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Vegetable Grafting: A Multiple Crop Improvement Methodology

T. Lakshmi Tirupathamma[1*], C. Venkata Ramana[2], L. Naram Naidu[2] and K. Sasikala[3]

[1]Department of Vegetable Science, College of Horticulture, Dr. Y.S.R. Horticultural University, V.R. Gudem-534101, India.
[2]Horticulture Research Station, Dr. Y.S.R. Horticultural University, Lam Farm, Guntur-522034, India.
[3]Department of Agronomy, College of Horticulture, Dr. Y.S.R. Horticultural University, V.R. Gudem-534101, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Grafting is a simple method of propagation in which desired rootstocks are obtained to induce vigor, precocity, enhanced yield and quality, better survival under biotic and abiotic stress conditions. Grafting reduced the dependency upon chemicals required to treat the soil borne diseases and has opened new vista in organic farming of vegetables. Grafting is the popular technology among vegetable growers and researchers to develop resistance in the crops or improve tolerance to biotic and environmental stresses in the various crops mentioning solanaceous and cucurbitaceous crops. The technology of grafting is potential in promoting the cultivation of vegetables in customized and fragile agricultural-ecosystem. It is a alternative tool

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**Corresponding author: E-mail: cvr.venkat@gmail.com;*
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which is rapid in case of relatively slow breeding methodology and useful in sustainable horticulture which takes low input for future agriculture system. Further, inventions in mechanized and robotic grafting have given a fillip to this novel eco-friendly approach. Mechanization will considerably reduce the cost of grafted seedling production in the future.

Keywords: Abotic; biotic; grafting; methods; vegetable; yield.

1. INTRODUCTION

Vegetables are considered as an important component in the diversification of horticulture to provide food and nutritional security for the growing population. There are several factors limiting vegetable production *i.e*. biotic (pest and disease incidence) and abiotic factors (environmental and soil stresses) in India. Development of new varieties or hybrids and standardization of crop management practices have helped to surmount these constraints. Among these, grafting has become popular as an agricultural practice [1].

Grafting involves two parts (a rootstock and scion) of different plants which forms a single, plant. Rootstock is a plant already has an established, healthy root system and is selected for their ability to resist under abiotic and biotic stress condition or their ability to increase vigor, precocity and enhanced yield and quality. The scion of the grafted procures the upper portion of the plant and it can be selected for its quality of fruit characteristics.

Grafting is an ancient technique, in vegetables first literature reports available in 17th century book written by Hong. The production of grafted vegetables in Asia is widespread. Use of grafted seedlings for vegetable cultivation was originated in Japan and Korea in late 1920s with grafting of watermelon (*Citrullus lanatus*) onto bottle gourd (*Lagenaria siceraria*) root stock [2]. Later, brinjal (*Solanum melongena*) was grafted on to scarlet eggplant (*Solanum integrifolium*) in 1950s. Since, then the cultivated area of grafted vegetables, as well as different kinds of vegetables being grafted, has consistently increased. Presently most of the watermelons, musk melons, (*Cucumis melo)* cucumber (*Cucumis sativus* L.), tomato and brinjal in Korea and Japan are grafted before being transplanted to the main field or green houses. In Japan, percentage of grafted plants area in verse of the total production area is 93% in case of water melons and 90 % for cucumbers and 79 % for eggplant and 58% for tomato. In Japan (92%), Korea (98%) and China (40%), major share in watermelon production is from grafted seedlings [3]. In Europe, Spain is leading in grafted seedlings production with 129 million grafted seedlings followed by Italy (47 million grafted seedlings) and France (28 million grafted seedlings) [4].

2. PURPOSE OF VEGETABLE GRAFTING

Vegetable grafting was first adopted to enhance their ability to cope up with biotic stresses. Lately, this technique has also been proposed to enhance vegetable tolerance to abiotic soil stresses, such as low soil temperature, drought, salinity and flooding [3,5]. In general, vegetable grafting has been motivated by the need to increase plant yields. Grafting has also paved a way for enhancing water and nutrient uptake and increasing plant vigor and extending duration of economical harvest time. Grafting reduce the dependency upon chemicals required to treat the soil to avoid the soil borne diseases and has opened new vista in organic farming of vegetables [6]. Grafting is an eco-friendly approach which controls soil borne diseases and increases the yield of cultivars [1]. This eco-friendly method for sustainable production using resistant rootstock reduces dependence on agrochemicals [7].

2.1 Achieve Soil Borne Disease and Pest Resistances / Tolerances

One of the major advantages of using grafted plants is to utilize the strong tolerance or resistance of rootstocks to certain soil borne diseases. The rootstock showed significant tolerance to major soil borne diseases, such as those caused by *Fusarium* spp., *Verticillium* spp. and *Pseudomonas* spp. even though the degree of tolerance varies considerably with the rootstocks. The disease tolerance in grafted seedlings may be entirely due to the tolerance of stock plant roots to such diseases.

Hybrid squashes (*Cucurbita maxima* Duchesne × *Cucurbita moschata* Duchesne) are widely used as melon rootstocks are highly resistant to fusarium wilt and tolerant to verticillium wilt, monosporascus suddenwilt, and gummy stem blight [8]. Grafting is used to stop soil-borne diseases such as *Fusarium* wilt in Cucurbitaceous crops (cucumber, melon etc.) and Bacterial wilt in Solanaceous crops (tomato, pepper etc.) [7]. Pepper scion ('Nokkwang') grafting onto breeding lines ('PR 920', and 'PR 921', and 'PR 922') resistant to both *Phytophthora* blight and bacterial wilt revealed greater survival rate when inoculated with *Phytophthora capsici* and *Ralstonia solanacearum* [9]. Eggplant is grafting onto *Solanum sisymbrifoliun* resistan*t to* Verticilium wilt [10]. Water melon grafting onto bottle gourd improves the resistant to fusarium wilt [11]. Eggplant grafting onto shin-tosa rootstocks improves the vegetative growth rate at low temperature [12].

2.2 Acquire Tolerance to Abiotic Stresses

To induce resistance against low and high temperature, grafts were generally used**.** For the production of fruiting vegetables under the winter greenhouse conditions, tolerance to extreme temperature is crucial [13]. Grafted watermelons had a greater tolerance when watered with saline water than did the non-grafted plants and also resistant to flood [1]. Fig leaf gourd rootstock has been used commercially to increase the tolerance of cucumber, watermelon, melon and summer squash to low soil temperature. Grafting led to salt and flooding tolerance [14], improved water use efficiency [15], increased nutrient uptake [16] and alkalinity tolerance [17]. The process helps in the survival rate of plants under low temperature stress as more Linolenic acid is present. Chilli revealed highest yield in increased-temperature when grafted with sweet pepper rootstocks [18]. Grafting decreases the negative effect of boron, copper, cadmium, and manganese toxicity [19]. In tomato, grafting resulted in the formation of more number of internodes and flowers in outdoor cultivation and number and total weight of fruits in indoor cultivation [20]. Grafted watermelon seedlings under low temperature have high antioxidants and anti oxidative enzyme activities in leaves than the self-rooted seedlings [21].

2.3 Increased Plant Vigor Promotion (Reduced Fertilizer and Agrochemical Applications)

The rootstock's vigorous root system is often capable of absorbing water and nutrients more efficiently than scion roots and serves as a good supplier of endogenous plant hormones. However, the rootstock effect varies with the cultivar and growing season [22]. Vigorous root system rootstock of cucumber can significantly absorb water so less frequent irrigation can be practiced. Using vigorous rootstocks agrochemical application frequency can be deceased. In watermelons, the amount of chemical fertilizers can be reduced to about one-half to two-third as compared to the standard recommendation for the non-grafted plants [23]. This is especially true for nitrogen fertilizers during early seedling growth for the safe setting of fruits at the desired node positions for early fruit set. Early fruit set is crucial for the early harvesting in greenhouses to secure good market prices. Otherwise the fruit set as well as the fruit quality at harvest will not be high enough to secure highest market grading.

Table 1. Different vegetables and objectives of grafting

Vegetable	Objective of grafting
Cucumber	Tolerance to Fusarium wilt, *Phytophthora melon*is, cold hardiness, favourable sex ratio.
Melon	Tolerance to Fusarium wilt, wilting due to physiological disorders, Phytophthora disease, cold hardiness, enhanced growth.
Watermelon	Tolerance to Fusarium wilt, wilting due to physiological disorders, cold hardiness and drought tolerance.
Tomato	Tolerance to *Fusarium oxysporum* f.sp. *radicis-lycopersici*, corky root (*Pyrenochaeta lycopersici*), better colour, greater lycopene content and tolerance to nematode.
Brinjal	Tolerance to bacterial wilt (*Pseudomonas solanacearum*), *Verticillium albo-atrum*, *Fusarium oxysporum*, low temperature, nematodes, induced vigour and enhanced yield.

2.4 Influence on Sex Expression

Due to flow of substances, changes occur in the flowering pattern of the grafted scion. *Cucurbita hardwickii* scion grafted on monoecious or gynoecious cultivars of cucumber expressed increased total flower and pistillate flower. *Sicyos angulata* is a qualitatively short day wild species was induced to flower not only by grafting it onto a flower induced plants of the same species but also by intergeneric grafting on day neutral plants of *Luffa cylindrica* under non inductive long day conditions. Further it was observed that *S. angulata* developed both staminate and pistillate inflorescence with similar sex expression even when one of the cucumber cultivars was andromonoecious.

2.5 Improving Quality Traits

Grafting improves fruit quality under both optimum growth conditions and salinity. The fruit size of grafted watermelons rootstock having vigorous root systems is often significantly increased compared to the fruit from intact plants, and many growers practice grafting mainly for this reason. It is also known that other quality characteristics, such as fruit shape and skin color, rind thickness, and soluble solids concentrations are influenced by rootstock. In cucumbers, especially those for export, external color and bloom development are important quality factors. Even though these are usually regarded as cultivar-specific hereditary characteristics, they can be greatly influenced by the rootstock. The fruit quality of the shoot, at least partially, depends on the root system [24]. In soilless tomato cultivation, grafted plants had higher marketable yield, fruit quality and pH content of fruits depending on rootstocks [25].

2.6 Enhancing High Yield

Grafting is associated with noticeable increases in fruit yield in many fruiting vegetables regardless of infection with certain soil-borne diseases. Up to 54% increase in marketable yield was obtained with „Kagemusia" and 51% with „Helper" rootstocks in tomato [26]. There were also significant decreases in abnormal fruits in plant grafted onto most rootstocks as compared with the own-rooted "Seokwang" tomato. Similar yield increases have been reported by other researchers on watermelon, cucumber [1], melon, pepper, and eggplant.

The prolonged duration of fruit harvest in grafted plants is believed to be due not only to the disease tolerance of the rootstock, but also to enhanced water and mineral uptake [27]. The yield increases, obtained by the extended duration of fruit harvest, are most apparent under the unfavorable environments of protected cultivation. However, it should be remembered that the rootstock effect varies greatly with scion cultivar, even in the same crop. In problematic soils, grafts have been used to increase yield in case of cultivated plants [7]. They give higher yield of tomato *cv*. 'Monroe' grafted onto rootstock of 'Beaufort'. In greenhouse as well as in open-field, grafted plants gave more yield than non-grafted ones [28]. Tomato plants grafted onto 'Heman' and 'Primavera' produced higher yield in the greenhouse and the open field. Water use efficiency and yield were higher in grafted plants. The researchers of Korea and Japan have reported increases of 25 to 50% in yield of grafted tomato, melons, pepper, eggplant and watermelon compared to non-grafted plants. Cucumber plants grafted onto pumpkin rootstocks had 27% more marketable fruit per plant than self-rooted cucumber [29]. A squash interspecific hybrid rootstock increased watermelon yield and increased fruit size [30].

2.7 Others-physiology, Peculiarity, Hobby, and Education

Grafting can be demonstrated for various other reasons. For example, tomatoes, eggplants, pepinos can be grafted on potatoes so that four or more different kind of vegetables could be harvested from a plant. Chinese cabbages and cabbages may be grafted on top of radish with radish roots. Grafting can be made for some physiological studies such as flower induction and early flowering. Grafting is also commonly used for bioassays of virus infection. Use of grafted plants is highly recommended for hydroponics to avoid rapid spread of root disease within the system [11].

2.7.1 Popular interactions

Inter-Generic: Watermelon and bottle gourd, Cucumber and pumpkin, Melon and wax gourd.

Inter-Specific: Tomato and tomato, Eggplant and eggplant.

2.7.2 Methods of grafting

Different grafting techniques were adopted for different scions and rootstocks; they depend on grafting objectives, farmers' experience, and post grafting management conditions; and moreover, the survival rate of grafted plants depends on compatibility between scion and rootstock, quality and age of seedlings, quality of the joined section, and post-grafting management. The initial grafting method used for melon was cleft grafting but after the introduction of the tongue approach grafting method, its use diminished greatly. The tongue approach method became widespread in Asia because of its higher success rate and the uniform growth of grafted seedlings. In Spain, high proportions (more than 90%) of watermelon plants are grafted using the one cotyledon method. Tomato and eggplants are mostly grafted by cleft and tube grafting. Tongue approach is used in grafting Cucurbitaceae especially for cucumber. Slant-cut grafting is easier and has recently become popular for watermelon and melon. This method was developed mainly for robotic grafting. These methods have been discussed as under:

1. Cleft grafting: This method is widely used in crops like tomato and brinjal. The seeds for the root stock are sown 5-7 days earlier than the scion. The seedlings at 4-5 leaf stage are selected for grafting and are cut at right angles; each with 2-3 leaves remaining on the stem. The stem of scion is cut in a wedge shape and the tapered end fitted into a cleft cut in the end of the rootstock. The graft is held firm with a plastic clip. It is a simple and easy method. It is suitable for rootstocks with wide hypocotyls. It can be practiced in all vegetables.

2. Tongue approach grafting: This method is commonly used on members of the cucurbitaceous vegetables because it ensures a higher survival rate. It is because of the root of the scion remains until the formation of the graft union. In this method, seeds of cucumber are sown 10-13 days before grafting and pumpkin seeds 7-10 days before grafting, to ensure uniformity in the diameter of the hypocotyl of the scion and rootstock. The shoot apex of the rootstock is removed so that the shoot cannot grow. The hypocotyl of the scion and rootstock are cut in such a way that they tongue in to each other and the graft is secured with a plastic clip. The hypocotyl of the scion is left to heal for 3-4 days and then crushed between the fingers or partially cut below the graft. This step is used to wean the scion off of its own roots. Finally, the stem is completely cut off with a razor blade three or four days after being crushed.

3. Slant grafting: This is also known as one cotyledon grafting. It has recently been adopted by commercial seedling nurseries. It is applicable to most vegetables. It has been developed for robotic grafting. Rootstock should be sown 7 – 10 days before scion sowing to ensure uniform diameter of hypocotyls and to hold the scion on rootstock perfectly. Grafting can be done by making slant cuts on both root stock and scion by retaining only one cotyledon leaf on the rootstock. Grafted plants should be maintained in the dark at 25°C and 100% humidity for three days for successful graft union.

4. Hole insertion grafting: This is also called as top insertion grafting. This is most popular in cucurbits. When scion and rootstock have hollow hypocotyls, this method is preferred. In this method grafting can be performed by making hole on the top of the root stock and by inserting the scion in that hole which should be prepared in such a way to similar diameter as math with hole measurements of stock. One person can produce 1,500 or more grafts/day. To achieve a high rate of success, relative humidity should be maintained at 95%. After healing, temperature should maintain at 21-36°C up to transplanting.

5. Tube or Japanese Grafting: This grafting has been developed for vegetable seedlings grown by plug culture. This method makes possible to graft small plants grown in plug trays two or three times faster than the conventional method. The smaller the plants, the more plants can be fitted into healing chambers or acclimation rooms. Cut rootstock under cotyledons in a 45o or sharper angle. Prepare the scion with matching hypocotyl width cut in the same angle at about 5- 10 mm below the cotyledons. Place one tube a half way down on top of the cut end of rootstock hypocotyl. Insert the scion into the grafting tube so that cut surface aligns perfectly with that of rootstock. Move the tray filled with grafted plants to proceed for healing up to 7 days.

6. Pin grafting: It is also same as the slant grafting. In this instead of grafting clips, to hold the grafted position, specially designed pins are used. The ceramic pin is nearly about 15 mm long and 0.5 mm in diagonal width of the hexagonal cross-section. The pins are made of natural ceramic so it can be left on the plant without any problem. The price of ceramic pin is fairly high so that alternative methods are being sought. Experimental results revealed that bamboo pins, rectangular in cross-sectional shape, could successfully replace the expensive ceramic pins at much lower price.

2.7.3 Grafting machines and robots

Grafting is a procedure that has a high labour demand, particularly in large commercial nurseries, which need to produce thousands of grafting seedlings in a short period of time. It is estimated that of graft 3,000 cucumbers, 42 man-hours are required, with 70% of this time being spent for the union of root stocks and scion. Although the filling of the growing plates with soil or a soilless substrate, seeding, irrigation, fertilizer application and the control of the environment in the green house can be carried out and controlled automatically, the actual grafting of seedlings is largely carried out manually. The need to satisfy high demand, but at the same time reduce production costs, makes the adoption of mechanization for grafting is necessity.

Today several types of simple grafting machines or fully automatic robots are available on the Japanese and Korean markets which can graft the Solanaceous species with a high percentage of success. These machines and robots can graft as 600-1200 seedlings per hour, compared to 150-180 seedlings per hour by a specialized worker. The robots employ suitable computer programmes that can select, sort and graft uniform seedlings [11]. The first semiautomatic cucumber grafting system was commercialized in 1993. A simple grafting machine can produce 350–600 grafts/hour with 2 operators, whereas manual grafting techniques produce about 1,000 grafts / person / day. A fully automated grafting robot performing 750 grafts/hour with a 90-93% success rate [11].

3. FACILITIES REQUIRED FOR GRAFTING

Selection of rootstock and scion: Suitable root stocks for grafting vegetables are those with good compatibility , resistance to low temperature, soil pathogens (Fusarium, Verticilium) and nematodes, encourage good growth of the scion, increase production and do not reduce quality. These rootstocks belong to the same, or a related, genus or they are F_1 hybrids between related species. A good number of rootstocks with some of the characteristics are found on the market. Growers have the ability to select the most suitable rootstocks for the growing season they are interested in, the cultivation method that they are going to follow (green house or open field), the soil and climatic conditions of the area and the cultivars [7]. Select the desirable rootstock and scion at two true leaf stage. Stem diameter of scion should be same as that of rootstock.

Screening chamber: Seedlings of root stock can be raised in pots with diameter of 6 cm (one plant per pot). The seedlings of scion can be raised in flat beds. The seedling nursery has provisions to prevent viral diseases and also for providing shade. Most of the viral diseases have a latent period. Therefore, it is important to prevent the diseases at the seedling stage. Since, vectors transmit the viral diseases, raising seedlings in a nylon net house is beneficial. The upper half of the screening chamber is covered with UV resistant double layer polythene sheet to avoid the penetration of UV rays into the chamber and to protect the seedlings from UV rays. Silver shading net (50% light cut) is suggested to be used for covering the screen house. The temperature can be decreased by two to three degrees in summer season with this type of shading.

Grafting chamber: Grafting chamber should provide a suitable environment for healing of grafted union in a shortest period after grafting. The suitable climatic conditions inside a chamber are 25-30°C, relative humidity not less than 85% and suitable low light intensity (3–5 Klux). High temperature and fluctuation of relative humidity in summer can increase transpiration and respiration rates and result in wilting of scion, due to which healing can be failed resulting in wilting of scion. In this chamber grafts should be kept for 5-7 days.

Acclimatization room: This is mainly used for hardening and to prevent leaf burning and wilting of the just healed seedlings, the grafted seedlings should be placed in a suitable environment and not under direct sunlight for acclimatization. Gradual increase of light intensity can be manipulated by different degrees of shading. Usually it takes 7-10 days for acclimatization as hardening treatment.

4. ESTIMATING OF GRAFTING SUCCESS

Grafting considered to be successful when a complete union of the vascular system of the rootstocks and scion is achieved, allowing the unhindered transfer of water and nutrients from the rootstocks of the scion and the transfer of photosynthates and growth substances from the scion to the rootstock. In small commercial nurseries with no specialized equipment, grafting success depends on the experience of the grower and the nursery personnel, and is assessed visually by the appearance of grafted seedlings and the growth of the scion. In contrast, in modern, well -equipped commercial nurseries, the success of grating is determined with methods such as:

Thermic cameras: In successfully grafted plants. water is transferred smoothly from the root to the leaves of the scions where, due to transpiration, the temperature is 2-3^0 c lower than that of the leaves of the unsuccessfully grafted seedlings. Intermediate leaf temperature are recorded in the case of partly successful grafting because of the greater difficulty in water transfer in this case [31].

A vertical cut at the surface of the graft: When tomato is grafted on to a tomato rootstocks, the vascular system is connected directly. However, when tomato is grafted on to an eggplant rootstocks, the grafted surface, and when grafted on to Solanum torvum Sw. this curve is even larger [31].

Measurement of the electric wave: Electric wave transferred from the scion to the rootstocks through the surfaces area of their connection. This transfer is related to the histological changes that occur during the union of the rootstocks and scion. The electrical resistance between the rootstocks and scion, grafted tomatoes is high for 2-3 days after grafting, due to the fact that during this time isolative tissue is formed and increases. Over the next 3-4 days the electrical resistance steadily declines as the formation of isolative tissue decreases, and finally falls to zero (which is the value for non-grafted stems) as callus is formed [31]. At this stage, complete union of the vascular systems of the rootstock and scion has been achieved, and in tomato the plant's hydraulic system becomes fully operational within 4-5 days of grafting [31].

Tips for a Successful Graft Union:

a. Hardening: This can be achieved by exposing the plants to full sun and some water stress in the days before grafting. It makes the plants short and increases the tolerance to water stress.

b. Turgidity: Turgidity in the plants can be maintained by providing irrigation a few hours before being grafted.

c. Shade: Always a shady location is to be preferred for taking up grafting operation.

For a High Survival Rate in Grafting:

Care of seedling before grafting: For a successful grafting, it is important that the rootstocks and scions are of approximately the same size (Height and diameter). depending on the grafting method to be applied. Seedlings (rootstocks and scions) are irrigated regularly, and are exposed to sunlight for 2-3 days prior to grafting. During grafting every effort must be made to increase the possibility for complete union of the vascular systems of the rootstock and scion [31]. For this, it is recommended to maximize the grafting surface and to keep the cut surfaces moist and in constant contact by the use of appropriate clips until the union is complete.

Care of seedlings after grafting: Cared seedling after grafting refers mainly to acclimatization. If seedlings begin to wilt they must be immediately sprayed with water. The amount and duration of shading depends on the atmospheric conditions. More shading is needed during sunny days.

Field Management of Grafted Seedlings: The field management of grafted plants is like the management of non-grafted plants. However, a few specific practices for off-season production should be noted:

a. Raised beds and shelters: Clear polyethylene covered rain shelters can be used to shield plants from direct impact of heavy rainfall and provide some shade.

b. Depth of Transplanting: The graft union must be kept above the soil line. The closer the graft union is to the soil line, the more likely adventitious roots from the scion will develop and grow into the soil. If this occurs, disease can bypass the resistant rootstock and may lead to infection and death of the entire plant.

c. Removal of adventitious roots: Remove adventitious roots that develop on the scion before they reach the soil. To prevent infection from soil-borne diseases, the scion tissue must not come into contact with the soil.

d. Staking and pruning: Grafted plants should be staked two to three weeks after transplanting. Indeterminate tomatoes should be pruned so as to allow two main stems to develop. It is very important that plants be tied securely to stakes. This will prevent vines from sliding down and the scion stem contacting the soil.

Problems Associated With Vegetable Grafting:

Various problems are commonly associated with grafting and cultivating grafted seedlings. Major problems are the labor and techniques required for the grafting operation and post graft handling of grafted seedlings for rapid healing for 7 to 10 days. An expert can graft 1200 seedlings per day (150 seedlings per hour), but the numbers vary with the grafting method. Similarly, the post graft handling method depends mostly on the grafting methods. Also, improper management of post grafting environment (high temperature, high humidity, direct overhead water, excessive light and insufficient light). Excessive light in the post grafting environment that force newly grafted plant to perform activities, such as photosynthetic that are difficult to heal and growth. Uneven senescence, in sufficient sanitation at any stage from seed sowing through grafted plant healing, can promote the onset and transmission of the disease. Expensive rootstock seeds and grafting equipments etc., pose a major problem.

5. CONCLUSION

Grafting is a viable proposition that revitalizes modern vegetable production in challenging environments. With vegetables, the goal of grafting is not just variety preservation, but crop preservation. The method gives farmers a measure to control over soil borne diseases and waterlogged soils, helping them bring in a good harvest despite difficult growing conditions. It fits well into the organic and integrated crop management systems. Large scale commercial production of vegetable seedlings is expanding rapidly in many developed countries and this will lead to an increased commercial supply and use of grafted vegetable seedlings throughout the world. Further, inventions in mechanized and robotic grafting is a fillip for this eco-friendly approach.

6. FUTURE PROSPECTS

Identification of compatible disease resistant rootstocks with tolerance to abiotic stresses is the basic requirement for continued success. Healthy grafted seedlings at reasonable price are the key point for wider use. Methods/ techniques should be of low cost so that these could be adopted by farmers for commercial production. More investigation needed for minimize post grafting losses. There are scopes for breeders and companies of India to develop resistant rootstocks. The agencies should be involved in marketing these rootstocks to the field e.g. Dai power: Rootstock for Capsicum and Chilli. It is tolerant to diseases like Bacterial wilt, Phytophthora blight, Mosiac virus. Researches, extension specialists and seed companies need to work together to integrate this modernized technology as an effective tool for producing high-quality vegetables. Sharpening of grafting skills and healing environment need to be standardized for its application on commercial scale. Further research needs to focus on rootstock development, more efficient grafting robots, and development of acclimatization facilities. This research should considerably reduce the cost of grafted seedling production in the future.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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