varieties showed uniform effects on leaf growth, with neither significantly influencing the number of leaves in grafted grape plants. Previous research by Somkuwar et al. (2015) highlights the role of rootstock in supporting scion vegetative growth. Buesa et al. (2023) found that *Vitis riparia* rootstocks enhanced vegetative growth and yield in *Vitis vinifera* scions by promoting shoot growth, leaf number, and leaf area. Number of leaves on grapevines grafted with different rootstocks is illustrated in Fig. 5. Figure 5 reveals that Jupiter scion had fewer leaves on Isabella (7.67 ± 1.15) compared to Tleki (8.00 ± 1.00) and Kober (9.00 ± 2.00) rootstocks. In contrast, Transfiguration scion had more leaves on Isabella (13.33 ± 2.08) than on Kober (10.67 ± 1.53) and Tleki (10.00 ± 1.00) rootstocks. Transfiguration scion on Isabella rootstock exhibited strong performance with a higher number of grape leaves, although the difference was not statistically significant.

# 3.5. Success of grape grafting

Grafting success rates for grapevines with different rootstocks are presented in Table 2. Letters ‘a’, ‘b’, and ‘c’ denote significant differences in grafting success. Transfiguration-Isabella (marked with ‘a’) showed the highest success rate, followed by Transfiguration-Kober and Transfiguration-Tleki (marked with ‘b’), while Jupiter combinations (marked with ‘c’) had the lowest success rates, indicating scion type strongly influences grafting success, with rootstock playing a secondary role. The results (Table 2) reveal a significant scion-rootstock interaction effect on the success rate of grape grafting (Tedesco et al., 2021). Transfiguration scions grafted onto Isabella rootstocks (V2B1) achieved the highest success rate (90.00 ± 10.00%), significantly outperforming other combinations. Transfiguration scions on Kober (V2B2) and Tleki (V2B3) rootstocks had lower grafting success rates of 63.33% and 65.00%, respectively. In contrast, Jupiter scions had the lowest success rates, ranging from 41.67% to 46.67%, across all rootstocks. Isabella rootstock significantly enhances grafting success with Transfiguration scions,

outperforming Kober and Tleki rootstocks. With a P-value of 0.005, the grafting success rates differ significantly between combinations (Yuan et al., 2016), highlighting the importance of scion-rootstock selection. Scion-rootstock selection plays a crucial role in determining grape grafting success. Krishankumar et al. (2025) showed *Vitis riparia* rootstocks outperformed *Vitis vinifera* in grafting success, highlighting the impact of genetic and environmental factors on grafting outcomes. Grafting success rates for grapevines with different rootstocks are illustrated in Fig. 6. Figure 6 reveals that Jupiter scions had lower grafting success rates on Isabella (41.67%), Kober (43.33%), and Tleki (46.67%) rootstocks. In contrast, Transfiguration scions on Isabella rootstocks achieved a significantly higher grafting success rate of 90.00%, outperforming Kober (65.00%) and Tleki (63.33%) rootstocks. This study indicates that Transfiguration scions grafted onto Isabella, Kober, and Tleki rootstocks outperform Jupiter scions, demonstrating promising potential for grape cultivation in Indonesia. Transfiguration scions on Isabella rootstocks showed exceptional performance with a notably higher grafting success rate. The role of grafting technique in mitigating abiotic stresses and enhancing yield and quality of grape production could aid farmers in improving grape cultivation quality under stress conditions (Bahadur et al., 2024).

Grafting success shows a strong positive correlation with shoot growth variables (see Fig. 7). Grafting success strongly correlates with shoot diameter (r = 0.77), number of leaves (r = 0.82), and shoot length (r = 0.66), suggesting that enhanced shoot growth and leaf development boost grafting success (Suresh and Muneer, 2025). Time of shoot emergence negatively correlates with grafting success (r = -0.49), suggesting earlier emergence supports better grafting outcomes. Shoot growth variables like shoot length and diameter (r = 0.79) and shoot diameter and leaf number (r = 0.64) show strong positive correlations, reinforcing the importance of optimal vegetative growth for grafting success. Enhancing shoot growth and leaf number can be a key strategy for improving grafting success. These findings enhance understanding of growth parameters and grafting success in valuable grapevine hybrids, contributing to improved grape cultivation programs (Filimon et al., 2019). *In vitro* micropropagation is an excellent choice for the long-term conservation of grape germplasm, allowing access to actively growing plant materials without seasonal restrictions (Celebi-Toprak and Kayhan, 2012). This study recommends the V2B1 scion-rootstock combination for grape cultivation in Indonesia, potentially meeting the growing demand for grapes.

# 4. Conclusions

This study revealed significant effects of scion-rootstock combinations on shoot length (P = 0.037), shoot diameter (P = 0.010), and grafting success (P = 0.005), but not on emergence time (P = 0.178) or leaf number (P = 0.079), as the latter two exceeded the 0.05 significance threshold. Although not statistically significant, the Transfiguration-Isabella combination showed a trend toward accelerated shoot emergence (8.67 ± 2.08 d) and increased leaf number (13.33 ± 2.08). The Transfiguration-Isabella combination exhibited notable shoot length (13.67 cm) and shoot diameter (2.03 cm), highlighting the significant impact of grafting on grape cultivation outcomes. The Transfiguration-Isabella combination achieved a 90% grafting success rate, correlated with increased shoot length and diameter. Grafting

success in Transfiguration-Isabella (V2B1) combinations, influenced by accelerated shoot emergence, increased shoot length, shoot diameter, and leaf number, indicates strong compatibility due to enhanced shoot growth. This study's findings can aid farmers in selecting suitable grape seedlings, potentially boosting grape production in Indonesia.

# Declarations


### Acknowledgment

This research was funded by Universitas Nasional's Competitive Research Grant Scheme (Grant No. 331, 2024) and supported by Universitas Ibn Khaldun Bogor through research facilities.


### Data availability statement

The data that support the findings of this study are available from the corresponding author, [MA], upon reasonable request.

# References


1. Agbangba, C. E., Aide, E. S., Honfo, H., Kakai, R. G. (2024). On the use of post-hoc tests in environmental and biological sciences: A critical review. Heliyon, 10, e25131. https://doi.org/10.1016/j.heliyon.2024.e25131
2. Alibabaei, F., Saebnoori, E., Fulazzaky, M. A., Talaeikhozani, A., Roohi, P., Moghadas, F., Abdullah, N. H., & Alian, T. (2021). An evaluation of the efficiency of odorant removal by sodium ferrate (VI) oxidation. Measurement, 179, 109488. https://doi.org/10.1016/j.measurement.2021.109488
3. Andrade, C. (2024). Understanding factorial designs, main effects, and interaction effects: Simply explained with a worked example. Indian Journal of Psychological Medicine, 46, 175–177. https://doi.org/10.1177/02537176241237066
4. Bahadur, A., Singh, P. M., Rai, N., Singh, A. K., Singh, A. K., Karkute, S. G., & Behera, T. K. (2024). Grafting in vegetables to improve abiotic stress tolerance, yield and quality. The Journal of Horticultural Science and Biotechnology, 99, 385–403. https://doi.org/10.1080/14620316.2023.2299009
5. Buesa, I., Torres, N., Tortosa, I., Marín, D., Villa-Llop, A., Douthe, C., Santesteban, L. G., Medrano, H., & Escalona, J. M. (2023). Conventional and newly bred rootstock effects on the ecophysiological response of *Vitis vinifera* L. cv. Tempranillo. Agricultural Water Management. 289, 108560. https://doi.org/10.1016/j.agwat.2023.108560
6. Carvalho, E. V., Cifuentes-Arenas, J. C., Raiol-Junior, L. L., Stuchi, E. S., Girardi, E. A., & Lopes, S. A. (2021). Modeling seasonal flushing and shoot growth on different citrus scion-rootstock combinations. Scientia Horticulturae, 288, 110358. https://doi.org/10.1016/j.scienta.2021.110358

7. Celebi-Toprak, F., & Kayhan, F. (2012). *In vitro* propagation and preservation of important grape cultivars (*Vitis vinifera* L.) and rootstocks. Journal of Biotechnology, 161, 46
8. Chibanda, C., Agethen, K., Deblitz, C., Zimmer, Y., Almadani, M. I., Garming, H., Rohlmann, C., Schütte, J., Thobe, P., Verhaagh, M., Behrendt, L., Staub, D. T., & Lasner, T. (2020). The typical farm approach and its application by the agri benchmark network. Agriculture, 10, 646. https://doi.org/10.3390/agriculture10120646
9. Chitarra, W., Perrone, I., Avanzato, C. G., Minio, A., Boccacci, P., Santini, D., Gilardi, G., Siciliano, I., Gullino, M. L., Delledonne, M., Mannini, F., & Gambino, G. (2017). Grapevine grafting: Scion transcript profiling and defense-related metabolites induced by rootstocks. Frontiers in Plant Science, 8:654. https://doi.org/10.3389/fpls.2017.00654
10. Daler, S., Kılıç, T., Hatterman-Valenti, H., & Kaya, O. (2025). Graft compatibility of local grapevine varieties with grapevine rootstocks in Yozgat Province. Horticulturae, 11, 803. https://doi.org/10.3390/horticulturae11070803
11. Djenar, N. S., Fulazzaky, M. A., Rinaldi, K., Santoso, B., Sulaeman, S. A., Mardiah, M., Fan, H., & Yulianthina, S. (2024). Evaluation of a gluten-based edible film incorporated with beetroot extract and ZnO nanoparticles as an active food packaging system. ACS Food Science & Technology, 4, 1511–1526. https://doi.org/10.1021/acsfoodscitech.4c00123
12. Feng, M., Augstein, F., Kareem, A., & Melnyk, C. W. (2024). Plant grafting: Molecular mechanisms and applications. Molecular Plant, 17, 75–91. https://doi.org/10.1016/j.molp.2023.12.006
13. Ferro, M. V., Catania, P., Miccichè, D., Pisciotta, A., Vallone, M., & Orlando, S. (2023). Assessment of vineyard vigour and yield spatio-temporal variability based on UAV high resolution multispectral images. Biosystems Engineering, 231, 36–56. https://doi.org/10.1016/j.biosystemseng.2023.06.001
14. Filimon, R. V., Filimon, R. M., Patraş, A., & Rotaru, L. (2019). Grape quality and ornamental potential of interspecific cultivars for temperate climate vineyards. The Journal of Horticultural Science and Biotechnology, 95, 65–75. https://doi.org/10.1080/14620316.2019.1631127
15. Gerami, A. (2008). Incomplete factorial experiments in completely randomized and randomized complete block designs. Statistics & Probability Letters. 78, 2058–2065. https://doi.org/10.1016/j.spl.2008.01.075
16. Gianluca, A., Filippetti, I., Pastore, C., Sangiorgio, D., Valentini, G., Bortolotti, G., Kertész, I., Nguyen, L. L. P., & Baranyai, L. (2025). Prediction of berry sunburn damage with machine learning: Results on grapevine (*Vitis vinifera* L.). Biosystems Engineering, 250, 62–67. https://doi.org/10.1016/j.biosystemseng.2024.12.006
17. Grassi, F., & De Lorenzis, G. (2021). Back to the origins: Background and perspectives of grapevine domestication. International Journal of Molecular Sciences, 22, 4518. https://doi.org/10.3390/ijms22094518
18. Guerriero, V., Scorzini, A. R., Di Lena, B., Di Bacco, M., & Tallini, M. (2024). Climate fluctuations and growing sensitivity of grape production in Abruzzo (Central Italy) over the past sixty years.

Geographies, 4, 769–780. https://doi.org/10.3390/geographies4040042

19. He, Z., Zhang, Y., Xun, C., Zhang, Z., Ma, Y., Wei, X., Wan, Z., & Wang, R. (2025). Analysis of the differences among *Camellia oleifera* grafting combinations in its healing process. Plants, 14, 2432. https://doi.org/10.3390/plants14152432
20. Karabulut, B., & Çelik, H. (2022). Determination of grafting success and carbohydrate distributions of Foxy grape (*Vitis labrusca* L.) varieties grafted on different American grape rootstocks. Horticulturae, 8, 949. https://doi.org/10.3390/horticulturae8100949
21. Khadatkar, A., Sawant, C. P., Thorat, D., Gupta, A., Jadhav, S., Gawande, D., & Magar, A. P. (2025). A comprehensive review on grapes (*Vitis* spp.) cultivation and its crop management. Discover Agriculture, 3, 9. https://doi.org/10.1007/s44279-025-00162-2
22. Krishankumar, S., Hunter, J. J., Alyafei, M., Souka, U., Subramaniam, S., Ramlal, A., Kurup, S. S., & Amiri, K. M. A. (2025). Influence of different scion-rootstock combinations on sugars, polyamines, antioxidants and malondialdehyde in grafted grapevines under arid conditions. Frontiers in Plant Science, 16:1559095. https://doi.org/10.3389/fpls.2025.1559095
23. Luvisi, A., Panattoni, A., Bandinelli, R., Rinaldelli, E., Pagano, M., & Triolo, E. (2012). Ultra-High Frequency transponders in grapevine: A tool for traceability of plants and treatments in viticulture. Biosystems Engineering, 113, 129–139. https://doi.org/10.1016/j.biosystemseng.2012.06.015
24. Maj, G., Klimek, K., Kapłan, M., Syrotyuk, S., Korobka, S., Syrotyuk, H., Dybek,B., & Wałowski, G. (2025). Use of rootstock as a tool for leaves management in wine production for regent grape. Fuel, 398, 135504. https://doi.org/10.1016/j.fuel.2025.135504
25. Menezes, I. C., Santos, M., Bugalho, L., & Pereira, M. G. (2024). The effects of tree shade on vineyard microclimate and grape production: A novel approach to sun radiation modelling as a response to climate change. Land, 13, 1970. https://doi.org/10.3390/land13111970
26. Migicovsky, Z., Cousins, P., Jordan, L. M., Myles, S., Striegler, R. K., Verdegaal, P., & Chitwood, D. H. (2021). Grapevine rootstocks affect growth-related scion phenotypes. Plant Direct, 5, e00324. https://doi.org/10.1002/pld3.324
27. Miot, H. A. (2018) Correlation analysis in clinical and experimental studies. Jornal Vascular Brasileiro, 17, 275–279. https://doi.org/10.1590/1677-5449.174118
28. Mokarram, M., Pourghasemi, H. R., & Pham, T. M. (2023). Identification of suitable location to cultivate grape based on disease infestation using multi-criteria decision-making (MCDM) and remote sensing. Ecological Informatics, 76, 102142. https://doi.org/10.1016/j.ecoinf.2023.102142
29. Nicolosi, E., Lakso, A. N., Allegra, M., Gentile, A., Distefano, G., & Ferlito, F. (2020). Scion-rootstock interactions influence the growth and behaviour of the grapevine root system in a heavy clay soil. Australian Journal of Grape and Wine Research, 26, 68–78. https://doi.org/10.1111/ajgw.12415
30. Nisar, N., Verma, S., & Pogson, B. J. (2012). Inflorescence stem grafting made easy in Arabidopsis. Plant Methods, 8, 50. https://doi.org/10.1186/1746-4811-8-50
31. Oliveira, C. R. S. d., Mendonca Junior, A. F. d., & Leão, P. C. d. S. (2024). Rootstock effects on fruit yield and quality of 'BRS Tainá' seedless table grape in semi-arid tropical conditions. Plants, 13,

2314. https://doi.org/10.3390/plants13162314

32. Pangestuti, R., Rahmadi, P., Siahaan, E.A., Nisa, K., Poeloengasih, C.D., Kurnianto, D., & Lideman, (2025). “Sea grape”-based traditional foods in Indonesia: a glimpse into the tropical coastal culinary heritage. Journal of Ethnic Foods, 12, 20. https://doi.org/10.1186/s42779-025-00281-7
33. Pina, A., & Errea P. (2005). A review of new advances in mechanism of graft compatibility - incompatibility. Scientia Horticulturae, 106, 1–11. https://doi.org/10.1016/j.scienta.2005.04.003
34. Rasool, A., Mansoor, S., Bhat, K. M., Hassan, G. I., Baba, T. R., Alyemeni, M. N., Alsahli, A. A., El-Serehy, H. A., Paray, B. A., & Ahmad, P. (2020). Mechanisms underlying graft union formation and rootstock scion interaction in horticultural plants. Frontiers in Plant Science, 11, 590847. https://doi.org/10.3389/fpls.2020.590847
35. Riaz, S., De Lorenzis, G., Velasco, D., Koehmstedt, A., Maghradze, D., Bobokashvili, Z., Musayev, M., Zdunic, G., Laucou, V., Walker, M.A., Failla, O., Preece, O. J., Aradhya, M., & Arroyo-Garcia, R. (2018). Genetic diversity analysis of cultivated and wild grapevine (*Vitis vinifera* L.) accessions around the Mediterranean basin and Central Asia. BMC Plant Biology, 18, 137. https://doi.org/10.1186/s12870-018-1351-0
36. Schultz, H. R. (2016). Global climate change, sustainability, and some challenges for grape and wine production. Journal of Wine Economics, 11, 181–200. https://doi.org/10.1017/jwe.2015.31
37. Shivran, M., Sharma, N., Dubey, A. K., Singh, S. K., Sharma, N., Sharma, R. M., Singh, N., & Singh, R. (2022). Scion-rootstock relationship: Molecular mechanism and quality fruit production. Agriculture, 12, 2036. https://doi.org/10.3390/agriculture12122036
38. Somkuwar, R. G., Taware, P. B., Bhange, M. A., Sharma, J., & Khan, I. (2015). Influence of different rootstocks on growth, photosynthesis, biochemical composition, and nutrient contents in ‘fantasy seedless’ grapes. International Journal of Fruit Science, 15, 251–266. https://doi.org/10.1080/15538362.2015.1031564
39. Steiner, M., Grace, J. B., Bacher, S. (2021). Biodiversity effects on grape quality depend on variety and management intensity. Journal of Applied Ecology, 58, 1442–1454. https://doi.org/10.1111/1365-2664.13899
40. Suresh, P., & Muneer, S. (2025). Light spectrum mediated improved graft-healing response by enhanced expression of transport protein in vegetables under drought conditions. Plant Physiology and Biochemistry, 225, 109780. https://doi.org/10.1016/j.plaphy.2025.109780
41. Tan, H., Zhang, M., Xie, Q., Shen, T., Xu, M., Fang, Y., & Ju, Y. (2025). Effects of regulated deficit irrigation at different times on organic acids, phenolics and antioxidant capacity of Cabernet Sauvignon grapes. Scientia Horticulturae, 345, 114143. https://doi.org/10.1016/j.scienta.2025.114143
42. Tedesco, S., Erban, A., Gupta, S., Kopka, J., Fevereiro, P., Kragler, F., & Pina, A. (2021). The Impact of Metabolic Scion-Rootstock Interactions in Different Grapevine Tissues and Phloem Exudates. Metabolites, 11, 349. https://doi.org/10.3390/metabo11060349

43. Wang, Y., Li, Y., Sun, T., Milne, E., Yang, Y., Liu, K., Li, J., Yan, P., Zhao, C., Li, S., Duan, B., Li, J., & Wan, X. (2023). Environmental impact of organic and conventional wine grape production, a case study from Wuwei wine region, Gansu Province, China. Ecological Indicators, 154, 110730. https://doi.org/10.1016/j.ecolind.2023.110730
44. Warschefsky, E. J., Klein, L. L., Frank, M. H., Chitwood, D. H., Londo, J. P., von Wettberg, E. J. B., & Allison J. Miller, A. J. (2016). Rootstocks: Diversity, domestication, and impacts on shoot phenotypes. Trends in Plant Science. 21, 418–437. https://doi.org/10.1016/j.tplants.2015.11.008
45. Woodard, V. (2023). Five hands-on experiments for a design of experiments course. Journal of Statistics and Data Science Education, 31, 225–235. https://doi.org/10.1080/26939169.2023.2195889
46. Yang, H., Tan, T., Ren, G., Liu, Y., Liu, Z., Xia, S., Wu, Z., & Zhang, Y. (2025). The dual nature of water hyacinth (*Pontederia crassipes*): Environmental threats and sustainable solutions. Water Biology and Security.4, 100359. https://doi.org/10.1016/j.watbs.2025.100359
47. Yin, Y., Yuan, J., Jia, N., Li, M., Liu, C., Sun, Y., Wang, X., Han, S., Gao, Q., Liu, S., & Han, B. (2025). Grafting 'red globe' (*Vitis vinifera*) onto multiple rootstocks: A systematic, multi-year evaluation focusing on fraft compatibility, vegetative growth, and fruit characteristics. Horticulturae, 11, 1006. https://doi.org/10.3390/horticulturae11091006
48. Yuan, H., Liqiang, Z., Qiusheng, K., Fei, C., Mengliang, N., Junjun, X., Nawaz, M. A., & Zhilong, B. (2016). Comprehensive mineral nutrition analysis of watermelon grafted onto two different rootstocks. Horticultural Plant Journal, 2, 105–113. https://doi.org/10.1016/j.hpj.2016.06.003
49. Zhang, L., Marguerit, E., Rossdeutsch, L., Ollat, N., & Gambetta, G. A. (2016). The influence of grapevine rootstocks on scion growth and drought resistance. Theoretical and Experimental Plant Physiology, 28, 143–157. https://doi.org/10.1007/s40626-016-0070-x

# Figures

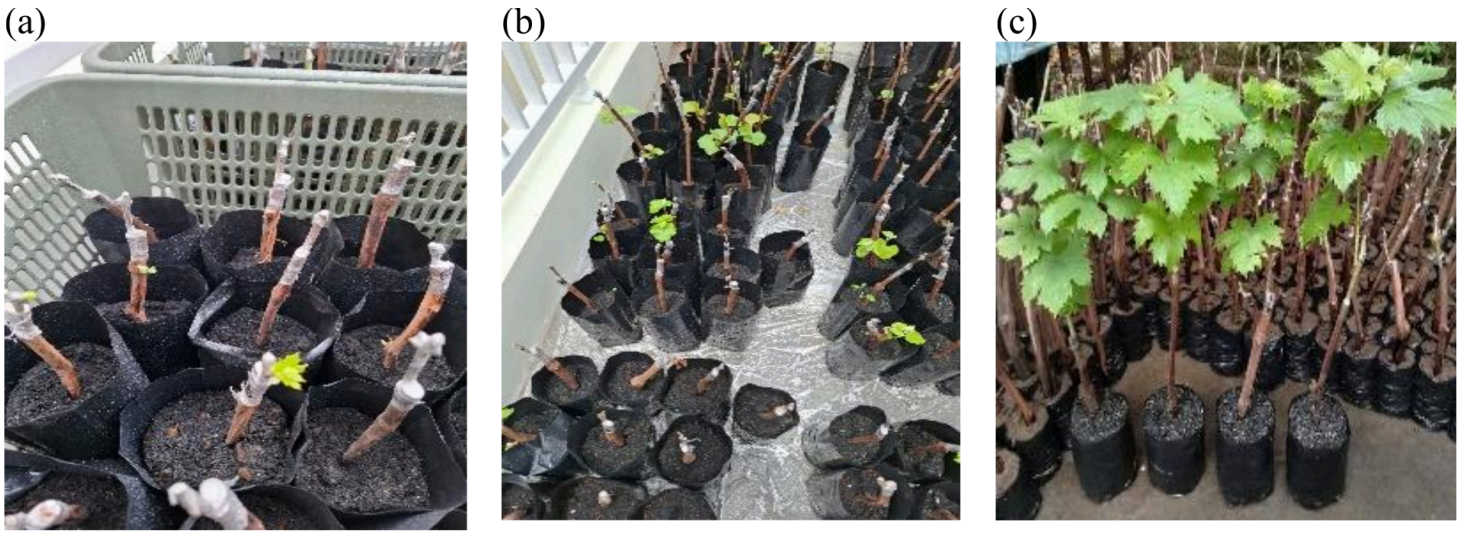



**Figure 1** Development stages of grafted grapevines: (a) initial shoot emergence, (b) shoot growth and alignment, and (c) successful grafting with established seedlings

**Figure 1**

**See image above for figure legend**

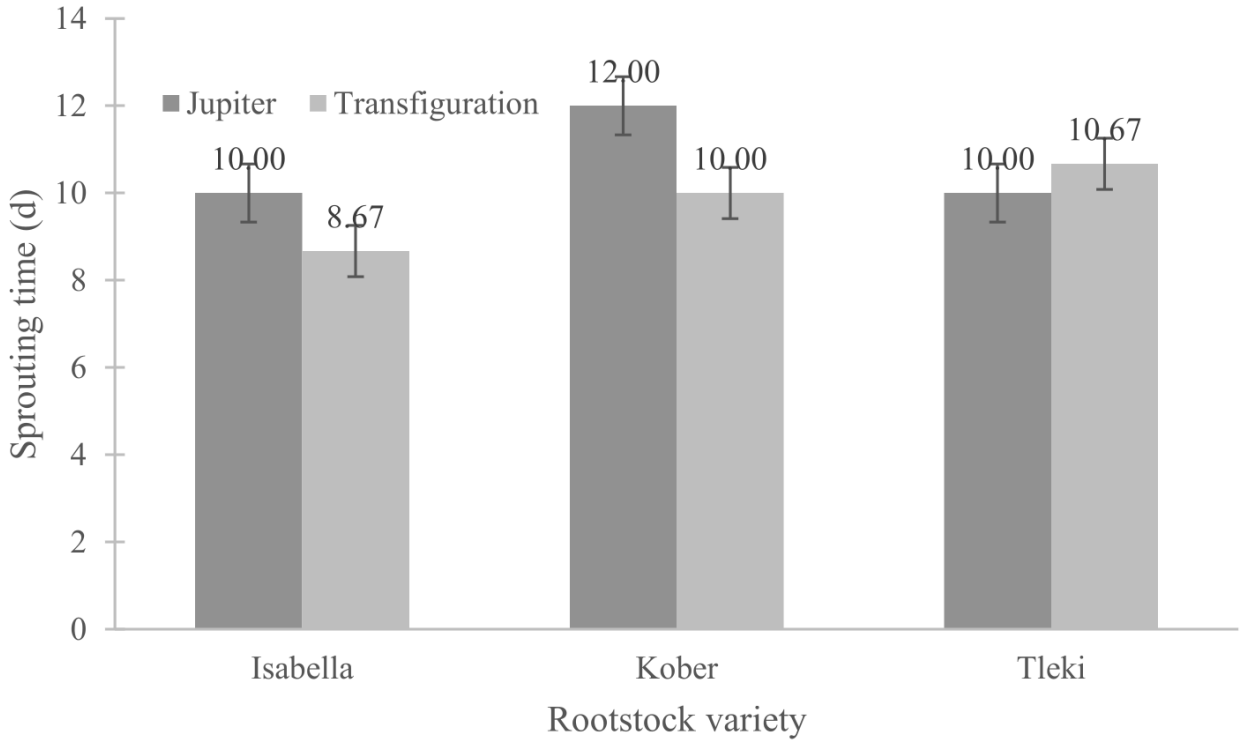



**Figure 2** Shoot emergence time of grafted grapevines with different scion-rootstock combinations

**Figure 2**

See image above for figure legend

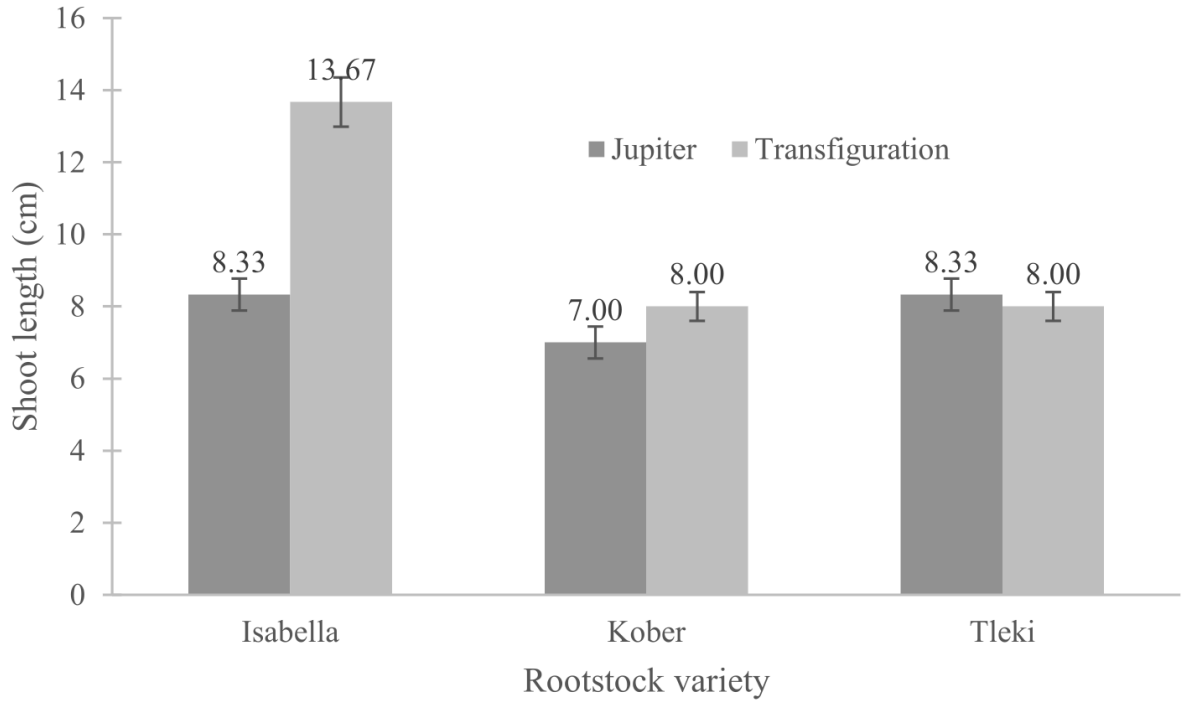



**Figure 3** Shoot length of grafted grapevines with different scion-rootstock combinations

**Figure 3**

See image above for figure legend

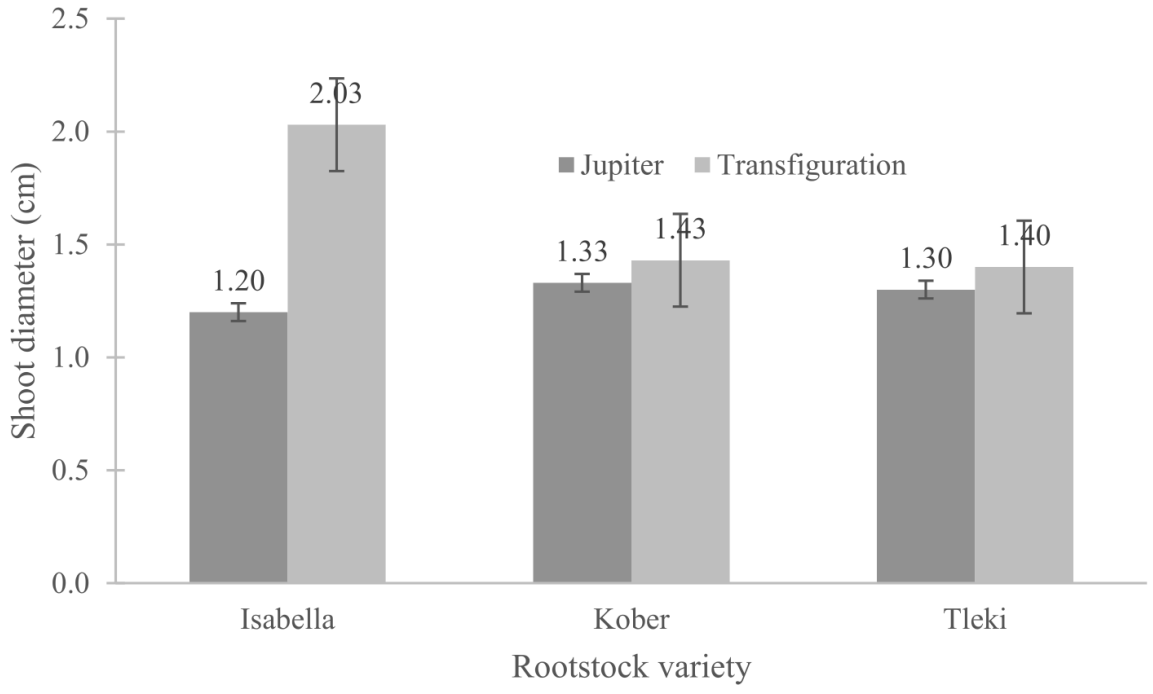



**Figure 4** Shoot diameter of grafted grapevines with different scion-rootstock combinations

**Figure 4**

See image above for figure legend

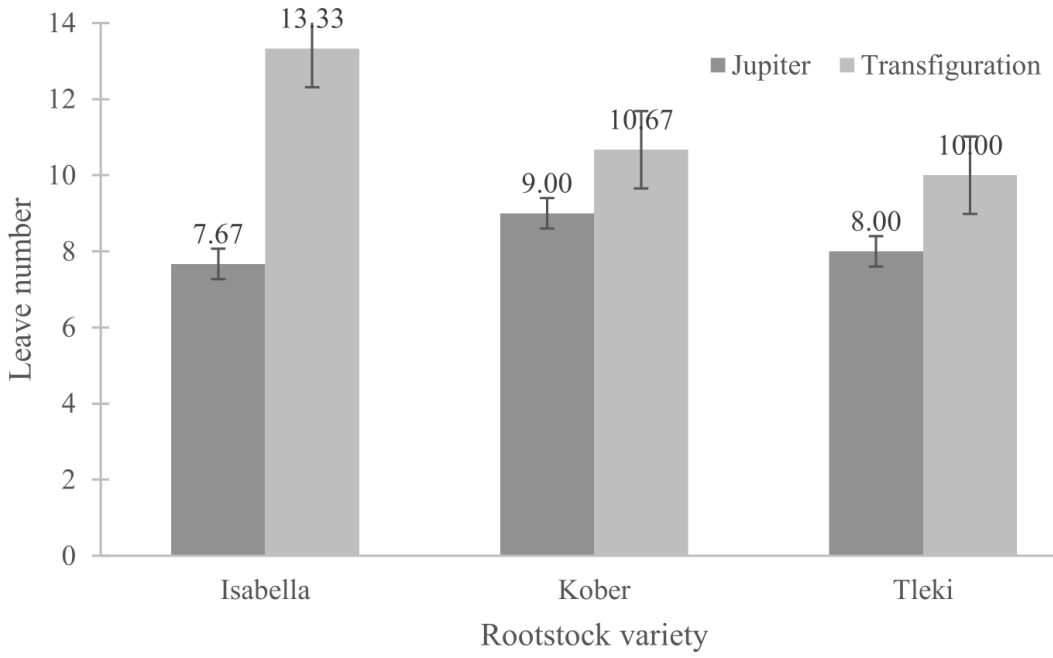



**Figure 5** Shoot leave number of grafted grapevines with different scion-rootstock combinations

**Figure 5**

See image above for figure legend

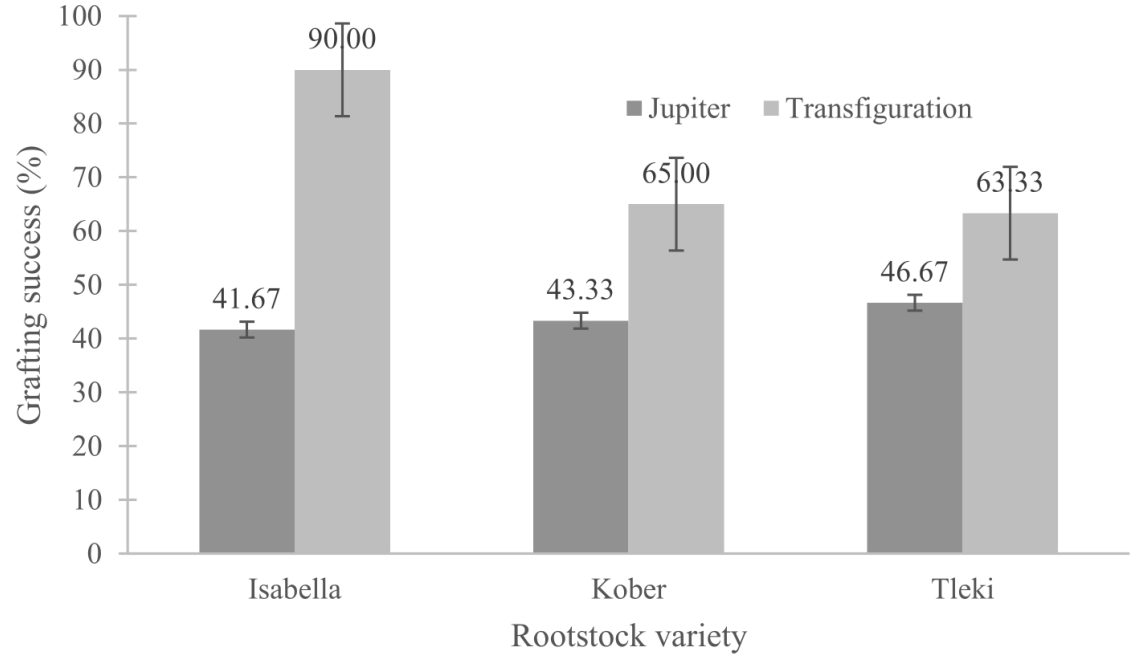



**Figure 6** Grafting success of grafted grapevines with different scion-rootstock combinations

**Figure 6**

See image above for figure legend

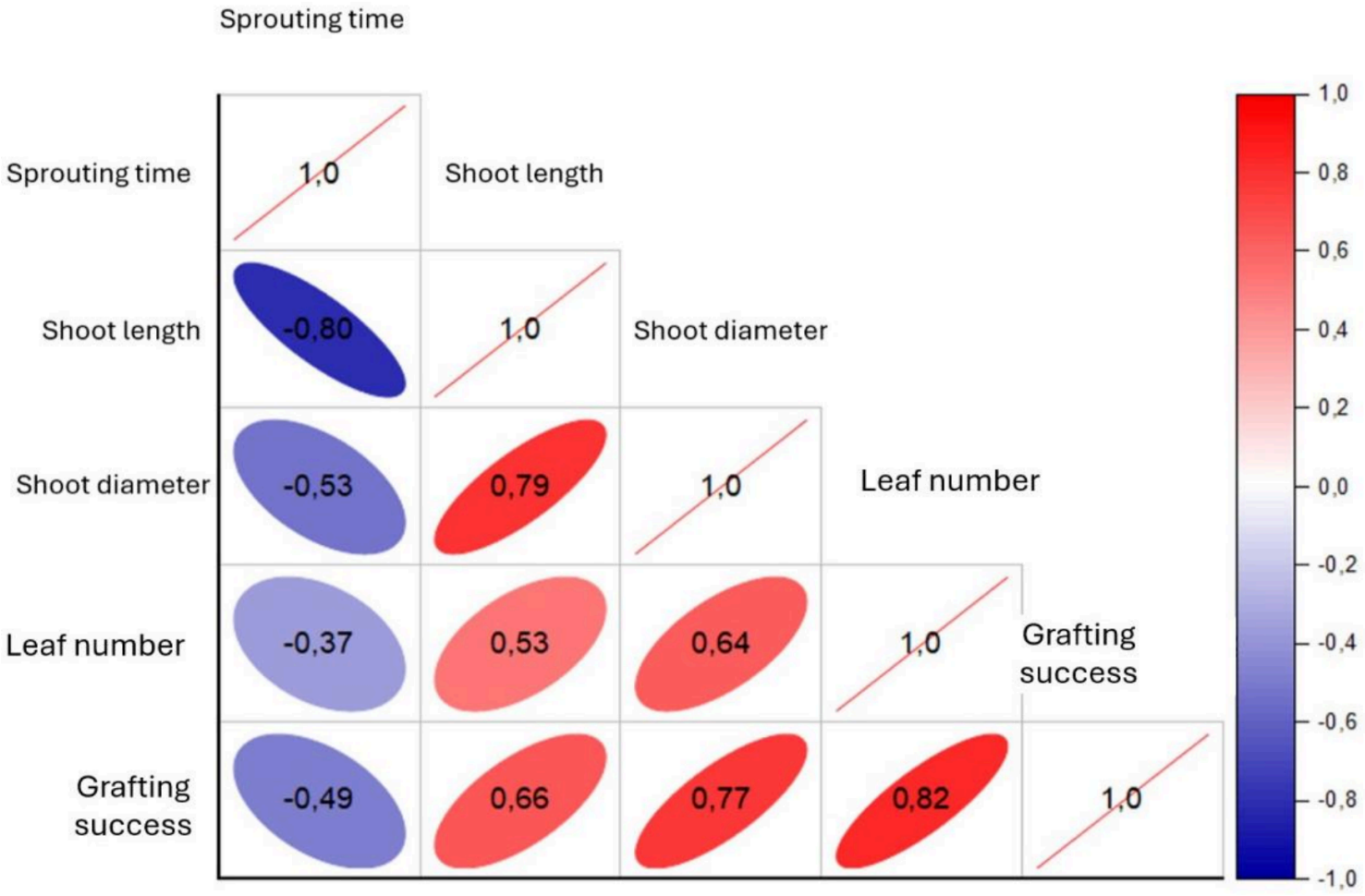



**Figure 7** Correlation between grafting success and shoot growth variables

**Figure 7**

See image above for figure legend