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Role of Rootstocks in Fruit Production–A Review

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Abstract—*Rootstocks play a crucial role in determining orchard efficiency in fruit crops. Combining the desirable attributes of two different plants by budding or grafting can produce different growth effects. The effect of rootstock on fruit quality in terms of physical traits and internal chemical compositions is well demonstrated in temperate fruit crops (Apple, Pears, Cherry etc.) as compared to tropical and subtropical fruit crops. This difference can illustrated by comparing the relative importance of rootstocks for precocity, yield, and tree size control, and through contrasts in annual phenological cycles, fruit respiratory behaviour, crop load and canopy management techniques. But these effects on physiological, biochemical and molecular fronts are still not understood. This review describes and discusses the rootstock effects on scion growth, vigour and habit, as well as scion precocity and abundance of flowering, the propensity of flowers to set fruits and yield efficiency in important fruits crops which are grown commercially in India.*

1. INTRODUCTION

At present, horticulture is recognized as a potential sector to enhance agricultural production, improve house hold nutritional security and income generation through diversification and employment, value addition and export. Inspite of the enormous success achieved in horticulture sector, several constraints still exist. Besides new emerging challenges, poor productivity per unit area continues to be a concern in most of the horticultural crops with climate change impacting the productivity further. There is need to address these issues in the area of biotic and abiotic stresses and their impact on different horticultural crops.

The role of rootstocks and its use in different fruit crops has significant impact on fruit crop production by influencing canopy architecture, nutritional uptake, flowering, yield and fruit quality [29]. Besides, it can also confront biotic and abiotic stresses such as soil pathogens, thermal stress, salinity and nutritional stress [28]. Due to limited availability of arable land and high market demand for fruit crops, they are frequently cultivated under unfavorable soil and environmental conditions like thermal stress, drought, flooding, salinity and contamination of organic pollutants. One way to substantiate or reduce these losses in production would be the use of appropriate rootstocks, which are capable of reducing the effect of external stresses on the scion [14]. Rootstocks have a primary role in determining orchard efficiency. They are responsible for water and mineral uptake and provide anchorage for the tree. Rootstocks determine tree size. Rootstocks can be used as interstems, a small piece inserted between the rootstock and scion in propagation process. These trees are known as “three piece” trees. Inter-stems can use to overcome incompatibility barriers between stock and scion and also it reduces the high vigour of desirable rootstocks. Rootstocks may provide some degree of tolerance to soils that are sometimes too wet or too dry. Identification and utilization of appropriate rootstocks in crops like apple, pear, citrus, mango and grapes in relation to vigour management, nutrient uptake, soil salinity, moisture stress and yield efficiency has been already studied in several countries. Rootstocks with immense potential for commercial exploitation are yet to be utilized to its full potential most of the commercial fruit crops in India. Therefore, it is important step to find a rootstock with the maximum desirable characteristics to meet the set of environmental conditions where the tree is to be grown. It means a root-stock considered best for a certain variety and environmental conditions may not be a best choice for some other variety and environmental regime. This review mainly emphasizing on several studies, which are principally focused on effects of rootstocks on scion growth and cropping, which would help to focus and coordinate future studies in this area.

2. ROLE OF ROOTSTOCKS IN MANGO

Mango is one of the most important tropical fruit of the world which is known as ‘king of fruits’ in India. Some attempts have been made to standardize the rootstocks for various scion varieties including the use of polyembryonic varieties for vigour management, salinity and drought tolerance as well as to improve fruit yield and quality. Vigour management plays an important role in mango, especially for high density planting and orchard management in terms of canopy management, harvesting and plant protection measures. According to [16] growth and bearing habit of ‘Dashehari’ mango on the seedling stock of ‘Dashehari’ itself, showed most vigorous nature and highest yield compare to other polyembryonic rootstocks. Similar results were reported from IIHR- Bangalore, based on 21 years study on the performance of ‘Alphonso’ which indicated nucellar seedlings of ‘Muvandan’, ‘Bappakai’ and ‘Olour’ were vigorous rootstocks in decreasing order of vigour while ‘Vellaikulumban’ seedling

imparted dwarfing in comparison to 'Alphonso' grafted on its own seedling [28]. Some factors like phenolic contents bark percentage and chlorophyll fractions were found to be very useful for determining the vigour of mango rootstocks at nursery stage [1]. [21] suggested that selection of size controlling rootstocks at the nursery stage can be made by assessing leaf water potential, total phenols/and or ABA. Fruit yield and productivity plays an important role in crops like mango where the productivity is very low in most of mango growing countries. [34] reported that yield and yield efficiency of 'Kensington Pride' was best on 'Sg. Siput' rootstock and it was poor with Sabre rootstock indicated the possibilities for manipulating mango scion productivity through rootstock genotypes. [27] found that 'Sinamaica' rootstock have the best adaptability to agro-ecological conditions of Maracaibo plain of Venezuela and produce higher yield and production efficiency with respect to different cultivars (Criollode Mara, Manzana and Sensation mango). 'Bappakai' was found to be best rootstock for 'Dashehari' followed by 'Muvandan' and 'EC 95862' [6]. 'Langra' grafted on 'Bappakai' rootstock recorded the highest fruits number/plant followed by 'Vellaikulumban' and 'Chandrakaran' [19].

Fruit quality also important aspect and some studies were done on this aspect in different countries. Rootstock trial conducted at IIHR, Bangalore for 21 years, indicated no significant effect of rootstocks (Vellaikulumban, Bappakai, Chandrakaran, Kurukan, Muvandan, Mylepelian and Olour) on fruit quality of 'Alphonso' mango [28]. Screening of mango rootstocks to salinity has shown that the polyembryonic cultivars 'Olour' and 'Bappakai' could withstand higher level of salinity [24]. [8] reported that 'Olour' as best salt tolerant rootstock compared to 'Kurukan'. Mango cultivar '13-1' was selected as a polyembryonic (3-6 embryos) rootstock for calcareous soils or for irrigation with saline water. Mango trees on '13-1' rootstocks showed excellent performance on soil containing 20% lime, three other cultivars on '13-1' rootstock showed good development on sandy soil with 10-20% lime [12]. [41] indicated the greater capability of 'Gomera-1' rootstock to saline conditions. Seedlings from stone of 'Kesar' variety was found to be better with significantly highest survival percentage, germination percentage and growth parameters with higher salt concentrations of water [38].

3. ROLE OF ROOTSTOCKS IN CITRUS

Role of rootstocks in citrus is one of the most debatable and discussed issues and its selection is a major consideration under planning of any citrus orchard. One thing can be safely said that choosing the right rootstocks is fundamental to the success of the orchard. The citrus rootstock scenario in India has been reviewed by [25]. The characteristics of some selected rootstocks are given in Table 1.

Table 1: Characteristics of some selected citrus rootstocks [3].

Rootstock	Horticultural performance			Reaction to						
	Yield	Quality	Plant vigour	Root rot	Citrus nematode	Tristeza	Exocortis	Salt	Drought	Root system
Rangpur lime	G	M	G	MT	S	R	S	R	R	D
Marmalade orange	G	M	G	MT	MT	R	S	R	R	D
Rough lemon	G	L	G	S	S	R	R	T	T	D
Cleopatra mandarin	M	M	M	T	S	R	R	MT	S	M
Sour orange	G	G	M	R	T	HS	T	T	MT	D
Sweet lime	M	M	G	S	MT	S	S	S	S	M
Trifoliate orange	L	M	L	R	R	R	H	HS	HS	SH
Troyer citrange	M	G	M	MT	T	MT	S	HS	HS	SH
Carrizo citrange	M	G	M	MT	T	MT	S	HS	HS	SH
Sweet orange	G	G	M	HS	HS	MT	R	S	S	M
Karna Khatta	G	M	M	S	MT	-	T	T	S	D
Nasnaran	M	G	M	S	MT	T	R	HT	S	M

G = good, M = Moderate, L = Poor or low, R = Resistant, T = Tolerant, MT = Moderately tolerant, S = Susceptible, HS = Highly susceptible, D = Deep, M = Medium, SH = Shallow, - = No information

4. ROLE OF ROOTSTOCKS IN GRAPES

Although grapevines can grow in soils with a wide range of pH (4.5-6.5), very acid soils present a problem. Based on vine growth, [15] found different responses of *Vitis* species or cultivars to low soil pH. The cultivars most tolerant to strong acid soils were *V. labrusca* cv. 'Concord' and 'Catawba', along with rootstock 'SO4' and'3309C', and the hybrid cultivar 'Seyval'; *V. vinifera* 'White Riesling' and 'Chardonnay' were the most intolerant. The use of acid-tolerant rootstocks, such as 'SO4' and '3309C', was highly recommended. According to [18] grape rootstocks *V. champini* and *V. vinifera* are considered to be tolerant to

salinity. [39] studied different grape rootstocks for certain level of salinity (0.4 or 2.3 dS/m) and concluded that grape cv. Shiraz grafted on 'Ramsey','1103 Paulsen' and '140 Ru' had higher wine K^+, pH and color hue rather than grafted on its own seedling. Same researchers also noted that grape cv. 'Sultana' grows vigorously when grafted on 'Ramsey', '1103P' and 'R2', rootstocks. On the basis of nature of tolerance to different salt concentrations (0, 50, 85, 120, 155 mM NaCI), [37] categorized different rootstocks as a sensitive (41 B, R. Lot, 110 R, 140 R and 161-49), moderately tolerant (13-5 and Ramsey) and tolerant (196-17, CH-1, CH-2 and Superior). [10] suggested that hybrids ('110R', '140Ru' and '1103P') from rootstocks *V. berlandieri* x *V. rupestris* can be used in drought prone areas where water is a limiting factor for grapevine productivity and he also noted that drought resistance classification of rootstocks might vary from country to country. Similarly [17] suggested that hybrids of *V. berlandieri* x *V. riparia* were more tolerant to drought.

There have been only a few studies related to rootstock effects on scion to cold hardiness. [20] found differences of cane and bud hardiness of rootstock 'K5BB', '3309C' and 'SO4'. Rootstock '3309C' had the most cold hardy canes and buds; its acclimation in fall was faster and declamation in spring was slower than 'K5BB' and 'SO4'. [35] found that the rootstock did not affect the distribution of hardy canes within the canopy; 'Seyval' grafted on '3309C' appeared to be the cold hardy.

Table : Characteristics of different grape rootstocks [11; 26 and 40].

			Resistance					
		Phylloxera	***M. incognita***	**Soil**	**Drought**		**Active Lime**	**Salt**
Rootstock	**Vigor**	**Resistance**	**(Root-Knot)**	**Preference**	**Tolerance**	**Wet Feet**	**Tolerance**	**Tolerance**
Riparia Gloire	Low/	High	Moderate	Deep/Fertile	Low	High	Low <6%	
	Moderate							
Saint George	Very High	High	Susceptible	Deep,	High	Low	14%	Moderate
			but Tolerant	Uniform				
				Loam				
1616 Couderc	Low	Moderate/	Moderate	Deep/Fertile		High	11%	Moderate/
		High						High
3309 Couderc	Moderate/	High	Susceptible	Deep Well-	Low	High	11%	Low/
	High			Drained				Moderate
44-53	Moderate	Moderate/	Susceptible	Loam/Good	Moderate	High	10%	
Malegue		High		Fertility				
101-14	Low/	High	Moderate	Heavy Clay	Low/	High	9%	Very Low
Millardet Et	Moderate				Moderate			
De Grasset								
Swarzmann	Low/	High	Some	Deep/Fertile	Low/		6-9%	
	Moderate				Moderate			
41B Millardet		Low	Susceptible	Dry Lime	Low/	Low	40%	Very Low
Et De Grasset					Moderate			
420A	Low	Moderate	Moderate	Deep/Fertile	Low	Moderate	20%	Low
Millardet Et								
De Grasset								
Oppenheim	Moderate	High	Moderate	Clay	Low	High	18%	Low
#4								
5BB Kober	Moderate	High	Moderate	Clay	Low	High	20%	Very Low
5C Teleki	Moderate	High	Moderate	Clay	Low	High	20%	
			High					
1103 Paulsen	High	High	Moderate	Clay, Lime	High	High	18%	Moderate
RS-3	Low		High	Sandy		Low-		Medium
						Medium		
RS-9	Medium		High			Low-		Medium
						Medium		
Kingfisher	High		High					
GRN-1	Moderate/	Very High	Very High		Moderate	Tolerant	Low	Low
	High							
GRN-2	Low/	Very High	Very High		Moderate	Moderate	Moderate	Moderate?
	Moderate							
GRN-3	Moderate+	Very High	Very High		Moderate/	Moderate	Moderate/	Moderate/
					High		High	High?
GRN-4	Moderate/	Very High	Very High		High	Moderate	Moderate/	Moderate/
	High						High	High?

Role of Rootstocks in Guava

At present, guava is propagated on seedlings raised from open pollinated seeds and not on uniform clonal rootstocks. [9] reported that *P. cattleianum, P. guinesee, P. molle* and Philippine guava were found suitable as rootstocks. On *P. cattleianum,* the trees were the tallest and gave the maximum yield. *P. pumilum* rootstock had dwarfing effect but fruits on this rootstock had maximum number of seeds, highest TSS and total sugars. Trees on *P. cujavillis* produced the largest fruits with the highest ascorbic acid content, though they were rough-skinned and not uniform. All rootstocks were free from wilt disease *(Fusarium solani /Macrophomina phaseoli)* except 'Allahabad Safeda' [36]. [31] recorded that rootstock aneuploid No. 82 impart dwarfness to 'Allahabad Safeda' in terms of plant height, plant spread and tree volume. They also recorded higher yield on this rootstock.

Role of Rootstocks in Apple

There is a great diversity in the type of material used for raising rootstock seedlings in apple. In Kashmir, wild indigenous 'Crab apple' known as 'Trel' is used, in Himachal Pradesh, seedlings of 'Crab C' are employed as rootstock [22]. The first rootstock trial of apple was initiated in 1937 at Chaubattia with 'Red Delicious', 'Jonathan' and 'Rymer' cultivars using Crab C, M 2, M 13, Merton 779, Merton 793 and 'Local Selection' (seedling selection from 'Ribbistin Pippin') rootstocks. After the introduction of M and MM series of rootstocks during early sixties, from East Malling Research Station, England, at Mashobra and Kotkhai in HP, Chaubattia in UP and Shalimar in J & K, elaborate varietal-cum-rootstock trials were initiated at Mashobra in 1967, Kotkhai in 1968, Chaubattia in 1969 and several locations in J & K in 1969. As a result, some promising rootstocks were identified for different apple growing regions in India *viz.* M 7, M 9, M 26, MM 106 and MM 111 for Himachal Pradesh; M 2, M 4, M 7, M 9 for J&K and Merton 779, MM 106, M 13 for Uttarakhand [2]. At Chaubattia, [23] observed that M 2 rootstock response to prolific bearing and high yield in 'Red Delicious', 'Jonathan' and 'Rymer' at earlier stages (5^{th} and 10^{th} years). Subsequently, the trend changed later years (20^{th} and 25^{th} years) which recorded maximum yields in 'Merton 779' and 'Crab C' rootstocks whereas Merton 779 and M 13 rootstocks produced higher yields than other rootstocks after 35^{th} year. Similarly, [30] observed that apple trees grafted on MM 106 rootstock had significantly higher fruit set, yield and yield efficiency than those on M 7. [5] observed that 'Starking Delicious' on MM 111, MM 106, MM 104 and M 4 rootstocks showed less reduction in growth, photosynthetic efficiency and nutrient uptake, and had higher stomatal resistance, lower transpiration rate, more accumulation of proline, ABA and carbohydrate under water stress (10 bar) and these rootstocks were thus considered more drought tolerant than M 2, M 7, M 9, M 25, M 26 and MM 109.

Role of Rootstocks in Pear

Fewer rootstocks choices are available for pears than for apples. Domestic pear seedlings (*Pyrus communis*) are still the most acceptable rootstocks for pear cultivars in terms of vigour, hardiness, and compatibility. However, all pear trees on seedling roots are susceptible to fire blight. Seedlings of *Pyrus calleryana* are adapted to many soil conditions and produce semi-vigorous growth. It is resistant to fire blight, but it's not sufficiently winter hardy. *Pyrus betulaefolia* seedlings are also adapted for many soil conditions and it's a winter hardy. The trees are vigorous, larger than 'Bartlett seedling', and moderately tolerant to fire blight. *Pyrus ussurensis* can be used as resistant to fire blight, pear *psylla*, and cold hardy.

Role of rootstocks in stone fruits

In India, the stone fruits like peach, plum, apricot and almond are generally propagated on their own seedling, while the cherry plants are raised on 'Paja' *(Prunus cerasoides)* seedlings. Commonly 'Behmi (*P. mira*)' is widely used as a rootstock for almond [4]. The relative contribution of organic and inorganic solutes to osmotic adjustment in three almond rootstocks subjected to soil salinity showed that leaf water and osmotic potentials were affected by salinity in GF677 and Bitter almond, but less so in GN15, suggesting a higher selectivity for K^+ and Ca^{2+}against Na^+ in this latter rootstock. Peach seedlings itself use as a rootstocks for peach plantation and plum, apricot, almond seedlings also used [7;33]. Peach seedlings generally shows susceptibility to nematode but 'Nemaguard' and 'Okinawa' showed tolerance to nematode attack [13]. Some nurseries also use 'Behmi' *(P. mira)* as rootstock for peach. Apricot can be used as resistant rootstock against root knot nematode. Western sand cherry, Almond, Nanking cherry are dwarfing rootstock for peach. For Plum (*P. domestica*) selections like 'Brompton' and 'Common plum' from*;* St. Julien, 'Common Mussel' and 'Damson' from *P. institia;* Myrobalan from *P. cerasifera;* peach *(P. persica),* apricot *(P. armeniaca),* almond *(P. amygdalus)* and some hybrids like Marianna plum *(P. cerasifera × P. munsoniana)* are used as rootstocksin other countries. In India, peach, apricot, behmi (natural hybrid of almond and wild peach) and plum seedlings are commonly used as rootstocks [33]. The main cherry rootstocks in other countries are Hazard *(P. valium)* and Mahler *(P. mahaleb)* seedlings, while Stockton Morello *(P. cerasus)* is also occasionally used. In India, the most common rootstock in Kashmir, Himachal Pradesh and Kumaon Hills of UP is 'Paja' (*P. cerasoides*) [32], though old plantations are invariably on Mazzard or Mahaleb rootstocks [33]. For exceptional hardiness the seedlings of 'Russian sour cherries' could be used for *Prunus besseyi* [33].

5. CONCLUSION

The effect of rootstocks and inter-stocks pertaining to growth, flowering, fruit set, yield efficiency and fruit quality attributes of fruit crops are complex and poorly understood. Studies on

understanding the mechanisms underlying these effects would help for future rootstock breeding and selection. A better understanding of endogenous growth substances, rootstock-scion interactions, soil or climatic factors needed to be studied, which would aid more efficient selection and use of rootstocks in the future. There is an urgent need to evolve rootstocks tolerant to biotic and abiotic stresses in different tropical, sub-tropical and temperate fruit crops.

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