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Review Article

Perspectives of Vegetable Grafting in Pakistan: Current Status, Challenges and Opportunities

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Abstract

In Pakistan vegetables are grown on fairly a large area and help to fulfill the food requirements of increasing population. The average yield of vegetables in Pakistan is lower compared with the other vegetables growing countries; several reasons contribute towards this low yield such as biotic factors (diseases and pest attack), abiotic factors (low and high temperature stress, high light intensity, water scarcity, and salinity), seed quality, and potential of local vegetable's cultivars. Vegetable grafting is commercially practiced in more than 28 countries across the world. According to the best of our knowledge, up till now there is no research work or practical application of vegetable grafting in Pakistan. Thus in this review we have tried to highlight the importance of vegetable grafting, and how this technique can help uplift/boost up the vegetable sector of Pakistan. Additionally, a working model has been suggested for the development of vegetable grafting in the country. In Pakistan, vegetables such as cucumber, melon, watermelon, tomato, pepper, and bell pepper are sown in plastic tunnels during winter (November and December) to get off season/early produce, however, because of low temperature during the early crop growth period (November-February), a slow rate of growth is observed. Grafting of these vegetable onto selected low temperature tolerant rootstocks can enhance the growth and productivity of vegetables. On the contrary, watermelon, muskmelon, tomato and chilies cultivated under field conditions during the summer season (March-September) suffer from higher temperatures and water scarcity. The use of appropriate rootstocks can enhance the heat and drought tolerance of these vegetables. In short, grafting can be utilized to overcome a large number of problems associated with vegetable production in Pakistan such as soil borne and foliar pathogens, nematodes attack, low and high temperatures stress, salt and heavy metals stress, drought and flooding stress. Additionally, grafting can improve the yield; prolong harvesting period and postharvest life of vegetables, provided appropriate rootstocks are utilized. Grafting of vegetables ensures limited use of inputs (pesticides and fertilizers), thus protects environment, promotes organic vegetable production; and it can help to uplift the economic status of farmers of Pakistan.

Keywords: Vegetable sector development; Seedling nurseries; Rootstock selection; Grafted transplants; Abiotic stress

Introduction

Sustainable agriculture is the first pillar of food security. According to the estimates of United Nations' Department of Economic and Social Affairs, by the year 2030, world have to feed 8.5 billion peoples. Agriculture sector meets the global food requirements, and known as single largest sector that provides jobs to 40% of the global workforce (FAO, 2014; UN, 2015). Likewise in other countries, agriculture is the dominating sector of Pakistan, providing food to the fast-growing population of the country. It contributes 19.8% to gross domestic product (GDP), employs 42.3% of the labour force, provides livelihood to 62% of the rural population, and contributes more than 66% to the export earnings (MOF, 2015–2016). The horticulture is an important subsector of agriculture that contributes 12% in the GDP of Pakistan (Akhtar *et al.*, 2013). According to an estimate the country's horticulture export earnings exceeded 641 million dollars during 2015–2016. In addition to the agronomic crops, fruit and vegetables are cultivated on commercial scale and helps fulfill the dietary requirements of the increasing population of the country. Vegetables are considered as the protective food, being rich source of vitamins, minerals, dietary fiber (Sandeep *et al.*, 2013), carbohydrates and proteins (Hameed *et al.*, 2016). A large number of vegetables have been reported to possess substantial medicinal value and helps mitigate certain diseases; for example onion and garlic have antibacterial

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characteristics, *Cucurbitaceae* and *Solanaceae* vegetables contains vitamin D reserves and strengthen bones (FAO/WHO, 2004). In Pakistan, more than 30 different kinds of vegetables are grown on commercial scale (Hameed *et al.,* 2016), the area, production, and yield of some important vegetables is provided in Table 1. Potato, tomato, onion, pepper, cabbage, cauliflower, spinach, cucumber, eggplant, okra, peas, carrot, turnips, pumpkin, bottle gourd, watermelon, and melons are the leading ones that are being utilized as cooked or raw.

Currently, the vegetable consumption in Pakistan is nearly 100 g per capita per day, while according to WHO recommendation this should be 400 g per capita per day (FAO/WHO, 2004). Similarly according to another report, nutritionists recommend a daily intake of 150 g of root vegetable and 250 g of leafy vegetables for effective nourishment (FAO, 1998). There are several reasons of this low consumption of vegetables that includes availability of vegetables and financial concerns. The yield of vegetables grown in Pakistan is lower compared with other vegetables producing countries (Table 2), for example the average yield of cucumber in Pakistan is 15.40 tons per ha and 42.10, 48.19, 49.44, 60.95, 73.06, and 87.19 tons per ha in Mexico, China, Japan, Portugal, Greece, and Spain, respectively; and similar is the case with other vegetables such as watermelon, melons, eggplant and peppers. Interestingly in all these countries, vegetable grafting is widely adapted (Table 3) that seems one of the major reason of improved vegetables' yield (Lee *et al.,* 2010; Bie *et al.,* 2015, 2017). According to a recent report Bie *et al.* (2017) summarized that grafting improves the yield of melon (3–92%), watermelon (22–43%), cucumber (9–57%), pepper (9%), eggplant (28%), tomato (5–80%), and artichoke (22%). Considering the importance and uses of vegetable grafting worldwide, this review article highlights the issues and challenges of vegetable industry of Pakistan, and how vegetable grafting can be utilized to solve those problems and trigger the vegetable sector of Pakistan. Additionally, a working model has been suggested for the development of vegetable grafting in Pakistan.

Constraints in Vegetable Production of Pakistan

Biotic factors: Among various factors contributing towards low average yield, biotic factors such as soil borne fungal diseases and pest attack (Nawaz *et al.,* 2016a; Jiskani, 2017) are considered leading ones. Vegetable diseases such as root rot of eggplant, tomato, melon, watermelon, and cucumber (Farzana *et al.,* 2016), collar rot of chilies (Naz *et al.,* 2007) and other soil borne and foliar fungal diseases (Usman *et al.,* 2014) reduce vegetables' yield in Pakistan. Nematodes also pose a serious threat to vegetables' production and considerably reduce the yield and quality of the produce (Anwar and McKenry, 2012; Shakeel *et al.,* 2012).

Abiotic factors: Abiotic factors such as salinity (Khan, 2012; Ziad *et al.,* 2016), low and high temperature stress (Saeed *et al.,* 2007), high light intensity, and water scarcity (Iqbal, 2010; Khan, 2014) are reported to reduce the yield and quality of vegetables crops. Khan (2012) reported that about 532,770 hectares of land is affected by salinity and sodicity in Pakistan. On these salt affected areas, either the crops cannot be grown, or if grown the yield and quality of produce is substantially compromised. Similarly, water shortage is another problem that affects the yield and quality of vegetable crops in Pakistan (Iqbal, 2010; Bajkani *et al.,* 2013; Khan, 2014). With the passage of time, the problem of water scarcity is becoming more serious in Pakistan.

Availability of Inputs

The seed is the basic input of plant growth, development and yield. Seed quality and low potential of local cultivars is also a problem that contributes towards reduced crops yield (Bajkani *et al.,* 2013, Raza, 2016). Additionally, the higher prices of inputs such as seed/hybrid seed, fertilizers and pest control products (fungicides and insecticides) limits the use of these products and results in production and quality losses of vegetable crops.

Sewage Irrigation and Heavy Metal Stress

In Pakistan, vegetables are produced in urban and peri-urban areas and sewerage water is utilized as a source of irrigation. Several studies conducted at different geographical locations of Pakistan (Lahore, Mardan, Gilgit Baltistan, Swabi, Khairpur, Sukkur, Hydrabad, Karachi) suggests that these vegetables contains exceptionally higher concentration of heavy metals such as Cd, Cu, Cr, Ni, Co, Ar, Hg, and Pb and these metals pose serious health risks to the consumers (Jamali *et al.,* 2007; Abbas *et al.,* 2010; Khan *et al.,* 2010a; Noor-ul-Amin *et al.,* 2013; Mahmood and Malik, 2014). The constraints regarding vegetables' production are summarized in Table 4, and most of these problems can be minimized by the use of appropriate rootstocks.

Opportunities

To overcome the constraints faced by vegetable industry of Pakistan, selection and breeding of vegetable cultivars, use of hybrid seed (Raza, 2016), growing vegetables in plastic tunnels/greenhouses (Shaukat, 2014; Aazim, 2016; AARI, 2017), and exogenous application of plant growth regulators/bio-stimulators marketed by various pesticides and fertilizer companies are used. Recently the use of plant growth promoting rhizobacteria has been reported by some of the farmers to improve the growth of vegetable crops (personal communication). In technologically advanced countries arbuscular mycorrhizal fungi and the use of natural and synthetic chelators (Treeby *et al.,* 1989; Bocanegra *et al.,* 2006) are utilized to enhance the growth and productivity of agronomic and vegetable crops through improving the ion uptake. The details of those can be found

Table 1: Area and production of important vegetables produced in Pakistan (2014)

Vegetable	Area (hectare)	Production (ton)	Yield (tones/hectare)	Reference
Cabbages and other brassicas	4,938	77,159	15.6256	FAO, 2014
Carrots and turnips	30,225	524,462	17.3519	FAO, 2014
Cauliflowers and broccoli	12,689	220,637	17.3881	FAO, 2014
Chilies and peppers, dry	62,742	145,856	2.3247	FAO, 2014
Coriander	5,297	2,868	0.54	AMIS, 2014
Cucumbers and gherkins	3,426	52,766	15.4016	FAO, 2014
Eggplants (aubergines)	8,325	82,999	9.9698	FAO, 2014
Garlic	7,430	64,473	8.6774	FAO, 2014
Ginger	282	126	0.4468	FAO, 2014
Melons, and other cantaloupes	18,607	227,002	12.1998	FAO, 2014
Okra	14,855	112,983	7.6057	FAO, 2014
Onion	133,922	1,740,184	12.99	AMIS, 2014
Peas	44,858	28,204	0.63	AMIS, 2014
Potato	159,902	2,901,148	18.14	AMIS, 2014
Pumpkins, squash and gourds	25,843	251,741	9.7412	FAO, 2014
Spinach	8,635	102,513	11.8718	FAO, 2014
Sweet potatoes	1,422	12,130	8.5302	FAO, 2014
Tomato	62,930	599,588	9.53	AMIS, 2014
Turmeric	5,281	67,807	12.84	AMIS, 2014
Watermelons	36,809	538,904	14.6405	FAO, 2014

Source: Food and Agricultural Organization (FAO, 2014); Agricultural Marketing and Information Service, Government of Punjab, Pakistan (AMIS, 2014)

Table 2: Comparison of yield (tons/ha) of different vegetables grown in various countries

Country	Chilies	Eggplant	Melons	Watermelon	Cucumber
Egypt	3.09	25.30	27.98	28.77	22.70
Greece	4.43	23.14	17.63	43.32	73.06
India	1.92	19.06	22.35	14.07	6.34
Mexico	1.82	82.81	28.79	27.40	42.10
Pakistan	2.32	9.97	12.20	14.64	15.40
Spain	2.89	59.91	31.53	47.83	87.19
Thailand	3.69	32.59	-	21.14	9.61
Turkey	2.38	31.10	16.90	24.67	26.98
China	6.75	36.73	33.39	40.29	48.19
Australia	-	-	26.88	40.64	19.22
Israel	-	31.73	17.33	11.94	64.85
Japan	-	33.72	22.96	33.10	49.44
Malaysia	0.81	-	-	16.27	20.88
Philippines	-	10.66	9.24	18.74	6.83
Portugal	-	13.88	6.54	27.63	60.95
UAE	-	35.36	16.46	28.10	32.89
USA	-	37.56	26.77	33.48	16.20

Source: Food and Agricultural Organization (FAO, 2014)

somewhere else and focus of this review is how vegetable grafting can be utilized as a tool to solve a large number of problems associated with the vegetable industry of Pakistan.

History of Vegetable Grafting

Grafting is an ancient technique; a Chinese book written in 1st century BC and a Korean book in 17th century reported that grafting was practiced to produce large sized gourd fruits (Lee and Oda, 2003). Some other grafting references available in the Bible, ancient Greek and Chinese literature suggests that grafting was practiced in the Asia, Europe, and the Middle East in the 5th century BC (Melnyk and Meyerowitz, 2015). Grafting is utilized in fruits crops since the centuries however; its use is comparatively new in vegetable crops. The commercial vegetable grafting originated in the early 20th century with an objective to control the soil-borne pathogens (Louws *et al.,* 2010). On scientific grounds, vegetable grafting was launched for the first time in Korea and Japan in late 1920s by grafting watermelon onto gourd rootstocks to manage soil borne diseases (Ashita, 1927; Yamakawa, 1983), and this new technique was disseminated to the farmers by the agricultural extensions workers. During early 1930s commercial grafting of watermelon onto bottle gourd (*Lagenaria siceraria* (Mol.) Standl) and summer squash (*Cucurbita moschata* Duch.) was started to control *Fusarium* wilt (Oda, 2002; Sakata *et al.,* 2007, 2008). In cucumbers, to reduce soil borne diseases and impart vigor to the scions, grafting is believed to be started in 1920 but was applied on commercial scale in 1960 (Fuji and Itagi, 1962; Sakata *et al.,* 2008). As for as the *Solanaceae* crops are concerned, eggplant (*Solanum melongena* L.) was grafted onto scarlet eggplant (*S. integrifolium* Poir.) in 1950s (Oda,

Table 3: The list of countries where grafted vegetables are produced/or cultivated on commercial scale

Name of countries		
China	Turkey	Belgium
Japan	Cyprus	Latvia
Korea	Bulgaria	Greece
Spain	Germany	Morocco
USA	Mexico	Argentina
Italy	Romania	Philippine
France	Croatia,	Egypt
The Netherlands	Bosnia	Iran
Canada	Herzegovina	Portugal
Israel	-	-

Source: (Bie *et al.*, 2017; Lee *et al.*, 2010)

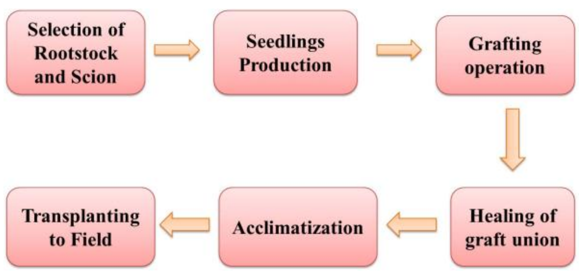

Fig 1: Summary of the steps involved in the production of grafted vegetable's transplants. (Modified from Bie *et al.*, 2017)

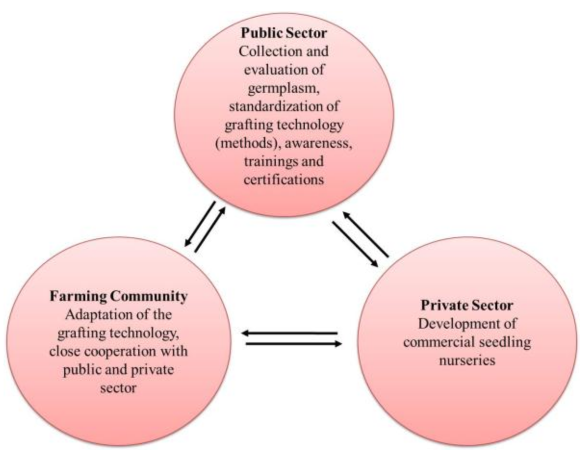

Fig. 2: A proposed working model for the development of vegetable grafting technology in Pakistan

1999), similarly grafting in tomato was started in 1960s (Lee and Oda, 2003). In 1950s, with the rapid development of protected cultivation (green houses and tunnel for off season vegetables production) farmers become dependent on grafting to control soil-borne and other pathogens (Kubota *et al.*, 2008; Lee *et al.*, 2010). The scientific work on screening and development of rootstock was started in 1960s in Korea (Kim, 1984). Up to 1990, the percentage of grafted transplants cultivation of *Solanaceae* and *Cucurbitaceae* vegetables increased up to 59% in Japan and 81% in Korea (Lee, 1994). Currently, most of the greenhouse-cultivated cucurbits are grafted in China, Japan, Korea, Turkey and Israel, and grafted vegetables being cultivated in more than 28 countries across the world (Table 3).

Production of Grafted Transplants

Grafting is practiced in *Cucurbitaceae* (watermelon, melons, cucumber, pumpkin, bitter gourd, squashes, and lufa) and *Solanaceae* (tomato, eggplant and peppers) vegetables. The production of grafted transplants include different steps such as selection of rootstock and scion cultivars, plantlet production, grafting operation (creation of physical union), healing of graft union, and acclimatization of grafted transplants (Lee *et al.*, 2010; Bie *et al.*, 2017) (Fig. 1). To produce grafted transplants of vegetables, the seeds of selected cultivars of rootstock and scions are sown in the seedling trays to produce plantlets. For most of the *Cucurbitaceae* vegetables grafting operation is practiced after the emergence of two true leaves of the rootstock while in *Solanaceae* vegetables grafting is practiced at four true leaves stage. In the grafting operation, the two parts of different plants (rootstock and scion) are joined together in a way that both grows together and make a new grafted transplant (Janick, 1986). For this purpose different grafting methods such as hole insertion grafting, tongue grafting, splice grafting, cleft grafting, and pin grafting are utilized (Lee *et al.*, 2010, Bie *et al.*, 2017). These days the mechanical grafting is also popular and grafting robots are utilized to perform the grafting operation in Korea, Japan, the Netherlands, Spain, and USA (Bie *at al.*, 2017). The proper care of grafted transplants is necessary to get higher success ratio of the grafting process. Loss of moisture from the scion may lead towards the wilting and failure of graft union. Thus, during the first 48 h after grafting, transplants are placed at high humidity (95%) and temperature is maintained at 27–28ºC (82ºF) (Bie *at al.*, 2017). The use of various types of controlled environment (temperature and humidity) healing chambers enhance the graft union success ratio by up to 95% (Dong *et al.*, 2015), and the use of these healing champers is widely practiced in Japan, Korea, China, Spain, and USA (Kawai *et al.*, 1996; Lee *et al.*, 1998; Bie *et al.*, 2017). The details about the grafting methods, graft union healing and acclimatization process can be found in Bie *et al.* (2017).

Benefits of Vegetable Grafting

Vegetables grafting not only improves crops' yields and product quality (Huang *et al.*, 2009; Rouphael *et al.*, 2010), it is also utilized for enhancing plant vigor, tolerance to low and high temperatures (López-Marín *et al.*, 2013), mitigating salinity and heavy metal stress (Schwarz *et al.*, 2010; Huang *et al.*, 2013a; Penella *et al.*, 2015, 2016), improving endurance to drought and flooding stress

Table 4: Constraints in vegetable's production sector of Pakistan and the potential of vegetable grafting to solve these constraints

Constraints	Potential of vegetable grafting to solve the Constraint
Abiotic	
Salinity (Khan, 2012; Ziad *et al.,* 2016)	Alleviate salt stress tolerance (Huang *et al.,* 2013a; Penella *et al.,* 2015, 2016)
Heavy metals stress (Jamali *et al.,* 2007; Abbas *et al.,* 2010; Khan *et al.,* 2010a; Noor-ul-Amin *et al.,* 2013; Mahmood and Malik, 2014)	Improves heavy metals stress tolerance (Savvas *et al.,* 2010)
Water scarcity (Iqbal, 2010; Khan, 2014)	Enhances drought stress tolerance (Schwarz *et al.,* 2010)
Higher temperatures during summer season (Saeed *et al.,* 2007)	Improves high temperature stress tolerance (Schwarz *et al.,* 2010; López-Marín *et al.,* 2013)
Low temperatures during winter season	Improves low temperature stress tolerance (Lee *et al.,* 2010; Bie *at al.,* 2017)
Biotic	
Nematodes attack (Anwar and McKenry, 2012; Shakeel *et al.,* 2012)	Can be minimized (Lee *et al.,* 2010; Barrett *et al.,* 2012; Bie *et al.,* 2017)
Soil born and foliar diseases of vegetables (Naz *et al.,* 2007; Usman *et al.,* 2014; Farzana *et al.,* 2016; Nawaz *et al.,* 2016a; Jiskani, 2017)	The diseases infestation can be minimized (Sakata *et al.,* 2006; Gu *et al.,* 2008; Louws *et al.,* 2010; Arwiyanto *et al.,* 2015; Miles *et al.,* 2015, Suchoff *et al.,* 2015)
Insects attack	No report available, needs investigations
Other production related problems	
Low yield (FAO, 2014, Hameed *et al.,* 2016; Table 2)	Increases yield of vegetables (Huang *et al.,* 2009; Lee *at al.,* 2010; Rouphael *et al.,* 2010, Bie *et al.,* 2017)
Reduced harvesting span	Can be prolonged (Lee *et al.,* 2010; Bie *et al.,* 2017)
Postharvest life (Saeed & Khan, 2010)	Improves postharvest life of vegetables (Zhao *et al.,* 2011)
Fruit quality/nutritional value	May be improved (Huang *et al.,* 2009; Rouphael *et al.,* 2010)

Note: The selection of specific rootstocks can help to solve the specific problem. There is not a single rootstock that may be utilized to solve all the problems of a vegetable

(Schwarz *et al.*, 2010; Bhatt *et al.*, 2015) and resistance to foliar pathogens (Louws *et al.*, 2010; Arwiyanto *et al.*, 2015; Miles *et al.*, 2015, Suchoff *et al.*, 2015), managing root knot nematodes (Lee *et al.*, 2010), controlling weeds (Dor *et al.*, 2010; Louws *et al.*, 2010), prolonging the harvesting period (Lee *et al.*, 2010), improving postharvest life (Zhao *et al.*, 2011), and produce new plant species (tetraploids) (Fuentes *et al.*, 2014). Similarly, grafting improves nutrient uptake and utilization efficiency in a number of vegetable crops (Pulgar *et al.*, 2000; Zen *et al.*, 2004; Lee *et al.*, 2010; Huang *et al.*, 2013b, Schwarz *et al.*, 2013; Huang *et al.*, 2016a, b, c; Nawaz *et al.*, 2016b; Nawaz *et al.*, 2017). According to a report, the economic analysis of tomato cultivation in Northern Florida showed that the net farm returns were increased by up to 630 USD to 6,151 USD per hectare in grafted tomatoes compared with non-grafted ones, and this increase was mainly attributed to the improved yield (Djidonou *et al.*, 2013). According to another report, the cost benefit analysis showed that grafting can be utilized as an effective measure to control root knot nematodes (*Meloidogyne* sp.) for organic tomato production (Barrett *et al.*, 2012).

Current Status of Vegetable Grafting

The statistics about the use of grafted transplants are difficult to obtain worldwide because of increasing trends and sometimes the data is not updated. The trend of grafted vegetable production varies country-wise, and even within the country. East Asia is the largest market for vegetable grafting because of high concentration of cucurbits and other grafted vegetables. For example in Korea, Japan, and China, 99%, 94% and 40% of watermelon are produced through grafted transplants (Bie *et al.*, 2017). In case of S*olanaceae* crops, about 60–65% tomatoes and eggplants, and 10–14% peppers are produced through grafted transplants. Under protected cultivation systems such as greenhouses and tunnels, the ratio of grafted transplants is exceptionally higher and almost all cucumbers, watermelons, and tomato in Spain, Italy, Turkey and Israel are produced through grafted transplants. Similarly, in the Netherlands all the tomato under soilless culture conditions utilize grafted tomato transplants (Bie *et al.*, 2017). In France, tomato and eggplants are particularly grafted to enhance resistance to soil borne pathogens and nematodes. Currently, vegetable grafting is expanding worldwide particularly in Eastern Europe, North and South America, India and Philippines. Some countries such as Canada and China have large-scale and well established nurseries that produce millions of grafted transplants annually. In China, over 1,500 commercial nurseries are producing grafted transplants. Some countries such as Canada export grafted transplants to Mexico, thus the international trading of grafted vegetable transplants is rapidly increasing (Bie *et al.*, 2017). Grafting is widely used for fruit crops in Pakistan (Ahmed *et al.*, 2006, 2007; Khan *et al.*, 2010b); however, according to the best of our knowledge, for vegetable crops, grafting is not being practiced in the country, therefore present review article highlights the potential of vegetable grafting to solve the problems of vegetable industry of Pakistan.

Applications of Vegetable Grafting Technique in Pakistan

Considering the diverse applications of vegetable grafting worldwide, this technique has the potential to solve the problems of vegetable industry of Pakistan and can help boost farmer's income by improving the crops yield and reducing the cost incurred on purchase of huge amount of fertilizers and pest control products.

In Pakistan, the trend of protected vegetable cultivation is increasing. It is difficult to obtain the statistics about protected cultivation of vegetables in Pakistan,

Table 5: Characteristics of some important rootstocks utilized for different vegetables

Name of Scion	Name of Rootstock	Resistance to diseases	Response to nutrient availability in scion tissues	Some other characteristics	References
Tomato (*Solanum lycopersicum)*	Maxifort, He-Man (*S. lycopersicum* L. × *S. habrochaites* S. Knapp and D. M. Spooner)	Resistance to bacterial wilt and nematodes, multiple disease resistance	Improves availability of N, P, Ca, Mg, Mn, Zn, B, Fe and Cu to the scion	Salt tolerant	Savvas *et al.*, 2009; Colla *et al.*, 2010; Borgognone *et al.*, 2013
	Solanum torvum	Disease resistant	Improves nutrients availability to the scion	Nematode tolerant, good vigor, no negative impact on fruit quality, salt tolerant	Colla *et al.*, 2010; Lee *et al.*, 2010
	AR-9704 Tomato (*Solanum lycopersicum* L.)	-	Improves availability of P, and S while, reduces uptake and transport of Na and Cl to the scion	Salt tolerant	Fernández-García *et al.*, 2002; Colla *et al.*, 2010
	Solanum lycopersicum cv. Tmknvf2	-	Improves availability of Fe to the scion	Salt tolerant	Rivero *et al.*, 2004; Colla *et al.*, 2010
	Solanum lycopersicum Mill. cv. Radja	-	Improves availability of K to the scion	Salt tolerant	Estan *et al.*, 2005; Colla *et al.*, 2010
Chilies *Capsicum annum*	*Capsicum annuum* L.× *Capsicum chinensis* Jacq	-	Improves availability of K to the scion	Superior growth and yield	Lee *et al.,* 2010
Eggplant (*Solanum melongena*)	*Solanum torvum*	Disease resistant	Improves nutrients availability to the scion	Nematode resistant, good vigor, salt tolerant	Colla *et al.*, 2010; Lee *et al.*, 2010
	S. torvum Sw. × *S. sanitwongsei Craib*	Resistance to bacterial wilt	Improves nutrients availability to the scion	Nematode resistant, good vigor, salt tolerant	Colla *et al.*, 2010; Lee *et al.*, 2010
Watermelon (*Citrullus lanatus*)	Hongdun (*Citrullus lanatus* Sp.)	-	Improves availability of K to the scion	-	Lee *et al.*, 2010; Huang *et al.,* 2013b
	Jingxinzhen No.4 (*Cucurbita moschata* Duch.)	*Fusarium* tolerance	Improves availability of Mg to the scion	Low temperature tolerant, vigorous root system, salt tolerant	Colla *et al.,* 2010; Lee *et al.,* 2010; Huang *et al.,* 2016b
	Ferro, RS841 (*Cucurbita maxima* × *C. moschata*)	*Fusarium* tolerance	Improves availability of N, Ca, K, Mg to the scion	Low and high temperature tolerant, vigorous root system, salt tolerant	Colla *et al.,* 2010; Lee *et al.,* 2010; Yetisir *et al.,* 2013
	Cucubirta maxima var. Dulce maravilla	*Fusarium* tolerance	Improves availability of Fe to the scion	Low temperature tolerant, vigorous root system, salt tolerant	Rivero *et al.,* 2004; Colla *et al.,* 2010; Lee *et al.,* 2010
	Keumsakwa, Unyong, Super Unyong (*Cucubirta pepo*)	*Fusarium* tolerance	Improves nutrients availability to the scion	Low temperature tolerant, vigorous root system	Lee *et al.,* 2010
	FR Dantos, Partner, Renshi, FR Combi, TanTan (*Lagenaria siceraria*)	*Fusarium* tolerance	Improves nutrients availability to the scion	Vigorous root system, salt tolerant,	Lee and Oda, 2003
Melon (*Cucumis melo*)	*C. maxima* × *C. moschata* (Shintoza, RS-841, and Kamel)	*Fusarium* tolerance	Improves availability of N, P, Ca, K, Mg, Mn, and Zn to the scion. Reduces uptake and transport of Na and heavy metals to the scion	Low and high temperature tolerant, vigorous root system, salt tolerant	Ruiz *et al.,* 1997; Colla *et al.,* 2010; Lee *et al.,* 2010; Bautista *et al.,* 2011; Salehi *et al.,* 2014
	Keumsakwa, Unyong, Super Unyong (*Cucubirta pepo*)	*Fusarium* tolerance	Improves nutrients availability to the scion	Low and high temperature tolerant, vigorous root system, flooding tolerant	Lee *et al.,* 2010
	Rootstock #1, Kangyoung, Keonkak, Keumgang (*Cucumis melo*)	*Fusarium* tolerance	-	Improves fruit quality	Lee *et al.,* 2010
Cucumber (*Cucumis sativus*)	Heukjong (black seeded figleaf gourd) (*Cucurbita ficifolia* Bouché)	Good disease resistance against soil borne pathogens and downy mildew	Improves nutrients availability to the scion	Low temperature tolerance, vigorous root system, salt tolerant	Gu *et al.,* 2008; Colla *et al.,* 2010; Lee *et al.,* 2010
	Butternut, Unyong #1, Super Unyong, PPMR-1 (*Cucurbita moschata* Duch.)	*Fusarium* tolerance, powdery mildew	-	Improves fruit quality, salt tolerant	Sakata *et al.,* 2006; Colla *et al.,* 2010; Lee *et al.,* 2010
	Shintozwa, Keumtozwa, Ferro RZ, 64-05 RZ, Gangryuk Shinwha (*C. maxima* × *C. moschata*)	*Fusarium* tolerance, powdery mildew	Improves nutrients availability to the scion	Low temperature tolerance, vigorous root system, salt tolerant	Sakata *et al.,* 2006; Colla *et al.,* 2010; Lee *et al.,* 2010

according to a report it covers an area of over 18,000 ha only in Punjab province, and an increasing trend has been observed during the last two decades (AARI, 2017). The growth rate of protected cultivation system has been estimated 25–40% in Punjab province, and 10% in Sindh and Khyber Pakhtunkhwa provinces (Shaukat, 2014). According to another report, the area under protected cultivation is very high, that is estimated around 100,000 to 120,000 ha and most of this lies in Punjab province (Aazim, 2016). In protected cultivation system, sowing of some summer vegetable such as cucumber, melon, watermelon, tomato, pepper, and bell pepper is practiced in winter

(November-December) to get off season/early crops to maximize economic returns. Low temperatures, during the early crop growth period (November-February) reduces rate of growth. Grafting of these vegetable onto selected low temperature rootstocks (Table 5) can enhance the growth and productivity of these vegetables. Similarly, most of the watermelon, muskmelon, tomato, and chilies are also cultivated under field conditions during summer season (March-September) that suffer from higher temperature and water scarcity. The use of appropriate rootstocks can enhance the heat and drought tolerance of these vegetables. Similarly, other problems such as soil borne and foliar pathogens, nematodes attack, low and high temperatures stress, salt and heavy metals stress, drought and flooding stress can also be minimized. Moreover, grafting improves the yield, harvesting period and postharvest life of vegetables; provided, appropriate rootstocks are utilized. Some recent development such as the installation of greenhouses and hydroponic cultivation systems by public and private sector in Pakistan further necessitates the adoption of vegetable grafting technique. To get benefit from vegetable grafting technology, the screening and selection of compatible and appropriate rootstock for a specific problem is very important that need attention of plant biologists working in public and private sector of Pakistan.

Conceptual Framework for the Development of Vegetable Grafting in Pakistan

As vegetable grafting is not practiced in Pakistan, following working model has been devised for its development: 1) The research and development organizations should collect the germplasm (cultivated and wild) of different rootstock cultivars of graftable-vegetables (melons, watermelon, cucumber, tomato, bitter gourd, eggplant and peppers) and test their graft-compatibility with locally adapted commercially cultivated scion cultivars. The adaptability of rootstocks to local soil and environmental conditions should also be investigated, and then some better performing disease resistant and nutrient efficient rootstocks should be selected for each vegetable. The list of some important rootstocks utilized in different countries along with their characteristics is provided in Table 5; which may serve as a reference for initial selection and start of rootstocks screening studies in Pakistan. The detailed information of rootstocks responses to different diseases, biotic and abiotic stresses, nutrient availability, and rootstock to scion compatibility can be found in previously published reviews (Lee, 1994; Lee and Oda, 2003; Davis *et al.*, 2008; Lee *et al.*, 2010; Louws *et al.*, 2010, Savvas *et al.*, 2010; Nawaz *et al.*, 2016b; Bie *et al.*, 2017). 2) Public and private sector involved in vegetable research and development may import the rootstock and scion cultivars from other countries (China, Korea, Japan, Spain), test their adaptability to local conditions and get those cultivars registered with provincial or federal seed certification departments. 3) Different methods of grafting should be tested and best methods should be finally selected for further utilization and commercialization in Pakistan. The details about the production process of grafted transplants, grafting methods, and post-graft healing requirements are discussed in detail by Lee *et al.* (2010), and Bie *et al.* (2017). 4) The benefit-cost analysis should be performed by the researchers and the results should be shared with the stakeholders to attract the farming community to adopt this technology. 5) Mass awareness campaigns and farmer trainings about vegetable grafting technology may help in adapting this eco-friendly technology on large scale (Fig. 2). 6) The government of Pakistan particularly funding agencies such as Ministry of Science and Technology (MoST), Pakistan Agricultural Research Council (PARC), Higher Education Commission of Pakistan (HEC), Punjab Agricultural Research Board (PARB), Pakistan Science Foundation (PSF), and Pakistan Council for Science and Technology (PCST) have to play a leading role by providing funds to conduct research and development work on vegetable grafting technology in Pakistan. For example "Fruit and Vegetable Development Project" was launched by Government of Punjab, which helped to raise the area and production of fruit and vegetables across the province. Similarly, during the last few years, Government of Punjab, through Department of Agricultural Extension, is supporting the vegetable growers by providing subsidy on the installation of tunnels to enhance the area under protected cultivation of vegetables.

Conclusion and Future Perspectives

Vegetable grafting is a viable technique that can be utilized to alleviate biotic and abiotic stresses leading towards improved productivity and economic returns. Grafting is an eco-friendly technology, because this helps to reduce the use of pesticides and fertilizers in vegetable production and thus promotes organic vegetable production. Grafting vegetables onto selected rootstocks can obviously reduce the heavy metal contents in the scion tissues (Savvas *et al.*, 2010, 2013; Xin *et al.*, 2013; Nawaz *et al.*, 2016b; Zhou *et al.*, 2016) and help to reduce the health hazards. Soilless culture is getting popularity in Pakistan; vegetable grafting can further enhance the benefits and usefulness of this technique. Additionally, the adoption of vegetable grafting at commercial level creates a lot of job opportunities for the workers, because of high labour requirements for the grafting operation and other associated tasks such as seedlings production and after care, and transport and transplanting practices. In the international market the trading of grafted transplants is increasing rapidly, with the development of grafted vegetable industry in Pakistan this option can be availed to earn foreign exchange; because the labor costs are lower in Pakistan compared with other countries producing grafted vegetable transplants.

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