Effect of Growing Conditions and Grafting Time on Root Parameters, Plant Survival and Economics of Softwood Grafting in Sweet Orange (*Citrus sinensis* L. Osbeck) cv. Nucellar

Radhika V. Mhaskey[1*], Santosh R. Barkule[2], Shivaji J. Shinde[3] and Tushar D. Belkhode[4]
[1]*M. Sc. (Hort.) Scholar, Department of Horticulture, VNMKV, Parbhani.*
[2]*Associate Professor, Department of Horticulture, VNMKV, Parbhani.*
[3]*Professor & Incharge, Banana Research Station, Nanded.*
[4]*M. Sc. (Hort.) Scholar, Department of Horticulture, VNMKV, Parbhani.*

Abstract: *The present study was conducted during 2024–2025 at the Central Nursery, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, to evaluate the effect of growing conditions and grafting time on root parameters, plant survival and economics of softwood grafting in sweet orange (Citrus sinensis L. Osbeck) cv. Nucellar under open field and polyhouse conditions at 15 days interval from 15th July to 30th October. The interaction between growing conditions and grafting time revealed that, the C_2D_3 combination (polyhouse, 15th August) was the most effective, recording the highest values for root length (44.50 cm), primary root diameter (9.20 mm), number of secondary roots (34.90), fresh root weight (19.80 g), dry root weight (7.40 g), and plant survival (98.90%). This treatment also achieved the maximum benefit–cost ratio (1.86), highlighting its technical and economic feasibility for large-scale commercial propagation of sweet orange.*

Keywords: *Grafting time, growing conditions, nucellar, softwood grafting, sweet orange*

Introduction

Sweet orange (*Citrus sinensis* L. Osbeck), is a member of the family Rutaceae (2n = 18), which is most popular fruit worldwide. It is believed to have originated from hybridization among early citrus species, with its cultivation traced back to China, Southeast Asia, and the Malay Archipelago, from where it spread globally (Xu *et al*., 2013; Atta *et al*., 2012) [18,3]. Today, it is widely grown across tropical and subtropical regions. The tree of sweet orange is a shallow-rooted woody perennial, 6–15 m tall, bearing fragrant white flowers and round fruits containing 40–50% juice. The peel comprises flavedo, albedo and vascular bundles, with the flavedo rich in carotenoids and essential oils like valencene and limonene (Goudeau *et al*., 2008; Sharon-Asa *et al*., 2003) [6,16]. Conventionally, sweet orange is propagated by seed or T-budding. However, T-budding requires 18–20 months for production of quality planting material and often transmits viral diseases, contributing to citrus decline (Ahlawat, 1997; Gopi *et al*., 2010) [1,4]. To meet the increasing demand for planting material, faster and safer methods like softwood grafting are being explored. This technique enables rapid multiplication, reduces nursery duration, and produces quality planting material. The success of softwood grafting depends on appropriate timing and favourable growing conditions. Suitable temperature and humidity enhance plant activity, carbohydrate accumulation, and sprouting (Anil *et al*., 2022) [2]. Protected structures such as polyhouses provide these conditions, ensuring better callus formation, stronger graft unions, and higher survival (Priyanka *et al*., 2023) [13]. Considering this, the present investigation was undertaken to study the effect of growing conditions and grafting time on root parameters, plant survival, and economics of softwood grafting in sweet orange (*Citrus sinensis* L. Osbeck) cv. Nucellar**.**

Materials and methods

The present investigation entitled "Effect of growing conditions and grafting time on root parameters, plant survival and economics of softwood grafting in sweet orange (*Citrus sinensis* L. Osbeck) cv. Nucellar" was carried out during 2024-2025 at the Central Nursery, Vasantrao Naik Marathwada Krishi Vidyapeeth Parbhani. The experiment was laid out in a factorial randomized block design consisting of sixteen different treatments with two replications.

Table 1: Treatment Details

Sr. No.	Treatments	Treatment combinations	Treatment details
1.	T_1	C_1D_1	Open field + 15th July grafting
2.	T_2	C_1D_2	Open field + 30th July grafting
3.	T_3	C_1D_3	Open field + 15th August grafting
4.	T_4	C_1D_4	Open field + 30th August grafting
5.	T_5	C_1D_5	Open field + 15th September grafting
6.	T_6	C_1D_6	Open field + 30th September grafting
7.	T_7	C_1D_7	Open field + 15th October grafting
8.	T_8	C_1D_8	Open field + 30th October grafting
9.	T_9	C_2D_1	Polyhouse + 15th July grafting
10.	T_{10}	C_2D_2	Polyhouse + 30th July grafting
11.	T_{11}	C_2D_3	Polyhouse + 15th August grafting
12.	T_{12}	C_2D_4	Polyhouse + 30th August grafting
13.	T_{13}	C_2D_5	Polyhouse + 15th September grafting
14.	T_{14}	C_2D_6	Polyhouse + 30th September grafting
15.	T_{15}	C_2D_7	Polyhouse + 15th October grafting
16.	T_{16}	C_2D_8	Polyhouse + 30th October grafting

In this study, one-month-old nucellar scion shoots of sweet orange (about 10 cm long and 3 mm thick) were grafted onto 3–4 month old Rangpur lime rootstocks. Rootstocks were headed back to 15 cm, split vertically, and wedge-shaped scions were inserted and tied with 150-gauge polythene strips, then covered with polythene caps until sprouting. The grafts were maintained under polyhouse and open field conditions, with regular irrigation, removal of lateral shoots, vermicompost application at 45-day intervals, and routine weeding. To protect against pests, foliar sprays of Abamectin 1.9% EC (0.5 ml L^{-1}) were applied every 15 days.

Results and Discussion:

The data collected during the experiment on various root parameters, plant survival and economics of sweet orange grafts as influenced by growing conditions, grafting time and their interactions were presented in Table 2 and Table 3.

Root parameters

Effect of growing conditions

Growing conditions had a significant influence on root development of sweet orange grafts. Polyhouse-grown grafts consistently recorded superior performance, with maximum root length (41.14 cm), primary root diameter (7.30 mm), number of secondary roots (31.72), fresh root weight (16.20 g), and dry root weight (5.86 g). In contrast, grafts maintained under open field conditions exhibited the lowest values for these parameters, with 32.74 cm root length, 5.30 mm primary root diameter, 25.77 secondary roots, 12.26 g fresh weight, and 3.28 g dry weight. The significant advantage of polyhouse may be attributed to a favourable and stable climatic conditions with optimum temperature and humidity, which promotes root elongation, secondary root proliferation, and overall root development. On the other hand, in open field conditions, plants exposed to fluctuating moisture regimes that hampered root development. Similar findings were reported by Kumar and Shukla (2012) [8], Muralidhara and Doreyappa (2019) [10], Nithya *et al*. (2022) [12] and Sarfaraj (2022) [15].

Effect of grafting time

Grafting time had a notable effect on root traits. Grafts made on 15th August (D_3) exhibited maximum root length (40.70 cm), root diameter (7.72 mm), number of secondary roots (32.35), fresh root weight (16.90 g), and dry root weight (5.75 g). These values were statistically at par with grafts prepared on 30th August (D_4) and 30th July (D_2), which also showed higher root traits. Conversely, grafts performed on 30th October (D_8) consistently recorded minimum values for all parameters, root length (29.20 cm), primary root diameter (5.27 mm), number of secondary roots (24.65), fresh root weight (11.48 g), and dry root weight (3.25 g). The superior performance of grafts during August can be attributed to favourable soil moisture, moderate temperature, and active physiological status of rootstocks, which supported callus formation and rapid root initiation. In contrast, late October grafting affected due to fluctuating temperature and declining soil moisture, causing stress and limiting root growth. These observations corroborate earlier reports in fruit crops, Kumar and Shukla (2012) [8], Roshan *et al*. (2013) [14], Sarfaraj (2022) [15] and Negi and Upadhyay (2023) [11].

Interaction effect of growing conditions and grafting time

The interaction between growing condition and grafting time further emphasized the combined influence of environment and season. The highest values were observed under polyhouse, 15th August (C_2D_3) with maximum root length (44.50 cm), primary root diameter (9.20 mm), number of secondary roots (34.90), fresh root weight (19.80 g), and dry root weight (7.40 g). These values were statistically at par with C_2D_4 (polyhouse, 30th August) and C_2D_2 (polyhouse, 30th July) for several parameters. Conversely, the minimum values were consistently recorded in open field, 30th October (C_1D_8), which showed only 22.60 cm root length, 4.55 mm root diameter, 19.70 secondary roots, 10.00 g fresh weight, and 2.00 g dry weight. The superior performance of grafts during mid-August under polyhouse conditions highlights the synergistic effect of controlled environment and optimum seasonal timing, ensuring better callus activity, root proliferation, and biomass accumulation. These results are in line with reports of Kumar and Shukla (2012) [8], Nithya *et al*. (2022) [12], Sarfaraj (2022) [15] and Negi and Upadhyay (2023) [11].

Table 2: Effect of growing conditions, grafting time and their interactions on root parameters and plant survival of sweet orange

Treatment	Root length (cm)	Diameter of primary root (mm)	Number of secondary roots	Fresh weight of root (g)	Dry weight of root (g)	Plant survival percentage (%)
Growing condition(C)						
C_1 (Open)	32.74	5.30	25.77	12.26	3.28	76.68
C_2 (Polyhouse)	41.14	7.30	31.72	16.20	5.86	97.30
SE m±	0.193	0.077	0.141	0.184	0.064	0.261
CD at 5%	0.588	0.233	0.429	0.558	0.195	0.795
Time of grafting(D)						
D_1 (15^{th} July)	38.70	6.20	29.75	14.27	4.74	86.25
D_2 (30^{th} July)	39.67	6.47	30.72	15.80	5.07	88.00
D_3 (15^{th} August)	40.70	7.72	32.35	16.90	5.75	93.50
D_4 (30^{th} August)	40.07	7.20	31.70	16.34	5.45	94.25
D_5 (15^{th} September)	37.27	6.07	28.62	13.37	4.50	93.05
D_6 (30^{th} September)	35.90	5.85	26.92	13.03	4.00	83.25
D_7 (15^{th} October)	34.00	5.62	25.25	12.65	3.80	80.02
D_8 (30^{th} October)	29.20	5.27	24.65	11.48	3.25	77.62
SE m±	0.386	0.153	0.282	0.367	0.128	0.523
CD at 5%	1.175	0.467	0.859	1.117	0.389	1.590
Interaction (C x D)						
C_1D_1	34.65	5.25	27.90	12.95	3.49	75.00
C_1D_2	36.05	5.60	28.60	13.35	3.75	77.50
C_1D_3	36.90	6.25	29.80	14.00	4.10	87.50
C_1D_4	36.30	5.90	29.85	13.58	3.90	88.50
C_1D_5	33.50	5.15	26.50	11.90	3.25	87.20
C_1D_6	32.40	4.95	23.70	11.50	3.00	70.00
C_1D_7	29.50	4.80	20.50	10.85	2.75	65.05
C_1D_8	22.60	4.55	19.70	10.00	2.00	62.75
C_2D_1	42.75	7.15	31.60	15.60	6.00	97.50
C_2D_2	43.30	7.35	32.85	18.25	6.40	98.50
C_2D_3	44.50	9.20	34.90	19.80	7.40	99.50
C_2D_4	43.85	8.50	33.95	19.10	7.00	100.00
C_2D_5	41.05	7.00	30.75	14.85	5.75	98.90
C_2D_6	39.40	6.75	30.15	14.57	5.00	96.50
C_2D_7	38.50	6.45	30.00	14.45	4.85	95.00
C_2D_8	35.80	6.00	29.60	12.96	4.50	92.50
SE m±	0.546	0.217	0.399	0.519	0.181	0.739
CD at 5%	1.662	0.660	1.214	1.579	0.551	2.248

***Each value is average of three determinations**

Plant Survival %

Plant survival was significantly influenced by growing conditions, grafting time, and their interaction. Polyhouse recorded the highest survival (97.30%), while the open field showed the lowest (76.68%). Among grafting times, 30th August grafts achieved maximum survival (94.25%), which was statistically at par with 15th August (93.50%) and 15th September (93.05%), whereas 30th October grafts recorded the minimum (77.62%). The interaction effect revealed that polyhouse, 30th August grafts attained cent percent survival (100%), at par with polyhouse, 15th August (99.50%) and polyhouse, 15th September (98.90%), while the lowest survival (62.75%) was observed in open field, 30th October grafts. The higher survival in polyhouse during August–September was mainly due to favourable weather conditions that supported better graft union and establishment. These findings are similar with Mulla *et al*. (2011) [9], Sivdu *et al*. (2014) [17], Gotur *et al*. (2017) [5] and Karna *et al*. (2018) [7].

Economics

The economics of sweet orange grafting were strongly influenced by environment and timing. Polyhouse conditions recorded higher B:C ratios than open field due to better survival and reduced losses. The maximum ratio (1.86) was noted on 30th August in polyhouse, at par with 15th August (1.85) and 15th September (1.84), while the lowest (1.26) occurred on 30th October in open field. The superior returns during August–September under polyhouse may be attributed to favourable temperature and humidity supporting rapid healing and strong establishment.

Table 3: Interaction effect of growing conditions, grafting time on benefit-cost ratio of sweet orange

Treatments	Benefit-cost ratio
C_1D_1	1.50
C_1D_2	1.55
C_1D_3	1.75
C_1D_4	1.77
C_1D_5	1.74
C_1D_6	1.40
C_1D_7	1.30
C_1D_8	1.26
C_2D_1	1.81
C_2D_2	1.83
C_2D_3	1.85
C_2D_4	1.86
C_2D_5	1.84
C_2D_6	1.79
C_2D_7	1.76
C_2D_8	1.72

Conclusion

Polyhouse conditions, particularly when grafting on August 15th and August 30th, significantly enhanced root growth, plant survival and economic returns in sweet orange propagation. The best performance was recorded in C_2D_4 (polyhouse, August 30th), achieving superior root development, 100% survival, and the highest benefit–cost ratio (1.86). Conversely, late-season grafting in open field conditions resulted in poor root performance, lower survival and reduced profitability.

REFERENCES:

[1] *Ahlawat, Y.S. (1997). Status of virus and virus like pathogens infecting citrus in India and future strategies for citrus improvement. Indian Phytopathology. 50, 192-193.*

[2] *Anil, Paikra, M.S., Deshmukh, U.B., Singh J., Nishad D., Paikra, P. and Kumar, D. (2022). Studies on softwood grafting of tamarind (Tamarindus indica L.) under different growing condition. The Pharma Innovation Journal. 11(7),1627-163.*

[3] *Atta, S., Zhou, C.Y., Zhou, Y., Cao, M.J. and Wang, X.F. (2012). Distribution and research advances of Citrus tristeza virus. Journal of Integrative Agriculture. 11(3), 346–358.*

[4] *Gopi, V., Gouri Sankar, T., Girish Kumar, A., and Gopal, K. (2010). Diagnosis of Citrus yellow mosaic virus by PCR and ELISA in sweet orange (Citrus sinensis Osbeck). Journal of Plant Disease Sciences, 5(2), 158–162.*

[5] *Gotur, M., Sharma, D.K., Chawla, S.L., Joshi, C.J., & Navya, K. (2017). Performance of wedge grafting in guava (Psidium guajava L.) under different growing conditions. Plant Archives. 17(2), 1283–1287.*

[6] *Goudeau, D., Uratsu, S.L., Inoue, K., daSilva, F.G., Leslie, A., Cook, D., Reagan, R.L. and Dandekar, A.M. (2008). Tuning the orchestra: Selective gene regulation and orange fruit quality. Plant Science. 174(3), 310–320.*

[7] *Karna, A.K., Varu, D.K., Patel, M.K. & Panda, P.A. (2018). Effect of grafting time on success of softwood grafting in mango (Mangifera indica L.). International Journal of Current Microbiology and Applied Sciences. 7(8), 3072- 3077.*

[8] *Kumar, A. and Shukla, A.K. (2012). Standardization of bench grafting in custard apple. HortFlora Research Spectrum. 1(2), 149–152.*

[9] *Mulla, B.R, Angadi, S.G, Mathad, J.C, Patil Andu, V.S, Mummigatti, V. (2011). Studies on softwood grafting in jamun (Syzygium cuminii Skeels.). Karnataka Journal Agriculture Sciences. 24 (3), 366-368.*

[10] *Muralidhara, B.M. and Gowda, I.D. (2019). Soft wood grafting-A novel and rapid multiplication technique in Coorg mandarin (Citrus reticulate Blanco). Journal of Horticultural Sciences. 14(1), 7-12.*

[11] *Negi, N.D. and Upadhyay, S.K. (2023). Studies on the effect of different graft combinations and grafting dates in Citrus species under mid-hill conditions of Himachal Pradesh. Himachal Journal of Agricultural Research. 49(1), 93–98.*

[12] *Nithya, S., Kamble, A.K., Jholgikar, P., Nanjappanavar, A., Awati, M. and Patil, A.G. (2022). Standardization of grafting time in different red pulp guava (Psidium guajava L.) hybrids by softwood grafting. International Journal of Horticulture and Food Science. 4(1), 173–175.*

[13] *Priyanka, T.N., Hiremath, J.S., Nataraja, K.H., Pushpa, T.N., Nandhimath, S. and Masuthi, D.A. (2023). Softwood Grafting in Tamarind (Tamarindus indica L.). Asian Journal of Agricultural and Horticultural Research. 10(4), 227-235.*

[14] *Roshan, R.K., Pebam, N. and Panchbhai, D.M. (2013). Effect of rootstock age and time of softwood grafting on grafting success in Aonla (Emblica officinalis). Acta Horticulturae. 975, 265–268.*

[15] *Sarfaraj (2022). Effect of different time and growing conditions on success and growth rate of softwood grafting in guava (Psidium guajava L.) (Master's Thesis). Banda University of Agriculture and Technology, Banda, Uttar Pradesh, India.*

[16] *Sharon-Asa, L., Shalit, M., Frydman, A., Bar, E., Holland, D., Or, E., Lavi, U., Lewinsohn, E. and Eyal, Y. (2003). Citrus fruit flavor and aroma biosynthesis: isolation,*

functional characterization, and developmental regulation of Cstps1, a key gene in the production of the sesquiterpene aroma compound valencene. The Plant Journal. 36(5), 664–674.

[17] *Sivudu, B.V., Reddy, M.L.N., Baburatan, P. and Dorajeerao, A.V.D. (2014). Effect of structural conditions on veneer grafting success and survival of mango grafts (Mangifera indica L.cv. Amrapali). Plant Archives: An International Journal. 14(1), 71–75.*

[18] *Xu, Q., Chen, L. L., Ruan, X., Chen, D., Zhu, A., Chen, C., Bertrand, D., Jiao, W., Hao, B., Lyon, M., Chen, J., Gao, S., Xing, F., Lan, H., Chang, J., Ge, X., Lei, Y., Hu, Q., Miao, Y. and Ruan, Y. (2013). The draft genome of sweet orange (Citrus sinensis). Nature Genetics.* 45*(1), 59–66.*