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Comparative evaluation of grafting time and techniques for *Mangifera indica* L. under subtropical conditions of Himachal Pradesh

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ABSTRACT

The success of mango grafting varies with technique and seasonal timing, particularly under the subtropical conditions of Himachal Pradesh. This study evaluated two grafting methods wedge and veneer across six different months (July, August, September, October, February, and March). Observations were recorded on graft success, bud break, leaf emergence, sprout length, plant height, number of leaves, leaf area, graft survival, and saleable plants. The results revealed that veneer grafting in August was significantly superior, exhibiting the highest graft success rate (70.00%), earliest bud break (16.33 days), and leaf emergence (17.62 days). Veneer grafting also outperformed wedge grafting in terms of plant growth and survival parameters. Based on these findings, veneer grafting during August is recommended as the most effective method for mango propagation in subtropical regions of Himachal Pradesh, ensuring optimal success and plant quality.

Key words: Mango, wedge grafting, veneer grafting, propagation, graft success rate, graft survival.

INTRODUCTION

Mango (*Mangifera indica* L.), often referred to as the “king of fruits,” is an integral part of India’s agricultural and economic landscape. It is cherished not only for its rich flavour and nutritional value but also for its significant contribution to the livelihoods of farmers and allied industries. India is the largest producer of mangoes (Thakor 1), with several renowned cultivars like Alphonso, Dashehari, Langra, and Kesar, each recognized for their unique taste and aroma. However, mango cultivation faces several challenges, particularly in regions where climatic variations impact growth, fruit development, and productivity. Himachal Pradesh, known for its diverse agro-climatic zones, offers a unique environment for mango cultivation, particularly in its subtropical region (Rana *et al.,* 2). These regions experience moderate temperatures, distinct seasonal variations, and specific soil conditions, which influence mango tree growth. While these conditions are generally favourable, fluctuations in temperature, humidity, and rainfall often present obstacles to successful cultivation. Mango propagation is a critical aspect of orchard establishment, and the choice of propagation method can significantly impact tree growth, fruit quality, and overall orchard productivity (Antwi-Boasiako *et al.,* 3). Traditional seed propagation in mango leads to considerable genetic variability, resulting in trees that differ in fruit quality, yield, and growth habits. Seed-grown trees tend to be taller, take longer to bear fruit, and are difficult to manage in commercial orchards. In contrast, vegetative propagation techniques, such as grafting, enable the production of true-to-type plants with consistent traits, early fruiting, and improved orchard efficiency. Among the commonly used grafting methods, veneer grafting and cleft grafting are widely practiced, but their success in subtropical regions like Himachal Pradesh remains inconsistent due to variations in environmental conditions and rootstock selection. This study hypothesizes that by optimizing propagation methods, including selecting the most effective grafting techniques and rootstock-scion combinations, mango plant survival, growth, and productivity can be significantly improved in Himachal Pradesh. The research aims to identify the best grafting method that ensures a higher success rate, better plant vigor, and enhanced fruiting potential under local climatic conditions. To achieve this, different grafting techniques will be tested under varying climatic conditions to determine their impact on plant survival, growth rates, and fruit development. Beyond improving propagation practices, this research has broader implications for mango cultivation in Himachal Pradesh and similar agro-climatic regions. The findings will contribute to the development of sustainable mango production systems by promoting standardized propagation techniques that enhance orchard productivity and profitability. By ensuring that propagation methods

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are adapted to local environmental conditions, mango growers can achieve higher success rates in orchard establishment and long-term productivity. Furthermore, climate change poses additional challenges to mango cultivation, making it crucial to develop propagation techniques that can withstand shifting weather patterns. Standardized and climate-resilient propagation practices will not only benefit mango growers in Himachal Pradesh but also provide a model for other regions facing similar challenges. By advancing knowledge on mango propagation and its interaction with climatic conditions, this study aims to support the sustainable growth of the mango industry in India and beyond, ensuring long-term productivity, profitability, and resilience in mango cultivation.

MATERIALS AND METHODS

The study was conducted at the nursery block of the College of Horticulture and Forestry, Neri, Hamirpur (H.P.), during 2020–22, to evaluate the effects of grafting timings on the success of wedge and veneer grafting in mango. Geographically, the experimental block of the fruit nursery is situated at an elevation of 619 m above mean sea level, at 31°41'49.98" N latitude and 72°28'02.21" E longitude. Mango seeds procured from wild mango plants were used to raise seedling rootstocks for grafting. These stones were planted in polybags filled with a growing medium consisting of soil, sand, and farmyard manure (FYM) in equal proportions. The polybags, measuring 22 × 13 × 10 cm, contained 1–1.5 kg of the growing medium, which was disinfected before planting. A single mango stone was sown in each bag, followed by watering using a sprinkler. The bags were then placed in a net house for seedling development.

Veneer and wedge grafting techniques were applied to one-year-old seedlings, using scion shoots selected from the current season's growth of the Dashehari and Langra as mother tree. These scions were defoliated seven days prior to grafting to enhance carbohydrate accumulation and reserve food materials, thereby promoting early bud sprouting. Scions measuring 12–15 cm with 3–4 axillary buds were collected and transported to the grafting site on the day of grafting. The graft unions were wrapped with polythene strips, which were removed after 90 days. Both grafting techniques were performed during the first fortnight of each selected month, namely July, August, September, October, February, and March. The methods for veneer and wedge grafting followed the protocols (Majumdar and Rathod, 4).

The experiment was conducted using completely randomized block design (CRD) with three replications per treatment. Each treatment combination consisted of six grafting months (July, August, September, October, February, and March) and two grafting methods (veneer and wedge). Observations on mango grafts were recorded every other day for bud sprout initiation and first leaf emergence, and at 30, 45, and 60 days after grafting for other parameters. Statistical analysis was conducted using SPSS for student's t-test to determine significant differences ($p < 0.05$) among treatments.

RESULTS AND DISCUSSION

The results clearly show that both the timing and method of grafting had a significant effect on graft success, leaf area, and the percentage of saleable plants. Among the tested months, August proved to be the most suitable, consistently producing the highest graft survival rates (93.73%) and saleable plants (66.67%) for both wedge and veneer grafting methods. These outcomes are in agreement with previous studies (Ullah *et al.,* 5; Karana *et al.,* 6). The favourable environmental conditions in August moderate temperatures, high relative humidity, and adequate rainfall played a key role in supporting successful grafting by promoting callus formation and vascular connection between scion and rootstock (Matsushita 7).

Veneer grafting performed significantly better than wedge grafting under optimal conditions, likely due to its less invasive nature. It involves a shallow cut on the rootstock, causing minimal damage to vascular tissues, which supports quicker callus development and faster healing. This method also exerts less stress on the plant, enabling more efficient allocation of resources to graft union formation (Gupta *et al*., 8; Yadav *et al.*, 9). In contrast, wedge grafting requires a deeper incision, which can disrupt cambial continuity and increase the risk of desiccation and infection, thereby reducing graft success. Interestingly, wedge grafting showed comparatively better performance in March in terms of leaf area and saleable plants. This suggests that during cooler months, when physiological activity is reduced, the deeper wedge cut may help secure a more stable graft union and prevent scion desiccation. Conversely, veneer grafting in February was the least successful, with only 75.37% graft survival and 16.00% saleable plants, likely due to low temperature and humidity impairing callus formation and healing.

The timing of bud break varied notably with both the grafting method and the month of grafting. August consistently resulted in the earliest bud break for both wedge and veneer grafting, as shown in Figure 1. These results are in agreement with

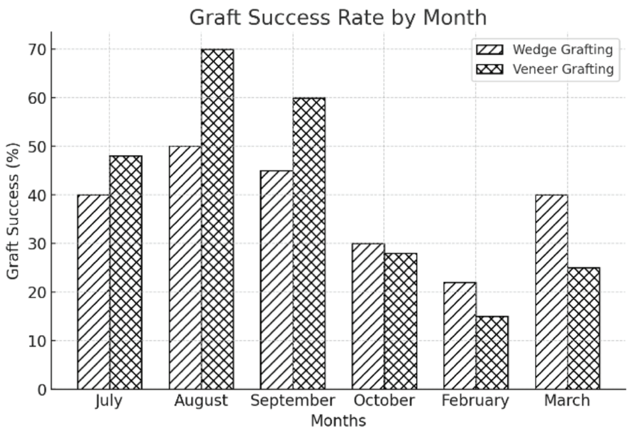

Fig. 1. Effect of grafting time and grafting technique on graft success (%)

earlier studies (Karna *et al*., 6; Kaur *et al.,* 10; Islam *et al.,* 11), who also reported the shortest sprouting time in August-grafted mango plants. This early bud break can be attributed to August's favourable climatic conditions specifically high temperatures and humidity which enhance sap flow and metabolic activity. Increased sap flow supports the translocation of water, nutrients, and plant hormones like auxins, which are vital for cell division and elongation at the graft junction (Matsushita, 7). Additionally, high humidity minimizes desiccation at the graft site and promotes rapid callus formation, which is critical for successful graft union and early bud emergence.

Among the methods, veneer grafting in the first fortnight of August recorded the shortest bud break period (16.33 days), while the longest (30.90 days) was observed in veneer grafting during February. This trend is supported by the findings of that veneer grafting typically leads to faster bud sprouting than more invasive methods like wedge grafting (Singh *et al.,* 12; Kumar *et al.,* 13; Nayak *et al.,* 14). The advantage of veneer grafting lies in the minimal incision it requires, allowing close cambial contact between the scion and rootstock, which facilitates quicker vascular connection and healing. The stable attachment achieved in veneer grafting also reduces the risk of graft misalignment or mechanical stress, thereby promoting a more reliable and faster bud break. In contrast, wedge grafting's deeper incision can delay the alignment of cambial tissues, reduce sap flow, and extend the healing period, ultimately slowing bud emergence (Sebeky, 15; Mag'Omba *et al.,* 16).

On the other hand, veneer grafting in February showed delayed bud sprouting (30.90 days), likely due to lower temperatures and reduced humidity during that period. These conditions slow down metabolic processes and reduce the rate of sap flow in plant tissues, making it harder for the graft union to form quickly. In cooler months, the rate of auxin and cytokinin production important hormones for callus formation and bud break may be lower, leading to a delay in graft union healing and bud sprouting. Thus, the combination of optimal environmental conditions in August, along with the physiological advantages of veneer grafting, likely contributed to the early bud break observed in this period. In contrast, the cold temperatures and low humidity in February resulted in slower graft healing, leading to delayed bud break, particularly in veneer grafted plants.

Figure 2 and Table 2 clearly demonstrate that first leaf emerged earliest in August, with veneer grafted plants taking a minimum of 17.62 days. In contrast, February exhibited the longest duration, with veneer grafted plants taking 36.12 days. These results are consistent with findings in guava, which also indicated that August was the month with the shortest time to first leaf emergence (Gotur *et al.,* 17). The observed trend in this study supports the notion that August's favorable environmental conditions, including higher humidity, promote the early sprouting of leaves. As noted, the shortest duration for both bud break (16.33 days) and first leaf emergence (17.62 days) were observed in veneer grafted plants in August. This is in stark contrast to February, where bud break extended to 30.90 days and leaf emergence took 36.12 days. This pattern is supported by the statistical significance in the data, which highlights the significant differences between these months. The favourable temperature and humidity conditions in August likely enhanced sap flow, promoting faster cambial alignment and early bud sprouting (Karna *et al.,* 6; Chophel *et al.,* 20). Higher humidity helps reduce desiccation of the graft site, which in turn promotes the growth of active

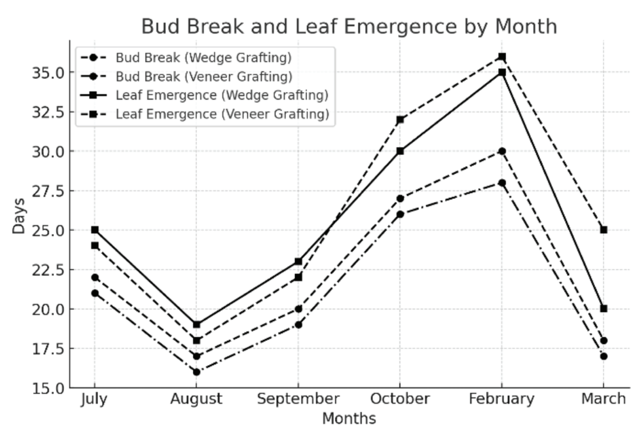

Fig. 2. Effect of grafting time and grafting technique on days to bud break and days to 1st leaf emergence.

tissues (Visen *et al.,* 18). This physiological process accelerates cellular differentiation and vascular tissue development (xylem and phloem), which facilitates the uptake of water and nutrients, enhancing rapid growth and ultimately leading to earlier leaf emergence (Hababi *et al.,* 19). The veneer grafting method, in particular, showed a quicker sprouting (16.33 days for bud break and 17.62 days for leaf emergence) compared to wedge grafting, which generally required a longer time for both bud break and leaf emergence across all months (e.g., 18.42 days for bud break and 20.15 days for leaf emergence in August). This may be attributed to the effective contact between the cambial layers of the stock and scion in veneer grafting, leading to quicker vascular connection and more efficient tissue regeneration. This faster union leads to quicker bud sprouting and leaf emergence. Furthermore, February's colder temperatures and lower humidity led to slower metabolic processes, resulting in delayed bud break and leaf emergence. The decreased sap flow and reduced hormonal activity under these conditions hindered the rapid development of vascular tissues, thereby prolonging the time taken for both bud break and leaf emergence. Thus, the observed differences in bud break and leaf emergence time align closely with the environmental factors (temperature and humidity) and grafting methods discussed. The veneer grafting method in August benefitted from optimal environmental conditions, which facilitated faster cambial alignment, active tissue growth, and early leaf emergence. In contrast, February's less favourable conditions resulted in slower physiological processes, leading to a longer time for bud break and leaf emergence.

Table 1 concludes that both the factors considered in the present study significantly influenced sprout length at 60 days after grafting. Sprout length was generally greater in veneer grafting compared to wedge grafting across all months. Veneer grafting done in the month of August resulted in the maximum (10.06 cm) sprout length whereas, minimum (2.58 cm) was found in the veneer grafted plants in the month of February. The results are in close conformity with reported findings that veneer grafting resulted in the highest sprout length (12 cm), primarily due to the ease of graft union formation (Habibi *et al.,* 19; Chophel *et al.,* 20). This was attributed to the continuity of the graft parts with the mother tree, ensuring a steady nutrient supply to the scion. Also, highest sprout length in August month was observed (Shivendu, 21). This might be due to healing took place fast in the month of August because of presence of appropriate environmental conditions in terms of temperature and relative humidity in polyhouse. These conditions enhance the process of photosynthesis which resulted in supply of abundant food material and increases sprout length. Plant height values in table 1 followed a similar trend to sprout length, with veneer grafting generally resulting in taller plants across all grafting times at 60 DAG compared to wedge grafting. The maximum plant height (30.24 cm) was observed in August for both grafting methods, whereas the minimum height (22.35 cm) was recorded in wedge grafted plants in February. These results align with previous studies, which also reported maximum plant height in August (Kaur *et al.,* 10). The favorable environmental conditions in August, characterized by higher humidity and optimal temperature, likely

Table 1: Effect of grafting time and technique on sprout length, plant height and no. of leaves at 60 DAG.

Time of grafting/ grafting method	Sprout length (cm)				Plant height (cm)				Number of leaves			
	Wedge ± SE	Veneer ± SE	p-value	T test	Wedge ± SE	Veneer ± SE	p-value	T test	Wedge ± SE	Veneer ± SE	p-value	T test
T1 (July)	5.34 ± 0.23	7.47 ± 0.35	0.010	'S'	25.08 ± 0.31	27.35 ± 0.28	0.004	'S'	7.07 ± 0.42	9.19 ± 0.36	0.014	'S'
T2 (August)	7.99 ± 0.29	10.06 ± 0.33	0.005	'S'	27.77 ± 0.41	30.24 ± 0.45	0.007	'S'	11.22 ± 0.38	13.50 ± 0.30	0.002	'S'
T3 (September)	6.12 ± 0.26	8.06 ± 0.31	0.006	'S'	26.09 ± 0.39	28.18 ± 0.35	0.012	'S'	10.02 ± 0.44	10.86 ± 0.41	0.218	'NS'
T4 (October)	4.80 ± 0.21	4.09 ± 0.24	0.075	'NS'	24.31 ± 0.33	22.80 ± 0.30	0.037	'S'	6.43 ± 0.40	5.15 ± 0.28	0.048	'S'
T5 (February)	3.09 ± 0.22	2.58 ± 0.18	0.117	'NS'	22.35 ± 0.36	23.03 ± 0.32	0.244	'NS'	5.08 ± 0.35	5.12 ± 0.31	0.958	'NS'
T6 (March)	7.13 ± 0.25	4.84 ± 0.20	0.002	'S'	26.21 ± 0.38	25.96 ± 0.34	0.707	'NS'	9.07 ± 0.37	5.87 ± 0.29	0.001	'S'

Table 2: Effect of grafting time and technique on leaf area, graft survival and total saleable plants.

Time of grafting/ Grafting methods	Leaf area (cm²)				Graft survival (%)				Total saleable plants (%)			
	Wedge ± SE	Veneer ± SE	*p*-value	T test	Wedge ± SE	Veneer ± SE	*p*-value	T test	Wedge ± SE	Veneer ± SE	*p*-value	T test
T_1 (July)	27.46 ± 0.86	29.36 ± 0.51	0.0287	'S'	86.26 ± 1.04	87.46 ± 0.65	0.6414	'NS'	37.33 ± 0.29	46.67 ± 0.53	0.0002	'NS'
T_2 (August)	41.85 ± 0.62	46.39 ± 0.39	0.0043	'S'	88.56 ± 0.76	93.73 ± 0.56	0.0102	'S'	48.00 ± 0.51	66.67 ± 0.38	0.0000	'S'
T_3 (September)	38.11 ± 0.83	40.79 ± 0.23	0.0682	'NS'	86.24 ± 0.34	90.18 ± 0.40	0.0022	'S'	44.00 ± 0.32	58.67 ± 0.89	0.0001	'S'
T_4 (October)	28.05 ± 0.81	24.94 ± 0.18	0.0081	'S'	84.40 ± 0.21	86.38 ± 0.12	0.0003	'S'	29.33 ± 1.13	26.67 ± 0.48	0.1030	'S'
T_5 (Feb)	18.39 ± 0.92	16.59 ± 0.45	0.1180	'NS'	80.28 ± 0.75	75.37 ± 0.36	0.0063	'S'	22.67 ± 0.52	16.00 ± 0.28	0.0006	'S'
T_6 (March)	33.49 ± 0.08	21.51 ± 0.14	0.0000	'S'	86.21 ± 0.17	78.33 ± 0.66	0.0003	'S'	38.67 ± 0.49	20.00 ± 0.37	0.0000	'S'

facilitated rapid healing and enhanced the activity of cambial tissues. This led to increased cell division, promoting callus formation and boosting the overall growth of grafted plants. The combination of these environmental factors is essential for supporting vigorous growth and height development in grafted seedlings (Islam *et al.,* 21). The data pertaining to number of leaves presented in table 2 was found to be consistently higher in veneer grafting compared to wedge grafting across all months at 60 DAG. The maximum number of leaves (13.50) was observed in plants veneer grafted in August, while the minimum (5.08) was recorded in wedge grafted plants in February. Similarly, the highest number of leaves in August (Gotur *et al.,* 17). The enhanced leaf production during this period can be attributed to favourable environmental conditions that promote efficient nutrient translocation, leading to improved growth and development of the grafted plants. The data in Table 2 pertaining to leaf area was largest in August for both grafting methods at 60 DAG, with veneer grafted plants exhibiting the largest leaf area (45.89 cm²) in August, while the minimum leaf area (16.09 cm²) was observed in veneer grafted plants in February. These results align with findings from previous studies where the highest leaf area was reported in veneer grafted plants during August using 9-day defoliated scion wood (Majeed *et al.,* 22). The high number of leaves in August likely increased the cell multiplication capacity of the bud meristem, resulting in a larger leaf surface. This increased leaf area enhances photosynthetic activity, which may have contributed to the higher synthesis of photosynthates, further supporting the growth and leaf area expansion in grafted plants (Hart *et al.,* 23; Dewangan *et al.,* 24). The analysis of the data presented in Table 2 reveals that both grafting time and grafting method had a significant effect on graft survival percentage. Irrespective of the grafting time, August was consistently observed as the most favourable time for both wedge and veneer grafting in terms of graft survival. Among the two grafting methods, wedge grafting in August showed the highest survival rate at 93.23%, while the lowest survival rate was recorded in veneer grafted plants in February at 74.87%. These findings align with those observed in other species, such as cashew (Hart *et al.,* 23) and sapota (Kaur *et al.,* 25), where August was also identified as the period with the highest graft survival. The optimal temperature and relative humidity during August likely facilitated early cambial contact between the stock and scion, promoting rapid callus formation, which contributed to higher graft survival (Sadeghi-Majd *et al.,* 26; Abdel-Mohsen *et al.*, 27). The data presented in Table 2 show that both grafting time and grafting method had a significant impact on the saleable plant's percentage. August emerged as the most suitable time for both wedge and veneer grafting, as the highest proportion of saleable plants was observed in plants grafted during this month, regardless of the grafting method. Specifically, veneer grafting in August produced the highest percentage of saleable plants (66.17%), whereas the lowest percentage (15.50%) was recorded in veneer grafted plants in February.

Veneer grafting consistently resulted in higher graft success across all grafting times compared to wedge grafting. This could be attributed to the quicker healing process in veneer grafting, as it exposes a smaller area compared to wedge grafting, which involves two interfaces and a larger exposed surface area. This larger area requires a longer period for the tissues to heal and form a strong union between the scion and rootstock. The results of this study align with those of Mango grafting experiments, where veneer grafting in August resulted in 76.51% saleable plants (Mng'Omba *et al.,* 16). Regarding sprout initiation, plants grafted during the first fortnight of August showed the quickest bud sprouting, while those grafted in March took the longest. This finding is consistent with previous studies (Mng'Omba *et al.,* 16, Kaur *et al.,* 10), where August grafts exhibited the fastest bud break due to the high temperature and humidity, which increase sap flow in the scion. This enhanced sap flow aids the union of scion and rootstock, promoting quicker graft success. The findings in the present study are in line with those of (Pandey *et al.,* 28), who observed the earliest sprouting and highest survival rates in August. Similarly, studies on mango grafting have shown that grafts performed during the wet season (July–August) result in quicker sprouting compared to those done in September or October (Singh *et al.,* 12, Kumar *et al.,* 13; Sabeky, 15, Mng'Omba *et al.,* 16). The favourable temperature (28–30°C) and relative humidity (70–80% RH) during August create optimal conditions for graft union formation, contributing to the higher percentage of saleable plants.

The present investigation highlights the significant influence of grafting time and method on the overall success, growth, and saleability of mango grafts. Among the treatments, veneer grafting during August emerged as the most effective, showing the highest graft success and survival percentages, quickest bud break and leaf emergence, and superior vegetative growth parameters including plant height, number of leaves, and leaf area. The enhanced performance in August can be attributed to favourable environmental conditions moderate temperatures and high relative humidity that facilitate rapid callus formation, better cambial alignment, and efficient nutrient and water uptake. Veneer grafting also provides a more secure and less invasive union between scion and rootstock, further enhancing graft establishment. Based on these findings, veneer grafting in the month of August is strongly recommended for achieving optimal propagation efficiency and commercial success in mango cultivation.

AUTHOR'S CONTRIBUTION

Conducted preliminary field trails, recording observation, analysis of data and preparation of manuscript (NA); Conducted preliminary field trails, Conceptualization of study and Proof reading (SKS).

DECLARATION

Author declares that the MS is not under consideration anywhere else, Authors have no conflict of interest

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