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# Vegetable Grafting: Methods, Uses and Opportunities for Nepal: A Review

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## ABSTRACT

Grafted vegetable seedlings have been used from the early 20th century. This technique has been utilized extensively in East Asia and the European countries where it has developed as a multimillion-dollar industry. The increase in land area under protected cultivation, intensive use of land, scarcity of production resources and changing climate leading to unpredictable weather has caused a rapid increase in the use of grafted vegetables. However, in Nepal, where the productivity of vegetable crops is quite low and the breeding activities are inadequate, use of grafted vegetables is still unexploited. Therefore, this technique can be an important intervention to improve the overall production system of Solanaceous and Cucurbitaceous vegetables. Methods of vegetable grafting, their current uses, research carried out in Nepal and the possible opportunities are discussed in this review paper. Cleft, splice, tongue approach, hole- insertion and pin grafting are the methods currently in use. Grafting can be used to overcome the problems caused by various soil borne disease and nematodes and abiotic stresses like, low and high temperature stress, water stress, salinity, metal and organic pollutants while increasing the yield and extending crop duration in vegetable production. In Nepal, few research have been carried out on vegetable grafting with majority of them on assessment of tolerance to soil borne diseases. Utilization of this technique in Nepalese conditions provide ample opportunities for researchers and academicians to conduct researches and for breeding companies to develop resistant rootstocks. By implementing this method, vegetable industry can improve the overall yield, its quality and reduce hindrances in production.


**Key words:** Grafting, Opportunity, Quality, Sustainability, Vegetable.

Grafting may be defined as the natural or artificial union of plant parts to produce a single plant. When plant parts unite, vascular continuity is established between them resulting in a genetically composite organism which functions as a single plant (Davies *et al*., 2011). In fruit trees, it is a centuries old practice done to enhance the quality and quantity of produce by Chinese, Romans and Europeans even in the ancient times (Oda and Lee, 2003). However, in vegetables, it is a fairly new practice developed in the early 20th century although literature regarding vegetable grafting can be dated back to 17th century. The earliest grafted vegetable seedlings were produced in Japan and Korea when watermelon (*Citrullus lanatus*) were grafted into pumpkin (*Cucurbita moschata*) rootstocks to introduce resistance against Fusarium wilt in water melons (Sakata *et al*., 2005). Since then, the use of grafted cucurbit seedlings took pace and it rapidly developed and spread since 1930 when bottle gourd (*Lagenaria siceraria*) was developed as a stable rootstock for watermelon (Oda and Lee, 2003). In 1959, *Solanum integrifolium* (scarlet eggplant) was used as rootstock for scions of eggplant (*Solanum melongena*) in large scale production to overcome soil-borne diseases such as verticillium wilt, fusarium wilt, bacterial wilt and nematodes (Oda, 1999). From Japan and Korea, the use of grafted seedlings spread to the European nations in the late 1900's and from there, throughout the world. Nowadays, the use of grafted tomatoes, peppers, watermelon and cucumbers is quite high in developed nations for greenhouse production.

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The use of grafted vegetable plants is done to enhance plant vigor, increase the yield (Ropokis *et al*., 2019), tolerance to diseases, tolerance to temperature stress, enhance uptake of nutrients (Nawaz *et al*., 2017), improve drought tolerance (Kumar *et al*., 2017), increase tolerance to metal and organic pollutants, extend the crop duration, increase salt tolerance *etc.* (Bletsos *et al*., 2003; Edelstein, 2004; Khah *et al*., 2006; Lee *et al*., 2010; Schwarz *et al*., 2010). The researches done on grafting of tomato, eggplant and cucurbits have shown significant positive effect upon the yield, quality, resistance to soil borne diseases, water stresses, salinity and tolerance to toxic chemicals in the soil due to grafting (Yassin and Hussen, 2015). Because of this, the use of grafted seedlings as propagules for cultivation is progressively increasing in the vegetable industry sector throughout the world. The increment in area under protected cultivation, intensive land use (Edelstein, 2004), advantages in yield, limited options for controlling soilborne diseases (Kubota *et al*., 2017) and the development of new techniques and methods for grafting (Gaion *et al*., 2018) has also resulted in increased use of this technique. To illustrate, in Korea and Japan alone, about 92 and 95% of all cultivated watermelon are grafted plants (Lee *et al*., 2010). In Italy, 100% of melons, 78% of cucumber and 85% of eggplants cultivated in greenhouse are grafted plants (Miles *et al*., 2016). Although the use of grafted seedlings for vegetable production is already developed as a multimillion dollar industry in the East Asia and the West, it still hasn't been started commercially in Nepal.

Nepal has a significant variation in altitude from 60 masl to 8848 masl which results in a great diversity in agro-climate from tropical areas to the temperate where almost all types of vegetables can be grown year-round. The uncultivated arable land is abundant (6.99% of total land area) and the water resources are also plenty (AICC, 2019) which can be utilized for the expansion of vegetable cultivation. The area under commercial vegetable farming is increasing every year. The area used for vegetable cultivation was 2,84,135 hectares in 2016/17 which escalated to 2,86,864 hectares in 2017/18 (AICC, 2019). Also, in recent years, the production of vegetables under protected cultivation is getting exponential momentum in Nepal (Atreya *et al*., 2020).

Nonetheless, the productivity is quite low compared to neighboring nations. In India, the average productivity of vegetables is 17. 97 Mt/ ha (GOI, 2018) and in China, it was 27.8 tons/ha with annual increment of 0.44% in 2001 (Liu *et al*., 2004) while it is only 13.79 M t/ha in Nepal in 2018 (AICC, 2019). The incidence of pests and diseases (Lamichhane *et al*., 2011; Pretty and Barucha, 2015), inadequate disease and pest resistant cultivars (Welbaum, 2015), biotic and abiotic stresses, exposure of plants to extreme weather events due to climate change (Ahuja *et al.*, 2010; Phphi *et al*., 2017), poor soil management (Kharal *et al*., 2018) and low fertilizer use are some reasons for low productivity of vegetables. Besides this, the incidence of soil borne diseases, stresses, soil acidity and alkalinity increases with increased crop intensity in protected cultivation (Lee *et al*., 2010) also leads to low yields. Thus, the use of high-yielding, disease resistant cultivars and quality planting material that can tolerate stress are the primary requisites for increasing the productivity of vegetables.

However, in a country like Nepal, where modern technological advances in vegetable breeding are not adopted and negligible portion of agricultural investment is on breeding (Joshi, 2017), it is quite difficult to develop and release superior plant varieties with desired characteristics. Thus, the grafted vegetables can play a major role to increase the vegetable production by introducing resistance to pest and diseases and increasing tolerance to stresses since it is a proven technique for enhancing the potential of a crop.

Thus, this review paper aims to discuss and review the methods of vegetable grafting followed around the world, review the uses of grafted vegetable plants and their advantages. It also targets to study the researches on vegetable grafting done in Nepal and suggest the opportunities offered by vegetable grafting for academicians, vegetable seed industry and the producers in Nepalese scenario.

## Methods of vegetable grafting

Currently, vegetable grafting is practiced on the fruit vegetables belonging to family Solanaceae and Cucurbitaceae but the selection of a particular grafting method depends primarily on the type of crop used (Lee, 1994), the grower's experience, personal choice, purpose of grafting (Lee *et al*., 2010) and the cost incurred (Maurya, 2019). Conventionally, splice and cleft grafting is more popular with Solanaceous vegetables while tongue approach grafting ensures higher survival of Cucurbitaceous vegetables when grafted (Yassin and Hussen, 2015). The various methods used for grafting different rootstocks in different vegetables is shown in Table 1.

### Cleft grafting

It is also known as wedge or apical grafting and it is mostly used for solanaceous vegetables. In this method, a vertical incision of about 0.5 cm is made at the center of rootstock after decapitating it and a scion with wedge shaped end is inserted at the center of the incision before tying the graft union with a plastic clip or parafilm (Johnson *et al*., 2011) (Fig 1 A, B).

### Splice grafting

It is also known as top grafting or tube grafting and is one of

**Table1:** Grafting methods employed for various vegetable crops.

| Vegetable | Rootstock | Method employed |
|---|---|---|
| Brinjal | *Solanum torvum, S. sissymbrifolium,* *Solanum khasianum* | Tongue and cleft method, Cleft method, Both tongue and cleft methods |
| Tomato | L. *pimpinellifolium, S. nigrum* | Only Cleft method Tongue and cleft methods |
| Cucumber | *C. moschata, Cucurbita maxima* | Hole insertion and tongue method |
| Water melon | *Benincasahispida, C. moschata, C. melo,* *C. moschata× C. maxima, Lagenariasiceraria* | Hole insertion and cleft, Hole insertion and cleft, Hole insertion and splice grafting |
| Bitter gourd | *C. moschata, Lagenariasiceraria* | Hole insertion and tongue method, Hole insertion |

Source: Maurya *et al.* (2019).

the most popular grafting method for solanaceous vegetables. In cucurbits, it is slightly modified and called one cotyledonsplice grafting (Lee *et al*., 2010). According to Johnson *et al*. (2011), both the rootstock and scion are cut at $45^0$ angle with matching cut and are clipped together with a grafting clip (Fig 2 A, B). The major advantage of this method is that sturdy and healthy grafted seedlings are produced due to proper attachment of the vascular bundles (Oda and Lee, 2003).

### Tongue approach grafting / side grafting

Although this method is applicable for both Solanaceous and Cucurbitaceous vegetables, it is most widely practiced on the latter. In this method, a slanting cut is made on the rootstock stem in downward direction and upward direction in the scion stem at 30°-45° angle (Fig 3). The rootstock and scion are then attached together at the point of cut and held together with grafting clips. This method requires rootstock and scion of equal diameter so, sowing time of scion and rootstock seedlings should be adjusted accordingly.

### Hole insertion grafting

This method is most popular among Cucurbits when the rootstock and scion have hollow hypocotyls. A hole is made on the rootstock and scion is inserted inside it (Fig 4). It is most popular with watermelon seedlings when they are grafted unto rootstocks of bottle gourd or squash (Maurya *et al*., 2019). Although this method requires higher skill, it is more popular among the commercial growers because it does not require additional labour for clipping, transplanting, cutting and removal of the grafting clip (Lee *et al*., 2010).

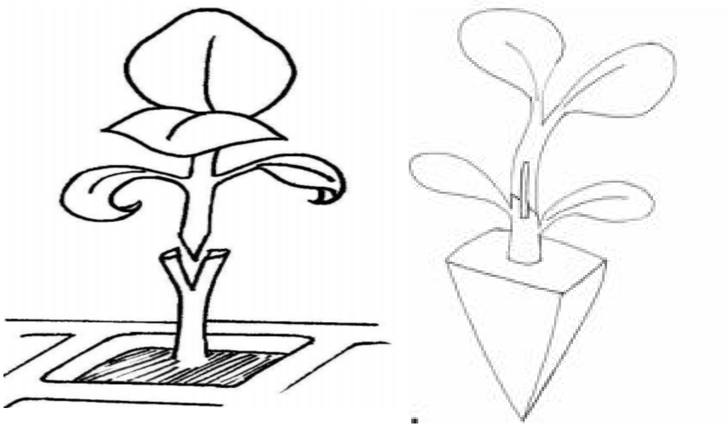
### Pin grafting

This method is quite similar to splice grafting but especially designed pins are used for holding the grafted seedlings instead of the grafting clips (Lee *et al*., 2010) (Fig 1B).

## Utilization of grafting on vetetables

### To improve the yield and fruit quality

Several research trials conducted on grafting of Cucurbits and Solanaceous vegetables have shown an increase in the yield of crops. Khah *et al*. (2006) demonstrated a yield increment in plants grafted unto “Henan” rootstock by 32.5% and 12.8% in greenhouse and open field cultivation respectively compared to self-grafted plants in “Big Red” tomato variety. Similarly, Moreno *et al*. (2016) conducted an experiment in watermelon using “Marathon” (*Cucurbita*



A B

**Fig 1:** Grafting method in vegetables. (A) Cleft Grafting, (B) Pin grafting.
Source: Johnson *et al.* (2011), Davis *et al.* (2008).

A B

**Fig 2:** Splice grafting (A and B). Source: Johnson *et al.* (2011).

*maxima x Cucurbita moschata* hybrid) and Bottle Gourd (*Lagenariasiceraria*) as rootstocks and found yield to increase by 136% and 159% in grafted plants than the non-grafted ones also with an improvement in fruit quality in the former. Similar results have been observed on eggplants (Sabatino *et al*., 2018), cucumber (Noor *et al*., 2019), sweet pepper (del Amor *et al*., 2008) and other cucurbits (Salam *et al*., 2002; Lee and Oda, 2003; Colla *et al*., 2006).

The previous studies on the effect of grafting on fruit quality are not consistent. While many fruit qualities have been reported to improve, some fruit quality parameters are unaffected while some are hindered due to grafting. The physical quality attributes like size, shape, colour and absence of defects have improved (Pogonyi *et al*., 2005; Pradhan *et al*., 2017). Fredes *et al*. (2017) reported an increase in the glucose and malic acid content of watermelon when grafted with citron melon rootstocks. However, they reported no significant difference on flesh sugars and acid content due to the intervention. Dijdonou *et al*. (2016) recorded no difference in total titratable acidity and the ratio of soluble solid content (SSC) to TTA in field grown tomatoes grafted onto "Beaufort" or "Multifort" rootstocks compared to non- or self-grafted plants. Nonetheless, they found reduction in the Vitamin C content by 22%.

While some authors have reported a decrease in total sugar content in grafted vegetable crops (Qian *et al*., 2004; Liu *et al*., 2006), others have obtained an increase in soluble solids, Vitamin C content, total soluble sugars and sugar-acid ratio (Proietti *et al*., 2008; Huang *et al*., 2009; Gan *et al*., 2018). Therefore, more extensive researches need to be carried out in the future to understand the effect on fruit quality and development of possible techniques to improve the fruit quality in grafted plants.

**To combat soil borne diseases**

Grafting of vegetables have been used most extensively and successfully for the control and management of soil borne diseases in both open and protected cultivation since grafted plants have proved to offer resistance to a large number of diseases. A large number of studies on vegetable grafting have exhibited successful control of major soil borne diseases like Verticillium wilt (Curuk *et al*., 2009; Papadaki *et al*., 2017), Fusarium wilt (Yetisir *et al*., 2003; Sakata *et al*., 2008), Bacterial wilt (McAvoy *et al*., 2012) and root knot nematodes (Lian *et al*., 2007).

**To improve tolerance to abiotic stresses**

Grafting has also been utilized to improve tolerance and improve yield under various environmental stress conditions

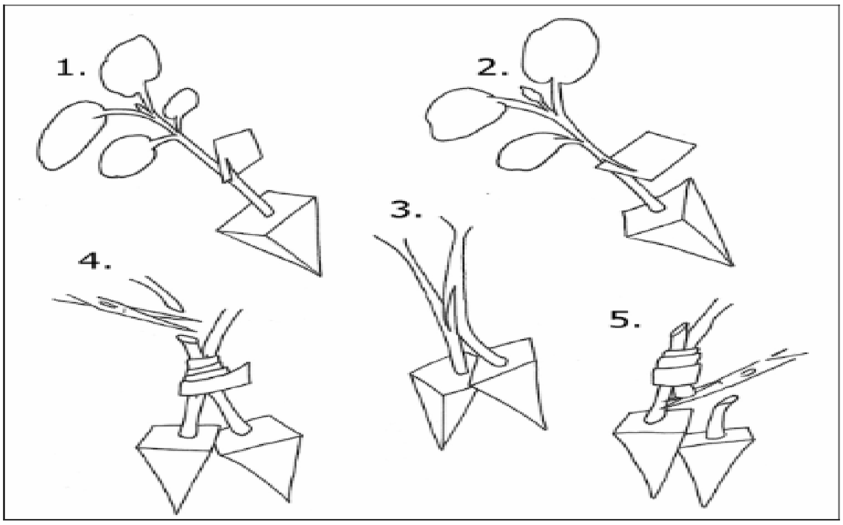


**Fig 3:** Tongue approach grafting. Source: Hassel and Memmott (2008).

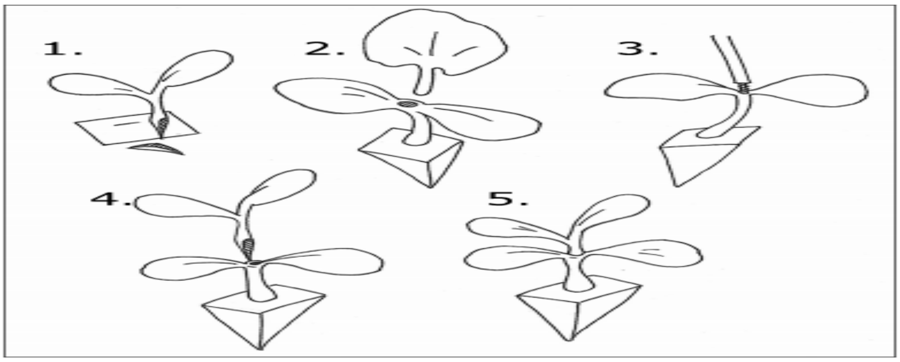


**Fig 4:** Hole insertion grafting. Source: Hassel and Memmott (2008).

like water stress (Lopez-Marin *et al*., 2017), salinity stress (Wahb-Allah and Mahmoud, 2014), low and high temperature stress (Schwarz *et al*., 2010) and soil pollutants in both Cucurbits and Soalanceous vegetables. For example, the use of eggplants as rootstocks for tomato plants has exhibited more tolearance to higher soil temperature (Abdelmageed and Gruda, 2009). Thus, the utilization of this method has helped to improve productivity under sub-optimal conditions.

## Research on vegetable grafting in nepal

Not much of research has been carried out in Nepal with regards to vegetable grafting. It was initiated in Nepal with the conduction of training to scientists and technicians in Khumaltar, NARC in 2007 (Timila and KC, 2014). Subsequently, researches were carried out in Agriculture Research Station, Malepatan, Pokhara on brinjal and tomato by using wild rootstocks for grafting. It included testing of rootstocks and the evaluation of the grafted plants (Timila and KC, 2014). Specifically, the grafting experiments till date has been carried merely on solanaceous vegetables for management of two prominent soil borne disease in Nepal, Bacterial wilt and Root Knot Nematode (Timila *et al*., 2016).

In an experiment to evaluate wild eggplant species/ genotypes as rootstock against bacterial wilt, Timila *et al*. (2016) found indigenous wild eggplant (*Solanum turvom*), exotic wild eggplant (*S. sisymbriifolium*) and exotic eggplant genotype, EG 195 from AVRDC to be resistant to bacterial wilt. Following through on another experiment, Timila and Manandhar (2016) reported bacterial wilt susceptible tomato variety Pusa Ruby grafted on wild eggplant showed 100% survival until 12 weeks after inoculation of bacterial wilt pathogen compared to cent percent mortality of non-grafted ones within 3 weeks.

At another stance, Baidya *et al.* (2017) found wild eggplant *S. sisymbriifolium* as a prominent rootstock for resistance against root knot nematode along with bacterial wilt. In experiments carried out for 2 consecutive years, 2009/10, at Hemza, Kaski, the author co. found presence of no nematode galls on root system of tomato grafted on *S. sisymbriifolium*, while 75% of root system were galled in case of non-grafted tomatoes. In addition, significantly higher yield (37%) and increased crop life span was observed in grafted tomatoes.

KC *et al.* (2012) while assessing reaction of various rootstocks of eggplant, tomato and chili to root knot nematode, found out no presence of root knot nematode galls in root system of wild eggplant; *S. torvum*, *S. sisymbriifolium* and AVRDC Chilli accession PP 02337-750 among many. They also reported 22-37% yield increase in grafted tomatoes compared to non-grafted ones.

Inspired by the research findings, various farmers groups and individual growers of Syangja and Hemja, Kaski are commercially producing and selling grafted seedlings of tomato on rootstocks: *S. sisymbriifolium* and *S. torvum* on demand basis.

While these researches have shown promise and paved a path for vegetable grafting in Nepal, the exploitation of this method to manage diseases, overcome stresses, increase yield and quality of fruits is still untapped in our scenario. It is difficult to find documented reports on the use of grafted vegetables in the farmer's level.

## Need for vegetable grafting in nepal

Intensive vegetable farming started gaining pace and uprise in Nepal since last two decades with better availability of quality input materials, technology transfer and adoption of protected cultivation (Thapa and Dhimal, 2017). Many areas like peri urban parts of Kathmandu valley, Chitwan plains, Lalbandi, Dang valley have developed into a prominent vegetable hub. In Kathmandu valley alone, 570 hectares of land is utilized for protected cultivation of tomato (MoALD, 2017/18). Mono cropping has been a basic feature of these land farms which in turn have prompted ever increasing soil borne disease incidence. Bacterial wilt, Root knot nematode, Fusarium wilt, Phytophthora wilt have been a regular turmoil of soils of these vegetable hubs (Timila and KC, 2014). Although some tomato and eggplant varieties are recognized and cropped as bacterial wilt resistant crop, their resistance is limited to selective strains and biovars only. In case of sweet pepper, breeding for resistance against the soil borne pathogens has not been expectedly successful (Cerkauskas, 2004).

Recently, crops like sweet peppers and eggplants are being promoted to grow in semi determinate and indeterminate fashion. This requires the crops to be grown for a longer time period which makes them more prone to soil borne diseases and extreme climatic conditions. In such scenario, grafting of vegetables can play a major role in preventing disease susceptibility and to ensure crop longevity. Grafting on resistant rootstocks doesn't merely stand as a choice for solanaceous crops but the only alternative to overshadow pathogens of soil.

Summer gourds and melons are grown extensively in eastern and central plains of Nepal. The area under cucurbitaceous vegetables has also increased significantly in recent decades (MoALD, 2017/2018). These crops suffer tremendously with consequences of climatic uncertainty, persistent drought or abrupt flooding. Grafting can be seen as a better option to manage the abiotic stress on these gourds and melons.

Government of Nepal has been promoting organic farming in last few years. Karnali Province is taking measures to develop itself into organic province of Nepal. In this case, vegetable grafting remains as the best management tool to drive organic farming in a sustainable path since it can help avoiding the use of chemical pesticides for pest control (Pérez-Alfocea, 2014).

## Opportunities for vegetable grafting

Since works on vegetable grafting is quite limited, there are ample opportunities for researchers, professors and academicians to make studies. Surveys can be made to identify the largely untapped wild and resistant rootstocks. Researches can be done on biotic stresses, soil borne diseases, environmental stresses, plant vigor, fruit yield and quality. Activities like verification of rootstocks and developing grafting as a method of reducing pesticide use are also largely unexploited thus, provide an opportunity. The breeders can also work on the development of resistant rootstocks. For the entrepreneurs and growers, this can be an effective tool to improve overall yield and quality of vegetables while avoiding the hindrances in vegetable production.

### Challenges in vegetable grafting

The main challenge in adoption of vegetable grafting in production is the higher cost of the seedlings. The production of these seedlings requires rootstock and scion seed, extra labour for grafting as well as special care to seedlings after grafting which in turn, raise the price for grafted seedlings (Edelstein., 2004; Lee *et al*., 2010; Yassin and Hussen, 2015) although several studies have shown higher overall benefit associated with the use of grafted vegetable seedlings (Djidonou *et al*., 2013; Genova *et al*., 2013; Genova *et al*., 2015). Another challenge may be the lack of diffusion and adoption of this technology due to poor extension practices. Since researches for the recommendation of proper stock/ scion combinations and breeding for development of suitable rootstocks are still lacking in Nepal, this technique is difficult to adapt by potential growers without extensive research beforehand.

## CONCLUSION

Grafted vegetable seedlings have been used to increase the yield as well as to overcome the various biotic and abiotic stresses in vegetable production throughout the world. The increase in protected cultivation of vegetables, intensive cropping cycles, scarcity of production resources and changing climate has led to rapid increase in the use of grafted vegetables.Since Nepal has low vegetable productivity, this technique can be an important intervention to improve the overall production system of Solanaceous and Cucurbitaceous vegetables by overcoming various constraints in production. For this, site specific rootstocks recommendation based on field-based research and development seems necessary. Meanwhile, the research on various aspects of this technology is quite limited and almost unexploited in Nepal. Therefore, there are ample opportunities for researchers, academicians, breeding companies and the vegetable industry to use its advantages.

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### Conflict of interest

The authors declare no conflict of interest with anyone.

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