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GRAFTING: A RAPID AND SUSTAINABLE TOOL TO MITIGATE ABIOTIC STRESSES IN VEGETABLE CROPS

Pradeep Kumar*, P.S. Khapte and Anurag Saxena
ICAR-Central Arid Zone Research Institute, Jodhpur (Rajasthan)-342003

ABSTRACT

Of late, grafting has emerged as an effective tool in successful vegetables production, though it is in practice for centuries in woody perennial crops, by exploiting its potentials primarily to tackle the issues prevailing under intensive vegetables production system such as soil pests/ pathogens. However, recent researches have demonstrated that the adverse effects of certain abiotic stresses (moisture stress, thermal stress, salinity, alkalinity, heavy metals) on shoots of commercial improved cultivars could also be effectively minimized by grafting them onto suitable hardy rootstock genotypes. Using grafted transplants in fruiting vegetables (tomato, brinjal, pepper, cucumber, muskmelon and watermelon) has become common practice in many parts of the world, with being more popular in East Asia and Western world (Europe, U.S. and Middle East) for both greenhouse as well as open field vegetables cultivation. However, in India is still in infancy stage, despite being a number of environmental factors cause significant losses in vegetable production. Particularly, arid and semi-arid regions, where vegetables production suffer from limited water availability, prevalence of salinity in soil and water, and toxic elements in contaminated soils and sewage irrigating water, etc. Hence, there is immense potential to increase the vegetables production under such constraint conditions by exploiting the benefit of grafting. In fact, grafting enables joining the attributes of two dissimilar plants into one, which means the inherent resistance of resistant/ hardy rootstock (for drought, salinity etc.) could be provided to the susceptible commercial scion cultivar by way of grafting. Moreover, despite several adversity arid and semi-arid regions hold good wealth in terms of biodiversity of vegetables species, especially in cucurbitaceous species. Many lines collected from this regions are documented for specific traits including for drought and salinity stress and fruit quality (sweetness and shelf life), besides various diseases. These need to be exploited as potential rootstock materials to improve the commercial one through grafting.

Key words: Grafting, vegetables, abiotic stress, (semi) arid region.

INTRODUCTION

India has attained a quantum jump in vegetable production and current vegetables production is around 163 million tonnes from an area of 9.3 million hectare (NHB, 2014) and occupies second position, after China, with a share of 14% in the global vegetables production. However, in spite of attaining remarkable growth in vegetables production, there are still several constraints including low and uneven crop productivity across the countries, limited irrigation facilities, climate change, etc. due to which our national average productivity of vegetables is lower (17.4 t/ha) than many countries such as China (23.4 t/ha), and even the world average (19.4 t/ha). Further, the productivity of vegetables under arid and semi-arid regions are much lower than the national average, for example productivity of Rajasthan is merely 9.3 t/ha (NHB, 2014). The reasons of lower productivity in the state like Rajasthan, mainly comprising of arid and semi-arid climate, can be many. The common occurring features of these fragile ecosystems include moisture stress, poor quality irrigation water, soil or water salinity and heavy metals toxicity. These abiotic factors not just have negative implications one vegetable crop production but also disrupt nutritional as well as economic viability of these regions.

VEGETABLE GRAFTING: PASTS TO PRESENT

Grafting has been employed for centuries in woody-perennials but, its exploitation in herbaceous vegetables started lately. Although, a self-grafting technique to produce a large cucurbit fruit through multiple graftings was described in ancient books written in China in the 5th century and in Korea in the 17th century (Lee and Oda, 2003), the commonly used herbaceous grafting technique was reportedly first utilized by a watermelon farmer in Japan by grafting watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai] on squash (*Cucurbita moschata* Duch.) rootstock to increase yield and tackle pests/ disease problems, in the late 1920s (Kubota et al., 2008). However, vegetable production using grafted seedlings at commercial scale was firstly started in Japan and Korea three decades ago (Lee et al., 2010). It was introduced in Europe in the early 1990s as a means to control root diseases of soil or hydroponic systems (Lee et al., 2010). The exponential increase in adoption of grafting in vegetable transplants seen, especially in the Western world (American, European and Middle East countries), after the ban on the use of fumigant methyl bromide in 2005 by the Montreal Protocol (Cohen et al., 2012). The prime use of grafting in fruiting vegetables was to improve plant tolerance against soil borne pathogens (Crinò et al., 2007) but its application dramatically increased over the years in mitigating the negative effects of other stresses too. Lately, its potential was realized and exploited to overcome the various abiotic stresses in fruiting vegetables.

VEGETABLE GRAFTING *VIS-À-VIS* ABIOTIC STRESSES

The prerequisite for any successful commercial crop production is the availability of cultivars with desired characteristics of either yield, quality or resistance to pests or diseases. Vegetable is a fast growing sector with having frequent changing demand of produce quality. There is huge competition in this sector with respect to supply of quality produce with specific requirement for domestic as well as export market. However, the choice of vegetable cultivars of high yield potential and quality with resistance to pests/ diseases and particularly abiotic stresses are limited, thus presenting a big challenge to the breeders of public sector or seed companies. Though, the development of resistant lines in vegetable crops for biotic or abiotic stresses by breeding or genetic engineering is possible, it takes considerable time before commercial varieties are available for production (Nilsen et al., 2014). Moreover, the cross-incompatibility beyond the species or genera may limit the scope of resistance gene transfer through breeding.

One possible way to improve resistance in existing high-yielding commercial cultivars is by grafting them onto the robust/ hardy rootstock genotypes, belonging to same or different species, genera and even possible onto the wild species of same or different genus. Grafting is a sustainable approach and now regarded as a faster alternative tool to the relatively slow breeding methodologies in increasing plant tolerance to different biotic or abiotic stresses of important fruiting vegetables of solanaceae (tomato, brinjal and capsicum) and cucurbitaceae (cucumber, watermelon and muskmelon) families (Flores et al, 2010). Moreover, grafting restricts input of agrochemicals against soil borne pathogens and is, therefore, considered an environmentally friendly cultivation technique, which is strongly recommended for integrated crop management systems (Rivard and Louws, 2008).

Recent published reports claimed that grafting could efficiently mitigate the adverse effects to abiotic stresses such as salinity, alkalinity (Colla *et al.*, 2010a; 2013), nutrient deficiency (Savvas *et al.*, 2010), thermal (sub- and supra-optimal) stress (Venema *et al.*, 2008; Schwarz et al., 2010), drought stress (Sa´nchez-Rodrı´guez *et al.*, 2013), and heavy metals (Savvas *et al.*, 2013; Kumar *et al.*, 2015a,b,c) in different fruiting vegetables. Indeed, the influence of the rootstock on the mineral content in aerial parts of the plant was attributed to physical characteristics of the root system, such as lateral and vertical development, which resulted in enhanced uptake of water and minerals, this being one of the main motives for the widespread use of grafted rootstocks (Heo, 1991). A wide range of studies have demonstrated that the rootstock mediated positive effects in grafted plants under different abiotic stresses is due to better nutrients uptake and translocation, biosynthesis and contents of photosynthetic pigments, photosynthetic activity, antioxidant activity, lower oxidative stress, etc. (Rouphael et al., 2008; He at al., 2009; Dietmar et al.,2010; Colla et al., 2013).

Drought/ moisture stress

Moisture stress depresses crops yield due to decreased nutrient uptake by the root and transport to the shoot because of a restricted transpiration rate affecting active transport and membrane permeability (Kramer and Boyer 1995). Mini-watermelons grafted onto a commercial *Cucurbita* rootstock 'PS 1313' resulted in more than 115% and 60% higher total and marketable yields under deficit irrigation as compared with non-grafted plants, mainly due to an improvement in water and nutrient uptake (N, K, and Mg) in grafted plants (Rouphael et al., 2008). Moreover, grafting tomato (cv. BHN 602) onto rootstock 'Kkung Jjak' increased qualitative drought-tolerance as compared to the non-grafted tomato plants (Nilsen et al., 2014). Pepper plants grafted onto hardy rootstock genotypes viz., Atlante, PI-152225 and ECU-973 were found more tolerant to water stress as demonstrated by higher marketable yields as compared to non-grafted cultivar, under water deficit conditions (Penella *et al.*, 2014).

Salinity

Salinity is one of the major environmental constraints, particularly in arid and semiarid regions, that limit crop productivity and quality. Most of the vegetable crops are highly susceptible to soil salinity even at low electrical conductivity in the saturated soil extract (Shannon and Grieve, 1998). Improvement of growth and yield have been observed in many grafting combinations of fruit vegetables grown under saline conditions. Although, the positive effect induced by rootstock on salinity tolerance in shoot increased with the level of stress as observed in tomato (Martinez-Rodriguez et al., 2008), where grafting 'Moneymaker' onto either 'Radja' or 'Pera' improved tomato fruit yield compared to self-grafted 'Moneymaker' when plants were grown at 50 mM NaCl, effects were less visible at 25 mM NaCl. Grafting watermelon 'Fantasy' cultivar onto 'Strongtosa' rootstock reduced the decrease of shoot weight and leaf area due to the increase of salinity in comparison with non-grafted plants (Goreta et al., 2008). In cucumber, grafting cv. 'Jinchun No. 2' onto bottle gourd rootstock 'Chaofeng 8848' alleviated the negative effect of salinity on shoot dry weight (Huang et al., 2009). Moreover, the higher crop performance of cucumber plant 'Akito' grafted onto rootstock 'PS1313' was observed under Na_2SO4 than under NaCl conditions. The better performance of grafted cucumber recorded with Na_2SO4 than with NaCl was attributed to the inability of the rootstock to restrict Cl^- shoot uptake, thus Cl^-, which continues passing to the leaves, becomes the more significant toxic component of the saline solution (Colla et al., 2012).

Alkalinity

Alkaline soils are wide spread throughout the agricultural regions, particularly those with semi-arid climates (Troeh and Thompson, 2005). Alkaline soils are generally characterized by low bioavailability of plant nutrients and bicarbonate ions present in soil solution interfere with the uptake of macro elements, in particular P, K and Mg (Pissaloux et al., 1995). Based on the performance of grafted tomato plants onto rootstocks of brinjal, datura (*Datura patula*), orange nightshade (*Solanum luteum* Mill.), local Iranian tobacco (*Nicotiana tabacum* L.), grown under alkaline conditions (0, 5, and 10 mM $NaHCO_3$), use of datura rootstock provide a useful tool to improve alkalinity tolerance of tomato plants under $NaHCO_3$ stress (Mohsenian et al., 2008). Substantial differences in the agronomical, physiological and biochemical responses between grafting combinations of watermelon plants (cv. 'Ingrid') was observed by Colla et al. (2010b). In particular, the watermelon plants were either non-grafted or grafted onto two bottle gourd rootstocks ('Macis' and 'Argentario') and two pumpkin rootstocks ('P360' and 'PS1313') and exposed to two levels of nutrient solution pH, specifically 6.0 or 8.1 dS m^{-1}. Plants grafted onto pumpkin rootstocks and exposed to an excessively high external pH level were exceptionally better in maintaining higher net assimilation rates, strong capacity to accumulate Fe in the aerial part, and a better plant nutritional status (higher P and Mg) in the shoot tissue, compared to others those grafted onto bottle gourd rootstocks and non-grafted plants, whose plants shown leaf chlorosis symptoms.

Heavy metals

Concerted efforts are being made in reducing heavy metals accumulation in the plants to reduce their probable effects on plants and also human being, upon ingestion of contaminated food, grown in contaminated soil or water. Root genotypes can play a crucial role in the defence mechanisms against heavy metals by way of controlling their uptake (Savvas et al., 2013). Studies have shown that some vegetable rootstocks can limit the uptake and/ or translocation of heavy metals with or without affecting the nutrient elemental concentration in plants. A substantial reduction of Sr, Mn, Cr, Ti, Pb, Ni, and Cd in the shoots and fruits of 'Arava' melon was observed when plants it was grafted onto commercial *Cucurbita* rootstock 'TZ-148' as compared to non-grafted plants, irrigated with secondary treated sewage water or fresh water for 4 years (Edelstein and Ben-Hur, 2012). Similarly, a significant reduction of Cd in fruit and shoot tissues of brinjal was noticed in plants grafted onto *S. torvum*, due to restricted root-to-shoot metal translocation (Arao et al., 2008; Mori et al., 2009). Reduced Cd content in the aerial plant parts (leaves + stems + fruits) tomato plants (cv. 'Ikram') was observed, when it was grafted onto a commercial tomato rootstock 'Maxifort', compared non-grafted or self-grafted plants Kumar et al. (2015c). They further observed that tomato grafted onto rootstocks 'Unifort' and especially 'Maxifort' could effectively mitigate the adverse effects of Ni on plants by maintaining better leaf nutritional status, higher chlorophyll content and a higher Fv/Fm ratio Kumar et al. (2015b). Besides, the plant biomass production as well as fruit yield were also higher in 'Maxifort' –rootstock grafted tomato plants. Kumar et al. (2015a) demonstrated that tomato plants grafted onto 'Maxifort' rootstock could effectively mitigate the adverse effects of Cd stress (25μmol) by maintaining better physiological and metabolic plant activities. Besides, there was less interference of Cd in root-to-shoot translocation of nutrients in grafted plants.

PROSPECTS OF VEGETABLE GRAFTING IN HOT (SEMI) ARID ECOSYSTEM

The commercial application of grafting in India is still in nascent stage, though there are a number of limiting factors, which substantially diminish vegetable production. In particular of arid region, abiotic factors like high temperatures, moisture stress, salinity, poor water quality, soil and water contamination by heavy metals greatly affect the vegetables production. Grafting technique can be a boon for vegetable production to cope up with this problem in fruiting vegetables. Beside, grafting can also minimize the crop loss occur due to major pests and diseases and nematodes prevailing under intensive vegetable cultivation either under field or protected conditions.

Despite several adversities, (semi) arid regions of India are bestowed with a great deal of genetic potential in locally available genetic materials in terms of land races and farmers cultivars of economic vegetable such as watermelon (*Citrullus lanatus*), round melon (*Citrullus fistulosus*), cucumber (*Cucumis sativus*), muskmelon (*C. melo*) and some related under-utilized species like local water melon/mateera (*Citrullus lanatus*), snap melon/kachra (*C. melo* var. *momordica*) and kachri (*C. melo* var. *agrestis* or *callosus*) and their wild relatives such as *C. hardwickii, C. prophetarum,* tumba/bitter melon (*Citrullus colocynthis*), 'tatumba'-natural cross of tumba and mateera. The availability of vast and diverse genetic resources including those available in this region could serve a potential genetic materials to improve resistance to certain biotic or abiotic stresses. The available vast genetic potential in terms of landraces or related under-exploited or wild species of vegetable crops in arid regions could successfully be exploited, in particular, by using as rootstocks in grafting to enhance resistance to biotic and particularly abiotic stresses in commercial cultivars.

This shows that grafting technology in fruiting vegetables has huge potential in promotion of vegetable cultivation in non-traditional and fragile agro-eco system such as arid and semi-arid regions of India, where water stress, salinity, heat stress and metal toxicity are common constraints for crop production. The efforts are to be made to harness the potential indigenous cucurbit genetic materials for increasing resistance to such stresses in commercial vegetables such as watermelon, muskmelon and cucumber by way of this rapid and sustainable tool of grafting.

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