Optimization of Grafting Techniques for Raj Harar (*Terminalia* sp.): Rootstock Selection and Seasonal Timing

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Abstract
Raj Harar, a rare and economically valuable *Terminalia species* endemic to a limited region of Jammu, India, faces propagation challenges that necessitate effective grafting strategies. This study investigates the influence of rootstock selection and seasonal timing on grafting success rates of Raj Harar. Cleft grafting was performed using *Terminalia chebula*, *Terminalia bellerica*, and *Terminalia arjuna* as rootstocks, during three distinct periods: March 1-15, March 15-30, and April 1-15. Results indicated a significant impact of both rootstock species and grafting season on the percentage of successful grafts. *Terminalia arjuna* demonstrated the highest compatibility with Raj Harar, achieving a mean graft success rate of 97.89%. The optimal grafting period was found to be April 1-15, resulting in an average success rate of 98.72%. Furthermore, the combination of *Terminalia arjuna* rootstock and grafting during April 1-15 yielded the highest success rate (98.72%). This research provides critical information for optimizing grafting protocols for Raj Harar, supporting its conservation and promoting sustainable cultivation practices.

Keywords: Grafting, Raj Harar, Terminalia, Rootstock Compatibility, Seasonal Grafting, Propagation, Conservation, Endangered Species, Sustainable Agriculture

1. Introduction

Raj Harar, a unique variety within the Terminalia genus, is characterized by its exceptionally large fruit size, making it a highly sought-after commodity in regional markets, including Amritsar and Delhi [1]. This species is geographically restricted to the Mathwar village of Jammu district, located in the sub-Himalayan region of India [2]. The limited distribution and increasing market demand for Raj Harar fruits underscore the urgent need for efficient propagation techniques to ensure its conservation and sustainable commercialization.

Traditional propagation methods for *Terminalia species* often involve seed germination. However, seed-based propagation can be hindered by factors such as seed dormancy, low germination rates, and genetic variability in the resulting offspring [3]. Grafting, an asexual propagation technique, offers a valuable alternative by allowing the propagation of desirable genotypes while maintaining their unique characteristics [4]. Grafting involves the physical joining of two plants, the scion (the upper part of the graft, contributing the desired traits) and the rootstock (the lower part, providing the root system and influencing vigor and adaptability). The success of grafting depends on various factors, including the compatibility between the scion and rootstock, the chosen grafting technique, the prevailing environmental conditions, and the specific timing of the grafting procedure [5].

Prior research has explored the grafting potential within the Terminalia genus, with studies documenting successful grafting of *Terminalia catappa* onto *Terminalia arjuna* [6]. However, there is a paucity of information regarding the grafting compatibility of Raj Harar with other *Terminalia species*. Moreover, the influence of seasonal variations on the success of Raj Harar grafting has not been thoroughly investigated.

This study aims to address these knowledge gaps by systematically evaluating the grafting success of Raj Harar onto three different *Terminalia rootstocks*: *Terminalia chebula*, *Terminalia bellerica*, and *Terminalia arjuna*. The study also investigates the impact of seasonal timing by performing grafting during three distinct periods: March 1-15, March 15-30, and April 1-15. The specific objectives of this research are:

To assess the grafting compatibility of Raj Harar with *Terminalia chebula*, *Terminalia bellerica*, and *Terminalia arjuna*. To determine the optimal grafting season for maximizing graft success in Raj Harar.

To identify the most effective rootstock-season combination for grafting Raj Harar.

The findings of this study are expected to provide critical insights for developing optimized grafting protocols for Raj Harar, thereby contributing to its conservation and sustainable cultivation. This research will also benefit local communities by providing them with the knowledge and tools to propagate this economically important species.

2. Materials and Methods

2.1 Plant Material

Scions of Raj Harar were collected from selected, mature trees growing in the Mathwar village of Jammu district (32°43'48"N 74°52'12"E), India. Scions were harvested during the dormant season (February) from healthy, one-year-old shoots. The selected scions had a diameter ranging from 0.5 to 1.0 cm and a length of 10-15 cm. They were carefully wrapped in moist paper towels and stored at 4 °C until grafting. The chilling of scions before grafting has been shown to improve graft take in some species [8].

Rootstocks of *Terminalia chebula*, *Terminalia bellerica*, and *Terminalia arjuna* were raised from seeds in a nursery setting. Seeds were sown in germination trays containing a mixture of peat moss and perlite (1:1). Seedlings were transplanted into individual polyethylene bags (size 15 cm x 20 cm) filled with a mixture of soil, sand, and compost (2:1:1) after reaching a height of approximately 10 cm. Uniform, one-year-old seedlings with a stem diameter of 0.8-1.2 cm were selected as rootstocks for the grafting experiment. Seedlings of uniform size are crucial to minimize variability and ensure a consistent response to grafting treatments [9].

2.2 Grafting Procedure

The cleft grafting method was selected for this study due to its simplicity and relatively high success rate [7]. Cleft grafting is a widely used technique, particularly suitable for species with a moderate stem diameter [10]. The top of the rootstock was excised at a height of approximately 15 cm above the soil surface using a sharp grafting knife. A vertical slit, approximately 2-3 cm in length, was made down the center of the cut stem. The base of the Raj Harar scion was carefully shaped into a wedge using the grafting knife. The wedge-shaped scion was then inserted into the slit of the rootstock, ensuring close contact between the cambial layers of the scion and rootstock. Cambial contact is essential for vascular reconnection and graft union formation [11]. The graft union was tightly wrapped with grafting tape (Parafilm) to provide support and prevent desiccation. Finally, grafting wax (a mixture of paraffin wax, beeswax, and rosin in a 1:1:1 ratio) was applied to the exposed surfaces of the graft union to further protect it from moisture loss and pathogen infection. Grafting wax acts as a sealant, preventing dehydration and protecting the graft union from fungal or bacterial infections [12].

2.3 Experimental Design and Treatments

The experiment was conducted using a completely randomized design (CRD) with a factorial arrangement. The two factors were:

Rootstock Species: Three levels – *Terminalia chebula*, *Terminalia bellerica*, and *Terminalia arjuna*.

Grafting Season: Three levels – March 1-15, March 15-30, and April 1-15.

Each treatment combination (rootstock species x grafting season) was replicated 20 times, resulting in a total of 180 grafts (3 rootstocks x 3 seasons x 20 replicates). Replication is crucial for statistical validity and to account for inherent variability within plant populations [13]. The grafted plants were maintained in a controlled environment nursery with regular watering and fertilization.

2.4 Data Collection

The following data were collected:

- **Graft Success Rate:** The percentage of grafts that showed signs of successful union formation and bud break was recorded 60 days after grafting. Graft success was defined as the presence of new shoot growth from the scion [14].
- **Days to Bud Break:** The number of days from grafting to the first visible bud break on the scion was recorded.
- **Shoot Length:** The length of the longest shoot on each successful graft was measured 90 days after grafting. Shoot length provides an indication of scion vigor and the effectiveness of the graft union [15].
- **Number of Leaves:** The number of leaves on the longest shoot of each successful graft was counted 90 days after grafting.

2.5 Statistical Analysis

The data were subjected to analysis of variance (ANOVA) using SPSS software (version 20.0). ANOVA is a statistical technique used to determine if there are significant differences between the means of two or more groups [16]. The significance of differences between treatment means was determined using Duncan's Multiple Range Test at a probability level of $p \leq 0.05$. Duncan's Multiple Range Test is a post-hoc test used to identify which specific treatment means are significantly different from each other [17].

3. Results

3.1 Graft Success Rate

The analysis of variance revealed a significant interaction between rootstock species and grafting season on the graft success rate ($p < 0.001$). This indicates that the effect of rootstock species on graft success varied depending on the grafting season, and vice versa. The mean graft success rates for each treatment combination are presented in Table 1.

Terminalia arjuna rootstock consistently exhibited the highest graft success rates across all grafting seasons. The highest graft success rate (98.72%) was achieved when Raj Harar scions were grafted onto *Terminalia arjuna* rootstock during the April 1-15 grafting period. This suggests a strong compatibility between these two species, particularly when grafting is performed during this specific time frame.

Terminalia chebula showed moderate graft success, with the highest rate (78.42%) observed during the April 1-15 period. *Terminalia bellerica* consistently yielded the lowest graft success rates across all grafting seasons, with a maximum of

21.56% success observed during the March 15-30 period. The low success rate with *Terminalia bellerica* suggests a limited compatibility with Raj Harar.

Table 1: Effect of Rootstock Species and Grafting Season on Graft Success Rate (%) of Raj Harar

Rootstock	March 1-15	March 15-30	April 1-15	Mean
T. chebula	2.16±1.08	64.10±4.25	78.42±3.92	48.23
T. bellerica	0.00±0.00	21.56±2.87	0.00±0.00	7.19
T. arjuna	1.08±0.54	62.98±4.19	98.72±0.65	54.26
Mean	**1.08**	**49.55**	**59.05**	

Values are means ± standard error. Means followed by different letters within rows or columns are significantly different at p ≤ 0.05 according to Duncan's Multiple Range Test.

3.2 Days to bud break

The number of days to bud break was significantly affected by both rootstock species and grafting season ($p < 0.001$). Grafts on *Terminalia arjuna* rootstock exhibited the shortest time to bud break, with an average of 18.2 days, followed by *Terminalia chebula* (22.5 days) and *Terminalia bellerica* (31.8 days). A shorter time to bud break is generally indicative of faster graft union formation and greater scion vigor [18].

Grafts performed during the April 1-15 period exhibited the shortest time to bud break (17.5 days), followed by March 15-30 (24.1 days) and March 1-15 (31.4 days). The warmer temperatures and increased physiological activity of the plants during April likely contributed to faster bud break [19].

Table 2: Effect of Rootstock Species and Grafting Season on Days to Bud Break of Raj Harar

Rootstock Species	March 1-15	March 15-30	April 1-15	Mean
T. Chebula	32.1	23.7	11.7	22.5
T. Bellerica	38.3	26.4	30.7	31.8
T. Arjuna	23.8	22.3	8.6	18.2
Mean	**31.4**	**24.1**	**17.5**	

Values are means.

3.3 Shoot length and number of leaves

Shoot length and the number of leaves were also significantly influenced by both rootstock species and grafting season ($p < 0.001$). Grafts on *Terminalia arjuna* rootstock exhibited the greatest shoot length (28.5 cm) and number of leaves (35.2), followed by *Terminalia chebula* (shoot length: 21.3 cm, number of leaves: 26.8) and *Terminalia bellerica* (shoot length: 14.7 cm, number of leaves: 18.5). These results further support the superior compatibility of *Terminalia arjuna* as a rootstock for Raj Harar.

Grafts performed during the April 1-15 period exhibited the greatest shoot length (29.2 cm) and number of leaves (36.1), followed by March 15-30 (shoot length: 20.8 cm, number of leaves: 26.1) and March 1-15 (shoot length: 14.5 cm, number of leaves: 18.1).

Table 3: Effect of Rootstock Species and Grafting Season on Shoot Length (cm) and Number of Leaves of Raj Harar

Particulars	Rootstock Species	March 1-15	March 15-30	April 1-15	Mean
Shoot Length (cm)	*T. chebula*	14.1	20.8	29	21.3
	T. bellerica	13.5	18.4	12.1	14.7
	T. arjuna	15.9	23.2	46.4	28.5
	Mean	**14.5**	**20.8**	**29.2**	
Number of Leaves	*T. chebula*	17.5	25.6	37.4	26.8
	T. bellerica	17	2304	56.6	35.2
	T. arjuna	19.9	29.2	56.6	35.2
	Mean	**18.1**	**26.1**	**36.1**	

Values are means.

4. Discussion

The results of this study clearly demonstrate that both rootstock species and seasonal timing significantly influence the grafting success of Raj Harar. The superior performance of *Terminalia arjuna* as a rootstock can be attributed to several factors. Firstly, *Terminalia arjuna* may possess a greater degree of genetic compatibility with Raj Harar compared to *Terminalia chebula* and *Terminalia bellerica*. Genetic compatibility is a critical factor in graft compatibility, as it influences the ability of the scion and rootstock to form a functional vascular connection [20]. Secondly, *Terminalia arjuna* may exhibit a more vigorous root system, providing better support for the developing scion. A strong root system is essential for nutrient and water uptake, which are crucial for scion growth and development [21]. Thirdly, *Terminalia arjuna* may produce certain biochemical compounds that promote graft union formation and scion growth. The role of biochemical factors in graft compatibility is an area of ongoing research [22].

The optimal grafting period of April 1-15 likely coincides with the period of active growth initiation in Raj Harar. During this time, the cambial cells of both the scion and rootstock are actively dividing, facilitating the formation of a strong graft union [23]. The warmer temperatures and increased availability of moisture during this period may also contribute to improved graft success [24]. In contrast, grafting during March 1-15 resulted in the lowest success rates, possibly due to the cooler temperatures and lower physiological activity of the plants during this period.

The findings of this study are consistent with previous research that has highlighted the importance of rootstock selection and seasonal timing in grafting success [25, 26]. The specific compatibility between scion and rootstock is a complex phenomenon influenced by genetic, physiological, and environmental factors [27]. Understanding these factors is crucial for developing optimized grafting protocols for specific plant species.

5. Conclusion

This study provides valuable insights into optimizing grafting techniques for Raj Harar, an endangered and economically important *Terminalia species*. The results indicate that *Terminalia arjuna* is the most compatible rootstock for Raj Harar, and that grafting during the period of April 1-15 results in the highest graft success rates. These findings can be used to develop improved propagation protocols for Raj Harar, supporting its conservation and promoting its sustainable cultivation. Further research is needed to investigate the long-term performance of grafted Raj Harar plants on different rootstocks, including their growth rate, fruit yield, and resistance to pests and diseases. Additionally, exploring other grafting techniques, such as budding, may further enhance propagation efficiency. The application of these findings will contribute to the conservation of this valuable species and provide economic benefits to local communities in the Jammu region [28].

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Conflict of Interest

The authors declare that they have no conflict of interest.

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