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Vegetable grafting for abiotic stress tolerance

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Abstract
Due to limited availability of arable land, the high demand for offseason vegetables, vegetables are often cultivated under unfavourable conditions. These consist of salinity, water stress, alkalinity, heavy metals and excessive amounts of trace elements. Plants exposed to adverse chemical soil conditions which exhibit various physiological and biochemical disorders that cause stunted growth and severe yield loss. Grafting high yield scions onto resistant rootstocks has been a common practice to overcome such stresses to growth in the last four decades in both the Solanaceae and Cucurbitaceae (Schwarz *et al.* 2010) [21], to improve the sustainability and profitability of organic vegetables cultivation and to increase yield and fruit quality. A number of grafting techniques are employed in vegetable crops like cleft grafting, tongue grafting etc. For grafting in vegetables many new innovations are developed such as Grafting Robots, Micro-grafting etc. Cucurbits may be grafted onto pumpkin will provide some drought tolerance in sandy soil (AVRDC, 2013) [1]. Grafted vegetables have the potential to survive under abiotic stress. It is a rapid another means to the moderately slow breeding methodology. Grafting is an eco-friendly technology which promotes organic vegetable production which minimizes the excess use of chemicals and their toxic residues in vegetables and environmental pollution. Hence, it is suggested that, adoption of grafting to attain the low input sustainable horticulture in future.

Keywords: organic vegetables, Grafting Robots, Micro-grafting, Abiotic stress

Introduction

Vegetables play a vital role in the maintenance of human health because it is one of the most important source of balanced diet, it provides energy besides supplying vital protective nutrients like minerals, vitamin and antioxidants. According to ICMR for a well-balanced diet, about 300 gram vegetables are required containing root vegetable, green leafy vegetables and others vegetables, but only 230 grams per capita is available (Vanitha *et al.*, 2013) [22]. Vegetables production in India has increased from 58.5 million tonnes to 175 million tonnes since 1991-92 to 2016-17 (Anonymous, 2017) [2].

Due to limited availability of arable land, the high demand for offseason vegetables, vegetables are often cultivated under unfavourable conditions. These include salinity, water stress, alkalinity, heavy metals and excessive amounts of trace elements. Plants exposed to adverse chemical soil conditions which exhibit various physiological and biochemical disorders that cause stunted growth and severe yield loss. Grafting is a vegetative, asexual plant propagation method. It is accomplished mostly by connecting two plant segments i.e. shoot piece known as ‘scion’ and the root piece called ‘rootstock’ (stock). Grafting high yield scions onto resistant rootstocks has been a common practice to overcome such stresses to growth in the last four decades in both the Solanaceae and Cucurbitaceae (Schwarz *et al.* 2010) [21], to improve the sustainability and profitability of organic vegetables cultivation and to increase yield and fruit quality, to induce resistance against low and high temperatures (Venema *et al.*, 2008) [23], to enhance nutrient uptake (Colla *et al.*, 2010a) [4], increase synthesis of endogenous hormones (Dong *et al.*, 2008) [7], improve water use efficiency (Rouphael *et al.*, 2008) [17], reduce uptake of persistent organic pollutants from agricultural soils (Otani and Seike, 2006, 2007) [15, 16], improve alkalinity tolerance (Colla *et al.*, 2010b) [5] and limit the negative effect of boron, copper, cadmium, and manganese toxicity manganese toxicity (Edelstein *et al.*, 2005, 2007; Rouphael *et al.*, 2008b; Savvas *et al.*, 2009) [8, 9, 18, 19].

Status of vegetable grafting

East Asia is the major marketplace for vegetable grafting because of high grafted vegetables. Korea, Japan and China produce 99%, 94% and 40% of grafted watermelon respectively (Bie *et al*., 2017) [3]. Through grafting, about 60-65% of tomato and eggplants and 10-14% of peppers are produced. At present, vegetable grafting is increasing worldwide mostly in Eastern Europe, North and South America, India and Philippines. International trading of grafted vegetable is rapidly increasing like Canada export their grafted vegetables to Mexico (Bie *et al*., 2017) [3].

Basic pre-requisites

1. Root stocks and scion selection: Select desirable rootstock and scion of same stem size for successful graft and to overcome incompatibility problem. At 2-3 true leaf stage grafting should be done. Selection of rootstock is based on viability, resistance to disease, adaptability to local environmental and soil condition. Similarly, selection of root stock depend upon purity, viability, yield, fruit quality and market demand.
2. Grafting compatibility: Between scion and root stock, callous formation should be taken place. Compatible of rootstock and scion minimizes the failure of graft even in later stage of growth.
3. Grafting Aids: frequently used aids for grafting are grafting clips, tubes, pins, and Grafting Blade.
4. Screen house: it is used for growing seedlings earlier to grafting.
5. Healing chamber/Grafting chamber: In grafting chamber, grafts should be kept at 25-30 ^{0}C with 85-90% relative humidity for 5-7 days in partial shade condition. It helps to reducing transpiration by maintaining optimum environmental conditions for better graft union.
6. Acclimatization chamber: prior to transplanting, hardening of grafted seedling is done in acclimatization chamber for 7-10 days to prevent grafting from leaf burning and wilting. The grafted seedling takes 7 to 10 days for acclimatization as hardening treatment.

Precautions

Before grafting seedlings are exposed to full sunlight and some water stress to increase tolerance to water stress. Timing of the operations during grafting should be strictly controlled. Grafting is done in early or late in the day to avoid water loss. Scions and rootstocks of same stem diameter and cut surfaces make good contact so that they are successfully connecting to each other. Correct sanitation measures have to be adopted. Graft is placed away from direct sunlight and greenhouse heater discharge. During the entire process of grafting the environmental conditions have to be controlled.

Methods of Vegetable Grafting

A number of grafting techniques are used in vegetable crops. These methods are:

1. **Hole insertion grafting/ Top insertion grafting:** The diameter of the scion stem must be smaller than the diameter of the rootstock stem so that the scion can be inserted into a hole made with a pointed probe between the two cotyledons of the rootstock.
2. **Tongue (Approach) Grafting:** In scion and rootstock, hypocotyls are cut in such a way that they tongue into each other and the graft is secured with a plastic clip.
3. **Cleft grafting:** Cut the rootstock horizontally and make an incision in the stem, cut the scion into a wedge and insert it into the rootstock then attach with a grafting clip.
4. **One cotyledon/Slant/Splice grafting:** It has recently been adopted by commercial seedling nurseries and applicable to most vegetables. This method has been developed for robotic grafting of cucurbits.
5. **Tube grafting:** It is similar to slant grafting except that in this method elastic tube is used instead of clips to secure root stock & scion joint.
6. **Pin grafting:** Is basically the same as the splice grafting. Instead of placing grafting clips to hold the grafted position, specially designed pins are used.

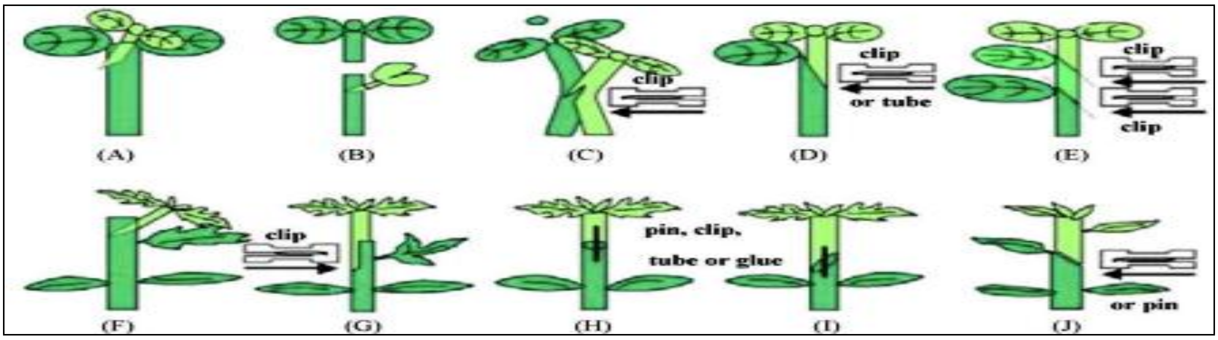

Fig 2: Major grafting methods in cucurbits and solanaceous vegetables: (A and B) hole insertion grafting; (C) tongue approach grafting; (D, E and J) splice grafting; (F, G) cleft grafting; (H and I) pin grafting.

Table 1: Grafting methods and rootstocks used in vegetable crops

Scion Plant	Rootstock	Method
Eggplant	*Solanum torvum*	Tongue and cleft method.
Tomato	*L. pimpinellifolium*	Only Cleft method
	S. nigrum	Tongue and cleft methods
Cucumber	*C. moschata*	Hole insertion and tongue method
	Cucurbita maxima	tongue method
Water melon	*Benincasa hispida*	Hole insertion and cleft method
	C. melo	Cleft method
Bottle gourd	*C. moschata*	Hole insertion and tongue method

Recent innovations of Vegetable Grafting:

Now a day's many new innovations developed to perform grafting in vegetables such as:-

1. Grafting Robots: can graft 1,000 tomato or eggplant seedlings per hour and has more functions such as automatically selecting matching rootstock and scion seedlings.

Table 2: Some robots developed for grafting vegetables

Robots	Model	Developed by	Vegetable crops
AG1000 robot	fully automated	Yanmar Agricultural Equipment Co. (Osaka, Japan) 1994,	Solanaceous
Iseki's GR800 & GR-600	Semi-automated	Helper Robotech Co., Gimhae, Korea (2004)	Cucurbits
Arnabat S.A.	Semi-automated	Barcelona, (Spain) 2000.	cucurbits, Solanaceous

1. **Micro-grafting:** In vitro grafting using very small or micro explants (< 1/1000th mm3) from meristematic tissues. This method provides rapid propagation of virus free plants. Micro grafting has been used in herbaceous plants.
2. **Double grafted and single grafted tomato:** Pomato is produced by grafting of tomato scions onto potato rootstocks by method of cleft grafting. Above the ground harvest over 500 cherry tomatoes with 100 Brix TSS. Single tomato grafts are Indigo Rose, Brandywine and Sun Sugar. Double grafted tomato plants are produced by using red and yellow pear tomato as scions and Big Beef or Geronimo rootstock.

Grafting of vegetable crops

Several vegetable, such as tomato, brinjal, watermelon, melon, and cucumber are grafted. Grafting in tomato was introduced commercially in 1960s (Lee and Oda, 2003) [14]. Watermelon is one of the vegetables in which grafting is performed intensively in the world (Yetisir *et al*., 2003) [24]. The development of rootstocks with resistance to a wide range of diseases, high compatibility and adoption of suitable grafting methods are the main constraint to increase yield of solanaceous crops through grafting.

Effect of grafting on abiotic stresses

Abiotic stress significantly affects vegetable production both in open field and greenhouse condition. Stresses cause various physiological and pathological disorders leading to severe crop loss. To induce resistance against low and high temperatures, increased nutrient uptake, increase synthesis of endogenous hormones and improved water use efficiency grafts were generally used. Grafted vegetables have the potential to survive under abiotic stress. Cucurbits may be grafted onto pumpkin will provide some drought tolerance in sandy soil (AVRDC, 2013) [1]. The higher marketable yield recorded with grafting was mainly due to an improvement in water and nutrient uptake (Schwarz *et al*., 2010) [21]. In watermelons, the quantity of chemical fertilizers can also be reduced to about one-half to two-third in grafted plants as compared to the standard recommendation for the non-grafted ones (Salehi-Mohammadi *et al*., 2009) [20]. Increased levels of heavy metals in farming constitute arising hazard to plant and human. Melon plants, cv. Arava grafted on the cucurbita rootstock i.e. TZ-48 found that B, Zn, Sr, Mn, Cu, Ti, Cr, Ni and Cd were lesser in fruits (Edelstein and Ben-Hur, 2007) [9]

Table 3: Relation of some rootstocks for Cucurbitaceae and Solanaceae crops and use of rootstock to improve characteristic.

Crop	Rootstock (species)	Improved feature	References
Watermelon	'PS 1313' (*C. maxima* × *C. moschata*)	Water use efficiency	Rouphael *et al*. (2008) [17]
	'TZ 148' (*C. maxima* × *C. moschata*)	Salinity	Edelstein *et al*. (2005)
Cucumber	Shintoza' (*C. maxima* × *C. moschta*)	High temperature	Lee *et al*. (2010)
	'Chaojiquanwang' (*C. moschata*)	Salinity	Huang *et al*. (2013)
Tomato	'AR9707' (*Solanum lycopersicum*)	Salinity	Fernández-García *et al*. (2004)
	'Beaufort' (*S. lycopersicum* × *S. habrochaites*)	Mineral uptake and metabolism	Djidonou *et al*. (2015)
Brinjal	*S. torvum*	Salinity	Giuffrida *et al*. (2015)

Conclusion

Grafting is a promising tool to enhance plant performance of vegetable grown under abiotic stresses conditions. With the invention of more efficient grafting robots and acclimatization facilities, the price of grafted seedlings could be considerably reduced. It is a rapid alternative means to the moderately slow breeding methodology. Grafting is an eco-friendly technology which promotes organic vegetable production which minimizes the excess use of chemicals and their toxic residues in vegetables and environmental pollution. Hence, it is suggested that, adoption of commercial use of grafting to attain the low input sustainable horticulture in future.

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