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EFFICACY OF TOP-WORKING TECHNIQUE IN KIWIFRUITS (*ACTINIDIA DELICIOSA*) UNDER TEMPERATE CONDITIONS OF CHITLANG, NEPAL

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ABSTRACT

Kiwifruits (*Actinidia deliciosa*) is an economically important fruit crop in Nepal but faces propagation challenges, particularly in cultivar adaptation and orchard management. Top-working, a grafting technique used to replace underperforming cultivars without replanting, offers a promising solution. This study evaluated the effects of scion cultivar, grafting timing, and wrapping material on top-working success under the temperate conditions of Chitlang, Nepal. Three scion cultivars ('Abbott', 'Bruno', and 'Monty'), three wrapping materials (parafilm, green nursery tape, and transparent plastic), and four grafting times (mid-February to late March) were tested in a randomized complete block design with 36 treatment combinations with three replications. Results showed that mid-season grafting (late February to early March) significantly improved sprout length, diameter, leaf number, and relative chlorophyll index, particularly when parafilm was used as the wrapping material. 'Bruno' and 'Monty' cultivars exhibited superior growth performance compared to 'Abbott'. Grafting operations are conducted during optimal seasonal conditions, resulting in significantly improved results. The grafts sprout faster, and parafilm wrapping promotes better healing of the graft union and longer shoots. This demonstrates the crucial relationships among the grafting period, the scion cultivar, and the wrapping material. The results provide valuable suggestions for enhancing graft success and early plant development, as well as offer helpful insights for improving kiwifruit propagation and orchard management in Nepal.

Keywords: *Actinidia deliciosa*, Cleft grafting, Orchard rejuvenation, Scion cultivar, Wrapping material.

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1. INTRODUCTION

Kiwifruit (*Actinidia deliciosa*), a nutrient-rich subtropical and temperate fruit native to China, has become a commercially significant crop worldwide due to its high vitamin C content, unique flavor, and versatility in both fresh and processed forms (Ferguson, 2016; Costa & Testolin, 2021; Nepal et al., 2025). Global production has expanded rapidly over the past three decades, with major producers including China, Italy, New Zealand, Iran, and Greece collectively accounting for over 80% of output (FAOSTAT, 2023). International demand continues to rise, driven by consumers' interest in functional foods and exotic fruit varieties. In Nepal, Kiwifruit cultivation has expanded steadily in the mid- and high-hill regions since its introduction in the 20th century, with districts such as Dolakha, Makwanpur, and Ilam emerging as key production areas (Rymbai et al., 2022; Rai & Rai, 2024; Rai, 2025; Rai et al., 2025). The crop's adaptability to diverse agro-climatic zones, along with its high market value and export potential, has promoted its adoption as a high-value alternative to major hill crops. However, challenges such as cultivar adaptation, orchard management practices, and propagation inefficiencies continue to constrain productivity.

Top-working is a specialized grafting technique widely utilized in perennial fruit crops to replace underperforming cultivars, rejuvenate aging orchards, or introduce improved genotypes without replanting entire orchards. This technique involves attaching new scion material to established rootstocks, enabling rapid canopy renewal and fruiting, often within two to three years (Ferguson, 2016). In kiwifruit, top-working is particularly useful for correcting sex misidentification in dioecious plants, incorporating disease-tolerant cultivars, and enhancing orchard uniformity (Rai & Rai, 2024; Rai et al., 2026). Furthermore, top-working utilizes existing, well-established root systems, which reduces establishment costs, minimizes juvenile periods, and mitigates environmental stress compared to replanting, aligning with sustainable orchard management principles.

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The success of top-working depends mainly on the timing of the operation, scion-rootstock compatibility, and the choice of wrapping materials that protect the graft union. Seasonal timing influences sap flow, callus formation, and subsequent shoot development, with late winter to early spring generally reported as optimal in temperate climates (Chalise et al., 2021; Nazir et al., 2023). Cultivar-specific traits such as growth vigor, cold tolerance, and bud break patterns also affect graft take rates and vegetative performance (Ferguson, 1991; Khan et al., 2025). Major wrapping materials, such as parafilm, nursery tapes and plastic strips, differ in elasticity, biodegradability, and moisture retention capacity, thereby influencing union healing and shoot growth (Zenginbal, 2007; Sharma et al., 2019).

Despite the demonstrated potential of top-working in kiwifruit orchard management, limited research exists on its optimization under Nepal's diverse hill agro-climatic conditions. Most prior studies have focused on single factors such as grafting methods or cultivar performance without integrating the interactive effects of scion selection, seasonal timing, and wrapping materials on graft success and vegetative vigor (Pandey et al., 2019; Rai & Rai, 2024). The present experiment was conducted in Chitlang, Nepal, to systematically evaluate the effects of three scion cultivars ('Abbott', 'Bruno', and 'Monty'), three wrapping materials (parafilm, green nursery tape, and transparent plastic), and four grafting operation timings (mid-February to late March) on kiwifruit top-working success and early growth performance under temperate mid-hill conditions.

2. MATERIALS AND METHODS

2.1. Study Area and Experimental Orchard Description

The study was conducted in the Kiwifruit orchard of Madan Bhandari University of Science and Technology (MBUST), located approximately 400 meters north of the university premises at Chitlang, Thaha Municipality, Ward No. 9, Makwanpur district of Bagmati Province, Nepal (Fig. 1). The orchard covers an area of 0.25 ha and is managed under fully organic practices.

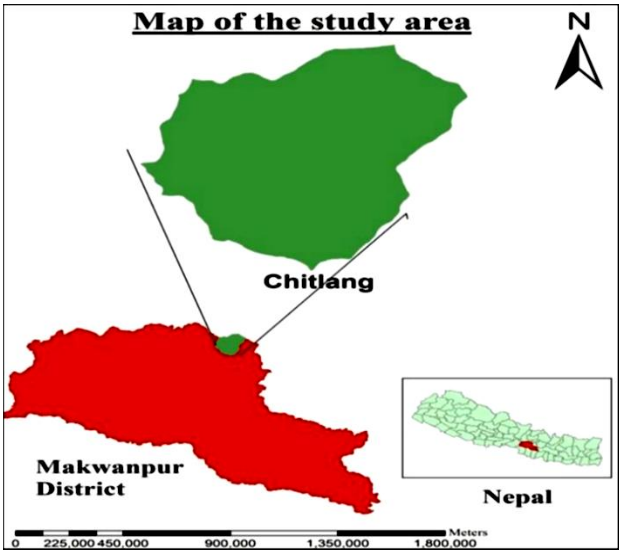

Fig. 1: Study Area (Chitlang, Thaha-9, Makwanpur).

Meteorological data were monitored from January to July 2025 to assess environmental influences on grafting success. The key parameters included wind speed, relative humidity, precipitation, and temperature (Fig. 2A-2D). Wind ranged from 1-4 m/s, humidity from 70-90%, and rainfall was negligible until May. Rainfall increased markedly from May to July, increasing soil water availability and supporting post-grafting growth. Concurrent seasonal increases in air temperature further favored graft union healing and canopy development.

2.2. Experimental Materials and Treatments

As a crucial part of this research, top-working was performed on standing kiwifruit vines in the orchard. The rootstocks were already established and were 2 years old at the time of the grafting operation. The rootstocks were all female cultivars. Scions were carefully selected and collected from the Horticulture Development Centre, Daman, Makwanpur, and the Temperate Fruits Rootstock Development Centre, Boch, Dolakha. The cultivars used in the top-working experiment were 'Abbott', 'Bruno' and 'Monty' (Table 1). Dormant scions are preferable because their lower transpiration rates reduce desiccation and pathogen susceptibility during handling (Hartmann et al., 2011). To preserve physiological integrity, the scions were stored in moist sphagnum moss wrapped in a jute sack, which maintained high humidity and minimized water loss.

Three grafting materials were selected for their practicality and ease of use; parafilm, green nursery tape, and transparent plastic. Parafilm is flexible, self-sealing, biodegradable, and retains moisture (Ferguson, 1991; Costa & Testolin, 2021). Green nursery tape, though non-biodegradable, is durable, water-resistant, and offers strong support (Rymbai et al., 2022). Transparent plastic is recycled, water-resistant, low-cost, and suitable for large-scale use, but lacks elasticity and biodegradability (Hasey, 1994). Grafting were scheduled in 2-week intervals across late winter to early spring to maximize success (Hartmann et al., 2011; Kozlowski & Pallardy, 1996). Cleft grafting was chosen for its simplicity and reliability in woody perennials (Hartmann et al., 2011).

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Table 1: Kiwifruit (*Actinidia deliciosa*) cultivars selected for the experiments

Cultivar	Description	Reason to choose	References
Abbott	Moderate vigor, early flowering; moderately tolerant to disease; limited regional cultivation; used in breeding and as pollen source.	Early flowering and useful in breeding programs; pollen source in orchards with mixed cultivars.	Ferguson (1991)
Bruno	Strong vegetative vigor, upright growth; highly productive and precocious; used as rootstock and fruiting cultivar.	High productivity, disease tolerance, and dual use as scion and rootstock.	Costa & Testolin (2021); Rymbai et al. (2022)
Monty	Vigorous with long internodes; suitable for cold climates; moderately disease-tolerant; limited modern commercial use.	Cold climate adaptability and historical commercial use.	Hartmann et al. (2011)

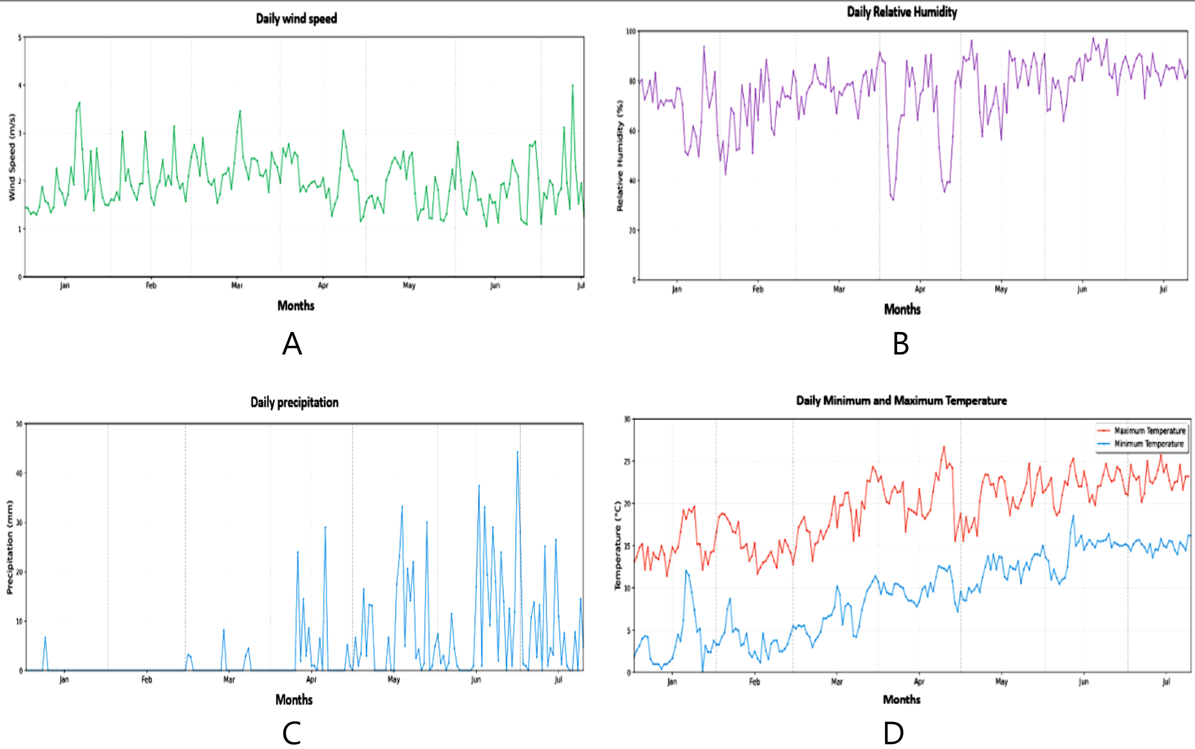

Fig. 2: Recorded meteorological parameters of the study area (A) Daily wind speed during the experiment duration. (B) Daily relative humidity of air during experiment period (C), Precipitation during experiment (D) Daily maximum and minimum temperature during experimental period.

2.3. Experimental Design

The experiment used a three-factor factorial Randomized Complete Block Design (RCBD) to control variability and ensure unbiased comparisons (Gomez & Gomez, 1984; Steel & Torrie, 1980). It evaluated three scion cultivars ('Abbott', 'Bruno', 'Monty'), three wrapping materials (parafilm, green nursery tape and transparent plastic) and four grafting times, producing 36 treatment combinations replicated three times (a total of 108 units). Replications were the vines where grafting operations were done. Each grafted vine was considered a unit, consisting of a single bud. This design enabled analysis of main and interaction effects, minimizing spatial variability and ensuring reliable data for optimizing kiwifruit grafting practices.

2.4. Data Collection and Analysis

The study included several key measurements to assess the growth attributing traits (Table 2). The formula LA = L × W × K was used to estimate leaf area, where L is the maximum leaf length (in cm), W is the maximum leaf width (in cm), and K is the correction factor (Montgomery, 1911). The value of K for kiwifruit leaves in this investigation was 0.73, which is in line with values reported for kiwifruit, based on calibration using 30 traced leaves. The top-working experiment commenced in February 2025 and concluded in July 2025. Grafting operations were carried out during February and March, while data collection was conducted over four months: April, May, June, and July (Ashraf et al., 2020). For each observation, all parameters were observed in a single time point.

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Table 2: The details of growth attributing traits, tools used for their measurement and references

Parameters	Tools	References
Sprout Length (cm)	Standard metric ruler	Hartmann et al., 2011
Sprout Diameter (mm)	Digital vernier caliper	Kozlowski & Pallardy, 1996
Number of leaves	Counting manually of each sprout	Ashraf et al., 2020
Relative chlorophyll index (SPAD unit)	SPAD meter on 3 fully expanded leaves from each sprout	Monje & Bugbee, 1992
Leaf area (cm^2)	Standard metric ruler on 3 fully expanded leaves from each sprout. Length from the base of petiole to tip and breadth from the widest point of the leaf and multiplying with the correction factor (K).	Ashraf et al., 2020
Days to sprouting	The number of days from the date of grafting to the first visible sprout emergence was recorded as "days to sprouting".	Hartmann et al., 2011

Data were analyzed using a linear mixed-effects model to account for the factorial randomized complete block design, where grafting time, cultivar, and wrapping material were treated as fixed effects and block was treated as a random effect. Model assumptions were evaluated by examining residual plots and both normality and homogeneity of variances were satisfied. When significant main or interaction effects were detected, post hoc comparisons were carried out using Tukey's HSD test to separate treatment means while controlling family-wise error. In addition, Pearson's correlation analysis was performed among growth & vegetative traits (sprout length, sprout diameter, number of leaves, relative chlorophyll index, leaf area, and days to sprouting) to assess the strength and direction of interrelationships following standard procedures for agricultural experimental data analysis (Mead, 2017).

3. RESULTS AND DISCUSSION

3.1. Linear Mixed Model (LMM) for growth Attributing Traits in Kiwifruit

The Mixed effects model i.e., LMM (Table 3) showed that the length of the sprouts was greatly affected by the grafting period, cultivar, and wrapping material. Longer sprouts were produced by later grafting dates, most likely as a result of improved genetic, temperature, and humidity conditions (Hartmann et al., 2011). Moisture-retentive wraps like parafilm were believed to promote better shoot growth by preventing graft desiccation (Zenginbal et al., 2006). The interaction between operation timing, cultivar, and wrapping material was significant, with optimal sprout length achieved when these factors were aligned (Hartmann et al., 2011). Less constrictive wraps allowed for more uniform growth (Mudge et al., 2009). The interaction effects were more important than the main effects, showing that optimal anatomical union thickness occurs when time, cultivar, and mechanical conditions are well-matched (Goldschmidt, 2014).

Table 3: The ANOVA of growth attributing traits in kiwifruit (*Actinidia deliciosa*)

Sources of variation	df	Sprout length		Sprout diameter		Number of leaves		Relative chlorophyll index		Leaf area		Days to first sprouting	
		F	Sig.	F	Sig.	F	Sig.	F	Sig.	F	Sig.	F	Sig.
Intercept	1	308.96	***	1366.43	***	516.92	***	1862.81	***	635.03	***	3329.11	***
Operation	3	3.10	*	1.88	ns	4.68	**	4.64	**	8.41	***	15.47	***
Scion cultivars	2	4.88	*	2.83	ns	2.25	ns	2.66	ns	5.90	**	5.75	**
Wrapping materials	2	6.22	**	3.14	*	6.35	**	1.20	ns	5.64	**	2.57	ns
Operation * Scion cultivars	6	4.74	***	3.64	**	3.84	**	2.36	*	5.76	***	2.97	*
Operation * Wrapping materials	6	4.56	***	3.44	**	4.71	***	2.11	ns	4.12	**	2.92	*
Scion cultivars * Wrapping materials	4	3.64	**	1.41	ns	2.40	ns	1.36	ns	2.50	*	1.66	ns
Operation * Scion cultivars * Wrapping materials	12	3.27	***	2.91	**	2.61	**	2.02	*	4.67	***	4.05	***
General mean		109.46		7.29		21.31		36.31		90.90		47.37	

*, **, and *** represent statistically significant at 0.05, 0.01, and 0.001, respectively. ns = non-significant; df = Degree of freedom.

The number of leaves per sprout was significantly influenced by treatments. Later grafting and higher humidity retention may have enhanced leaf expansion (Lee & Oda, 2002; Hartmann et al., 2011). Interaction effects also indicated that specific combinations of operation, cultivar and wrapping material favored leaf proliferation (Ashraf et al., 2020). Relative chlorophyll index was influenced by grafting time and cultivar, with later operations and more vigorous cultivars having higher chlorophyll levels (Lichtenthaler & Wellburn, 1983). Wrapping material had no significant effect, believably suggesting that chlorophyll content depends more on leaf physiological state (Liu et al., 2011).

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Leaf area was larger with optimal grafting timing and vigorous cultivars as found for bruno (Rouphael et al., 2010), and wrapping material as found for parafilm might have helped reduce water stress, promoting leaf expansion (Liu et al., 2011). Interaction effects showed that leaf expansion was maximized when environmental, genetic, and microclimatic conditions were synchronized (Rouphael et al., 2010).

All grafts have been established successfully, resulting in a 100% graft-take across cultivars, wrapping materials, and operation timings. Because no variation was observed, graft success was not subjected to further statistical analysis. However, operation time delayed sprouting in earlier grafts was due to lower temperatures (Hartmann et al., 2011). Cultivar differences affected budbreak, and wrapping material had minimal influence, indicating that budbreak is more dependent on temperature and cultivar (Ahmed et al., 2012).

3.2. Growth Patterns of Growth Attributing Traits

The sprout length (Fig. 3) indicates that late March grafting and parafilm wrapping, were most effective. Grafting on 28th March yielded the longest sprouts. Parafilm enhanced elongation likely by maintaining graft humidity (Zenginbal, 2007). Although Bruno showed slightly higher lengths, environmental and mechanical factors might have had a greater impact than genetic ones (Khan et al., 2025; Chalise et al., 2021). Sprout diameter growth (Fig. 4) showed steady thickening, with the 28th March operation producing the largest diameter by 120 days after topworking, likely due to prolonged cambial activity. Parafilm again facilitated thicker sprouts by improving cambial contact and preventing desiccation (Sharma et al., 2019). Scion cultivars showed minimal variation, reinforcing the influence of wrapping material over genetic factors.

Leaf count (Fig. 5) was highest with the 28th February grafts, especially at 90 and 105 days after topworking, due to parafilm's moisture-retaining properties (Zenginbal, 2007). The 28th February grafts lagged only slightly at 120 days after topworking. Monty exhibited slightly higher leaf counts, but cultivar differences were not statistically significant (Nazir et al., 2023). The relative chlorophyll index (Fig. 6) was highest for the 28th March grafts, suggesting that later grafting prolongs shoot vitality and photosynthetic activity. Wrapping materials and cultivars had minimal effect, though parafilm showed numerically higher values. This suggests that chlorophyll levels are influenced more by grafting time than by scion genotype or wrapping materials.

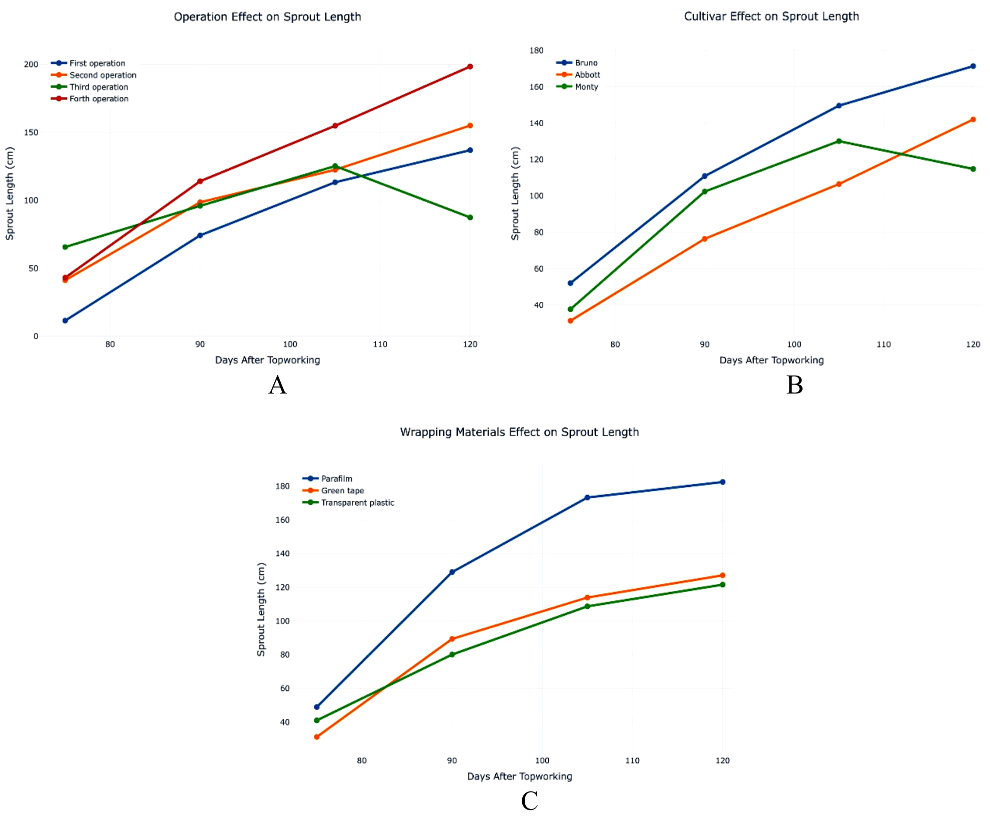

Fig. 3: Average sprout length (A) Across Operation Timings, (B) Across time, different Cultivars, and (C) Across different Wrapping materials.

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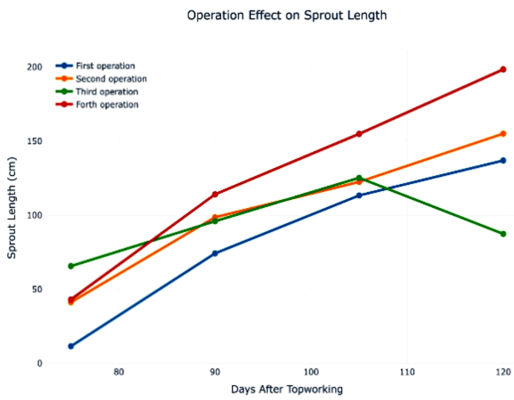
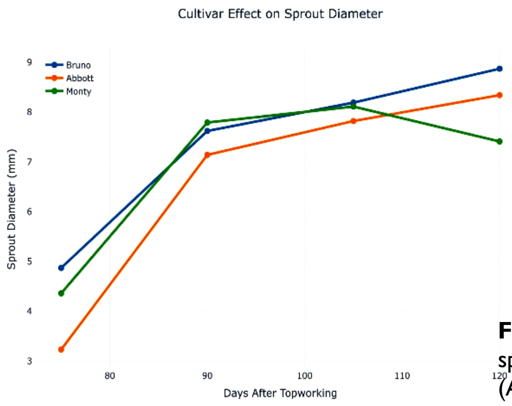


A



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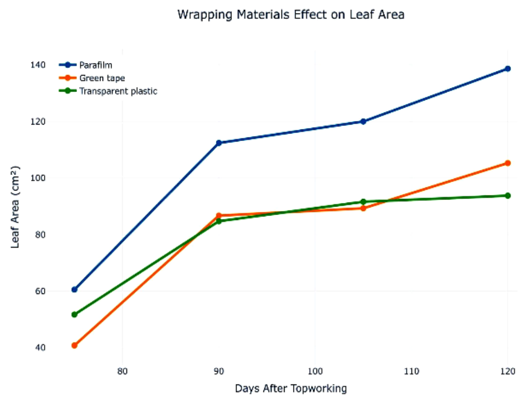

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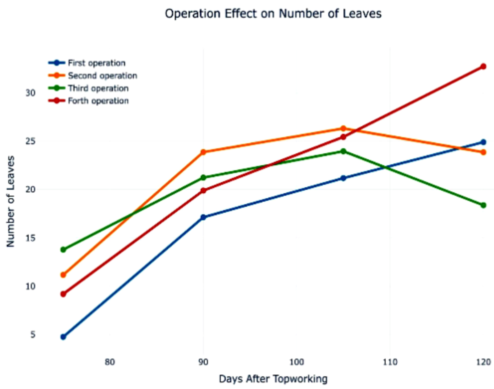
Fig. 4: Average sprout diameter (A) Across Operation Timings, (B) Time difference among Cultivars, and (C) across different Wrapping Materials.



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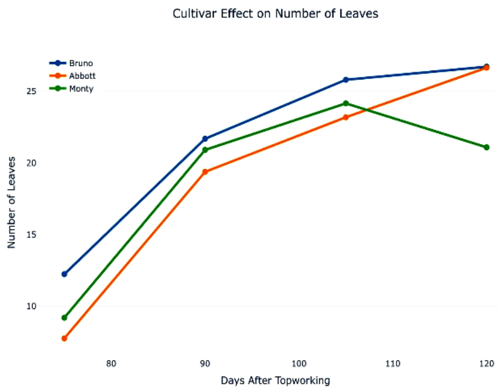

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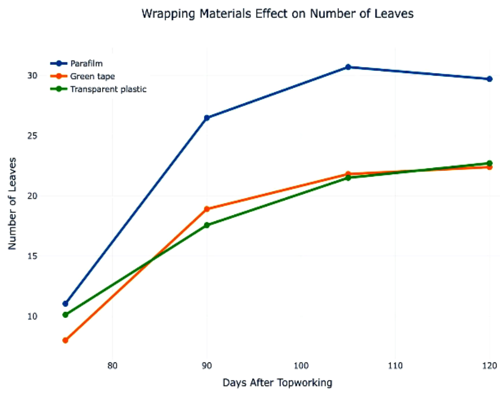

C

Fig. 5: Number of leaves (A) Across Operation Timings, (B) Across Time different Cultivars, and (C) Across different Wrapping Materials.

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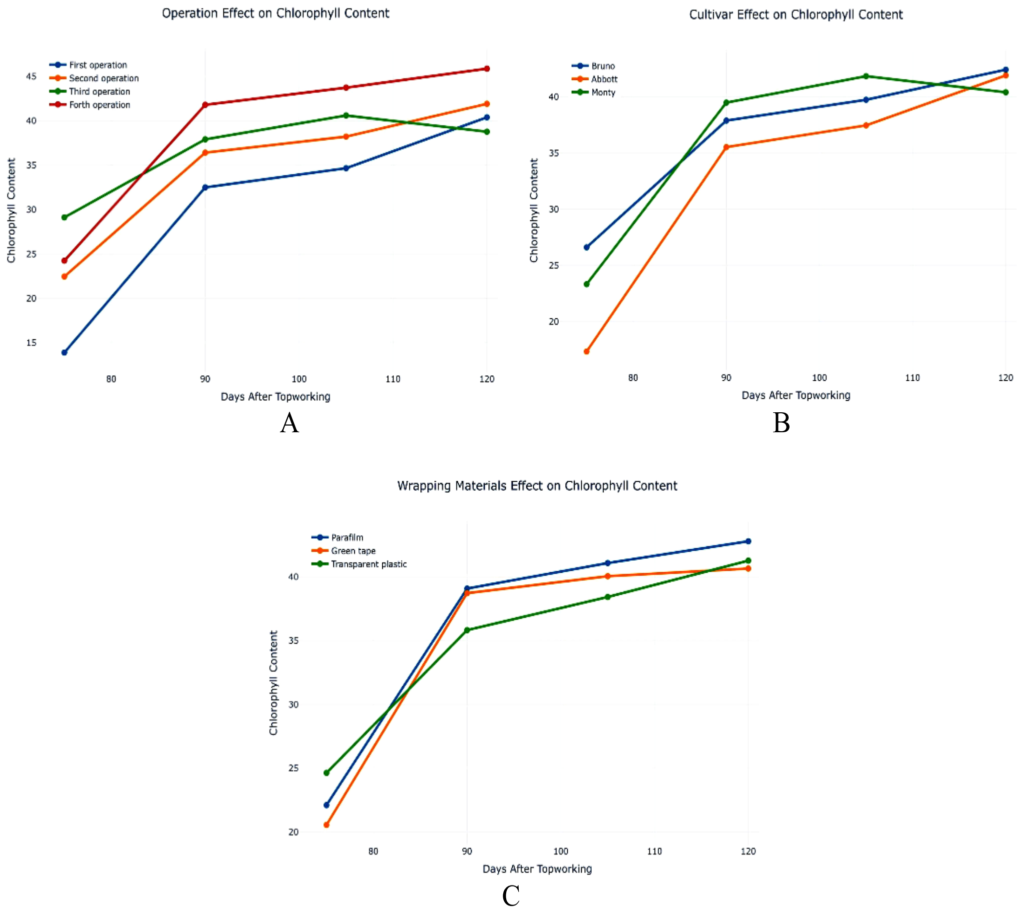

Fig. 6: Relative chlorophyll index (A) Across Operation Timings, (B) Across different Cultivars and (C) Across different Wrapping Materials.

Leaf area (Fig. 7) was significantly larger with later grafting, with the 28th March grafts producing the biggest leaves by 120 days after top working. This supports the connection between delayed bud break and increased leaf size (Nazir et al., 2023). Parafilm facilitated better leaf development through humidity control and faster healing (Chapai et al., 2024). Monty showed larger leaves on average, but genetic effects were overshadowed by environmental conditions (Khan et al., 2025). The 100% graft success obtained in this study may be attributed to careful selection of scion and rootstock material, optimal environmental conditions, and proper execution of grafting operations. While unusually high, similar success rates have been reported under controlled orchard conditions when experienced grafters and vigorous plant material are used (Hartmann et al., 2011). The graphs show that grafting time strongly influenced days to sprouting, with the third operation producing the fastest sprout emergence and the first operation the slowest. Among cultivars, 'Monty' sprouted earliest, while 'Abbott' was the slowest. Wrapping material also mattered, with transparent plastic slightly outperforming parafilm and green tape. Overall, synchronized time, cultivar and wrapping choice reduced days to sprout and improved graft success (Fig. 8).

3.3. Mean Performance of Fixed Factors in Growth Attributing Traits of Kiwifruit

Clear variation among the treatments was observed when their means were compared (Table 4). For operation periods, the 2nd and 4th grafting operations (late February and late March) produced significantly longer sprouts, larger leaf area and higher chlorophyll index (Mudge et al., 2009; Hartmann et al., 2011; Islam Zeb et al., 2017). Early operations with less vigorous cultivars and restrictive wraps performed poorest, likely due to incomplete callus formation under cool conditions (Hu et al., 2016; Pandey et al., 2019).

Parafilm consistently supported higher leaf counts, larger areas, and better sprout diameters by maintaining humidity and reducing stress (Zenginbal, 2007; Liu et al., 2011). Early grafts with less moisture-retentive wraps produced fewer leaves and smaller areas due to limited assimilate supply and delayed union formation (Hartmann et al., 2011). Regarding the performance of cultivars, vigorous cultivars like Bruno showed the highest sprout length, leaf number, and leaf area, while Abbott lagged in most traits and also required more days to sprout (Ashraf et al.,

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2020). Monty performed intermediately but was comparable to Bruno for leaf area and chlorophyll index.

Relative chlorophyll index was highest in Bruno grafted mid- to late season, reflecting physiological maturity and improved photosynthetic capacity (Lichtenthaler & Wellburn, 1983; Çelik et al., 2007). Sprouting was fastest in warm-season grafts, while early operations were delayed by low temperatures. Though wrapping had less effect, elastic wraps like Parafilm slightly hastened budbreak, likely by reducing water loss and enhancing graft protection (Mudge et al., 2009).

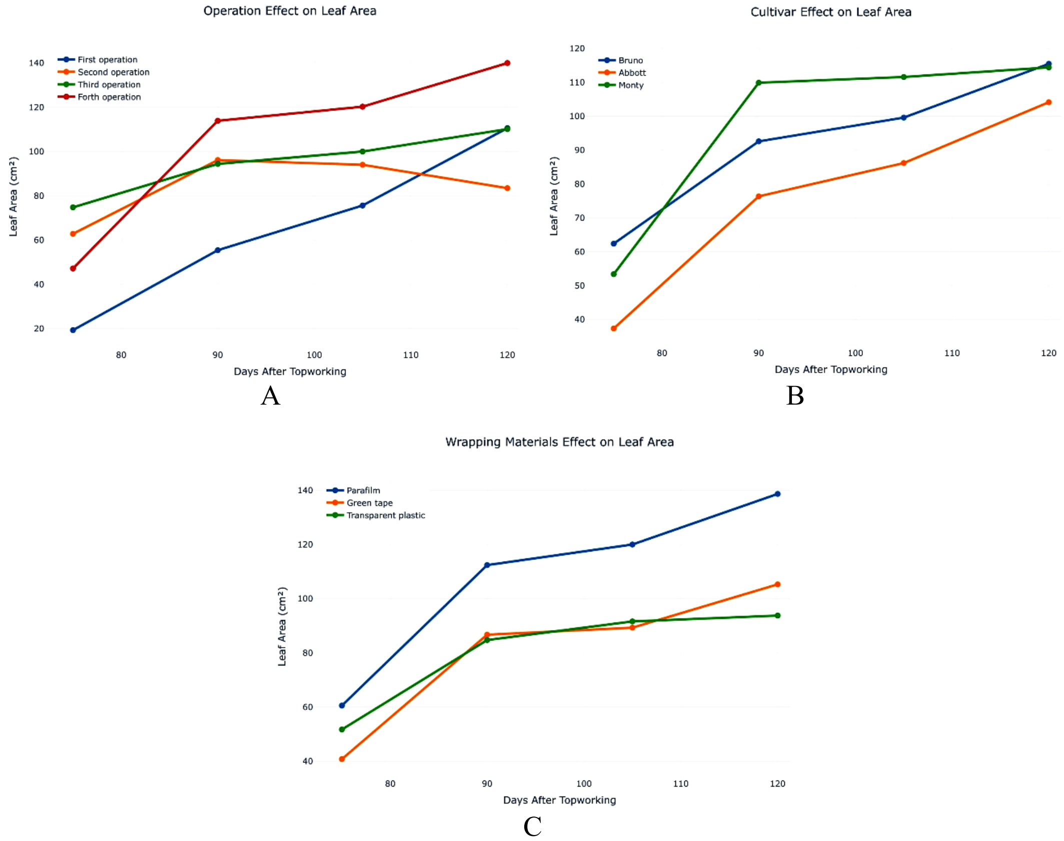

Fig. 7: The leaf Area (A) Across Operation Timings, (B) Across Time, different Cultivars, and (C) Across different Wrapping Materials.

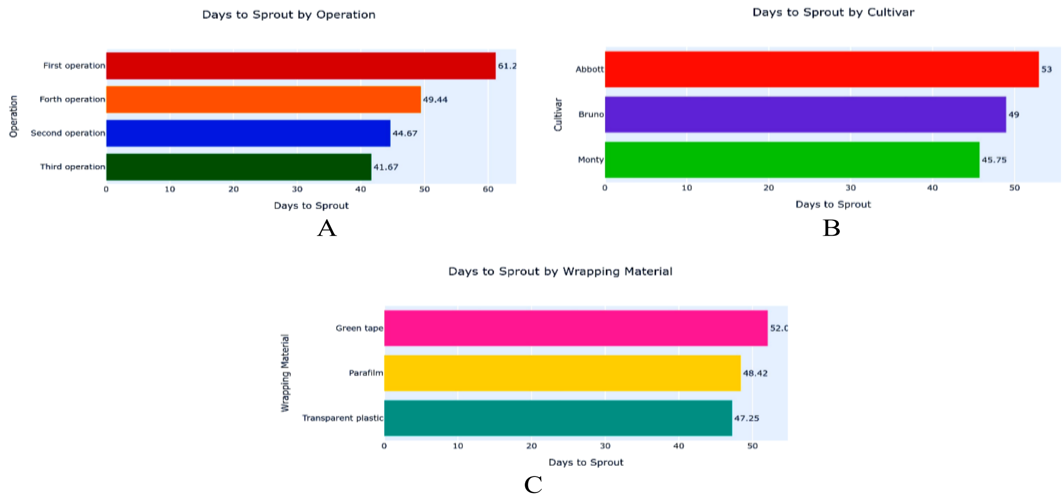

Fig. 8: Days taken to sprout (A) Across Operation Timings, (B) Across Time, different Cultivars, and (C) Across different Wrapping Materials.

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Table 4: Mean performance of different factors in growth attributing traits of kiwifruit (*Actinidia deliciosa*) (Tukey's HSD)

Treatments	Sprout Length(cm)	Sprout Diameter(mm)	No. of Leaves	Relative Chlorophyll Index (SPAD units)	Leaf Area (cm^2)	Days to Sprout
Factor: Operation						
1st operation	78.57^{b}	6.79^{a}	16.83^{b}	31.22^{b}	59.93^{b}	56.81^{a}
2nd operation	125.12^{a}	7.99^{a}	26.66^{a}	38.39^{a}	105.03^{a}	42.78^{b}
3rd operation	109.16^{ab}	6.95^{a}	21.25^{b}	36.27^{a}	96.71^{a}	43.70^{b}
4th operation	124.99^{a}	7.43^{a}	20.50^{b}	39.34^{a}	101.92^{a}	46.19^{b}
Factor: Cultivar						
Bruno	131.08^{a}	7.68^{a}	23.43^{a}	37.78^{a}	98.60^{a}	45.47^{b}
Abbott	83.91^{b}	6.63^{a}	18.65^{a}	33.56^{a}	73.41^{b}	51.31^{a}
Monty	113.39^{ab}	7.57^{a}	21.84^{a}	37.57^{a}	100.68^{a}	45.33^{b}
Factor: Wrapping materials						
Parafilm	140.49^{a}	7.93^{a}	26.02^{a}	38.02^{a}	107.66^{a}	45.03^{a}
Green Tape	92.62^{b}	6.72^{b}	18.65^{b}	36.03^{a}	79.44^{b}	49.58^{a}
Transparent Plastic	95.27^{b}	7.22^{ab}	19.25^{b}	34.86^{a}	85.60^{b}	47.50^{a}
General mean	109.46	7.29	21.31	36.30	90.90	47.37

Different letters indicate significant difference among means.

3.4. Correlation among the Variables

Correlation analysis showed strong positive associations among most growth & vegetative traits. Sprout length was highly correlated with sprout diameter, number of leaves, relative chlorophyll index, and leaf area (Table 5), suggesting that vigorous elongation is accompanied by thicker stems, more foliage, higher chlorophyll status, and larger canopy development (Sharma et al., 2019; Khatik, 2019). Similarly, sprout diameter, number of leaves, relative chlorophyll index, and leaf area were all positively and significantly interrelated, indicating coordinated growth responses. In contrast, days to sprouting showed significant negative correlations with all other traits, implying that earlier bud break is consistently associated with greater vegetative vigor (Sharma et al., 2025). These relationships highlight that rapid and early sprouting favors stronger shoot growth and larger leaf development, which are desirable characteristics for successful top-working in kiwifruit (Sehrawat et al., 2017).

Table 5: Correlation among the various growth attributing traits in Kiwifruit (*Actinidia deliciosa*)

Variables	Sprout length (cm)	Sprout diameter (mm)	Number of leaves	Relative chlorophyll index (SPAD units)	Leaf area (cm^2)	Days to sprout
Sprout length (cm)	1	0.784**	0.929**	0.648**	0.817**	-0.683**
Sprout diameter (mm)		1	0.849**	0.809**	0.809**	-0.565**
Number of leaves			1	0.659**	0.815**	-0.613**
Relative chlorophyll index (SPAD units)				1	0.773**	-0.501**
Leaf area (cm^2)					1	-0.653**
Days to sprout						1

** represents statistically significant at 0.01.

4. CONCLUSION

The study confirmed that the top-working technique is effective for kiwifruit management in Nepal's temperate mid-hills. Mid-season grafting (late February–early March) improved sapling growth traits, including sprout length, diameter, leaf number, relative chlorophyll index, and leaf area. Parafilm was the best wrapping material for graft union healing and shoot elongation. Among cultivars, 'Bruno' and 'Monty' outperformed 'Abbott'. Interactions among timing, cultivar, and wrapping material highlighted the need for synchronization to maximize graft success and early growth. The results provide practical recommendations for growers, while future research should assess long-term outcomes and economic impacts.

Declarations

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Author's Contributions: Developed the research proposal draft, methodology, conducted research, data analysis, wrote the manuscript (draft), revised, and edited. AN: Conducted the research, performed the data analysis, and revised the manuscript. HNG: Reviewed the concept, supervised the first author during the research conduct, revised, edited, and reviewed the manuscript. HKM: Review of concept, supervision of the field research, revising, editing, and rewriting of the manuscript. RR: Conceptualization, preparation of the first draft of the proposal, supervision of the research, data analysis, preparation of the framework of the manuscript, reviewing, editing, and rewriting of the manuscript.

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