RESEARCH ARTICLE
AGROBIOLOGICAL RECORDS
ISSN: 2708-7182 (Print); ISSN: 2708-7190 (Online)
Open Access Journal

GRAFTING OF KIWIFRUIT UNDER GREENHOUSE CONDITIONS: EFFICACY OF SCION CULTIVARS, WRAPPING MATERIALS, TECHNIQUES AND TIME OF OPERATIONS

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ABSTRACT

Kiwifruits (*Actinidia deliciosa*) is gaining importance as a fruit crop in Nepal, yet its propagation is often constrained by low graft success and limited information on optimal cultivars, grafting periods, and wrapping materials. This study evaluated the effects of grafting time, scion cultivar, grafting technique, and wrapping material on early graft performance under temperate conditions in Chitlang, Nepal. A randomized complete block design was employed, including four scion cultivars (Allison, Abbott, Bruno, and Monty), four grafting times from mid-February to late March, three grafting techniques (tongue, cleft, and side grafting), and three wrapping materials (parafilm, green nursery tape, and transparent plastic), resulting in 144 treatment combinations with four replications. Cultivar significantly influenced sprout length, diameter, number of leaves, and days to sprout, with Allison producing the longest sprouts (20.85 cm), moderately thick shoots (4.60 mm), the highest leaf number (9.06), and relatively early sprouting (53.39 days). Wrapping material also had a strong effect, with parafilm producing the highest sprout length (20.72 cm), largest leaf area (45.71 cm²), and highest leaf number (9.23), indicating superior early vegetative development. Grafting technique and operation timing were generally not statistically significant. Overall, 46.01% of grafts successfully sprouted, and survival among sprouted grafts was 93%. These results suggest that late-February grafting with Bruno scions wrapped in parafilm promotes rapid sprout emergence and vigorous early growth, providing practical guidance to improve kiwifruit grafting efficiency and nursery management in Nepal.

Keywords: Kiwifruit, Grafting, Scion cultivar, Wrapping materials, Greenhouse propagation, Sprouting, Vegetative growth traits.

Article History (ABR-26-015) || Received: 14-Jan-2026 || Revised: 28-Feb-2026 || Accepted: 22-Mar-2026 || Published Online: 11-Jul-2026

1. INTRODUCTION

Grafting is a well-established technique for vegetative propagation that connects a scion with a rootstock, allowing them to develop as a single organism. This method is extensively employed in horticulture for clonal propagation and for merging beneficial traits such as vigor, tolerance to stress, resistance to diseases, and high fruit quality (Ak et al., 2021; Rai, 2025a; Rai et al., 2025). In the context of fruit crops, grafting plays a pivotal role in contemporary orchard management by preserving genetic consistency, facilitating the rapid multiplication of outstanding cultivars, and ensuring greater uniformity within the fields and greater disease resistance (Loupit et al., 2023; Habibi et al., 2022; Rai et al., 2026). Its usage in kiwifruit (*Actinidia* spp.) is on the rise, especially as production and marketing expand into new territories (Rai, 2025b; Nepal et al., 2025).

Kiwifruit is dioecious and highly heterozygous, making seed propagation unpredictable due to genetic segregation and sex-related uncertainty (Rai & Rai, 2024). Therefore, grafting is crucial for producing reliable planting material that is true to type and for ensuring the efficient propagation of commercially valuable female cultivars. Through grafting, farmers can pair scions with rootstocks selected for advantageous physiological traits, such as cold resilience and pathogen resistance, while preserving the scion's superior fruiting qualities (Ashraf et al., 2025). Grafting also addresses the frequent problem of sex misidentification in seedlings, as it can transform unproductive male vines into fruitful female plants or help balance sex ratios in orchards (Meena & Singh, 2021).

Propagation in greenhouse settings has further enhanced the efficacy of grafting in kiwifruit. Controlled environments yield higher survival rates by providing ideal humidity, temperature, and shade, resulting in over 90% success in tender-stock grafting techniques (Lal et al., 2014). Greenhouses mitigate losses from desiccation,

Citation: Rai S, Nepal A, Giri HN and Rai R, 2026. Grafting of kiwifruit under greenhouse conditions: efficacy of scion cultivars, wrapping materials, techniques and time of operations. Agrobiological Records 25: 51-59. https://doi.org/10.47278/journal.abr/2026.046

pathogenic attacks, and environmental stress, facilitating year-round propagation, improved scheduling, and the production of uniform, healthy saplings. For nurseries and growers, grafting in protected environments boosts orchard establishment, reduces field mortality, and accelerates the expansion of elite cultivars (Deb & Gangmei, 2019; Mahmoud, 2021; Rymbai et al., 2022).

Despite the recognized benefits of grafting in kiwifruit, significant research deficiencies persist. Few studies have investigated the impact of various grafting methods, wrapping materials, and nursery conditions on graft success and initial growth across different climates and rootstock-scion combinations (Ashraf et al., 2025). There is still a lack of standardized protocols for wrapping, healing conditions, and acclimatization, which limits nursery-level propagation efforts. It is essential to address these gaps to enhance grafting efficiency and fortify kiwifruit production systems in regions such as Nepal, where commercial cultivation is experiencing rapid growth.

2. MATERIALS AND METHODS

2.1. Study Site

The experiment was carried out in the controlled greenhouse facility of Madan Bhandari University of Science and Technology, situated at Thaha Municipality, Ward 9, Makwanpur. This 15×6 square-meter greenhouse operates under fully organic management, which minimizes external chemical interference and thus provides a clean environment for propagation studies. This conforms to the recommendations for controlled grafting research in woody perennials, where microclimatic stability favors union formation (Hartmann et al., 2011). The duration of this study was from February to July 2025. Grafting was done in February-March, when kiwifruit is in a dormant-to-early-active physiological phase. This is a fitting seasonal window because kiwifruit is sensitive to rising spring temperatures and moderate humidity, which affect callus formation and vascular continuity (Kozlowski & Pallardy, 1996; Hartmann et al., 2011). Subsequent data collection was carried out from April to July to capture the relevant vegetative and physiological responses against the backdrop of the transitioning spring-to-summer climate of the mid hills.

2.2. Experimental Materials

The selection of *Actinidia deliciosa* as the study species was made in view of the species' global horticultural importance and its potential for cultivation across Nepal's mid-hill regions. Rootstocks were obtained from the Horticulture Development Centre, Dolakha; scions were obtained from Dolakha and Daman. Four commercial cultivars, namely Abbott, Bruno, Monty, and Allison, which have been extensively exploited in Nepal, have selected for the study (Table 1).

Table 1: Salient features of different scion cultivars used in the experiment

S.N.	Cultivar	Description	Reason to choose	References
1	Abbott	Moderate vigor, early flowering; moderately tolerant to disease; limited regional cultivation; used in breeding and as a pollen source.	Early flowering and useful in breeding programs; pollen source in orchards with mixed cultivars.	Ferguson (1991); Pandey & Tripathi (2014)
2	Bruno	Strong vegetative vigor, upright growth; highly productive and precocious; tolerant to *Psa*; used as rootstock and fruiting cultivar.	High productivity, disease tolerance, and dual-use as both scion and rootstock.	Rymbai et al. (2022); Costa & Testolin (2021)
3	Monty	Vigorous with long internodes; suitable for cold climates; moderately disease-tolerant; limited modern commercial use.	Cold climate adaptability and historical commercial use.	Zhu (1990)
4	Allison	Compact, moderately vigorous; early fruiting; medium to large, market-acceptable fruits; moderate *Psa* resistance; suited to high-density planting.	Early maturity, suitability for hill farming, good market traits.	Rymbai et al. (2022)

Three wrapping materials were compared: parafilm, green nursery tape, and transparent plastic strips. Parafilm is preferred generally in grafting contexts for its elasticity, self-sealing nature, and biodegradability (Ferguson, 1991; Costa & Testolin, 2021). Green nursery tape has been mentioned to have high tensile strength and can thus be used in vigorous woody species (Rymbai et al., 2022). Transparent polyethylene-based plastic strips were included because of their relatively lower cost and easy accessibility under local production systems (Zhu, 1990; Hasey, 1994). Both scions and rootstocks were preserved in damp sphagnum moss and packed in jute bags as suggested by Hartmann et al. (2011), since it assists in higher water retention and sphagnum moss possesses antifungal qualities.

2.3. Experimental Design

The experiment was a factorial Randomized Complete Block Design (RCBD) according to Steel & Torrie (1980) and Gomez & Gomez (1984), suitable for controlling environmental variation in greenhouse conditions. The four factors under test were: cultivar (Abbott, Bruno, Monty), wrapping material (parafilm, green nursery tape, transparent

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ISSN: 2708-7182 (Print); ISSN: 2708-7190 (Online)
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plastic), Technique (Tongue grafting, Side grafting, and Cleft grafting), and time of grafting (four dates between February 12 and March 26). This yielded 144 treatment combinations replicated four times, for 576 experimental units.

The factorial structure allowed investigation of both main effects and interactions among genetic material, mechanical protection, and climatic timing, which is important in woody plant propagation. Since grafting responses can vary substantially with subtle environmental or procedural shifts, a factorial RCBD provides the statistical robustness necessary for valid comparisons and inference. This methodological approach reflects principles outlined in horticultural experimentation standards.

2.4. Procedure

Three grafting methods were compared: tongue, side, and cleft grafting in accordance with recommended propagation methods for the genus *Actinidia* (Hartmann et al., 2011). Procedures were performed by experienced personnel to ensure consistency among treatments. Scions were collected and prepared to lengths of eight to ten centimeters with at least one dormant bud since dormant scions have lower transpiration rates, which favor survival (Hartmann et al., 2011). Each grafting operation took approximately five minutes. Scion tips were wrapped with tape to reduce water loss, according to Kozlowski & Pallardy (1996). Wrapping materials were tied securely to support the graft union for the proper callusing process.

Four grafting events were programmed every two weeks from February 12 to March 28. This interval approach offers an appropriate way to capture the changing environmental conditions, especially temperature and relative humidity, which influence cambial activity in the scion and rootstock. Previous works by Kozlowski & Pallardy (1996) and Hartmann et al. (2011), support the reasons behind the procedure. Post-grafting care included irrigation, weekly weeding, reinforcement of wrapping material as and when necessary, and biological pest control using *Trichoderma* and *Beauveria*. Following recommendations for organic systems by Richardson et al. (2009), bamboo stakes were used to prevent wind damage. Pre-coded aluminum tags enabled accurate treatment identification and monitoring, as reported by Kozlowski & Pallardy (1996).

2.5. Data Collection and Analysis

Greenhouse grafting significantly influences several morphological and physiological parameters in kiwifruit and other fruit crops by optimizing environmental conditions (Rahim Doust et al., 2023). Hence, growth and physiological parameters were measured as outlined below in Table 2 using standard horticultural measurement methods. Sprout length was measured using a standard ruler (Hartmann et al., 2011), the diameter of the sprout using a digital vernier caliper (Kozlowski & Pallardy, 1996), and leaf number by manual count (Ashraf et al., 2020). Chlorophyll content was measured using a SPAD meter on three fully expanded leaves (Monje & Bugbee, 1992). The leaf area was estimated by the correction factor method according to Ashraf et al. (2020); calibration was performed using graph paper tracing 30 leaves in order to determine an appropriate K value which came out to be 0.73.

Table 2: Data collection parameters and instruments used to measure data for grafting in Kiwifruit

S.N.	Parameters	Tools	References
1	Sprout length	Standard metric ruler	Hartmann et al. (2011)
2	Sprout Diameter	Digital vernier caliper	Kozlowski & Pallardy (1996)
3	Number of leaves	Counting each sprout manually	Ashraf et al. (2020)
4	Chlorophyll content	SPAD meter on 3 fully expanded leaves from each sprout	Monje & Bugbee (1992)
5	Leaf area	Using a standard metric ruler of 3 fully expanded leaves from each sprout. Length from the base of the petiole to the tip and breadth from the widest point of the leaf, multiplied by the correction factor (K).	Ashraf et al. (2020)
6	Days to sprouting	The number of days from the date of grafting to the first visible sprout emergence will be recorded as "days to sprouting".	Hartmann et al. (2011)

Graft success, survival, and post-sprouting mortality were calculated using the formula from Pandey et al. (2019). Observations were recorded 60 days after grafting and continued at 15-day intervals up to 120 days.

Percentage of graft success (%)= $\frac{Number\ of\ sprouted\ grafts}{total\ number\ of\ grafts} x\ 100$ (Pandey et al., 2019)

Dead grafts after sprouting (%)= $\frac{Number\ of\ dead\ grafts\ after\ sprouting}{total\ number\ of\ successful\ grafts} x\ 100$ (Pandey et al., 2019)

Survival percentage (%)= $\frac{No.\ of\ successful\ grafts - No. of\ dead\ grafts}{total\ successful\ grafts} x\ 100$ (Pandey et al., 2019)

Data analysis followed factorial RCBD procedures as outlined by Gomez & Gomez (1984). Descriptive statistics were calculated to assess variability. A linear mixed model (LMM) was used to test the main effects and interactions among cultivar, wrapping material, and time of operation. Where differences were significant, mean separation was conducted using Tukey HSD (Mead, 2017). Correlation analyses were performed in order to interpret relationships among the traits.

3. RESULTS AND DISCUSSION

3.1. Sprouting and Survival

Sprouting refers to the phase when a previously dormant bud begins to grow and produces a new shoot. In this investigation, the success rate of grafting was found to be 46.01 percent, while 53.99 percent of attempts were unsuccessful, indicating that grafting kiwifruit is a difficult task as shown in Fig. 2. This challenge is often attributed to physiological incompatibility and the sensitivity of *Actinidia* species to changes in environmental conditions, as reported by previous researchers (Pina & Errea, 2005; Hartmann et al., 2011). The high failure rate is likely due to poor cambial alignment, drying out of the graft surfaces, microbial contamination, or incorrect orientation of the scion and rootstock tissues (Goldschmidt, 2014). Considering the field conditions under which the experiments were conducted, variations in temperature and humidity, along with handling during preparation, likely contributed to the low success rate.

Once a viable graft union was formed, however, plant performance improved significantly (Fig. 1). The survival rate shown in Fig. 2 indicates only a minor mortality following union formation. This implies that the main challenge occurs during the initial phase of union formation rather than during the ongoing maintenance of the grafted plants. Similar research conducted in controlled environments has shown survival rates exceeding 90% once effective vascular connections have been established (Ashraf et al., 2020), which is consistent with the patterns observed in this study. These findings underscore the importance of optimizing the timing of the grafting process, selecting compatible combinations of scions and rootstocks, and ensuring proper wrapping and moisture retention during the initial healing stage. Enhancements in these aspects would help reduce early graft failures and improve the overall efficiency of kiwifruit propagation.

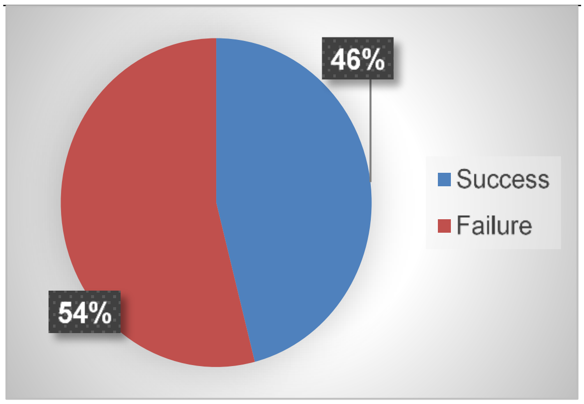

Fig. 1: Grafts success vs. failure in grafting of Kiwifruit.

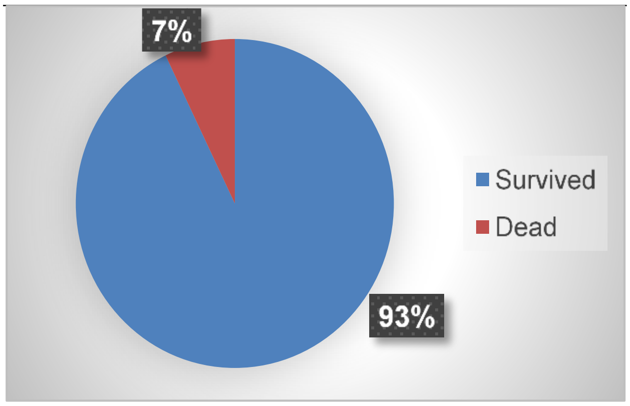

Fig. 2: Grafts survived vs dead in grafting of Kiwifruit.

3.2. Linear Mixed Model Effects of different Factors on Growth Attributing Traits of Kiwifruit

The analysis conducted using the linear mixed model (LMM), as presented in Table 3, revealed that cultivar and wrapping material characteristics were the main factors influencing the early performance of grafted kiwifruit plants in a greenhouse setting. In contrast, the timing of operations and the techniques employed for grafting exhibited relatively weak or inconsistent effects across various traits. Notably, sprout length was significantly affected by the identity of the cultivar (F=5.13, P<0.01) as well as the wrapping materials (F=11.19, P<0.001). This implies that the choice of scion cultivar significantly influences grafting success and subsequent sprout length due to genetic factors that determine compatibility with the rootstock (Long et al., 2022; Pembengo & Adnaya, 2024). Also, the significance of wrapping materials may suggest its ability to reduce water loss from the cut surfaces of the scion and rootstock, creating a humid microenvironment conducive to callus proliferation and differentiation into new vascular tissues (Wang et al., 2024). This observation furthermore underscores the combined impact of genetic vigor inherent to the plants and the moisture-retaining properties of the wrapping on the elongation of shoots, aligning with previous discussions regarding the importance of scion vigor and humidity control in the establishment of grafts (Hartmann et al., 2007; Aloni et al., 2010). Furthermore, the significant interaction between cultivar and technique (F=4.44, P<0.001) suggests that different genotypes respond variably to the grafting methods of tongue, side, or cleft. Additionally, the significant four-way interaction among operation, cultivar, technique, and wrapping material (F=4.12, P< 0.01) indicates that the success of elongation depends on the harmonious integration of biological characteristics and mechanical practices. This finding corroborates earlier assertions about the sensitivity of graft success to multiple interacting factors during the critical stage of union formation (Goldschmidt, 2014).

Table 3: The Linear Mixed Model (LMM) effects of different factors for growth-attributing traits in Kiwifruit (*Actinidia deliciosa*) in Chitlang (2025)

Sources of variation	df	Sprout Length		Sprout Diameter		Number of Leaves		Relative Chlorophyll Index (SPAD Units)		Leaf Area		Days to Sprout	
		F	Sig.	F	Sig.	F	Sig.	F	Sig.	F	Sig.	F	Sig.
Intercept	1	294.55	***	5293.4	***	1110.55	***	8652.46	***	434.49	***	7682.37	***
Operation	3	0.22	ns	1.65	ns	0.51	ns	1.35	ns	1.66	ns	0.09	ns
Cultivar	3	5.13	**	3.81	*	8.85	***	0.16	ns	0.81	ns	6.68	***
Technique	2	0.26	ns	1.02	ns	1.61	ns	2.69	ns	1.69	ns	1.41	ns
Wrapping material	2	11.19	***	2.52	ns	7.73	***	5.55	**	14.78	***	2.34	ns
Operation*cultivar	9	0.47	ns	2.73	**	1.15	ns	5.73	***	0.99	ns	1.71	ns
Operation*technique	6	2.09	ns	1.61	ns	1.21	ns	1.44	ns	2.83	*	1.15	ns
Operation*Wrapping material	6	1.03	ns	2.24	*	1.08	ns	1.44	ns	2.16	*	0.46	ns
Cultivar* technique	6	4.44	***	2.84	*	2.57	*	4.29	***	1.62	ns	1.06	ns
Cultivar*wrapping material	6	1.88	ns	4.11	***	2.44	*	8.89	***	3.45	**	2.48	*
Technique*wrapping material	4	2.09	ns	0.54	ns	0.61	ns	6.35	***	0.61	ns	0.21	ns
Operation*cultivar*technique	14	1.36	ns	1.44	ns	1.26	ns	1.71	ns	2.73	**	1.73	*
Operation*Cultivar*wrapping material	17	0.93	ns	2.34	**	1.28	ns	1.78	*	1.92	*	2.26	**
operation*technique*wrapping material	8	1.19	ns	2.75	**	2.31	*	1.71	ns	3.52	**	1.59	ns
cultivar*technique*wrapping material	8	0.97	ns	3.16	**	0.96	ns	1.99	ns	1.85	ns	1.43	ns
operation*cultivar*technique*wrapping material	4	4.12	**	5.33	***	3.58	**	2.04	ns	3.11	*	3.53	**

The diameter of sprouts exhibited a comparable pattern. The cultivar had a notable impact (F=3.81, P< 0.05), suggesting that genetic factors influence the extent of radial thickening during the initial growth phase. Various interaction effects, such as cultivar by wrapping (F=4.11, P<0.001) and operation by cultivar (F=2.73, P<0.01), underscore the intricate structural processes involved in callus formation and vascular reconnection. This finding aligns with observations that the development of thicker sprouts indicates a more robust vascular bridge and improved assimilate flow (Costa & Testolin, 2021; Agnello, 2019).

The number of leaves varied significantly across cultivars (F=8.85, P<0.001) and wrapping materials (F=7.73, P<0.001). Parafilm consistently yielded higher leaf counts, affirming its effectiveness in preserving humidity and reducing disturbances during union healing, as noted by Noor et al. (2019) and Rashedy & Hamed (2023). Significant interactions, including cultivar by technique (F=2.57, P< 0.05) and cultivar by wrapping (F=2.44, P< 0.05), further emphasize that the development of the canopy is influenced by both genetic characteristics and the micro-environmental conditions at the grafting site.

The relative chlorophyll index exhibited a pronounced response to the type of wrapping material used (F=5.55, P< 0.01), with transparent plastic yielding the highest values. Notable interactions, such as cultivar by wrapping (F=8.89, P<0.001) and technique by wrapping (F=6.35, P<0.001), indicate that chlorophyll accumulation is influenced by both compatibility and nitrogen assimilation during the graft-healing phase. These physiological changes align with previous discussions regarding graft-induced metabolic adjustments (Hartmann et al., 2007).

The leaf area was predominantly affected by the wrapping materials (F=14.78, P<0.001), with parafilm again achieving the highest values due to its excellent humidity-retention capabilities. Several significant interactions were noted, including operation by technique (F=2.83, P<0.05), operation by wrapping (F=2.16, P<0.05), and the three-way interaction of operation by technique by wrapping material (F=3.52, P<0.01). These results illustrate that leaf expansion is contingent not only on the wrapping material but also on the synergistic effects of technical handling and microclimate stability, as previously highlighted by Goldschmidt (2014).

Days to sprouting revealed a significant genotypic effect (F=6.68, P<0.001), with Abbott sprouting the earliest and Monty the latest. While the wrapping material alone did not show significance, the interaction between cultivar and wrapping (F=2.48, P<0.05) suggests that the timing of bud emergence is contingent upon specific combinations of scion and wrapping. The significant four-way interaction (F=3.53, P<0.01) indicates that early bud activation is influenced by a combination of genetic, operational, and micro-environmental factors. The use of moisture-retentive wrapping that accelerates sprouting is consistent with earlier findings regarding bud activation under optimal humidity conditions (Noor et al., 2019).

In summary, the results from the LMM indicate that cultivar identity and wrapping material type are the primary factors influencing early graft performance in kiwifruit. In contrast, the grafting technique and timing of the operation primarily affect outcomes through their interaction effects. These results highlight the necessity for meticulous optimization of both wrapping material and cultivar selection to enhance graft success and promote early vegetative growth.

3.3. Mean Comparison between the Significant Factors

The mean comparison in Table 4 revealed that cultivar identity significantly affected early graft performance. Allison demonstrated the longest sprouts, measuring 20.85 cm, and the highest leaf count at 9.06. In contrast, Monty showed the shortest sprouts at 15.87 cm, the smallest diameter of 4.21 mm, and the fewest leaves, totaling 6.47. This underscores the notable genotypic differences in vegetative vigor as noted by Costa & Testolin (2021) and Rashedy & Hamed (2023). Abbott was the earliest to sprout, taking 49.03 days, while Monty required the longest duration of 58.72 days, indicating variability in bud activation across cultivars.

Table 4: Mean comparison between the fixed factors

Factors	Sprout Length	Sprout Diameter	Number Leaves	of Relative Index	Chlorophyll Leaf Area	Days to Sprout
Operation						
First	17.32a	4.69a	8.46a	32.67a	36.94a	51.76a
Second	16.49a	4.54a	8.14a	32.99a	32.19a	50.95a
Third	18.03a	4.70a	8.39a	32.23a	34.93a	53.64a
Forth	16.52a	4.58a	8.28a	33.06a	35.56a	54.19a
Cultivar						
Allison	20.85a	4.60a	9.06a	32.53a	35.75a	53.39b
Bruno	16.07ab	4.70a	8.81a	31.77a	33.04a	50.84bc
Abbott	15.45b	4.93a	8.67a	33.57a	37.25a	49.03c
Monty	15.87ab	4.21b	6.47b	33.19a	33.42a	58.72a
Technique						
Tongue grafting	18.57a	4.69a	8.47a	33.21a	39.50a	51.24a
Side grafting	17.19a	4.49a	7.93a	31.92a	30.15a	54.98a
Cleft grafting	16.05a	4.67a	8.44a	32.97a	34.93aa	52.36a
Wrapping material						
Parafilm	20.72a	4.82a	9.23a	31.76b	45.71a	51.33a
Green tape	13.29b	4.48a	7.29b	32.62ab	27.55b	54.12a
Transparent plastic	16.28b	4.55a	8.19ab	33.83a	29.92b	53.11a

The type of wrapping material significantly influenced growth and development. Parafilm consistently yielded the greatest sprout length at 20.72 cm, leaf number at 9.23, and leaf area at 45.71 cm^2. This supports the notion that moisture-retentive and elastic wrapping materials enhance post-graft elongation, early hydraulic continuity, and canopy expansion, as evidenced by Noor et al. (2019) and Rashedy & Hamed (2023). Transparent plastic achieved the highest chlorophyll index of 33.83, indicating better pigment stability under controlled humidity and minimized evaporative loss, whereas green tape generally hindered sprout emergence and stunted growth.

The grafting technique exhibited relatively minor effects, with tongue grafting providing a slight advantage in leaf area and sprout length; however, these differences were not as pronounced as those attributed to cultivar and wrapping material. In summary, the findings highlight that the successful establishment of grafts in kiwifruit is predominantly influenced by the selection of cultivar and wrapping material, which collectively regulate elongation, leaf development, chlorophyll stability, and the timing of bud break, while the impact of the grafting technique remains largely secondary, as noted by Goldschmidt (2014).

3.4. Correlation among the Traits

The correlation analysis as mentioned in Table 5, yielded a strong and coherent pattern in growth traits. Sprout length was highly and positively correlated with sprout diameter (r=0.608**), leaf number (r=0.826**), and leaf area (r=0.601**), showing that vigorous elongation was complemented by thickening of shoots and expanding leaf canopy (Noor et al., 2019). Days to sprout showed negative correlation with almost all growth traits, particularly with sprout length (r=-0.434**), number of leaves (r=-0.574**), and leaf area (r=-0.359**), reflecting that the grafts which sprouted earlier established stronger vegetative systems (Goldschmidt, 2014; Rashedy & Hamed, 2023). Sprout diameter, leaf number, and leaf area were also strongly correlated with one another, affirming the view that structural robustness, foliage production, and photosynthetic development ran concurrently. A similar pattern has been revealed

ISSN: 2708-7182 (Print); ISSN: 2708-7190 (Online)
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in grafted tomatoes and cucurbits, in which vegetative traits reinforce one another during post-graft establishment (Lee et al., 2010; Costa & Testolin, 2021).

Table 5: Correlation among the traits measured while grafting in Chitlang

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					
sprout diameter (mm)	0.608**	1				
Number of Leaves	0.826**	0.681**	1			
Relative Chlorophyll Index (SPAD units)	-0.21**	-0.378**	-0.352**	1		
Leaf Area (cm^2)	0.601**	0.529**	0.531**	-0.353**	1	
Days to sprout	-0.434**	-0.439**	-0.574**	0.140*	-0.359**	1

The relative chlorophyll index had moderate negative associations with vegetative growth traits. This is indicative of a dilution effect where rapidly expanding leaves create more surface area but slightly lower pigment concentration per unit area. Despite that, the relationship with days to sprout was mildly positive, r=0.140*, indicating that slower sprouting may allow slightly higher pigment accumulation. Thus, early sprouting and greater structural development were key predictors of grafting success in the greenhouse environment reported by Ashraf et al. (2020).

4. CONCLUSION

This study demonstrates that scion cultivar and wrapping material are the primary factors influencing early graft performance in kiwifruit under temperate greenhouse conditions. Allison exhibited the most vigorous early growth, while parafilm consistently enhanced sprout length, leaf development, and leaf area. Grafting technique and operation timing had minimal direct effects but contributed through interactions with cultivar and wrapping material. Overall, 46.01% of grafts successfully sprouted, with 93% survival among sprouted plants. These findings indicate that selecting vigorous cultivars such as Allison and using moisture-retentive wrapping materials like parafilm can significantly improve graft success and early vegetative development, providing practical guidance for kiwifruit nursery management in Nepal.

Declarations

Funding: This research was carried out with the support of the internal fund of Madan Bhandari University of Science and Technology (MBUST), Chitlang, Thaha Municipality-9, Makwanpur, Bagmati Province, Nepal. There is no other research fund available to carry out this research.

Acknowledgement: The authors would like to express their profound gratitude to Prof. Rajedra Dhoj Joshi, President of Madan Bhandari University of Science and Technology (MBUST), Chitlang, Nepal, for the kind donation of research funds and stipends that made this study possible. We also thank MBUST's administrative personnel for their hard work in making it easier to acquire the required supplies and machinery. In addition, authors would like to express gratitude to Junior Technical Assistant, Asmita Rai and gardener Pradip Zimba for continuous help in maintaining greenhouse.

Conflicts of Interest: The authors declare that they have thoroughly examined and found no competing financial or other known personal interests regarding the works of the article. This declaration is made in the interest of maintaining the integrity and objectivity of our research.

Data Availability: The raw and analyzed datasets are available with corresponding author and would be provided upon reasonable request.

Ethics Statement: Not Applicable as no lives were involved in the experiments.

Author's Contributions: SR: Developed the research proposal draft, methodology, conducted research, data analysis, wrote the manuscript (draft), revised, and edited. AN: Conduct the research, perform the data analysis, and revise the manuscript. HNG: Reviewing the concept, supervising the first author during the research conduct, revising, editing, and reviewing the writing 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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