Effect of grafting time and growing conditions on growth dynamics of ber (*Ziziphus mauritiana*)

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ABSTRACT

The present study was conducted to evaluate the effect of grafting time and growing conditions on growth dynamics of ber (*Ziziphus mauritiana* L) under semi-arid conditions of Hisar, Haryana. The experiment involved wedge grafting of two cultivars, Gola and Umran, at eight different time intervals from the third week of January to the second week of March under open field and polyhouse conditions. The trial was laid out in a randomized block design with three replications. The results revealed that grafting time significantly influenced all growth parameters studied, whereas, growing conditions and cultivars showed variable responses. Grafting during the fourth week of February consistently recorded the highest values for leaf area (1,842.78 cm^2), chlorophyll 'a' (1.004 mg/g FW), chlorophyll 'b' (0.472 mg/g FW), fresh root weight (27.41 g) and dry root weight (15.21 g). In contrast, grafting during the third week of January resulted in the lowest values for most traits. Open field conditions generally performed better than polyhouse conditions in terms of leaf area and chlorophyll content. Among cultivars, Umran exhibited comparatively better vegetative growth, though differences were mostly non-significant. The study highlights that appropriate grafting time plays a crucial role in enhancing physiological efficiency and growth performance in ber. Late February emerged as the most suitable period for grafting under the prevailing agro-climatic conditions.

Keywords: Ber; Grafting time; Growing conditions; Wedge grafting; Growth dynamics; Chlorophyll content; Root biomass; Semi-arid region

INTRODUCTION

Ber (*Ziziphus mauritiana* L), belonging to the family Rhamnaceae, is one of the most important indigenous fruit crops of India and is widely recognized as the King of Arid Fruits. It is predominantly cultivated in the arid and semi-arid regions of India, particularly in Haryana, Punjab, Uttar Pradesh, Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, Andhra Pradesh, Tamil Nadu, West Bengal and Assam (Bal and Randhawa 2007). Ber is a resilient fruit tree well-suited to the arid and semi-arid regions and is well adapted to harsh climatic conditions, low water requirements and poor soil fertility. Its remarkable drought tolerance and ability to grow in marginal areas make it an ideal candidate for sustainable fruit cultivation under low-input systems (Singh and Joseph 2025). The fruits are a rich source of vitamin C, vitamin A, protein and many other essential minerals such as phosphorus (26.80 mg/100 g) and iron (0.76-1.80 mg/100 g) as reported by Morton (1987).

Despite its hardiness and wide adaptability, the productivity of ber remains suboptimal in many parts of the country. Low yield and poor orchard performance are mainly attributed to environmental stresses, erratic rainfall, declining soil health, inferior planting material and traditional management practices. Under such conditions, sustaining ber production requires the adoption of improved propagation techniques and climate resilient planting material. Propagation method plays a decisive role in determining the growth, yield and longevity of ber orchards. Among various vegetative propagation methods, grafting has been widely adopted as a reliable and commercially feasible technique in ber. Grafting enables the

combination of desirable traits of two different plant parts, the scion and the rootstock into a single plant system. The success of grafting depends largely on factors such as scion rootstock compatibility, physiological status of plant material, environmental conditions and grafting technique employed. A few cultivars are known for taste, size, amount of pulp and higher yields. The cultivars Umran, Gola and Kathaphal are the most promising cultivars of ber in north India (Azam-Ali et al 2006). However, the performance of these cultivars varies significantly depending on the rootstock used and prevailing soil and climatic conditions. Therefore, the study was planned to identify the most suitable propagation window and environment for ensuring successful graft union for production of high quality planting material of ber under prevailing agro-climatic conditions.

MATERIAL and METHODS

The experiment was carried out at the experimental orchard, Department of Horticulture, CCS Haryana Agricultural University, Hisar, Haryana, situated at 215.2 m amsl with coordinates of 29º10' N latitude and 75º46' E longitude. The experiment was conducted to study the wedge grafting in two ber cultivars Gola and Umran. One year old ber seedlings were used for grafting at different times viz 3rd week of January (T_1), 4th week of January (T_2), 1st week of February (T_3), 2nd week of February (T_4), 3rd week of February (T_5), 4th week of February (T_6), 1st week of March (T_7) and 2nd week of March (T_8) under polyhouse (medium cost polythene with fan and pad cooling system) and open field conditions. The experiment was laid out in the randomized block design with 32 treatment combinations with 3 replications.

Observations were recorded on leaf area per plant, chlorophyll 'a' content of leaves, chlorophyll 'b' content of leaves, fresh root weight per plant and dry root weight per plant. For the estimation of chlorophyll 'a' and chlorophyll 'b' content of leaves two leaves were collected from the middle of each plant after 90 days of grafting in each treatment. Leaves were washed, dried with filter paper, cut into discs (0.25 g) and dipped in test tubes containing 5 ml of dimethyl sulfoxide (DMSO) overnight as described by Sawhney and Singh (2002). The extracted chlorophyll in DMSO was estimated by recording its absorbance at 663 and 645 nm respectively, with the help of Spectronic 120 and its content was calculated from the following formula:

$$\text{Chlorophyll 'a'} = \frac{12.3 \times A_{663} - (0.86 \times A_{645})}{A \times W} \times V$$

$$\text{Chlorophyll 'b'} = \frac{19.3 \times A_{645} - (3.6 \times A_{663})}{A \times W} \times V$$

where V = Volume of DMSO (ml), A = Path length (cm), W = Weight of tissue taken (g)

The experimental data were analysed using the standard procedure for randomized block design. Analysis of variance (ANOVA) was performed and treatment means were compared using the critical difference test at the 5 per cent level of significance, following Panse and Sukatme (1985). Statistical analysis was carried out using the OPSTAT software developed by Sheoran et al (1998).

RESULTS and DISCUSSION

Leaf area per plant

Table 1 indicates that grafting time, growing conditions and cultivars significantly influenced leaf area per plant at 90 days after grafting. Across cultivars and environments, grafting in the fourth week of February produced the maximum leaf area (1,842.78 cm²), whereas, grafting in the third week of January resulted in the minimum (571.99 cm²), confirming the critical role of grafting time in regulating vegetative growth, as also reported by Dewangan et al (2022).

Plants grown under open field conditions recorded a significantly higher leaf area (1,201.94 cm²) than those under polyhouse conditions (1,149.76 cm²) across grafting periods and cultivars. Among cultivars, Umran consistently exhibited greater leaf area (1,200.50 cm²) than Gola (1,151.21 cm²), irrespective of grafting time and environment, corroborating the observations of Kumari et al (2023). A significant interaction between grafting time and growing conditions was observed, with the highest leaf area (1,936.29 cm²) recorded in plants grafted during the fourth week of February and the lowest (513.96 cm²) in those grafted during the third week of January under open field conditions. Similarly, the cultivars and grafting time interaction was significant, as Umran grafted in late February produced the maximum leaf area (1,907.87 cm²), while the same cultivar grafted in January showed one of the lowest values (571.96 cm²). In contrast, the cultivars and growing conditions interaction and the three way interaction were non-significant. These

Table 1. Effect of grafting time, growing conditions and cultivars on total leaf area per plant (cm^2) of ber (Grafting time × Growing conditions × Cultivars)

Grafting time	Gola		Umran		Mean
	Open field	Polyhouse	Open field	Polyhouse	
T_1	524.60	619.45	503.33	640.60	571.99
T_2	631.84	760.35	629.69	767.05	697.23
T_3	785.92	903.13	838.31	934.32	865.42
T_4	1,135.55	992.11	1,112.71	1,026.97	1,066.84
T_5	1,453.44	1,320.75	1,405.27	1,339.17	1,379.66
T_6	1,864.89	1,690.49	2,007.69	1,808.04	1,842.78
T_7	1,595.42	1,465.86	1,767.60	1,598.89	1,606.94
T_8	1,437.68	1,237.79	1,537.15	1,291.14	1,375.94
Mean	1,178.67	1,123.74	1,225.22	1,175.77	

Table 1. Contd….. (Growing conditions × Grafting time)

Growing condition	Grafting time								Mean
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	
Open field	513.96	630.77	812.12	1,124.13	1,429.36	1,936.29	1,681.51	1,487.41	1,201.94
Polyhouse	630.03	763.70	918.73	1,009.54	1,329.96	1,749.27	1,532.38	1,264.46	1,149.76
Mean	571.99	697.23	865.42	1,066.84	1,379.66	1,842.78	1,606.94	1,375.94	

Table 1. Contd….. (Cultivars × Grafting time)

Cultivar	Grafting time								Mean
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	
Gola	572.03	696.10	844.53	1,063.83	1,387.10	1,777.69	1,530.64	1337.73	1,151.21
Umran	571.96	698.37	886.32	1,069.84	1,372.22	1,907.87	1,683.24	1414.14	1,200.50
Mean	571.99	697.23	865.42	1,066.84	1,379.66	1,842.78	1,606.94	1375.94	

Table 1. Contd….. (Cultivars × Growing conditions)

Cultivar	Growing condition		Mean
	Open field	Polyhouse	
Gola	1,178.67	1,123.74	1,151.21
Umran	1,225.22	1,175.77	1,200.50
Mean	1201.94	1149.76	

$CD_{0.05}$

Grafting time: 28.37, Growing conditions: 14.18, Cultivars: 14.18, Growing conditions × Grafting time: 40.12, Cultivars × Grafting time: 40.12, Cultivars × Growing conditions: NS, Grafting time × Growing conditions × Cultivars: NS

T_1: 3rd week of January, T_2: 4th week of January, T_3: 1st week of February, T_4: 2nd week of February, T_5: 3rd week of February, T_6: 4th week of February, T_7: 1st week of March, T_8: 2nd week of March, NS: Non-significant

results align with Yu et al (2025), who emphasized that optimized grafting practices enhance physiological efficiency and overall plant growth.

Chlorophyll 'a' content of leaves

Data in Table 2 show that grafting time and growing conditions significantly affected chlorophyll 'a' content, whereas, cultivar differences were not statistically significant. Across environments and cultivars, the highest chlorophyll 'a' concentration {1.004 and 0.962 mg/g fresh weight (FW)} occurred in plants grafted during the fourth week of January and the first week of March respectively, which were at par. The lowest value (0.727 mg/g FW) was recorded in the third week of January. Plants grown under open field conditions exhibited significantly higher chlorophyll 'a' content (0.893 mg/g FW) than those in polyhouse conditions (0.868 mg/g FW), irrespective of grafting time and cultivar, consistent with reports linking environmental conditions to chlorophyll concentration and physiological activity (Elshahat et al 2025). The grafting time and growing conditions interaction was significant. Maximum chlorophyll 'a' content was obtained with grafting in the fourth week of February (1.013 mg/g FW), first week of March (0.978 mg/g FW), third week of March (0.958 mg/g FW) and second week of March (0.954 mg/g FW) under open field and fourth week of February (0.994 mg/g FW) under polyhpuse, which were at par.

The interaction between cultivars and grafting time, cultivars and growing conditions and three way interaction were non-significant. Fan et al (2022) reported improved chlorophyll content following grafting.

These findings agree with earlier studies linking improved nutrient availability and physiological efficiency to enhanced chlorophyll synthesis and greater photosynthetic capacity (Wang et al 2022).

Chlorophyll 'b' content of leaves

Data in Table 3 indicate that chlorophyll 'b' content was significantly influenced by grafting time. Across cultivars and environments, plants grafted during the fourth week of February recorded the highest chlorophyll 'b' content (0.472 mg/g FW), while the lowest value (0.257 mg/g FW) occurred in the third week of January.

Enhanced pigment accumulation under favourable environments has previously been associated with improved nutrient uptake and metabolic activity (Shahab et al 2013). The grafting time and growing conditions interaction was significant, with the maximum chlorophyll 'b' content (0.492 and 0.464 mg/g FW) observed in plants grafted during the fourth week of February and first week of March respectively, in open filed. The minimum chlorophyll 'b'content was observed in plants grafted in third week of January in open field (0.254 mg/g FW), in third week of January in polyhouse (0.261 mg/g FW) and fourth week of February in open field (0.272 mg/g FW), all being at par.

Disruptions in chlorophyll metabolism are known to impair photosynthesis and enzymatic activity, thereby, limiting pigment accumulation (Xiong et al 2023). The interactions of cultivars with grafting time and growing conditions were not significant. The three way interaction was also not significant. Chlorophyll concentration is strongly related to photosynthetic efficiency and nitrogen status key determinants of plant productivity as reported in apple (Ta et al 2021).

Fresh root weight

The data related to fresh root weight presented in Table 4 indicate that all treatments were found to be non-significant except grafting time, which influenced the fresh root weight. The plants grafted during the 4th week of February recorded the maximum fresh root weight (27.41 g), whereas, the minimum was observed in plants grafted during the 3rd week of January (18.54 g), irrespective of growing conditions and cultivars.

Similar findings regarding the effect of scion varieties on growth and biomass production in mango grafts were reported by Bobade et al (2018). All possible interactions among grafting time, growing conditions and cultivars were found to be non-significant. The results are in agreement with the findings of Fullana-Pericas et al (2020), who reported that grafting can influence plant physiological performance and biomass accumulation.

Dry root weight

The data in Table 5 indicate that grafting time significantly affected dry root weight, whereas, growing conditions and cultivar differences were non-significant. Across cultivars and environments, the highest dry root weight (15.21 g) was recorded in plants grafted during the fourth week of February, while the lowest value (10.81 g) was observed in third weekin of January. Overall, both fresh and dry root weights

Table 2. Effect of grafting time, growing conditions and cultivars on chlorophyll 'a' content of ber leaves (mg/g of fresh weight) (Grafting time × Growing conditions × Cultivars)

Grafting time	Gola		Umran		Mean
	Open field	Polyhouse	Open field	Polyhouse	
T_1	0.720	0.770	0.695	0.724	0.727
T_2	0.729	0.802	0.774	0.819	0.781
T_3	0.864	0.810	0.823	0.829	0.832
T_4	0.942	0.828	0.933	0.843	0.887
T_5	0.957	0.910	0.959	0.922	0.937
T_6	1.023	1.008	1.002	0.981	1.004
T_7	0.992	0.956	0.965	0.935	0.962
T_8	0.934	0.854	0.974	0.902	0.916
Mean	0.895	0.867	0.891	0.869	

Table 2. Contd….. (Growing conditions × Grafting time)

Growing condition	Grafting time								Mean
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	
Open field	0.708	0.752	0.843	0.938	0.958	1.013	0.978	0.954	0.893
Polyhouse	0.747	0.810	0.820	0.836	0.916	0.994	0.946	0.878	0.868
Mean	0.727	0.781	0.831	0.887	0.937	1.003	0.962	0.916	

Table 2. Contd….. (Cultivars × Grafting time)

Cultivar	Grafting time								Mean
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	
Gola	0.745	0.765	0.837	0.885	0.934	1.015	0.974	0.894	0.881
Umran	0.710	0.796	0.826	0.888	0.941	0.992	0.950	0.938	0.880
Mean	0.727	0.781	0.831	0.887	0.937	1.003	0.962	0.916	

Table 2. Contd….. (Cultivars × Growing conditions)

Cultivar	Growing condition		Mean
	Open field	Polyhouse	
Gola	0.895	0.867	0.881
Umran	0.891	0.869	0.880
Mean	0.893	0.868	

$CD_{0.05}$

Grafting time: 0.043, Growing conditions: 0.022, Cultivars: NS, Growing conditions × Grafting time: 0.062, Cultivars × Grafting time: NS, Cultivars × Growing conditions: NS, Grafting time × Growing conditions × Cultivars: NS

T_1: 3rd week of January, T_2: 4th week of January, T_3: 1st week of February, T_4: 2nd week of February, T_5: 3rd week of February, T_6: 4th week of February, T_7: 1st week of March, T_8: 2nd week of March, NS: Non-significant

Table 3. Effect of grafting time, growing conditions and cultivars on chlorophyll 'b' content of ber leaves (mg/g of fresh weight) (Grafting time × Growing conditions × Cultivars)

Grafting time	Gola		Umran		Mean
	Open field	Polyhouse	Open field	Polyhouse	
T_1	0.259	0.261	0.248	0.261	0.257
T_2	0.260	0.291	0.283	0.285	0.280
T_3	0.323	0.334	0.300	0.328	0.321
T_4	0.352	0.317	0.329	0.319	0.329
T_5	0.379	0.367	0.435	0.402	0.396
T_6	0.498	0.455	0.486	0.450	0.472
T_7	0.475	0.442	0.454	0.417	0.447
T_8	0.317	0.328	0.305	0.337	0.322
Mean	0.358	0.349	0.355	0.350	

Table 3. Contd….. (Growing conditions × Grafting time)

Growing condition	Grafting time								Mean
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	
Open field	0.254	0.272	0.312	0.340	0.407	0.492	0.464	0.311	0.357
Polyhouse	0.261	0.288	0.331	0.318	0.385	0.452	0.429	0.332	0.350
Mean	0.257	0.280	0.321	0.329	0.396	0.472	0.447	0.322	

Table 3. Contd….. (Cultivars × Grafting time)

Cultivar	Grafting time								Mean
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	
Gola	0.260	0.276	0.329	0.335	0.373	0.477	0.458	0.322	0.354
Umran	0.255	0.284	0.314	0.324	0.419	0.468	0.435	0.321	0.352
Mean	0.257	0.280	0.321	0.329	0.396	0.472	0.447	0.322	

Table 3. Contd….. (Cultivars × Growing conditions)

Cultivar	Growing condition		Mean
	Open field	Polyhouse	
Gola	0.358	0.349	0.354
Umran	0.355	0.350	0.352
Mean	0.357	0.350	

$CD_{0.05}$

Grafting time: 0.020, Growing conditions: NS, Cultivars: NS, Growing conditions × Grafting time: 0.028, Cultivars × Grafting time: NS, Cultivars × Growing conditions: NS, Grafting time × Growing conditions × Cultivars: NS

T_1: 3rd week of January, T_2: 4th week of January, T_3: 1st week of February, T_4: 2nd week of February, T_5: 3rd week of February, T_6: 4th week of February, T_7: 1st week of March, T_8: 2nd week of March, NS: Non-significant

Table 4. Effect of grafting time, growing conditions and cultivars on fresh root weight (g/plant)of ber (Grafting time × Growing conditions × Cultivars)

Grafting time	Gola		Umran		Mean
	Open field	Polyhouse	Open field	Polyhouse	
T_1	17.43	19.52	18.63	18.59	18.54
T_2	19.91	20.50	19.32	20.31	20.01
T_3	21.34	21.63	21.56	21.24	21.44
T_4	23.87	22.17	21.75	22.93	22.68
T_5	24.33	23.05	23.50	23.13	23.50
T_6	28.33	27.18	27.87	26.27	27.41
T_7	25.34	24.52	25.73	24.67	25.06
T_8	23.52	22.43	23.26	23.72	23.23
Mean	23.01	22.62	22.70	22.61	

Table 4. Contd….. (Growing conditions × Grafting time)

Growing condition	Grafting time								Mean
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	
Open field	18.03	19.62	21.45	22.81	23.92	28.10	25.54	23.39	22.86
Polyhouse	19.05	20.41	21.43	22.55	23.09	26.73	24.59	23.08	22.62
Mean	18.54	20.01	21.44	22.68	23.50	27.41	25.06	23.23	

Table 4. Contd….. (Cultivars × Grafting time)

Cultivar	Grafting time								Mean
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	
Gola	18.47	20.21	21.49	23.02	23.69	27.76	24.93	22.98	22.82
Umran	18.61	19.82	21.40	22.34	23.31	27.07	25.20	23.49	22.66
Mean	18.54	20.01	21.44	22.68	23.50	27.41	25.06	23.23	

Table 4. Contd….. (Cultivars × Growing conditions)

Cultivar	Growing condition		Mean
	Open field	Polyhouse	
Gola	23.01	22.63	22.82
Umran	22.70	22.61	22.66
Mean	22.86	22.62	

$CD_{0.05}$

Grafting time: 0.88, Growing conditions: NS, Cultivars: NS, Growing conditions × Grafting time: NS, Cultivars × Grafting time: NS, Cultivars × Growing conditions: NS, Grafting time × Growing conditions × Cultivars: NS

T_1: 3rd week of January, T_2: 4th week of January, T_3: 1st week of February, T_4: 2nd week of February, T_5: 3rd week of February, T_6: 4th week of February, T_7: 1st week of March, T_8: 2nd week of March, NS: Non-significant

Table 5. Effect of grafting time, growing conditions and cultivars on dry root weight (g/plant) of ber (Grafting time × Growing conditions × Cultivars)

Grafting time	Gola		Umran		Mean
	Open field	Polyhouse	Open field	Polyhouse	
T_1	10.50	11.09	10.42	11.21	10.81
T_2	11.33	11.64	10.67	11.48	11.28
T_3	12.30	12.21	11.55	11.56	11.90
T_4	12.38	12.33	12.76	12.40	12.47
T_5	13.53	12.49	13.45	13.24	13.18
T_6	15.74	14.80	15.60	14.70	15.21
T_7	14.67	14.30	14.60	13.68	14.31
T_8	13.26	13.33	12.77	13.17	13.13
Mean	12.96	12.77	12.73	12.68	

Table 5. Contd….. (Growing conditions × Grafting time)

Growing condition	Grafting time								Mean
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	
Open field	10.80	11.48	12.26	12.36	13.01	15.27	14.48	13.30	12.87
Polyhouse	10.82	11.07	11.55	12.58	13.35	15.15	14.14	12.97	12.70
Mean	10.81	11.28	11.90	12.47	13.18	15.21	14.31	13.13	

Table 5. Contd….. (Cultivars × Grafting time)

Cultivar	Grafting time								Mean
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	
Gola	10.46	11.00	11.92	12.57	13.49	15.67	14.64	13.02	12.84
Umran	11.15	11.56	11.89	12.37	12.87	14.75	13.99	13.25	12.73
Mean	10.81	11.28	11.90	12.47	13.18	15.21	14.31	13.13	

Table 5. Contd….. (Cultivars × Growing conditions)

Cultivar	Growing condition		Mean
	Open field	Polyhouse	
Gola	12.96	12.77	12.87
Umran	12.73	12.68	12.70
Mean	12.84	12.73	

$CD_{0.05}$

Grafting time: 0.39, Growing conditions: NS, Cultivars: NS, Growing conditions × Grafting time: NS, Cultivars × Grafting time: NS, Cultivars × Growing conditions: NS, Grafting time × Growing conditions × Cultivars: NS

T_1: 3rd week of January, T_2: 4th week of January, T_3: 1st week of February, T_4: 2nd week of February, T_5: 3rd week of February, T_6: 4th week of February, T_7: 1st week of March, T_8: 2nd week of March, NS: Non-significant

were greatest in late February grafted plants and lowest in mid-January grafts, suggesting that favourable grafting periods enhance shoot growth and assimilate translocation to roots. Increased root biomass has been linked to greater root number and length (Ingle and Venugopal 2009), while conducive environmental conditions promote root stimulating substances (Hussain et al 2016).

CONCLUSION

The present investigations clearly demonstrated that grafting time is a critical factor influencing growth dynamics in ber, while growing conditions and cultivar effects were comparatively less pronounced. Grafting performed during the fourth week of February resulted in superior performance across all major growth parameters, including leaf area, chlorophyll content and root biomass.

Open field conditions generally favoured better physiological and growth responses compared to polyhouse conditions. Although cultivar differences were mostly non-significant, cv Umran showed a slight advantage in vegetative growth traits. Overall, the findings suggest that late February is the most favourable grafting window for successful graft establishment and improved growth in ber under semi-arid conditions of Haryana. Adoption of this optimal grafting period can enhance the production of quality planting material and contribute to improved orchard performance.

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