



Seasonal Variability and Propagation Environment to Graft Success and Growth of Sapling in Tropical and Subtropical Fruit Crops: A Review

Nirajan Bhandari

10.18805/ag.R-161

ABSTRACT

Grafting is a widely used propagation technique in fruit trees. Anatomical proximity between scion and rootstock is the prerequisite for the successful graft-take and survival of the grafted plants. The success of grafting, subsequent growth of scion shoot and development of the successful grafts depend upon several factors like climatic conditions, the growth stage of scion and rootstock, methods of grafting, etc. The grafting response of fruit crops differs due to seasonal variability and environmental condition where grafting is carried out. A controlled environment with the congenial conditions for faster healing and callus formation results in better graft success, survival and growth of grafted plants.

Key words: Environmental condition, Graft success, Propagation, Seasonal variability.

Grafting is the horticultural technique that involves joining the two plant parts together so that they will readily unite to continue their growth together. The lower part of the combined plant is called rootstock while the upper part is called the scion in which cambial layers perfectly match and the tissues completely unite to form the whole plant (Poincelot, 1990). It is a natural or deliberate fusion of plant parts, as a result, a vascular continuity bridge is established between them (Pina and Errea, 2005) and the resulting genetically composite organism functions as a single plant. This technique is the most commonly used asexual propagation of commercially grown agricultural crops especially horticultural plants wherein the lower portion forms root *i.e.* rootstock and the upper portion form shoots *i.e.* scion which is selected from the stem, leaves, flowers, fruits, etc. (Hottes, 1925). The rootstock is raised from seeds in most cases (Sadhu, 1986). In this plant union, scion becomes the new shoot for the plant union and the rootstock supports the root system and conducts nutrients across the graft union into the shoot. According to Ziegler and Wolfe (1981), the following factors must be considered during grafting; it must be true to type, with a record of satisfactory production for at least 5 years, free from systemic diseases and must have attained maturity.

From a genetic perspective, grafting involves the creation and development of a composite genetic system by uniting two or more distinct plant parts of genotypes, each of them maintains their own and distinct genetic identity throughout the life period. A degree of compatibility is another important genetic consideration while performing grafting. Mudge *et al.* (2009) broadly define and categorize the limit of compatibility. Generally, interclonal/intraspecific grafts (rootstock and scion belonging to same botanical species) are nearly always compatible, interspecific/intrageneric

Institute of Agriculture and Animal Science (IAAS), Gauradaha-57200, Jhapa, Nepal.

Corresponding Author: Nirajan Bhandari, Institute of Agriculture and Animal Science (IAAS), Gauradaha-57200, Jhapa, Nepal. Email: iaasnirajan@gmail.com

How to cite this article: Bhandari, N. (2021). Seasonal Variability and Propagation Environment to Graft Success and Growth of Sapling in Tropical and Subtropical Fruit Crops: A Review. *Agricultural Reviews*. 42(1): 58-65. DOI: 10.18805/ag.R-161.

Submitted: 21-07-2020 **Accepted:** 05-11-2020 **Online:** 12-03-2021

grafts (rootstock and scion belonging to different species of the same genus) are usually compatible, intrageneric/intrafamilial grafts are rarely compatible and interfamilial grafts are essentially always incompatible. Andrews and Marquez (1993) recognize four potential factors that may contribute to incompatibility: (I) cellular recognition, (II) wounding response, (III) growth regulators and (IV) incompatibility toxins. In addition to graft incompatibility, graft failure also can be caused by anatomical mismatching due to poor craftsmanship, seasonal variability, environmental conditions and different diseases (Hartmann *et al.*, 2002).

Grafting is a well-developed and commonly used practice that has many physiological, biological and horticultural uses. Grafting may be used to enhance nutrient uptake (Colla *et al.*, 2010a), induce tolerance against low and high temperature (Rivero *et al.*, 2003 and Venema *et al.*, 2008), improve water use efficiency (Rouphael *et al.*, 2008a), increase the synthesis of endogenous hormones (Dong *et al.*, 2008), improve alkalinity tolerance (Colla *et al.*, 2010b), improve salt and flooding tolerance (Yetisir *et al.*, 2006 and He *et al.*, 2009), limit the negative effect of boron, copper, cadmium and manganese toxicity (Edelstein *et al.*, 2005;

Rouphael *et al.*, 2008b; Arao *et al.*, 2008 and Savvas *et al.*, 2009) and also reduce uptake of persistent organic pollutants from agricultural soils (Otani and Seike, 2006, 2007). Moreover, graft combination may alter sex expression and flowering of grafted plants by altering the amounts of hormone produced (Sato, 1996). The higher yield of grafted plants may be due to large size quality fruits as grafted plants are resistant to soil borne diseases, has a strong root system and greater photosynthetic activity (Xu *et al.*, 2005 and Qi *et al.*, 2006).

The success and subsequent growth of grafted saplings depend on many factors including environmental conditions, variety, method of grafting and selection of scion and rootstock materials (Hartmann *et al.*, 2002). The prevailing environmental conditions are primarily governed by the grafting seasons and propagation structures under which grafting is performed. The climatic factors like light, temperature, rainfall and humidity have a significant influence on the percentage of survival and establishment of grafts (Singh and Singh, 2006). This paper aims to review the recent research findings on the success, survival and growth of grafted saplings to varying seasonal and propagation environments in tropical and subtropical fruit crops.

Factors affecting grafting

Effect of grafting season on various growth parameters

The success/failure of grafting is highly correlated with the environmental conditions under which it is performed. One of the most important conditions for successful grafting is the selection of the appropriate season of grafting which is conducive to rapid graft healing and subsequently the formation of the graft union. A study conducted by Singh and Srivastava (1979) in meteorological data about the success of grafting revealed that high atmospheric humidity due to high rainfall and low maximum temperature coupled with high minimum temperature was very congenial to the union of the rootstock and scion. Similarly, high atmospheric humidity due to high rainfall and moderate temperatures was also found very congenial for the union of rootstock and scion (Singh and Srivastava, 1982). Swamy *et al.* (1993) reported that the success of grafting was highly correlated with higher monthly mean minimum temperature, afternoon relative humidity and the number of rainy days per month. However, grafting can be performed at any time of the year when suitable scion is available and protection from field hazards such as extreme climatic conditions, diseases and insects (Shah, 1992).

Days taken for sprouting

It is the time taken between grafting to the sprouting of the first bud. Various research reported that the bud sprouting process highly depends upon the climatic factors of a growing environment where grafting has been performed. The congenial weather conditions such as optimum temperature and high relative humidity help in early sprouting. Favorable climatic conditions and better water

availability play an important role in photosynthetic activity and early buds sprouting.

Joshi *et al.* (2000) reported that the minimum days were taken by March grafted custard apple (*Annona squamosa* L.) plants for sprouting. Tewari *et al.* (2004) recorded the minimum number of days (19.2 days) to sprouting in February while performing bench grafting in anola (*Embllica officinalis* L.). An experiment conducted by Prashant *et al.* (2007) on softwood grafting of mango (*Mangifera indica* L.) at fortnight intervals from August to December showed that the earliest sprouting (24.50 days) in the first fortnight of September. A study conducted by Giri and Lenka (2008) reported that the days taken for sprouting in the graft of wood apple (*Feronia limonia* Swingle) was minimum (8 days) in May. A study carried out by Patel *et al.* (2010) on softwood grafting in Khasi mandarin (*Citrus reticulata* Blanco) reported that the grafting from June 30th to August 15th gave the minimum days for sprouting. Similarly, Mulla *et al.* (2011) reported the number of days taken for sprouting was minimum (26.67 days) in June for softwood grafting in jamun (*Syzygium cumini* Skeel). In another study conducted by Salik *et al.* (2015) in sweet orange (*Citrus sinensis* L. Osbeck) reported that the first sprouting was observed in 26 days after grafting when grafting was carried out in 2nd week of February. A study conducted by Khan *et al.* (2018) observed that the earliest sprouting (29 days) was recorded in lemon (*Citrus limon* L.) when grafting was carried out on 29th June.

Number of sprouts and sprouts length

The optimum temperature and relative humidity have a vital role that determines the sprouting and number of sprouts by avoiding desiccation of buds through active sap flow in grafts. Patel *et al.* (2010) recorded the maximum number of sprouts (3.11) when softwood grafting was performed in Khasi mandarin during July. Research conducted to study the epicotyls grafting in mango showed that the maximum sprout length (20.05 cm) was observed when grafting was performed on 6th August (Islam and Rahim, 2010). The maximum number of sprouts (2.33) was recorded when grafting was performed during September and February in jamun (Ghojage *et al.*, 2011). Another study conducted by Mulla *et al.* (2011) recorded the highest sprout length (5.34 cm) from the grafts performed during May in jamun.

Number of leaves and leaf area

The variation in the number of leaves during different months and seasons is due to exposure to different temperatures and humidity. These fluctuating weather parameters ultimately affect the success and survival of grafts because they have a direct effect on cell activity and the growth of stock and scion. The favorable environmental conditions primarily accelerate the early bud breaking and secondarily influence the maximum leaf flushing as well as the maximum number of leaves due to early healing and graft union formation. The early formation of callus bridge between scion and rootstock ultimately enhance the transport and

movement of water and mineral nutrients through xylem and photosynthate through the phloem.

Islam *et al.* (2004) reported the highest number of leaves (22.16) in mango grafts prepared during June. Adhikari (2006) reported maximum leaves per sapling (47) on 31st January grafted sapling in acid lime (*Citrus aurantiifolia* Swingle) at Rampur, Chitwan. Kudmulwar *et al.* (2008) reported the highest number of leaves (21.93) in plants grafted during February in custard apple (*Annona squamosa* L.) by using Balanagar scion. A study carried out by Patil *et al.* (2010) reported the highest number of leaves (15.08) on the graft prepared during July in sapota [*Manilkara achras* (Mill) Foseberg] with a new seedling of Khirni [*Manilkara hexandra* (Roxb.) Dubard] rootstock. Mulla *et al.* (2011) reported the highest number of leaves (12.48) in the graft prepared during June while the highest leaf area (34.8 cm²) was observed during May in jamun. In another study conducted by Ghogage *et al.* (2011) on softwood grafting in jamun reported the highest number of leaves (9.33) when grafting was performed during February. A study carried out by Singh *et al.* (2012) showed that the veneer grafting performed on 30th June, 15th July and 30th July produced the maximum number of leaves (24) in mango. Angadi and Karadi (2012) observed that the graft performed during June gave the maximum number of leaves (12.64) and the highest leaf area (36.22 cm²) in softwood grafting in jamun. Chalise *et al.* (2013a) reported the highest number of leaves (48.47) on 14th November grafted saplings whereas lowest (21.93) on 13th January grafted saplings in mandarin at Dhankuta, Nepal. A study carried out by Khan *et al.* (2018) observed the maximum number of leaves (11.9) on the grafts prepared on 6th July in lemon. Nahar *et al.* (2018) reported a leaf area of 18.87 cm² when lime (cv. BAU lime-1) was grafted onto lemon rootstock in Bangladesh.

Graft height

Graft height is one of the important parameters that determine the marketable age and price of saplings. Graft height is highly influenced by different growth parameters such as the number of leaves, leaf area and numbers of primary and secondary branches. Early healing of graft and higher cell activity during the optimum season of grafting determine sprouting and growth of grafts. The greater the leaf area higher will be the photosynthetic activity and ultimately better the growth and development of grafts. The variation of graft height in different seasons might be attributed to prevailing environmental conditions along with the availability of dormant and swollen buds of scion in a bulging condition which promotes earlier sprouting and better growth.

An experiment was conducted to investigate the effect of rootstock age and grafting time on the success of custard apple in which maximum graft height (37.08 cm) was recorded when grafting was conducted during February (Pawar *et al.*, 2003). Patil *et al.* (2010) obtained the highest graft height (16.06 cm) when grafting was done during July in sapota. In a similar study on sapota, the highest graft

height was observed when grafting was carried out on 15th May (Ratna, 2012). Alka *et al.* (2010) reported that softwood grafting performed in jamun under Akola conditions showed that 15th September and 15th March grafted saplings were superior with respect to graft height. In another study carried out by Salik *et al.* (2015) in sweet orange observed that the maximum graft height (19.5 cm) was observed when grafting was carried on the 2nd week of February. A study carried out by Khan *et al.* (2018) observed that the highest graft height (9.9 cm) was recorded on graft prepared on 6th July in lemon.

Graft union success and survival

There is variation in graft success and survivability because of the variation of temperature and relative humidity during different months and seasons. The maximum graft success is directly related to prevailing optimum temperature and higher relative humidity. These congenial weather conditions facilitate early contact of the cambium layer of rootstock and scion resulting in early callus formation and initiation of subsequent growth.

Poon (1998) reported veneer grafting in the 2nd week of December had the highest grafting success (97.91%) as compared to other dates in mandarin. Nayak and Sen (2000) noticed that the percentage of veneer graft success was greater in July-August (78.80%) followed by January-March (75%) in mango. A study conducted by Chaitanya (2000) reported the highest grafting success in sapota cv. Kalipatti when grafting was carried out during May and July (90 and 85%) respectively. Gautam *et al.* (2001) suggested grafting from 16th to 31st January was the best time of grafting for mandarin at Lumle, Kaski. They observed the maximum grafting success (87.50%) on 31st January whereas minimum success (37.50%) on 20th November. A study conducted by Islam *et al.* (2003) in epicotyl grafting in jackfruit (*Artocarpus heterophyllus* L.) in which the highest success (49.55%) and highest survival (45.47%) was recorded by the grafts prepared during June whereas success was lower (10.08%) in the grafts prepared during April. Adhikari (2006) elucidated that the highest graft success (79.73%) was observed in acid lime grafted onto trifoliate orange (*Poncirus trifoliata* L.) rootstock on 16th January by shoot tip method in Chitwan. In another study, Simkhada (2007) suggested that April was the ideal time for veneer grafting in persimmon (*Diospyros kaki* Thunb.). The highest success percentage (82.50%) was recorded in the first fortnight of September in softwood grafting in mango (Prasanth *et al.*, 2007). Patil *et al.* (2010) reported the highest graft take (63.33%) during July in sapota. Research conducted by Ghosh *et al.* (2010) in softwood grafting in sapota observed the highest graft success (72%) on 1st July under Paschim Midnapur conditions of West Bengal. An investigation carried out by Chandra *et al.* (2011) reported the maximum graft success (85%) in pomegranate (*Punica granatum* L.) cv. Bhagwa after 90 days of grafting with wedge grafting performed on 30th January. Mulla *et al.* (2011) on softwood grafting in jamun noticed the highest graft success (100%) in November and May and highest graft survival

(93.33%). Uchoi *et al.* (2012) reported the highest graft survival (90.50%) during January in jamun. Singh *et al.* (2012) reported the veneer grafting performed on 15th July recorded the highest graft-take success (96.66%) and survival (90%) in mango. Research conducted by Chalise *et al.* (2013a) at Paripatle, Dhankuta reported the highest graft success (96.11%) on 13th January in mandarin. A study conducted by Kalabandi *et al.* (2014) in sapota var. Kalipatti noticed the highest graft survival (64.21%) when grafting was performed during August under Marathwada conditions. Grafting carried out on the 1st week of February had the maximum graft survival (89.30%) in sweet orange (Salik *et al.*, 2015). Bhandari (2018) reported the highest graft success and survivability on 25th January as compared to early dates in different citrus species at Kavre, Nepal.

Effect of propagation environment on growth parameters

Propagation environment and structures such as greenhouse, glasshouse, polyhouse, nethouse and mist chamber have a direct influence on the success and survivability of grafts. A fine water spray (intermittent mist) at frequent intervals reduces transpiration rate and leaf temperature by increasing relative humidity inside the propagating structures thereby creating a favorable environment for graft success and subsequent growth of saplings. The high temperature and high atmospheric humidity were very congenial for the formation of graft union between scion and rootstock (Hartmann *et al.*, 2002). Production of quality planting materials throughout the year is possible through modification of the growth environment to a certain extent (Khan, 1994). The propagation environment influences various growth parameters significantly by altering temperature, humidity, light and other climatic factors. Shade also plays an important role in grafting and provision of shade during and after grafting was found to have a positive effect on the success of grafting. Light is essential for photosynthetic activity and better nourishment of grafts. The rate of photosynthetic activity varies with the level of shade (Swamy *et al.*, 1993). The variation of graft success and subsequent growth of saplings under different coloured shade structures might be due to minor interference on the plant micro-climate which can modify both the quantity and the quality of transmitted sunlight.

Days taken for sprouting

Days taken for sprouting is greatly reduced under the protected condition compared to the open condition due to suitable environmental conditions for the formation of the graft union. The prevailing suitable temperature and relative humidity under the protected structures facilitate early contact of cambium layers of rootstock and scion, early callus formation and initiation of subsequent growth. A study conducted to determine the effect of colour of polyhouse (white, red and blue) and open condition on the sprouting of mango showed that the earliest graft was sprouted under red polyhouse which was significantly superior to open

conditions (Hema Nair *et al.*, 2002). Selvi *et al.* (2008) studied the effect of grafting environment (mist, 50% agro shade and tree shade) on the success of softwood grafting in jackfruit and observed that the lowest number of days (20.89 days) were taken under 50 per cent shade net for sprouting. A study conducted by Patel *et al.* (2010) reported the minimum days required for sprouting under polyhouse (34.67 days) followed by open condition and nethouse in Khasi mandarin. According to Visen *et al.* (2010), the time taken for sprouting was significantly reduced (12-13 days) under greenhouse conditions compared to open field while performing wedge grafting in guava (*Psidium guajava* L.) cv. Allahabad Safeda, Lucknow 49 and Lalit under North Indian plains. A softwood grafting performed in jamun under nethouse as well as open field conditions showed that the grafting operation carried out in open field conditions took significantly lesser days (22.9 days) for sprouting (Shinde *et al.*, 2010). A wedge grafting was performed in anola under polyhouse conditions took minimum days (6.5 days) for first sprouting compared to open field conditions (11.3 days) during November (Gurjar and Singh, 2012). A study revealed that the minimum mean number of days taken for sprouting of mango grafts under naturally ventilated polyhouse was 12.11 days while the highest mean number of days (13.46 days) taken for sprouting was recorded in partial shade under coconut trees (Sivudu *et al.*, 2014a). Similarly, another study carried out by Sivudu *et al.* (2014b) reported that the lowest number of days taken for sprouting was observed under a naturally ventilated polyhouse (10.60 days).

Number of sprouts and sprout length

Various researchers reported that the number of sprouts and sprout length is higher under the protected condition due to favorable growing environmental conditions. Patel *et al.* (2010) reported that the maximum numbers of sprouts (3.07) were recorded in polyhouse compared to open conditions (2.33) in softwood grafting in Khasi mandarin. Mulla *et al.* (2011) reported that the maximum sprout length was obtained under controlled conditions during February in jamun. A study revealed that the maximum sprout length was observed in naturally ventilated polyhouse (6.06 cm) followed by a partial shade under coconut (5.93 cm) while the lowest sprout length was recorded by grafting under open conditions (5.21 cm) in mango (Sivudu *et al.*, 2014a). Similarly, another study conducted by Sivudu *et al.* (2014b) recorded the highest sprout length (6.06 cm) under the partial shade of coconut followed by a naturally ventilated polyhouse (5.93 cm). Anushma *et al.* (2014) observed that the graft kept under a red coloured shade net recorded a significantly higher number of sprouts (2.31) whereas a lower number of sprouts (1.58) was recorded in grafts kept under a black shade net.

Number of leaves and leaf area

Grafting performed under protected condition has a greater number of leaves and leaf area. The favorable condition prevailing inside the structure induces rapid callusing and

early contact of cambial layers which enables the graft to heal quickly for the strongest graft union formation that ultimately results in faster and better growth and development of grafts. An investigation carried out by Hema Nair *et al.* (2002) observed the highest number of leaves per graft under red polyhouse which was significantly superior to open conditions. Shinde *et al.* (2010) reported that grafting operation performed in open conditions produced significantly the highest number of leaves (4.9) in jamun. Harshavardhan (2011) recorded the highest numbers of leaves (8.67) per graft under polyhouse condition during October in jackfruit. Sivudu *et al.* (2014a) reported a significantly higher number of leaves (17.34) in a natural ventilated polyhouse in mango. Similarly, another study carried out by Sivudu *et al.* (2014b) reported the highest number of leaves (24.60) per graft under open conditions and highest leaf area (478.96 cm²) per graft under naturally ventilated polyhouse. A study reported that the maximum number of leaves (12) was recorded on grafts kept under red shade net and the minimum number of leaves on grafts kept under blue shade net (8.22) in jamun (Anushma *et al.*, 2014).

Graft height

The various growth parameters such as the number of sprouts, number of leaves, leaf area, *etc.* determine the rate of photosynthesis and photosynthate accumulation that is ultimately required for the growth of graft. Various researchers reported that the graft height was generally observed higher in protected and controlled conditions. A study reported that the maximum graft height was observed under red polyhouse which was significantly superior to open conditions in jamun (Hema Nair *et al.*, 2002). Patel *et al.* (2010) studied softwood grafting in different growing conditions *viz.* polyhouse, nethouse and open conditions in which the highest graft height was observed in polyhouse (32.05 cm) followed by nethouse (27.35 cm) and lowest in open condition (21.99 cm). A study conducted by Sivudu *et al.* (2014a) reported the highest graft height (17.92 cm) under naturally ventilated polyhouse followed by a partial shade under coconut (17.62 cm) and shade net 50 per cent (17.59 cm) while the lowest graft height (17.03 cm) was recorded by grafting under the open condition in mango.

Graft union success and survival

Various researchers revealed that higher success of grafting under protected structures was due to congenial conditions that prevent the desiccation of scion and stock which results in better graft union formation and ultimately higher graft success and faster growth. In general, callus formation is better in protected structures due to suitable climatic conditions. The difference in graft success under different color structures might be attributed to variation in the light quality, photosynthesis, temperature and relative humidity (Hasanein *et al.*, 2011). Low-cost poly-cum-net tunnel (with polythene sheet covering a shade net) resulted in the highest recovery of grafts (90.87%) and graftable rootstocks

(95.02%) in cashew (*Anacardium occidentale* L.) (Lingaiah *et al.*, 2000). Baghel *et al.* (2002) reported the best success and survival of mango grafts under polyhouse conditions compared to open conditions.

A study conducted by Sundari and Reddy (2003) reported the highest graft success (50.10 to 59.81%) in cashew under fifty per cent partial shade condition compared to complete shade or open condition. Sagvekar *et al.* (2005) observed significantly higher grafting success under polyhouse as compared to open conditions in cashew cv. Vengurla-4. Visen *et al.* (2010) reported that the maximum graft success was observed in the greenhouse (81.71%) and minimum in open field conditions while performing an experiment in guava cv. Allahabad Safeda, Lucknow 49 and Lalit. A softwood grafting performed in jamun reported that the grafting performed in open condition gave significantly the highest survival (75.35%) of grafts (Shinde *et al.*, 2010). Patel *et al.* (2010) found that graft success was better under polyhouse as compared to other conditions in softwood grafting in Khasi mandarin. Harshavardhan (2011) noticed the highest per cent of graft success under polyhouse conditions during October in coastal Andhra conditions in jackfruit. A study conducted by Gurjar and Singh (2012) reported the maximum graft survival in polyhouse (98.30%) as compared to open field conditions (76%) while performing wedge grafting in anola during March. A study conducted by Sivudu *et al.* (2014a) observed the highest graft success under naturally ventilated polyhouse (71.27%) and lowest in open condition (62.06%) in veneer grafting in mango. In another study, the highest percentage of survival of mango grafts was recorded under naturally ventilated polyhouse (67.18%) and lowest under open condition (57.41%) (Sivudu *et al.*, 2014b). Anushma *et al.* (2014) studied the effect of colored shade nets (white, red, black, green and blue) on the success of softwood grafting in jamun and reported that the grafts kept under red coloured shade net resulted in significantly higher graft success (72.50%) and graft survival (96.87%) whereas significantly least graft success (47.50%) and graft survival (92.71%) was recorded in the grafts kept under blue shade net and white shade net respectively (Anushama *et al.*, 2014).

CONCLUSION

Grafting is one of the most common and widely practiced methods for the multiplication of fruit crops. The success and failure of grafting depend upon several internal and external factors. From various studies, researchers concluded that grafting seasons and propagation environments primarily decide the final success, survival and subsequent growth of grafts. The temperature, relative humidity and light are important factors that are governed by prevailing environmental conditions and propagation structures. The degree of compatibility between scion and rootstock is another most important factor and the complexity of stock-scion interaction can be another dimension of the study.

REFERENCES

- Adhikari, A. (2006). Effect of grafting season on success and growth of acid lime (*Citrus aurantifolia* Swingle) in Rampur, Chitwan. Doctoral dissertation, M. Sc. Thesis. Tribhuvan University, IAAS, Rampur, Chitwan, Nepal.
- Alka, G., Bharad, S.G., Mane, V.P. and Sarika, P. (2010). Seasonal variation in success of softwood grafting of jamun under Akola conditions. *Asian Journal of Horticulture*. 5(2): 266-268.
- Andrews, P.K. and Marquez, C.S. (1993). Graft incompatibility. *Horticultural Reviews*. 15: 183-232.
- Angadi, S.G. and Karadi, R. (2012). Standardization of Softwood Grafting Technique in Jamun under poly mist house conditions. *Mysore Journal of Agricultural Sciences*. 46(2): 429-432.
- Anushma, P.L., Swamy, G.S.K. and Gangadhara, K. (2014). Effect of colored shade nets on softwood grafting success in jamun (*Syzygium cumini* skeels). *Plant Archives*. 14(1): 293-295.
- Arao, T., Takeda, H. and Nishihara, E. (2008). Reduction of cadmium translocation from roots to shoots in eggplant (*Solanum melongena*) by grafting onto *Solanum torvum* rootstock. *Soil Science and Plant Nutrition*. 54(4): 555-559.
- Baghel, B.S., Nair, H. and Nema, B.K. (2002). Response of mango (*Mangifera indica* L.) grafts to coloured polyhouse/light. *South Indian Horticulture*: 50(1/6): 1-6.
- Bhandari, N. (2018). Effect of Grafting Dates and Species on Success, Survivability and Growth of Citrus Sapling at Kavre, Nepal. M.Sc. Thesis, Institute of Agriculture and Animal Science (IAAS), Tribhuvan University, Nepal.
- Chaitanya, H.S. (2000). Comparative evaluation of grafting methods in sapota (*Manilkara achras* (Mill) Foseberg) cv. Kallipatti. M.Sc. (Hort.) Thesis, University of Agricultural Sciences, Bangalore.
- Chalise, B., Baral, D.R., Gautam, D.M. and Thapa, R.B. (2013a). Effect of grafting dates, methods on success and growth of mandarin (*Citrus reticulata* Blanco) sapling. *Nepal Journal of Science and Technology*. 14(1): 23-30.
- Chandra, R., Jadhav, V.T., Sharma, J. and Marathe, R.A. (2011). Effect of grafting methods and time on scion sprouting, graft success and subsequent growth of grafted plants of pomegranate (*Punica granatum* L.) Bhagawa. *Acta Horticulturae*. 890: 83-86.
- Colla, G., Roupael, Y., Cardarelli, M., Salerno, A. and Rea, E. (2010b). The effectiveness of grafting to improve alkalinity tolerance in watermelon. *Environmental and Experimental Botany*. 68(3): 283-291.
- Colla, G., Suarez, C. M. C., Cardarelli, M. and Roupael, Y. (2010a). Improving nitrogen use efficiency in melon by grafting. *Hort Science*. 45(4): 559-565.
- Dong, H., Niu, Y., Li, W. and Zhang, D. (2008). Effects of cotton rootstock on endogenous cytokinins and abscisic acid in xylem sap and leaves in relation to leaf senescence. *Journal of Experimental Botany*. 59(6): 1295-1304.
- Edelstein, M., Ben-Hur, M., Cohen, R., Burger, Y. and Ravina, I. (2005). Boron and salinity effects on grafted and non-grafted melon plants. *Plant and Soil*. 269(1-2): 273-284.
- Gautam, I.P., Sah, D.N. and Khatri, B. (2001). Effect of time of grafting and budding on trifoliate rootstocks for appropriate mandarin orange saplings production. Lumle Working Paper (Nepal) No. 2001/20. Lumle Agricultural Research Station, Lumle, Kaski, Nepal.
- Ghojage, A.H., Swamy, G.S.K., Kanamadi, V.C., Jagdeesh, R.C., Kumar, P., Patil, C.P. and Reddy, B.S. (2011). Effect of season on softwood grafting in jamun (*Syzygium cumini* Skeels.). *Acta Horticulturae*. 890: 123-127.
- Ghosh, S.N., Bera, B. and Banik, B.C. (2010). Effect of cultivars and season on grafting success in sapota under Paschim Midnapur conditions of West Bengal. *Journal of Horticultural Sciences*. 5(2): 138-139.
- Giri, B. and Lenka, P.C. (2008). Studies on vegetative propagation of wood apple. *Orissa J. Hort.* 36(1): 124-125.
- Gurjar, P.S. and Singh, R. (2012). Performance of wedge grafting in aonla at poly house and open field conditions. *Environment and Ecology*. 30(3): 531-536.
- Harshavardhan, A. (2011). Standardization of propagation methods in jackfruit. M.Sc. (Horti.) Thesis submitted to Dr. Y.S.R. University, Andhra Pradesh.
- Hartmann, H.T., Kester, D.E., Devise, F.T. and Geneve, R.L. (2002). Hartmann and Kester's plant propagation: Principles and practices 7th ed Prentice Hall Upper Saddle River.
- Hasanein, N.M., Manal, M.H., El-Mola, G. and Mona, A.M. (2011). Studies on influence of different colors of shade on growth and yield of strawberries and different color of plastic mulch under low tunnels conditions. *Res. J. Agric. Biol. Sci.* 7(6): 483-490.
- He, Y., Zhu, Z., Yang, J., Ni, X. and Zhu, B. (2009). Grafting increases the salt tolerance of tomato by improvement of photosynthesis and enhancement of antioxidant enzymes activity. *Environmental and Experimental Botany*. 66(2): 270-278.
- Hema Nair, B., Baghel, S., Tiwari, R. and Nema, B.K. (2002). Influence of coloured polyhouse/light and methods of epicotyl grafting on vigour of mango grafts. *JNKVV Res. J.* 36: 51-54.
- Hottes, A.C. (1925). Practical plant propagation: an exposition of the art and science of increasing plants as practiced by the nurseryman, florist and gardener. A.T. De La Mare Company, New York.
- Islam, M.M., Haque, M.A. and Hossain, M.M. (2003). Effect of age of rootstock and time of grafting on the success of epicotyl grafting in jackfruit (*Artocarpus heterophyllus* L.). *Asian Journal of Plant Sciences*. 2: 1047-1051.
- Islam, M.N., Rahim, M.A. and Farooque, A.M. (2004). Standardization of time and grafting techniques in mango under Bangladesh condition. *Asian Journal of Plant Sciences*. 3 (3): 378-386.
- Islam, M.R. and Rahim, M.A. (2010). Performance of epicotyl grafting in different varieties of mango. *J. Agrofor. Environ.* 4(1): 45-50.
- Joshi, P.S., Bhalerao, P.S., Mahorkar, V.K. and Jadhav, B.J. (2000). Studies on vegetative propagation in custard apple (*Annona squamosa* L.). *PKV Research Journal*. 24(2): 103-105.
- Kalalbandi, B.M., Ziauddin, S. and Shinde, B.N. (2014). Effect of time of soft wood grafting on the success of sapota grafts in 50% shade net under Marathwada conditions. *Agricultural Science Digest-A Research Journal*. 34(2): 151-153.

- Khan, M.M., Shyamalamma, S. and Krishnamanohar, R. (1994). Relevance of Greenhouse Technology in India. Training Manual on Construction and Management of Low-cost Poly/Green Houses. 1-8 pp.
- Khan, M.R., Ghani, F., Bostan, N., Nabi, G., Muhammad, H., Ali, A., Amin, J. and Khalid, S. (2018). The influence of timing and position of scion on graft take success of lemon. *Pure and Applied Biology*. 7(1): 330-337.
- Kudmulwar, R.R., Kulkarni, R.M., Bodamwad, S.G., Katkar, P.B. and Dugmod, S.B. (2008). Standardization of soft wood grafting season on success of custard apple (*Annona squamosa* L.). *Asian Journal of Horticulture*: 3(2): 281-282.
- Lingaiah, H.B., Vishnu, V., Raju, G.T.T., Janakiraman, N. and Lakshman, M. (2000). Influence of growing conditions on the production of root stocks and grafting success in cashew (*Anacardium occidentale* L.). *Cashew*. 14(3): 9-13.
- Mudge, K., Janick, J., Scofield, S. and Goldschmidt, E.E. (2009). A history of grafting. *Horticultural Reviews*, Am. Soc. Hortic. Sci. 35: 437-493.
- Mulla, B.R., Angadi, S.G., Karadi, R., Patil, V.S., Mathad, J.C. and Mummigatti, U.V. (2011). Studies on softwood grafting in jamun (*Syzygium cumini* Skeels.). *Acta Horticulturae*. 890: 117.
- Nahar, A., Choudhury, M.S.H. and Rahim, M.A. (2018). Effect of scion defoliation and stock leaf retention on growth of grafted lime (cv. Bau lime-1). *Asian Journal of Medical and Biological Research*. 4(1): 44-48.
- Nayak, G. and Sen, S.K. (2000). Seasonal influence of veneer grafting of mango (*Mangifera indica* L.). *Environment and Ecology*. 18(1): 156-158.
- Otani, T. and Seike, N. (2006). Comparative effects of rootstock and scion on dielrin and endrin uptake by grafted cucumber (*Cucumis sativus*). *Journal of Pesticide Science*. 31(3): 316-321.
- Otani, T. and Seike, N. (2007). Rootstock control of fruit dielrin concentration in grafted cucumber (*Cucumis sativus*). *Journal of Pesticide Science*. 32: 235-242.
- Patel, R.K., Babu, K.D., Singh, A., Yadav, D.S. and De, L.C. (2010). Soft wood grafting in Mandarin (*C. reticulata* Blanco): A novel vegetative propagation technique. *International Journal of Fruit Science*. 10(1): 54-64.
- Patil, S.R., Suryawanshi, A.B. and Phad, G.N. (2010). Effect of season of grafting on percentage graft-take and growth of scion shoot of sapota on khirni rootstock. *International Journal of Plant Sciences (Muzaffarnagar)*. 5(1): 6-9.
- Pawar, D.M., Ingle, V.G. and Panchabhai, D.M. (2003). Effect of age of rootstock and time of grafting on success of softwood grafts of custard apple under local conditions. *Annals of Plant Physiology*. 17(1): 53-55.
- Pina, A. and Errea, P. (2005). A review of new advances in mechanism of graft compatibility-incompatibility. *Scientia Horticulturae*. 106(1): 1-11.
- Poincelot, R. (1990). *Horticulture: Principles and practical Application*. Englewood Cliffs, New Jersey: Prentice-Hall.
- Poon, T.B. (1998, May). Effect of grafting methods and time on mandarin sapling production at Dailekh. In: *Proceedings of the 2nd National Horticultural Research Workshop*, Khumaltar, Lalitpur (pp. 65-68).
- Prasanth, J.M., Reddy, P.N., Patil, S.R. and Pampanagouda, B. (2007). Effect of cultivars and time of softwood grafting on graft success and survival in mango. *Agricultural Science Digest*. 27(1): 18-21.
- Qi, H.Y., Li, T.L., Liu, Y.F. and Li, D. (2006). Effects of grafting on photosynthesis characteristics, yield and sugar content in melon. *Journal-Shenyang Agricultural University*. 37(2): 155-158.
- Ratna, S.S. (2012). Effect of time of grafting operation and varieties on the success and survivability of cleft grafting of sapota. Doctoral dissertation, Department of Horticulture, Bangladesh Agricultural University.
- Rivero, R.M., Ruiz, J.M., Sanchez, E. and Romero, L. (2003). Does grafting provide tomato plants an advantage against H₂O₂ production under conditions of thermal shock?. *Physiologia Plantarum*. 117(1): 44-50.
- Rouphael, Y., Cardarelli, M., Colla, G. and Rea, E. (2008a). Yield, mineral composition, water relations and water use efficiency of grafted mini-watermelon plants under deficit irrigation. *Hort Science*. 43(3): 730-736.
- Rouphael, Y., Cardarelli, M., Rea, E. and Colla, G. (2008b). Grafting of cucumber as a means to minimize copper toxicity. *Environmental and Experimental Botany*. 63(1-3): 49-58.
- Sadhu, M.K. (1986). *Vegetative Propagation Practices*. In: *Propagation of Tropical and Sub-tropical Horticultural crops* (1st edn.). Bose T.K., S.K. Mitra and M.K. Sadhu. Nayaproskash, Calcutta. India. pp 66.
- Sagvekar, V.V., Patil, B.P., Shingre, D.V., Gawankar, M.S. and Chavan, A.P. (2005). Success of cashew grafts cv. Vengurla-4 as influenced by polyshed environments. *J. Agromet*. 7(2): 262-267.
- Salik, M.R., Khan, M.N., Ahmad, S. and Azhar, M. (2015). Grafting time affects scion growth in sweet orange under arid environment. *Pak. J. Life Soc. Sci*. 13(1): 58-61.
- Satoh, S. (1996). Inhibition of flowering of cucumber grafted on rooted squash stock. *Physiologia Plantarum*. 97(3): 440-444.
- Savvas, D., Papastavrou, D., Ntatsi, G., Ropokis, A., Olympios, C., Hartmann, H. and Schwarz, D. (2009). Interactive effects of grafting and manganese supply on growth, yield and nutrient uptake by tomato. *HortScience*. 44(7): 1978-1982.
- Selvi, R., Kumar, N., Selvarajan, M. and Anbu, S. (2008). Effect of environment on grafting success in jackfruit. *Indian Journal of Horticulture*. 65(3): 341-343.
- Shah, R.B. (1992). *Trainer's manual No. 16 Citrus fruit*. Department of Agriculture, Central Agriculture Training Centre, Manpower Development Project, Kathmandu, Nepal. 523 p.
- Shinde, S.B., Saiyad, M.Y., Jadav, R.D. and Chavda, J.C. (2010). Effect of structural conditions on softwood grafting success and survival of jamun grafts (*Syzygium cumini* Skeels). *Asian J. Hort*. 2(5): 391-392.
- Simkhada, E.P. (2007). Study on graft incompatibility in 'Fuyu' persimmon (*Diospyros kaki*) grafted onto different rootstocks in relation to physiological and morphological behaviors. Doctoral dissertation, Ph.D. Thesis, University of Tsukuba. 81 pp.

- Singh, N.P. and Srivastava, R.P. (1979). Studies on the different aspects involved in veneer grafting in mango. *Progressive Horticulture*. 11: 67-74.
- Singh, N.P. and Srivastava, R.P. (1982). Studies on various factors involved in soft wood grafting in mango. *Progressive Horticulture*. 14(2-3): 117-120.
- Singh, R.R., Karuna, K., Ajit, K. and Abhay, M. (2012). Studies on the effect of time and methods of grafting on success and growth of mango graft. *Progressive Horticulture*: 44(1): 151-154.
- Singh, S. and Singh, A.K. (2006). Standardization of method and time of propagation in jamun (*Syzygium cumini*) under semi-arid environment of Western India. *Indian Journal of Agricultural Sciences*. 76(4): 242-245.
- Sivudu, B.V., Reddy, M.L.N., Baburatan, P. and Dorajeerao, A.V. D. (2014a). Effect of structural conditions on veneer grafting success and survival of mango grafts (*Mangifera indica* cv. Banganpalli). *Plant Archives*. 14(1): 71-75.
- Sivudu, B.V., Reddy, M.L.N., Dorajeerao, A.V.D. and Hussain, S.F. (2014b). Seasonal variation in success of veneer grafting of mango under Andhra Pradesh (India) conditions. *Plant Archives*. 14(1): 133-37.
- Sundari, N.S.S. and Reddy, M.L.N. (2003). Influence of shade on success and growth of soft-wood grafts in cashew. *Andhra Agricultural Journal (India)*. 50(1 and 2): 83-85.
- Swamy, K.R.M., Rao, V.V.B., Nagaraju, B. and Nayak, M.G. (1993). Commercial Propagation of Cashew Varieties. In: *Proceedings of the Golden Jubilee Symposium on Horticulture Research*.
- Tewari, R.K., Bajpai, C.K. and Kumar, S. (2004). Standardization of bench grafting technique for aonla. *Range Management and Agroforestry*. 25(2): 120-123.
- Uchoi, J., Raju, B., Debnath, A. and Shira, V.D. (2012). Study on the performance of softwood grafting in jamun (*Syzygium cumini* SKEEL). *Asian Journal of Horticulture*. 7(2): 340-342.
- Venema, J.H., Dijk, B.E., Bax, J.M., van Hasselt, P.R. and Elzenga, J.T.M. (2008). Grafting tomato (*Solanum lycopersicum*) onto the rootstock of a high-altitude accession of *Solanum habrochaetes* improves suboptimal-temperature tolerance. *Environmental and Experimental Botany*. 63(1-3): 359-367.
- Visen, A., Singh, J.N. and Singh, S.P. (2010). Standardization of wedge grafting in guava under North Indian plains. *Indian Journal of Horticulture*. 67(4): 111-114.
- Xu, C.Q., Li, T. L., Qi, H.Y. and Wang, H. (2005). Effects of grafting on growth and development, yield and quality of muskmelon. *China Veg*. 6: 12-14.
- Yetisir, H., Caliskan, M.E., Soylu, S. and Sakar, M. (2006). Some physiological and growth responses of watermelon [*Citrullus lanatus* (Thunb.) Matsum. and Nakai] grafted onto *Lagenaria siceraria* to flooding. *Environmental and Experimental Botany*. 58(1-3): 1-8.
- Ziegler, L.W. and Wolfe, H.S. (1981). The Kinds of Citrus Fruits. In: *Citrus Growing in Florida*. 3rd ed. The Univ. Presses of Fla., Gainesville. p. 12-62.