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"Homo- and Heterografting Effects on Compatibility and Growth in Dragon Fruit (*Hylocereus* spp.)"

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Abstract

This two-year study (2024–26) at ANDUAT, Kumarganj, Ayodhya, evaluated homografting and heterografting effects on graft compatibility and vegetative growth of Dragon fruit (*Hylocereus* spp.) under subtropical nursery conditions. Six combinations—HeteroRS, HeteroRH, HomoR, HeteroWS, HeteroWH, and HomoW—involving red- and white-fleshed scions grafted onto *Acanthocereus tetragonus, Cereus jamacaru*, and homologous rootstocks were assessed up to 90 days after grafting (DAG). Results showed HeteroRS and HeteroWS exhibited the fastest bud swelling (35.27 and 36.17 days) and highest graft success rates (89.17% and 87.33%), demonstrating strong compatibility with A. tetragonus. In contrast, HeteroRH and HeteroWH took nearly 60 days for bud swelling, reflecting slower vascular union with C. jamacaru, while homografts fell in between. By 90 DAG, HeteroRS and HeteroWS recorded the tallest shoots (190.80 and 188.60 cm), whereas HeteroRH and HeteroWH produced the greatest graft girth (up to 65.28 mm). Homografts consistently underperformed in shoot height and girth despite genetic similarity between scion and rootstock. Correlation analysis revealed bud-swelling duration was strongly negatively associated with graft success ($r = -0.93^{**}$) and positively linked to lateral shoot number ($r = 0.91^{*}$). PCA identified two components explaining 99.48% of variance, and cluster analysis grouped treatments by rootstock identity. Overall, heterografting outperformed homografting, with HeteroRS/HeteroWS ideal for rapid establishment and HeteroRH/HeteroWH better suited for structural vigor offering practical guidance for commercial dragon fruit propagation.

1. INTRODUCTION

Dragon fruit (*Hylocereus* spp.), widely known as pitaya or pitahaya, is a climbing perennial cactus of the Cactaceae family that has drawn considerable global interest owing to its economic potential, nutritional richness, antioxidant content, medicinal properties, and ability to thrive in marginal environments (Angonese *et al.,* 2021). The crop traces its origins to the tropical and subtropical zones of Central and South America, with *Hylocereus undatus*, *H. monacanthus*, and *H. megalanthus* representing the major cultivated species. In their natural forest habitats, these plants depend on tree canopies for structural support and protection from excessive heat and sunlight (Ortiz-Hernández and Carrillo-Salazar, 2012; Chen *et al.,* 2022). Dragon fruit's rising popularity worldwide stems from its resilience to poor soil and climatic conditions, efficient water use enabled by Crassulacean Acid Metabolism (CAM) photosynthesis, and growing market demand for both fresh consumption and processed products (Mizrahi, 2014). In India, the crop has demonstrated strong adaptability to semi-arid regions, positioning it as a valuable option for sustainable farming (Arivalagan *et al.,* 2019; Wakchaure *et al.,* 2020). Nevertheless, cultivation faces challenges from elevated temperatures and intense solar exposure, which can cause stem injury, reduced photosynthetic efficiency, and stunted development, particularly during the nursery and field establishment stages (Mizrahi, 2014). Addressing these constraints calls for suitable agronomic interventions to strengthen plant establishment and stress resilience.

Grafting stands out among propagation methods as an economical and efficient technique that merges beneficial scion characteristics with rootstocks offering enhanced water and nutrient uptake, greater stress tolerance, and improved vegetative vigor (Pina and Errea, 2005; Rouphael *et al.,* 2010; Rouphael *et al.,* 2018). Across numerous horticultural crops, this technique has proven effective in boosting resistance to drought, salinity, sodicity, and heat stress by improving underlying physiological and biochemical processes (Hartmann *et al.,* 2014; Albacete *et al.,* 2015; López-Serrano *et al.,* 2019; Borchetia *et al.,* 2020), largely through rootstock-driven regulation of hydraulic conductance, hormonal signaling, osmotic balance, and photosynthetic function (Albacete *et al.,* 2015).

Despite these benefits, grafting research in Cactaceae remains limited, with applications in dragon fruit largely restricted to ornamental purposes and overcoming poor substrate or soil-borne disease issues (Mizrahi, 2014). While rootstock identity and genetic relatedness are known to strongly influence graft compatibility and scion performance, scientific understanding of homografting versus heterografting using *Acanthocereus tetragonus* and *Cereus jamacaru* as rootstocks remains scarce (Albacete *et al.,* 2015). To address this gap, the present study examined how homo- and heterografting influence graft compatibility, vegetative growth, and physiological responses in dragon fruit under subtropical nursery conditions, comparing red- and white-fleshed *Hylocereus* scions grafted onto *Acanthocereus tetragonus, Cereus jamacaru*, and homologous rootstocks.

2. Materials and Methods:

2.1 Experimental site and plant material

The present investigation was conducted during two consecutive years 2024–25 and 2025–26 at the Main Experiment Station of Horticulture, Acharya Narendra Deva University of Agriculture and Technology (ANDUAT), Kumarganj, Ayodhya, Uttar Pradesh, India. The experiment comprised six grafting treatment combinations representing homo- and heterografting configurations. The study used six grafting combinations: HeteroRS (red-fleshed *H. monacanthus* scion on *Acanthocereus tetragonus*), HeteroRH (red-fleshed scion on *Cereus jamacaru*), HomoR (red-fleshed scion on its own rootstock), HeteroWS (white-fleshed *H. undatus* scion on *A. tetragonus*), HeteroWH (white-fleshed scion on *C. jamacaru*), and HomoW (white-fleshed scion on its own rootstock).

2.2 Grafting Methodology

Grafting employed the classical wedge/cleft technique adapted for *Hylocereus* (de Oliveira *et al.,* 2021). Grafted plants were potted in 8×6 inch polybags containing cocopeat, sand, and soil (1:1:2) and maintained under greenhouse conditions at ANDUAT's Main Experiment Station, Horticulture. Uniform irrigation, fertilization, and plant protection were provided; rooted plants were later transplanted near support poles.

2.3 Observations Recorded

Graft compatibility and establishment were assessed through four parameters: days to bud swelling (NDDW), measured from grafting to first visible scion bud swelling as an indicator of union formation speed; graft success percentage, calculated from successful grafts showing active growth and turgid unions; graft collar diameter (GC), measured with a digital vernier caliper to indicate vascular continuity; and lateral shoot number per plant (NLSP). Vegetative growth was evaluated via shoot height (HS30, HS60, HS90), recorded from union point to apex at 30, 60, and 90 DAG, and graft girth growth (GG30, GG60, GG90), measuring shoot circumference above the union zone at corresponding intervals to track secondary growth and vascular development.

2.4 Statistical Analysis

Data were analyzed via ANOVA, with treatment means compared using LSD test ($p \leq 0.05$); different lowercase letters denote significant differences, NS indicates non-significance. Pearson's correlation coefficients were computed at $p \leq 0.05$, 0.01, and 0.001, visualized as a color-coded ellipse heatmap. PCA was performed separately on standardized growth/graft compatibility and physiological/biochemical traits, with component retention based on scree plots and biplots displaying treatment scores and loadings. Hierarchical cluster analysis (Euclidean distance, Ward's linkage) grouped combinations by phenotypic similarity via dendrograms and heatmaps, all analyses conducted in RStudio.

3.0 Results and Discussion

3.1 Graft Compatibility and Establishment Traits

3.1.1 Number of Days Required for Bud Swelling (NDDW) and Graft Success Percentage

Significant differences emerged among grafting combinations for days required for bud swelling (NDDW). HeteroRS and HeteroWS recorded the shortest periods (35.27 and 36.17 days), indicating rapid physiological compatibility and early vascular continuity between *Hylocereus* scions and *Acanthocereus tetragonus, Cereus jamacaru* rootstocks. Conversely, HeteroRH and HeteroWH required the longest duration (60.17 and 59.63 days), suggesting extended anatomical union formation when genetically distinct *Hylocereus* species serve as rootstock and scion. HomoR and HomoW showed intermediate values (53.83 and 54.47 days).

The delayed bud swelling in HeteroRH and HeteroWH may stem from differences in cambial alignment and biochemical signaling at the interspecific union zone, consistent with Mekako and Nakasone (1975), who linked graft compatibility between divergent *Hylocereus* and *Acanthocereus tetragonus, Cereus jamacaru* species to scion establishment timing and vascular continuity. Similarly, Nerd *et al.* (1993) noted that interspecific grafts among divergent cactus partners prolong initial union formation.

Graft success percentage was not significantly different (NS) among treatments (range: 74.00% in HeteroWH to 89.17% in HeteroRS) (Table 1). High success in HeteroRS and HeteroWS aligns with Nerd and Mizrahi (1997), who attributed the effectiveness of *Acanthocereus tetragonus, Cereus jamacaru* rootstocks to their vigorous root systems and adaptable vascular architecture, while non-significance likely reflects inherent compatibility within tribe *Hylocereus*.

3.1.2 Graft Collar / Girth (GC) and Number of Lateral Shoots Per Plant (NLSP)

Neither GC nor NLSP differed significantly among the six treatments (NS) (Table 1). GC ranged from 25.85 mm (HomoR) to 39.43 mm (HeteroRH), while NLSP ranged from 4.83 (HeteroRS) to 5.40 (HeteroRH). The absence of significant treatment effects on these morphological parameters indicates that early-stage lateral shoot development and graft collar formation are primarily governed by the scion genotype rather than rootstock–scion interaction. Similar observations were reported in *Hylocereus undatus* by Ortiz-Hernández and Carrillo-Salazar (2012), who noted that lateral shoot development at early growth stages is less responsive to rootstock influence.

3.2 Vegetative Growth Parameters

3.2.1 Shoot Height (HS) at 30, 60, and 90 Days After Grafting

Shoot height showed no significant differences at 30 and 60 DAG, indicating uniform early elongation across treatments. By 90 DAG, however, significant differences appeared (LSD = 21.63): HeteroRS and HeteroWS recorded the greatest heights (190.80 and 188.60 cm), HomoR and HomoW the lowest (144.23 and 143.67 cm), with HeteroRH and HeteroWH intermediate (168.73 and 168.63 cm). This suggests a progressive growth-stimulating effect from *Acanthocereus tetragonus, Cereus jamacaru* rootstocks, consistent with Lim (2012), who linked vigorous rootstocks to enhanced nutrient/water uptake and hormone translocation. The widening divergence over time highlights the importance of extended evaluation periods for detecting rootstock effects.

3.2.2 Graft Girth Growth (GG) at 30, 60, and 90 Days After Grafting

Graft girth showed highly significant differences among combinations across all three measurement intervals (LSD: 7.90, 8.26, and 9.37 at 30, 60, and 90 DAG) in (Table 1). HeteroRH and HeteroWH consistently recorded the highest values (GG30: 58.96 and 57.45 mm; GG60: 62.57 and 61.76 mm; GG90: 65.28 and 64.71 mm), while HomoR and HomoW showed the lowest (GG30: 34.16 and 33.37 mm; GG90: 39.43 and 39.08 mm), with HeteroRS and HeteroWS intermediate throughout.

The superior girth in HeteroRH and HeteroWH likely reflects enhanced vascular connectivity and auxin-driven cell proliferation at the graft union, characteristic of vigorous interspecific rootstock–scion interactions (Hartmann *et al.,* 2014). Graft girth serves as a reliable marker of strong compatibility and efficient translocation of water, nutrients, and photoassimilates (Rouphael *et al.,* 2010). These results align with observations in other succulent and climbing cacti, where interspecific grafts on robust rootstocks consistently surpass homografts in secondary growth (Mizrahi *et al.,* 1997).

3.2.3 Correlation, Principal Component, and Cluster Analyses of Graft Compatibility and Growth Traits

The correlation heatmap revealed several key biological associations. NDDW correlated negatively with graft success (r = −0.93**), indicating delayed bud swelling compromises union integrity (Mauseth, 2006), while positive correlations between NDDW and NLSP (r = 0.91*), and between GC and NLSP (r = 0.86*), suggested that greater vascular development promotes lateral shoot vigor (Pina and Errea, 2005). GC correlated very highly with GG30, GG60, and GG90 (r = 0.99***), confirming its value as an early selection criterion, and shoot height traits (HS30–HS90) showed strong internal correlations (r = 0.93–1.00***). Negative correlations between graft success and both GC (r = −0.88*) and NLSP (r = −0.99***) pointed to a trade-off between initial establishment and vegetative vigor (Mudge *et al.,* 2009).

PCA extracted two components explaining 99.478% of total variance (PC1 = 62.971%; PC2 = 36.506%). PC1 represented a structural vigor axis, loaded by GC, GG30–GG90, and NLSP (0.898–0.997), with Success% loading negatively (−0.909); PC2 represented a shoot elongation axis dominated by HS30–HS90 and NDDW (−0.704). The biplot positioned HeteroRH and HeteroWH toward high PC1, HeteroRS and HeteroWS toward high PC2, and homografts toward low PC1, confirming their inferior girth performance (Kubota *et al.,* 2008; Djidonou *et al.,* 2013).

Hierarchical clustering identified three distinct groups: HeteroRH and HeteroWH clustered together with highest graft girth reflecting *Hylocereus* rootstock dominance; HomoR and HomoW formed a low-growth cluster; and HeteroRS and HeteroWS occupied an intermediate cluster with superior shoot height but moderate girth, confirming rootstock identity as the primary determinant of structural performance (Warschefsky *et al.,* 2016).

4. CONCLUSION

This two-year study on dragon fruit grafting at ANDUAT, Kumarganj, Ayodhya, found heterografting clearly superior to homografting. Grafts on *Acanthocereus tetragonus* (HeteroRS, HeteroWS) showed the fastest bud break (35–36 days), highest success rates (87–89%), and greatest shoot height (188–191 cm) by 90 DAG, favoring rapid establishment. Grafts on *Cereus jamacaru* (HeteroRH, HeteroWH) were slower to break bud but produced consistently superior graft girth, favoring structural strength. Homografts underperformed on both counts despite genetic matching, confirming that scion–rootstock identity alone does not ensure compatibility. Correlation analysis showed a trade-off between establishment speed and structural bulking (bud-swelling duration vs. success rate, r = −0.93**; girth traits, r = 0.99***), and PCA/clustering condensed the ten traits into two principal components (99.48% variance) reflecting structural vigor and shoot elongation, respectively. Overall, *A. tetragonus* and *C. jamacaru* emerge as promising rootstocks, to be selected based on whether rapid establishment or structural robustness is the priority.

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Table 1. Performance of Homo- and Heterografting Combinations in Relation to Graft Compatibility and Growth Attributes

Grafting	**NDDW**	**Success %**	**GC**	**NLSP**	**HS30**	**HS60**	**HS90**	**GG30**	**GG60**	**GG90**
HeteroRS	35.27b	89.17	26.43	4.83	38.47	85.83	190.80a	34.85b	41.55b	44.58b
HeteroRH	60.17a	74.17	39.43	5.40	37.40	83.97	168.73b	58.96a	62.57a	65.28a
HomoR	53.83a	82.50	25.85	5.03	31.23	72.00	144.23c	34.16b	36.55b	39.43b
HeteroWS	36.17b	87.33	26.23	4.93	38.23	84.43	188.60ab	33.80b	40.34b	44.18b
HeteroWH	59.63a	74.00	38.20	5.37	37.50	83.27	168.63b	57.45a	61.76a	64.71a
HomoW	54.47a	81.50	25.92	5.17	31.50	71.50	143.67c	33.37b	36.28b	39.08b
LSD(**p≤0.05**)	10.66	NS	NS	NS	NS	NS	21.63	7.90	8.26	9.37

Note: NDDW; No of days required for bud swelling, GC; Girth of color, NLSP; No of lateral shoot per plant, HS; Height of shoot (cm), GG; Graft girth (mm)

Table 2. Correlation Matrix Showing Relationships among Grafting and Growth Traits

	NDDW	Success %	GC	NLSP	HS30	HS60	HS90	GG30	GG60	GG90
NDDW	1	-0.93**	0.66	0.91*	-0.40	-0.39	-0.70	0.67	0.55	0.53
Success %	-0.93**	1	-0.88*	-0.99***	0.05	0.04	0.40	-0.88*	-0.81	-0.79
GC	0.66	-0.88*	1	0.86*	0.42	0.44	0.08	0.99***	0.99***	0.99***
NLSP	0.91*	-0.99***	0.86*	1	-0.04	-0.04	-0.39	0.86*	0.79	0.78
HS30	-0.40	0.05	0.42	-0.04	1	0.99***	0.94**	0.41	0.54	0.56
HS60	-0.39	0.04	0.44	-0.04	1.00***	1	0.93**	0.43	0.55	0.57
HS90	-0.70	0.40	0.08	-0.39	0.94**	0.93**	1	0.07	0.21	0.23
GG30	0.67	-0.88*	0.99***	0.86*	0.41	0.43	0.07	1	0.99***	0.99***
GG60	0.55	-0.81	0.99***	0.79	0.54	0.55	0.21	0.99***	1	0.99***
GG90	0.53	-0.79	0.99***	0.78	0.56	0.57	0.23	0.99***	0.99***	1

Note: NDDW; No of days required for bud swelling, GC; Girth of color, NLSP; No of lateral shoot per plant, HS;Height of shoot (cm), GG; Graft girth (mm)

Note: *** Correlation is significant at 0.001 level (two tailed), ** Correlation is significant at 0.01 level (two tailed), * Correlation is significant at 0.05 level (two tailed)