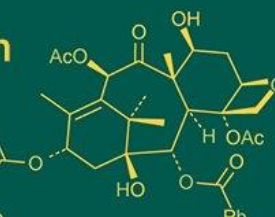
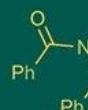
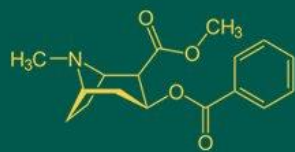


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Studies on budding time and techniques on seedling rootstock of apple (*Malus × domestica* Borkh.) var. Red Delicious

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Abstract

This study identifies the optimal interaction between budding time and technique for the mid-hill Garhwal Himalayas, establishing mid-September chip budding as the superior method for high-quality apple nursery production. Three timings (end of August, mid-September, and end of September) and two budding techniques (chip budding and T-budding) were combined in a factorial randomized full block design. Significant interaction effects between budding time and technique were observed for most growth and success parameters. Chip budding performed in mid-September (M₂T₂) recorded the highest bud take success (81.00%), longest sprout length (51.43 cm), thickest shoot diameter (0.89 cm), maximum branches per plant (34.93), highest number of leaves (70.47), earliest bud sprouting (198.28 days) and the highest sprouting percentage (91.00%). However, T-budding performed at the end of August (M₁T₁) recorded the largest leaf area (24.22 cm²). Overall, chip budding during mid-September proved to be the most effective for high-quality nursery production of apples in mid-hill agro-climatic conditions. The study uniquely establishes that the interaction of budding time and technique critically determines bud success and early growth of apple under the distinct mid-hill Garhwal Himalayan conditions, where earlier evidence was limited and inconclusive.

Keywords: Bud take success, red delicious, T-budding, chip budding and vegetative growth

Introduction

Apple (*Malus × domestica* Borkh.) is one of the most important temperate fruit crops globally, widely cultivated for its commercial and nutritional value. In 2023, global apple production reached approximately 97 million tonnes, with major contributions from China (~49.6 Mt), the USA, Turkey and India (FAO, 2024) [8]. In India, apple is predominantly cultivated in the Himalayan states of Jammu & Kashmir, Himachal Pradesh and Uttarakhand, where it forms the backbone of hill horticulture. According to the National Horticulture Board, Jammu & Kashmir contributes nearly 71% of national apple production (~909.6 thousand tonnes from 90.1 thousand ha), followed by Himachal Pradesh (180.6 thousand tonnes from 92.8 thousand ha) and Uttarakhand (~59.3 thousand tonnes from 51.8 thousand ha). (NHB, 2023) [17].

Commercial apple orchards are typically raised using vegetative propagation, particularly by budding or grafting scion cultivars onto seedling rootstocks such as crab apple (*Malus baccata*). However, propagation through seedlings introduces genetic variability due to cross-pollination, leading to non-uniform tree growth, prolonged juvenile periods and delayed bearing (Brown, 2011; Hartmann *et al.*, 2011) [6, 9]. Vegetative propagation through budding offers an efficient alternative, allowing true-to-type replication of cultivars and more uniform orchard establishment.

Among the budding techniques, T-budding and chip-budding are most widely practiced in apple propagation. These methods differ in terms of technique, ease of operation, and success under varying climatic conditions. The success of budding is highly influenced by the timing of operation, as it depends on the physiological state of the rootstock and scion, particularly the activity of the cambial tissues (Hartmann *et al.*, 2011) [9]. When compared to other tree propagation techniques like T-budding used in the apple propagation, new growth from chip buds is straighter and more uniform (Smith 2020) [22].

Previous studies have reported that budding during active cambial flow, typically from mid-August to late September, improves bud take success and shoot growth (Ahmad *et al.*, 2015; Thakur *et al.*, 2024) [2, 24]. The different timing of budding exhibited a significant negative correlation with bud take success, saleable plants, growth, and physiological traits. The highest bud takes success and plant growth was recorded in chip budding performed in the last week of August, significantly followed by budding performed in the 1st week of September (Verma *et al.*, 2025) [25]. However, these responses are highly location-specific and influenced by temperature, humidity and altitude.

In the Garhwal Himalayas, particularly in Bharsar, Uttarakhand, there is a lack of standardized recommendations for optimal budding techniques and timings suitable to mid-hill conditions. Farmers often rely on traditional practices without evidence-based guidance, which leads to inconsistent bud take and poor establishment of orchards. This study is novel in identifying a location-specific optimum combination of budding time and technique for apple propagation under the mid-hill Garhwal Himalayan conditions, which differ markedly from other apple-growing regions of India. Although research on budding in apples has been conducted in other temperate zones, studies focusing specifically on Garhwal conditions remain limited and inconclusive. Unlike earlier studies that examined budding time or method independently, the present work demonstrates that their interaction significantly influences bud success and early vegetative growth of crab apple (*Malus baccata*).

Therefore, in this study, apple plants were propagated using two budding methods T-budding and chip-budding performed at three different times (mid-August, end of August and mid-September). The resulting plants were evaluated for bud sprouting, success rate, shoot length, shoot diameter, leaf area and other physiological traits. This study aims to identify the most suitable method and timing combination to standardize apple propagation under mid-hill conditions of the Garhwal Himalayan region.

Materials and Methods

Experimental Site and Plant Material: This study was conducted during 2017-2018 at the fruit nursery field of VCSG UUHF, Bharsar, Pauri Garhwal, located in the mid-Himalayan region of Uttarakhand, India, under temperate agro-climatic conditions. The experimental materials consisted of scion buds from *Malus × domestica* cv. 'Red Delicious' and uniform, healthy crab apple (*Malus baccata*) rootstocks that were raised from seeds.

Irrigation and Fertilization Schedule: Slight irrigation was applied prior to bud planting to ensure a uniform soil surface and adequate moisture. For better success and growth, budlings were given frequent light irrigation, the field was kept weed-free, and foliar application of micronutrients was carried out at fortnightly intervals to promote faster growth.

Experimental Design and Treatment Details: The experiment was laid out in a Randomized Complete Block Design (RCBD) with a factorial arrangement, comprising two budding methods and three budding times, replicated four times. Each treatment plot consisted of 25 plants, amounting to a total of 600 budded plants.

Statistical Analysis: The recorded data were subjected to Analysis of Variance (ANOVA) to test the significance of treatment effects and their interactions. All statistical computations were performed using the OPSTAT statistical software developed by CCS Haryana Agricultural University, Hisar (Sheoran *et al.*, 1998) [19]. The average value of each treatment in each parameter was tested differently using (DMRT) Duncan multiple range analysis at the 5% level of probability on R-studio.

List 1: Treatment combinations were as follows

Treatment	Budding Method	Budding Time
M ₁ T ₁	T-budding	End of August
M ₁ T ₂	T-budding	Mid of September
M ₁ T ₃	T-budding	End of September
M ₂ T ₁	Chip budding	End of August
M ₂ T ₂	Chip budding	Mid of September
M ₂ T ₃	Chip budding	End of September

Parameters Recorded: Observations were recorded at appropriate intervals on the following growth and success attributes:

- **Days to Bud Sprouting:** Number of days from the date of budding to the emergence of the first sprout.
- **Sprouted Budded Plants (%)**

$$\text{Sprouted Percentage} = \frac{\text{Number of sprouted budded plants}}{\text{Total budded plants}} \times 100$$

- **Length of Longest Sprout (cm):** Average sprout length measured from base to tip using a measuring scale, recorded nine months after budding.
- **Diameter of Sprout (cm):** Measured at the midpoint of a randomly selected sprout per plant using a digital Vernier calliper.
- **Number of Branches per Sprout:** Counted manually for each sprout and averaged per treatment.
- **Number of Leaves per Sprout:** Total number of fully opened leaves per sprout counted and averaged.
- **Leaf Area (cm²):** Calculated using a digital leaf area meter. Twelve fully expanded leaves were randomly selected per replication, averaged, and multiplied by the average number of leaves to determine total leaf area per plant.
- **Bud Success Rate (%)**

$$\text{Bud success rate\%} = \frac{\text{Number of successfully established buds}}{\text{Total budded plants}} \times 100$$

Results and Discussion

Number of days taken to bud sprouting: The number of days required for bud sprouting varied statistically significantly depending on the budding time and how it interacted with the strategies. Chip budding, which was carried out in mid-September (M₂T₂), had the lowest number of days to bud sprouting (198.28 days). This early bud emergence could be caused by the rainy season's ideal climate, which includes high humidity, ideal temperature, and increased sap flow. These factors all work together to stimulate cambial activity and hasten the development of graft unions.

The results of the current experiment are supported by Ahmad *et al.*, (2015) ^[2], who similarly demonstrated a significant impact of budding technique and time on the number of days needed for bud sprouting in guava. They found that plants propagated by T-budding in September had the longest time to sprout (213.96 days), whereas those propagated by chip budding in August had the shortest time (174 days).

Per cent of sprouted budded plants (%): The percentage of sprouted budded plants was significantly impacted by time, budding techniques, and their combination, according to the data on sprouting percentage. Chip budding carried out in mid-September (M_2T_2) had the highest sprouting percentage (91.00%), suggesting ideal physiological and environmental circumstances for bud establishment. T-budding, which was carried out at the end of August (M_1T_1), came next, and it showed 87.00% sprouting. Favourable moisture, temperature and cambial activity all essential for successful vascular connection and bud development may be the cause of the enhanced performance in mid-September.

These results are consistent with those of Zenginbal (2007) ^[28] and Howard (1977) ^[11], who also noted that the first week to mid-September was when the greatest percentage of sprouted budded plants succeeded with chip budding in temperate fruits. Better scion maturity used for budding improved sprouting success. Favourable relative humidity and temperature during the post-budding period also supported bud growth. Higher sprouting observed from the last week of August to mid-September may be due to rapid sap flow in both rootstock and scion. These conditions likely ensured proper cambial and vascular continuity, which enhanced bud sprouting and aided the healing process.

Callus connection was noted 15-20 days after budding, according to Hartmann *et al.*, (2002) ^[10], and at this time, budding shouldn't be subjected to extremes of temperature. T-budding at the end of September produced the lowest bud sprouting (74.00%) (M_1T_3).

According to Thakur *et al.*, (2025) ^[23], chip budding on June 22 produced the highest sprouting percentage (96.67%), which they attributed to the rootstock's active physiological state and ideal climatic conditions at that time. Data represented under table 1 and fig. 1.

Table 1: Effect of budding method and time on number of days taken to bud sprouting and percent of sprouted budded plants (%) in apple (cv. Red Delicious)

Number of days taken to bud sprouting					Per cent of sprouted budded plants (%)			
Method (M)	Time (T)							
	T ₁	T ₂	T ₃	Mean (M)	T ₁	T ₂	T ₃	Mean (M)
M ₁	206.97	237.41	244.21	229.53 ^a	87.00	79.00	74.00	80.00 ^b
M ₂	217.00	198.28	224.73	213.33 ^b	84.00	91.00	81.00	85.34 ^a
Mean (T)	211.98 ^c	217.85 ^b	234.47 ^a		85.50 ^a	85.00 ^a	77.50 ^b	
Factors	SE(d)		CD _(0.05)		SE(d)		CD _(0.05)	
Method (M)	0.30		0.65		0.31		0.66	
Time (T)	0.37		0.79		0.38		0.81	
Method × Time (M×T)	0.52		1.12		0.53		1.15	

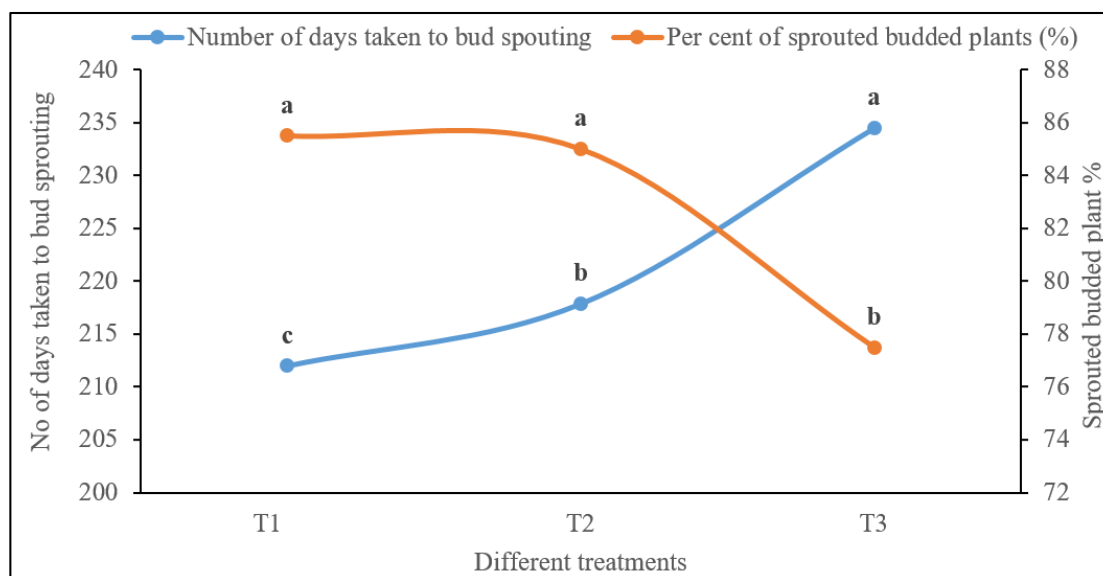


Fig 1: Connected scatter plot shows the number of days to bud sprouting (X-axis) and the percentage of budded plants (Y-axis) for two budding techniques (M_1 and M_2) over three budding times: the end of August (T_1), mid-September (T_2) and the end of September (T_3). SE (d) of Number of days taken to bud sprouting-0.52 and percent of sprouted budded plants (%)-0.53.

Shoot length (cm): The budding growth data indicated that the length of the longest bud sprout (51.43 cm), which was recorded at its maximum from chip budding in mid-September (M_2T_2), was significantly influenced by budding time, procedures and their interaction. The favorable climate

and higher leaf count, which enhanced the rate of photosynthesis and hence the creation of carbohydrates, are the causes of the increased average length of bud sprouts. These findings support those of Zenginbal (2014) ^[27], who found that in apples grown in cool climates and at high

elevations, the Mondial Gala cultivar, grafted using the chip budding method, had the longest shoot length (66.00 cm), while the Red Chief cultivar, grafted using the T-budding method, had the shortest shoot length (42.30 cm). Thakur *et al.*, (2025) ^[23] reported that the greatest scion length (92.70 cm) was produced using chip budding on June 22. Chip budding on May 22 yielded the highest scion length (139.42 cm), according to Sharma *et al.*, (2024) ^[18]. This suggests vigorous vertical development because of favourable physiological and environmental conditions that facilitated rapid shoot elongation.

Shoot diameter (cm): Regarding shoot diameter, the data relating to the interaction between various budding techniques and time was determined to be relevant. Chip budding in mid-September (M₂T₂) displayed the largest shoot diameter (0.89 cm), followed by T-budding at the end of August and chip budding at the end of August (0.72 cm). Better bud growth, which increases the absorption and transport of nutrients from the soil and actively participates in a variety of plant metabolic processes, may be the cause of the larger shoot diameter with the best time and techniques (Singh, 2001) ^[20]. At the end of September, T-budding showed a minimum shoot diameter of 0.38 cm

(M₁T₃). A statistical examination of the data by Celik *et al.*, (2006) ^[7] showed that the maximum shoot diameter (0.684 cm) of kiwi budding was significantly influenced by the dates, procedures, and their interaction with regard to stem thickness. According to a statistical study of the data by Ahmad *et al.*, (2012) ^[1], budding dates, techniques, and their combination significantly impacted the stem thickness of guava budding. Plants budded in September using T-budding had the highest stem thickness (58.425 cm), whereas plants budded in August using chip budding had the lowest (53.150 cm). Zeb (2002) ^[26] conducted a statistical analysis of the data and found that the highest shoot thickness (1.90 cm) observed during peach budding was significantly influenced by budding dates, procedures, and their interaction. Chip budding on June 22 produced the largest scion diameter of 0.503 cm, according to Thakur *et al.*, (2025) ^[23]. The 22nd May treatment also showed the largest scion diameter (1.268 cm), indicating stronger graft union and vigorous radial growth, which were probably aided by active cambial activity at the time (Sharma *et al.*, 2024) ^[18]. Data presented under table 2 and fig. 2.

Shoot length (cm)					Shoot diameter (cm)			
Method (M)	Time (T)							
	T ₁	T ₂	T ₃	Mean (M)	T ₁	T ₂	T ₃	Mean (M)
M ₁	42.12	17.63	11.10	23.62 ^b	0.72	0.50	0.38	0.53 ^b
M ₂	35.03	51.43	25.72	37.39 ^a	0.72	0.89	0.64	0.75 ^a
Mean (T)	38.58 ^a	34.53 ^b	18.41 ^c		0.72 ^a	0.70 ^a	0.51 ^b	
Factors	SE(d)		CD(0.05)		SE(d)		CD(0.05)	
Method (M)	0.15		0.34		0.013		0.028	
Time (T)	0.19		0.41		0.016		0.034	
Method × Time (M×T)	0.27		0.58		0.022		0.048	

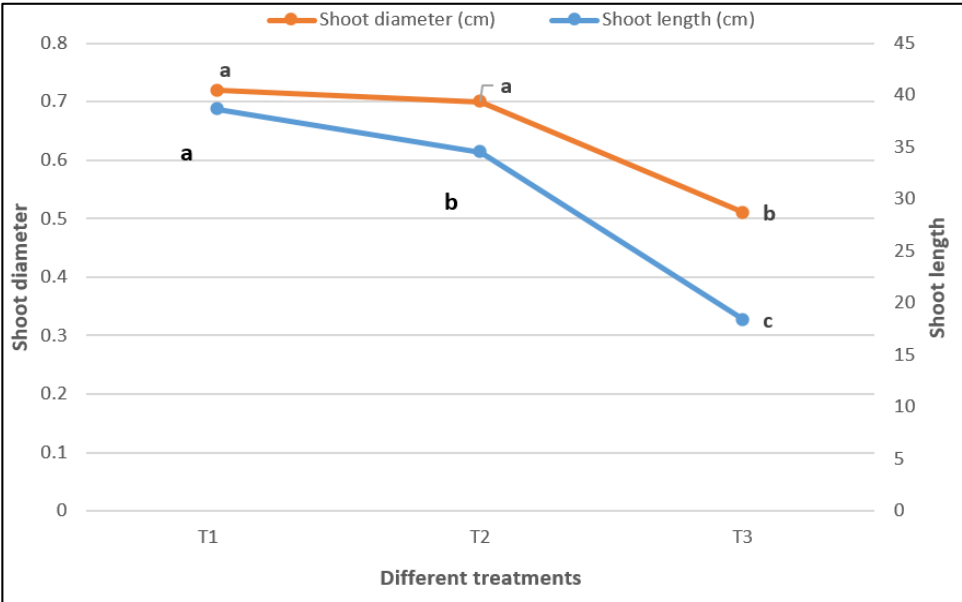


Fig 2: This radar chart shows how budding times (T₁: early August, T₂: mid-September, and T₃: late September) and budding techniques (M₁: T-budding, M₂: Chip budding) interact to affect apple shoot length and shoot diameter. SE (d) of Shoot length (cm)-0.27 and Shoot diameter (cm)-0.022.

Number of branches per budded plants: According to the data collected on the number of branches, there was a substantial interaction between time and various budding techniques. Midway through September (M₂T₂), chip

budding produced the most branches (34.93), while T-budding followed at the end of August (31.51). A higher number of branches could result from improved use of nitrogen, stored carbohydrates, and other elements. At the

end of September (M_1T_3), T-budding had the smallest number of branches (7.77).

The findings are consistent with Ahmad *et al.*, (2012) ^[1], who examined the impact of varying budding times on peach bud take success on peach rootstock that was budded at various intervals throughout June. The plants budded on June 15th showed the highest number of branches (14.8). The average branch count was significantly impacted. According to research by Maryam *et al.*, (2015) ^[16], the Guissi sour cherry scion grown in August using chip budding had the most lateral branches. Chip budding produced the same outcomes in Hungry Sour Cherry Scion when compared to other techniques. Bud formation occurred earlier in chip budding because the rootstock and scion formed a tight connection.

Number of leaves per budded plants: The data on the number of leaves per plant demonstrated that the interactions between various budding times and techniques were also shown to be significant in relation to the number of leaves. Midway through September (M_2T_2), chip budding produced the most leaves (70.47), followed by T-budding at the end of August (M_1T_1), and T-budding at the end of September (M_1T_3) produced the fewest leaves (25.52). Better bud growth and more branches may be the cause of the increased number of leaves using the best timing and techniques. The increased number of leaves could be the

result of favourable weather conditions. This increased soil nutrient uptake and translocation plays an active role in a number of plant metabolic processes.

Plants budded on June 28 had the greatest leaves per plant (37.00), whereas those budded on June 7 had the fewest leaves per plant (12.00), according to Hussain *et al.*, (2000) ^[12]. Their findings were consistent with these outcomes. Peach plants budded utilizing chip budding on August 28th had the most leaves (292.54), according to Akhtar *et al.*, (2000) ^[3]. This could be because the budding growth produced the most branches. Under ideal budding conditions, Kumari *et al.*, (2021) ^[15] found that sweet cherry nursery plants produced the most leaves (53.16). Strong shoot development and rapid vegetative growth both necessary for photosynthesis and overall plant productivity are reflected in a greater leaf count. This implies that favourable physiological circumstances that promoted active leaf start and supported shoot elongation were given by the selected budding technique and timing. Maryam *et al.*, (2015) ^[16] found that the Guissi sour cherry scion treatment, which used chip budding, produced the most leaves in August. Similarly, the Hungry sour cherry scion treatment also used chip budding to produce the most leaves in August. Buds grew, germinated, and absorbed water and nutrients more quickly as a result of improved and earlier chip budding. Data presented under table 3 and fig. 3.

Table 3: Effect of budding methods at different time on number of branches per budded plants and number of leaves per budded plants

Number of branches per budded plants					Number of leaves per budded plants			
Method (M)	Time (T)				Time (T)			
	T ₁	T ₂	T ₃	Mean (M)	T ₁	T ₂	T ₃	Mean (M)
M ₁	31.51	11.42	7.77	16.90 ^b	60.65	32.91	25.52	39.69 ^b
M ₂	24.75	34.93	19.28	26.32 ^a	49.97	70.47	41.26	53.90 ^a
Mean (T)	28.13 ^a	23.18 ^b	13.53 ^c		55.31 ^a	51.69 ^b	33.39 ^c	
Factors	SE(d)		CD(0.05)		SE(d)		CD(0.05)	
Method (M)	0.19		0.42		0.20		0.44	
Time (T)	0.24		0.51		0.25		0.54	
Method × Time (M×T)	0.34		0.73		0.36		0.77	

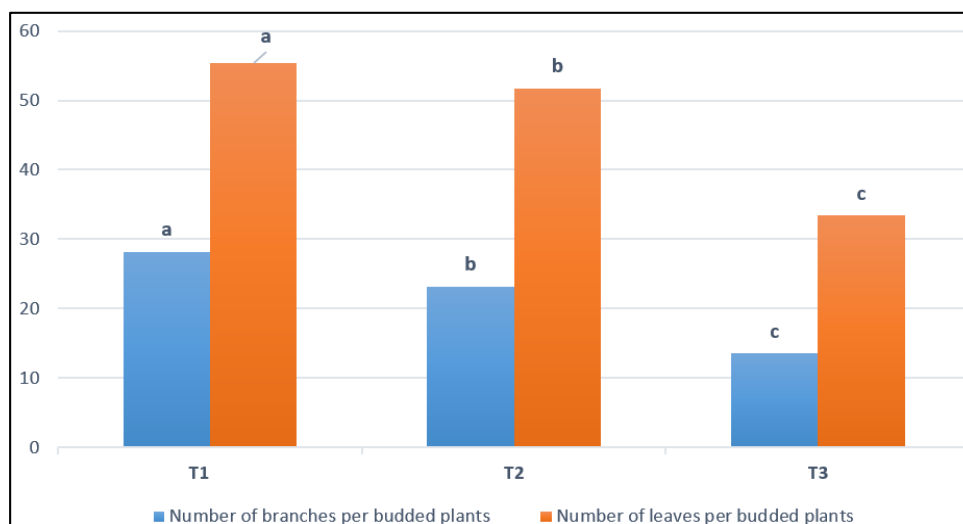


Fig 3: The number of branches and leaves per budded apple plant is affected by the interaction between the budding time (T₁: early August, T₂: mid-September, and T₃: late September) and budding method (M₁: T-budding, M₂: Chip budding). SE(d) of Number of branches per budded plants-0.34 and Number of leaves per budded plants-0.36.

Leaf area (cm²): In terms of leaf area, the relationships between various budding times and techniques were also found to be important. T-budding produced the largest leaf

area (24.22 cm²) at the end of August (M_1T_1) and chip budding followed at the end of August (M_2T_1). This may be because, in contrast to chip-budded plants, T-budded plants

sprout early, have leaf emergence, and grow vegetatively more quickly. At the end of September, T-budding produced the smallest leaf area (16.58 cm²) (M₁T₃).

The findings are consistent with those of Kumar and Ananda (2002) [14], who found that the highest leaf area on chip budding occurs in August and that the maximum number of leaves is directly correlated with the leaf area. Zeb (2002) [26] noted that Florida King, which was budded on the Peshawar indigenous rootstock of peaches, had the largest leaf area (45.26 cm²).

Increased individual leaf development is shown by the maximum leaf area (23.37 cm²) noted by Kumari *et al.*, (2021) [15], which has a direct effect on the photosynthetic efficiency of the plant. Bigger leaves provide a larger surface area for gas exchange and light absorption, which improves the buildup of carbohydrates. Better cellular growth and nutrient uptake are reflected in this increase in leaf area, which may be the consequence of a strong graft union and robust root-shoot communication.

Success rate of budded plants (%): The relationship between budding technique and time has a substantial impact on the success rate of budded plants. The chip budding that was done in mid-September (M₂T₂) and the T-budding that was done at the end of August (M₁T₁) had the highest success rates (81.00%). This implies that during these times, the scion and rootstock had the best physiological compatibility possible, which was reinforced by ideal environmental circumstances that improved vascular union and bud establishment in general. The better success may be owing to combined influence of congenial temperature, humidity and active state of scion and stock tissues, during this phase which promotes maximum regeneration of parenchyma cells in cambium region. It is

owing to the fact that budding in September generate optimal environmental conditions for the healing process of bud wounds and resulting in the establishment of normal vascular tissues at the bud union which result in optimum plant survival. The minimum success rate of plants (51.00%) was obtained with T-budding on end of September (M₁T₃). Similarly, budding late in the growing season contributed to unfavorable conditions for healing process which resulted in the poor formation of normal vascular tissue at the bud union.

The outcomes of the study conducted by, Khattak *et al.*, (2002) [13] observed in case of propagation methods (chip budding) of guava produced improved success of budded plants (80.00%). Beltz (1989) [5] obtained more than 80.00 percent bud-take with chip budding in fruit trees. Ananda *et al.*, (1998) [4] observed that highest percent of bud-take success (96.25%) chip budding in apple was recorded during October month in apple. Singh *et al.*, (1986) [21] reported that budding done in mid of September (T₃) offered the highest percent of success (95.30%), followed by mid of August (92.00%). Verma *et al.*, (2025) [25] The largest bud takes and plant development were obtained via chip budding during the last week of August, followed by budding during the first week of September.

According to Thakur *et al.*, (2025) [23], chip budding on June 22 had the greatest bud take success percentage, 96.67%. According to Kumari *et al.*, (2021) [15], the chip budding method produced the best percentage of bud-take success (52.21%). This could be because there is less necrotic tissue in the blanking between the scion and rootstock in chip budding, which leads in superior cambial continuity and vascular integration. Data represented under table 4 and fig. 4.

Table 4: Effect of budding methods at different time on leaf area (cm²) and success rate of sprouted budded plants (%)

Method (M)	Leaf area (cm ²)				Success rate of budded plants (%)			
	Time (T)							
	T ₁	T ₂	T ₃	Mean (M)	T ₁	T ₂	T ₃	Mean (M)
M ₁	24.22	18.36	16.58	19.72 ^b	74.00	68.00	51.00	64.34 ^b
M ₂	22.34	20.52	18.09	20.32 ^a	72.00	81.00	67.00	73.34 ^a
Mean (T)	23.28 ^a	19.44 ^b	17.34 ^c		73.00 ^b	74.50 ^a	59.00 ^c	
Factors	SE(d)		CD (0.05)		SE(d)		CD (0.05)	
Method (M)	0.15		0.33		0.48		1.05	
Time (T)	0.19		0.41		0.59		1.28	
Method × Time (M×T)	0.27		0.58		0.84		1.81	

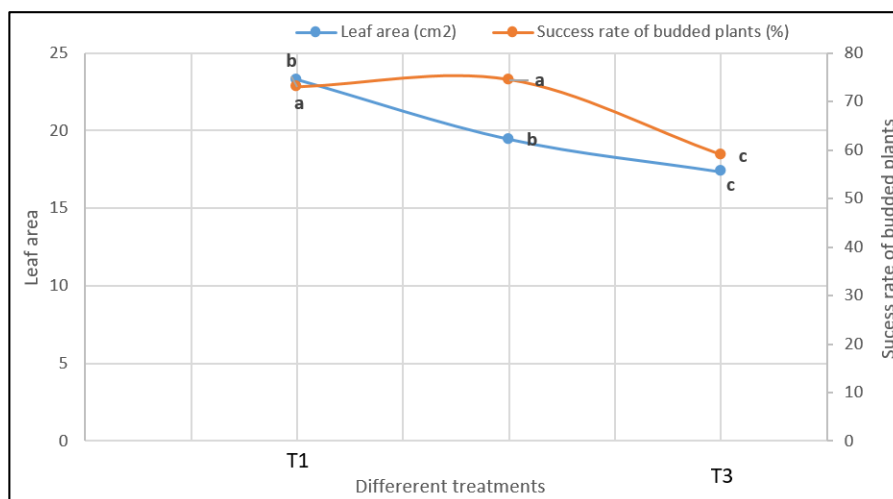


Fig 4: Effects of various budding timings (T₁: early August, T₂: mid-September, and T₃: late September) and budding techniques (M₁ and M₂) on apple plant leaf area (cm²) and bud success rate (%). SE(d) of Leaf area (cm²)-0.27 and Success rate of budded plants (%)-0.84.

Conclusions

Budding time and technique significantly influenced the early vegetative growth and success of apple (*Malus × domestica* Borkh.) nursery plants. Among the treatments, chip budding performed in mid-September resulted in superior bud sprouting, shoot elongation, stem diameter, leaf development, and overall bud take success. These findings indicate that adopting chip budding in mid-September can enhance nursery quality and efficiency under mid-hill conditions by aligning propagation practices with favorable environmental and physiological factors.

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