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Role of rootstocks to mitigate biotic and abiotic stresses in tropical and subtropical fruit crops: A review

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Abstract

Fruit cultivation not only plays a crucial role in nutritional security but also offers employment opportunities, higher income and productivity to the farming community. Biotic and abiotic stresses are the most ominous factors in fruit production, which reduces the growth and productivity thereby resulting in an impact on global fruit production and availability. Biotic and abiotic stresses, including drought, extremes of temperature, various pest and diseases, salinity in soil and water are problems which are becoming acute. There is an urgent need to improve biotic and abiotic stress tolerance in fruit crops by using traditional breeding and biotechnology approaches like gene silencing and transgrafting. Nowadays, the virus resistance transgenic rootstocks are developed by using small interfering RNA s (silencing RNA) method. Rootstock breeding in fruit crops is a great challenge due to difficulty in identification of tolerant or resistance rootstock for various purposes. In this paper, we have discussed the various biotic and abiotic stresses, resistance mechanisms, and available resistant rootstocks so far as well as challenges in rootstock breeding which can be helpful to manage stress conditions in fruit cultivation. Further research is needed to develop the resistance rootstocks by using modern rootstock breeding methods with various biotechnological approaches.

Keywords: Biotic and abiotic stress, rootstock breeding, resistance mechanism, gene silencing, silencing RNA and Trans grafting

Introduction

During recent decades, climate change, various biotic and abiotic stresses are the serious challenges being faced worldwide which influences the performance of fruit crops and showed a negative impact on global fruit production and availability. The reduction of yield due to poor utilization of land areas, poor adaptability under adverse biotic and abiotic stress condition, lack of awareness about the adoption of improved hi-tech horticultural practices, continuing reduction in the availability of cultivable area, low yielding varieties and inadequate technological up-gradation (Tsering dolkar *et al.*, 2018) ^[97]. The stresses like biotic and abiotic play crucial roles in the growth, survival, adaptability, productivity and yield of fruit crops (Redondo-Gomez, 2013) ^[83]. Biotic and abiotic stresses, including drought, extremes of temperature, various pest and diseases, salinity in soil and water are problems which are becoming acute (Flowers, 2004) ^[37].

Due to the limited availability of cultivable area and even that is not suitable for cultivation, fruits are cultivated under unfavourable soil and stress condition to meet the huge market demand for fruits. The rootstocks play a major role in fruit cultivation by influencing canopy architecture, adaptability to adverse climatic condition, nutritional uptake, flowering, yield and fruit quality. Besides, rootstocks can also be used for high-density planting (HDP) and build up resistance to biotic and abiotic stresses such as pest and diseases incidence, drought, salinity, nematode infections, thermal stress and nutritional stress (Reddy *et al.*, 2003) ^[82]. Among the abiotic stresses, salinity is one of the major ones that affect growth and yield of plants in arid and semi-arid areas throughout the world (Chelli i-Chaabouni *et al.*, 2010) ^[22]. Most of the plants produce osmoprotectant metabolites such as proline, glycine-betaine and soluble sugars to protect the cells against the damaging effects from salt stress. Halophytes plants which can survive and reproduce even under high salt concentration with 200 mM NaCl, Galophytes plants are cannot survive in salinity condition and eventually die.

However, most of the major fruit crops belong to this category. To alleviate these environmental stresses, adaptability and lower productivity only a few scientific approaches are available and one of the best concepts is the use of certain tolerant rootstocks in fruit cultivation which are capable of reducing the effect of external stresses. The rootstock yields a high degree of compatibility and resistant to major biotic (pests and diseases) and abiotic stresses (light, heat, salinity, drought, waterlogging and temperature tolerance, etc.) (Fig.1). Further, rootstock enhances nutrient uptake and improves flowering and fruit set by imparting disease and pest tolerance.

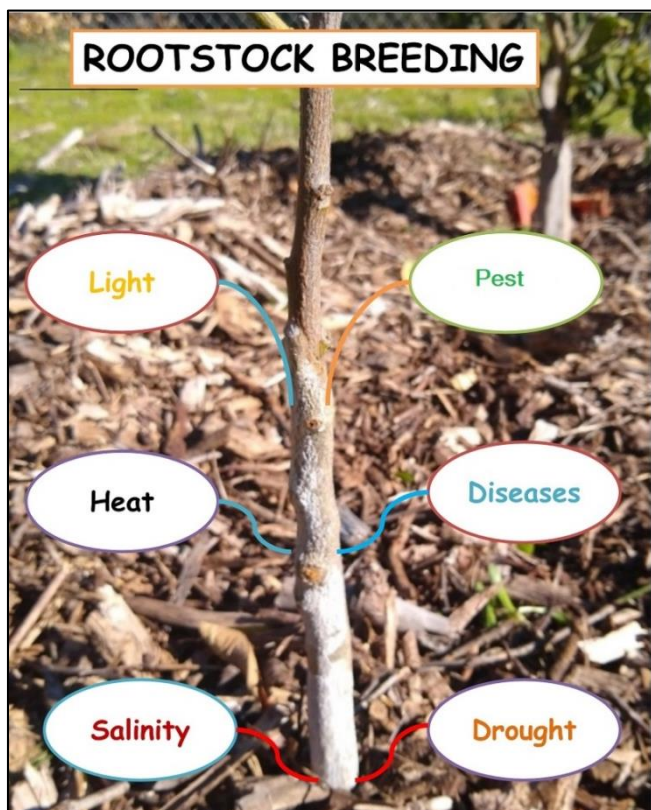


Fig 1: Objectives of Rootstock breeding

Rootstock breeding

Rootstock breeding in fruits is a great challenge to scientists because identification of tolerant or resistance rootstock is difficult. Rootstock breeding and selection is a new discipline and selection of seedling and clonal rootstocks substantially began in the 19th century. In rootstock breeding, germplasm conservation plays a major role because it is a source of resistant and used for various breeding activities. Resistance rootstock can be developed through conventional breeding methods. In the case of conventional rootstock breeding, development of rootstock takes a long time to get the desired output and maintenance of rootstock population under field condition is difficult. To overcome these difficulties, a modern biotechnological approach such as molecular assisted selection is used for easier screening of resistant rootstock. Vos and Shoeman (2000) [100] studied the selection of guava wilt resistant rootstock seedlings against *Penicillium vermoeseni* under *in-vitro* condition. The results revealed that

out of 30,000 guava seedlings only three showed 100% tolerance to guava wilt disease. Different types of markers involved in rootstock breeding that accelerate the selection process. In citrus, marker-assisted selection applied for rootstock breeding for identifying various biotic and abiotic stress tolerance rootstocks at an early stage. One of the marker assistant selections in citrus conducted by Xiang Xu *et al.*, (2010) [104] and its selection is based on gene locus "Tyr 1" controlling citrus nematode resistance. Somatic hybridization and protoplast fusions are used for creating intergeneric hybrids.

RNA silencing is one of the gene expression mechanisms that regulates endogenous gene expression and gives defense against viruses. In transgenic plants, RNA silencing has been transmitted between rootstock and scions through grafting. Virus resistance transgenic rootstocks were developed by using small interfering RNA s (siRNA s) mediated gene silencing method. By this way, siRNA s transported from the transgenic rootstocks that may enhance the virus resistance in non-transgenic scions. RNA interference (RNAi) is widely used for virus-resistant transgenic plants production. Plant parasitic nematodes are controlled by insecticides/nematicides but they are harmful to the environment, while other methods like crop rotation and resistant cultivars also very limited. In this case, RNA interference (RNAi) is applied to create resistance plants against devastating parasites. Marker-assisted selection in rootstock breeding can be used to evaluate resistance traits and new rootstocks with resistance to multiple diseases. The use of molecular markers in grapes has been explored for Pierce's disease resistance, dagger nematode resistance and powdery mildew resistance (Dalbo *et al.*, 2001) [28]. In citrus rootstock breeding, seven Random Amplification of Polymorphic DNA were found linked to the CTV resistance gene by bulked segregant analysis (Mestre *et al.*, 1997) [67]. Nowadays, the applications of molecular markers are most common and some markers like randomly amplified polymorphic DNA (RAPD), Inter Simple Sequence Repeat (Bagheri *et al.*, 2019) [9] fluorescently labelled sequence tag and simple sequence repeat (EST-SSR) are commonly helpful in rootstock breeding. Even in the citrus selection, randomly amplified polymorphic DNA (RAPD) analysis has been used for distinguishing nuclear embryos from zygotic (Bastianel *et al.*, 1998) [11].

Rootstocks resistance mechanism

The rootstock is a major contributor to the performance and longevity of the tree. Rootstock can determine the tree size, yield, fruit quality and also tolerance to biotic and abiotic stresses. Plants have built up resistance to various biotic and abiotic stress conditions by some types of resistance mechanisms (Fig.2). In general, plants have three types of resistance mechanism viz., morphological, biochemical and physiological. Morphological resistance is influenced by root characteristics like root structure, length, width and root hairs. Biochemical resistance offered by creating favourable condition *i.e* osmotic environment by which overcoming from stress conditions. Physiological resistance is created by the synthesis of toxins, tannins and phenolic acids etc (Fig.3).



Fig 2: Rootstock resistance mechanism

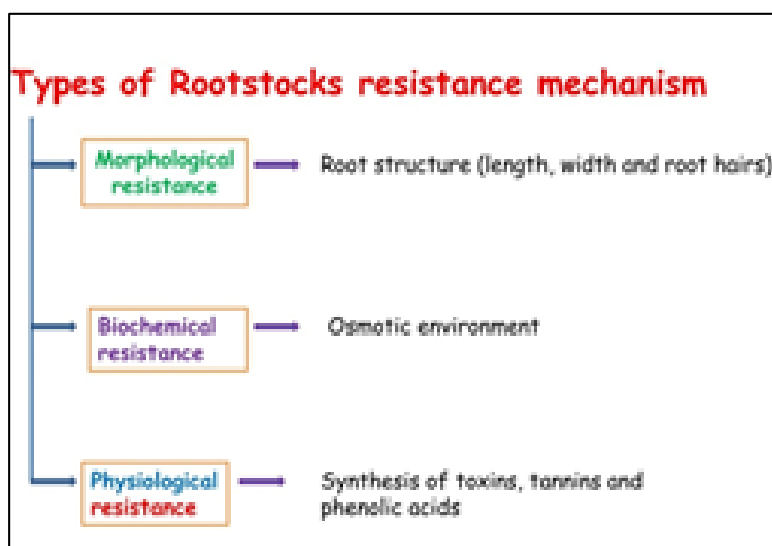


Fig 3: Types of rootstock resistance mechanism

Resistance mechanism to biotic stress

In grapes, the hypersensitive reaction of leaves and roots are linked and they showed resistance to *phylloxera* disease (Schmid *et al.*, 2001) ^[87]. Nematodes are a major problem which feeds the roots and causes damage to the root system. The nematode infected root system showed the reduction of water and nutrient uptake in the plant. Some rootstocks show resistance to nematodes by the mechanism of roots inhibits the entry of female nematodes thereby avoiding further multiplication of nematodes. Sathisha *et al.*, (2007) ^[86] found that rootstocks like 110 R, 1103 P, 99 R and B2-56 were showed the higher content of total phenols, flavonoids, proline and total protein. The higher phenolic content in rootstocks may help in reducing the disease incidence.

Resistance mechanism to abiotic stress

Plants react at the physiological, biochemical and genetic level to tolerate various adverse climatic conditions like drought, salinity, light and temperature. The mango rootstock 13-1 has the capacity to less salt retention than re-translocation in soil. Under the saline condition, accumulation of excess of Na^+ and Cl^- ions can cause ion toxicities, inhibit growth and reduces the yield. So the selection of rootstock for salinity tolerance that restricts these ions will serve under

saline condition. Plants showed resistance/tolerance to salinity by activating different mechanisms viz., salt avoidance, salt excretion, salt exclusion, osmotic adjustment and antioxidant defensive system. In case of drought stress, rootstocks produce abscisic acid which may involve the water conservation processes by stomatal closure. Some grapes rootstock like dogridge, 110 R, B2-56 and salt creek recorded the highest water use efficiency and relative water content at single leaf level thereby rootstocks overcoming the drought condition. Pavlousek (2011) ^[75] studied the evaluation of rootstock for drought tolerance and results revealed that Borner (*Vitis cinerea*) rootstock is suitable for drought condition. Water stress has a significant effect on shoot length and chlorophyll content. Some rootstocks are used for dwarfing purpose and that also be more drought-resistant. Moreover, increased drought resistance of rootstocks may show a negative effect on yield. Serra *et al.*, (2014) ^[88] found that the increased drought resistance in grapes often reduces yield while increasing water use efficiency. In this review, a clear overview of abiotic and biotic stress in mango, guava, grapes, loquat, pomegranate, avocado and citrus fruits are discussed.

Mango (*Mangifera indica* L.)

Mango, also known as 'King of fruits' is one of the commercial fruit crops cultivated throughout the tropical and subtropical countries for their immense value. Rootstocks have been used for the successful cultivation of mango in problematic soil, environmental stress condition, to improve the adaptability and in the adoption of high-density planting. Attempts were made to standardize the rootstocks including polyembryonic varieties for vigour management, salinity, water stress tolerance and ultimately improve yield and quality of mango. To alleviate these problems by using salt-tolerant polyembryonic mango cultivar '13/3' is being evaluated as salt rootstock for 'Kesar' mango at the Reliance mango plantation at Jamnagar (Gunjate, 2009) [45]. The nanoparticles viz., nano-zinc oxide (nZnO) and nano-silicon (nSi) effectively used to improve the salinity resistance mechanism and productivity in Ewais mango (Elsheery *et al.*, 2020) [35]. According to Rossetto *et al.*, (1996) [85] polyembryonic rootstocks like IAC 103 Macoca and IAC 108 Pindorama showed resistant to the fungi *C. fimbriata*. IAC 103 Macoca and IAC 107 Tiete polyembryonic rootstocks are used as resistance against fruit fly incidence. Ribeiro *et al.*, (1993) [84] reported that selection of mango rootstock resistant to wilt *Ceratocystis fimbriata* with two strains by inoculation of pathogen pure culture through soil watering which revealed that mango rootstocks like Carabao, Manga d Agua and Pico were immune to the race FITO 334-1 and highly resistant to FITO 4905. 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 and irrigation water containing 250 ppm. In Florida, polyembryonic rootstocks like turpentine are used for propagation (Zuazo *et al.*, 2006) [106]. In Australia, 'Kensington' seedlings are used as rootstock. Duran *et al.*, (2003) [32] found that Gomera-1 used as salt-tolerant which can restrict the uptake and transport of Cl⁻ and Na⁺ ions from the root system to the above-ground parts of the tree. Under the saline condition, mango root growth and function can be restricted by a high Na⁺/Ca²⁺ ratio (Fig.4). Cultivar stem in which the Na⁺/Ca²⁺ ratio was higher than in the rootstock stem (Duran *et al.*, 2003) [32]. Langra showed tolerance to salinity by the mechanism of less electrolyte leakage and which improves the relative water content, transpiration rate, stomatal conductance Ahmed *et al.*, (2020) [3]. Kannan *et al.*, (2004) studied that sixteen (16) putative of endophytic bacteria were isolated from sodicity tolerant polyembryonic mango rootstock of GPL-3 and ML-4 and evaluate tolerant strains by pot culture of rice under the saline condition of pH 9.35 and EC 4.2. The results have shown that strain CSR-M-16 increased root and shoot length of rice followed by CSR-M-8, CSR-M-9 and CSR-M-6 and these four isolates were found to be tolerant to high salt concentration (2.5 M NaCl) and also showed higher uptake of sodium when cultured under *in-vitro* conditions at this concentration. Cultivation of Kesar mango in the Saurashtra region of Gujarat in adverse growing conditions viz., salinity, drought and heat stress which affects growth and yield. To alleviate these adverse effects by using of Kesar grafted on salt-tolerant rootstocks (Balan, 2017) [10]. Luvaha *et al.*, (2007) [65] reported that water stress which reduces the gas exchange and chlorophyll content slightly increased in the rootstock. Limited work has been done in rootstock breeding in mango and more research studies are needed in this study area. The quality of rootstocks is determined by compatibility,

resistance to stresses, nutrient uptake, economic life and wider adaptability (Fig.5).



Fig 4: Salinity resistance rootstock



Fig 5: Quality of Rootstock

Guava (*Psidium guajava* L.)

Guava exceeds most of the tropical and subtropical fruit trees in adaptability and productivity due to its chilling, drought, and salinity tolerance (Yadava, 1996; Bezerra *et al.*, 2018) [105, 12]. The exogenous foliar application of putrescine has been used to provide better salt tolerance to guava seedlings (Ghalati *et al.*, 2020). A variety with in-built resistance to the biotic and abiotic stress besides high yielding capacity of good quality fruit is lacking. As stated by Usman *et al.*, (2013) [98], recombination breeding between varieties and wild species is one of the major approaches of guava improvement. Use of wild species for guava crop improvement to introduce certain gene(s) for specific traits viz., tolerance/ resistance to biotic stresses like wilt and nematode, abiotic stresses like salt and drought tolerance, dwarf stature, the precocious bearing has been one of the approaches. The exploitation of wild species requires extensive knowledge about flowering behaviour and its compatibility with the cultivated varieties. *Psidium cattleianum* is a small shrub, can adapt to many soil types and is a quite cold resistant (Normand, 1994) [73], tolerates shade (Cronk and Fuller 1995) [24], has good salt tolerance and flowers and early seed maturity (Cronk and

Fuller, 1995)^[24], the type of apomixis reported as disloporic origin (Souza-Pérez and Speroni (2017)^[93]. Inter-specific hybridization has been attempted to develop rootstocks resistant to guava wilt. During the rainy season bagging of guava fruits at marble stage significantly reduced the biotic incidence like a fruit fly, anthracnose and bird damage Sharma *et al.*, 2020^[91].

Higher levels of tolerance or resistance to root-knot nematodes are present in wild *Psidium* species such as *P. friedrichsthalianum*, *P. cattleianum* or *P. arayan* (Lozano *et al.*, 2008)^[63]. Utilization of wild species for guava crop improvement has been one of the ways to introduce certain gene(s) for specific traits viz., dwarf stature, biotic and abiotic stress. The exploitation of wild species requires extensive knowledge of crossability barriers and fertility of the hybrids. Interspecific hybridization has been attempted by several workers. The interspecific hybridization was carried out between *P. molle* and *P. guajava* and the interspecific hybrids developed are graft compatible with commercial varieties of *P. guajava*. They are being evaluated for wilt resistance (Anon. 2016-17; Negi and Rajan, 2007)^[8, 70] under various agro-climatic zones.

In recent years, root-knot nematodes (*Meloidogyne* spp.) are emerging as a major threat to guava cultivation in India. The primary source of infection is through infected potting mixture which is used for raising the planting materials. Nematodes start killing the plants from nursery stage to orchards which are in the establishing stage/ young orchards. In India, *M. enterlobii*, *M. incognita*, *M. javanica* and *M. indica* are the major root-knot nematodes recorded in guava (Hodda, *et al.*, 2012)^[49]. Nematode infection sites in the roots also predispose the roots to easy entry of soil-borne pathogenic fungi like *Fusarium* spp which makes the disease complex and is rapidly spreading major guava growing belts in India, which needs the most attention.

According to Freitas *et al.*, (2014)^[39], *P. friedrichsthalianum* (Costa Rican wild guava) and *P. cattleianum* var. *lucidum* (lemon guava) presented resistance or immunity to root knot nematode (*M. enterlobii*) and *Psidium guineense* (Costa *et al.*, 2012)^[23] showed tolerance to the nematode. In general, guava is moderately tolerant to salinity (4.7 to 8.0 dsm) however, its response to salinity depends upon the species/genotypes and its growth stages. It tolerates NaCl level up to 30 mM without serious growth depressions (Ali-Dinar *et al.*, 1999; Ebert *et al.*, 2002)^[4, 33]. The red guava is reported to possess a better salt tolerance compared to white guava (Ali-Dinar *et al.*, 1999)^[4]. Use of rootstocks has gained prominence in improving its degree of tolerance to abiotic stress like salinity. In the evaluation of guava rootstocks ('Crioula', 'Paluma' and 'Ogawa') for salt tolerance, by employing five levels of irrigation water salinity (0.6, 1.2, 1.8, 2.4 and 3.0 dS m⁻¹) in the initial development stage revealed that the increased salinity restricts the seedling emergence, growth and phytomass accumulation, and the most drastic effects occur at levels higher than 1.8 dS m⁻¹. The results revealed that cultivar 'Crioula' was more tolerant to salinity (Souza *et al.*, 2016)^[92].

Grapes (*Vitis vinifera*)

In viticulture, the rootstocks play a vital role to overcome the adverse effects of salinity, drought, pest and disease resistance and also to modify the scion physiology/ morphology in terms of vine vigour, fruitfulness, bunches and berry characters etc. Li *et al.*, 2019^[60] suggested that grafting is one of the ways to

create resistance to various biotic and abiotic stresses by grafting the grapevines onto resistant rootstocks. The use of acid tolerant rootstocks, such as 'SO4' and '3309C' was highly recommended for acid soils. Salinity is an important problem in grapevine cultivation include decreased the availability of soil-water and toxicity to vines due to accumulation of Cl⁻ and Na⁺ (Ibacache *et al.*, 2020)^[51]. Salt tolerance has been mainly associated with the ability of different cultivars, rootstocks or their combinations to accumulate or restrict Na⁺ and Cl⁻ in leaves or shoot. Walker *et al.*, (2004)^[101] found that selection of salt tolerant rootstock for grapes cultivar Sultana and it is grafted on various rootstocks viz., Ramsey, 1103 Paulsen, J17-69 and 4 hybrids (designated R1, R2, R3 and R4). Among the various rootstocks, Ramsey and R2 showed high to moderate Cl⁻ exclusion ability and suitable for salt tolerance in Sultana grapevine. But R2 rootstock is sensitive to Phylloxera disease. According to Mehanna *et al.*, (2010)^[66] the Salt creek rootstock recorded the higher shoot length, leaf area, leaf number, root length, root Ca content and had a significant reduction in stomatal diffusion resistance compared to 1103 Paulsen.

Under the saline condition, application of uni-sal or humic substance can alleviate the adverse effect of salinity on grape rootstock. Guo *et al.*, (2018)^[46] concluded that A15 rootstock had strong alkali resistance by secreting organic acids mainly oxalic acid and proton pump (VvPMA3) may play an important role in NaHCO₃ stress through promotion of organic acid secretion in the roots to reduce NaHCO₃ stress. Sharma *et al.*, (2011)^[90] reported that Thompson seedless vines grafted on Dog Ridge and salt creek do not withstand continual exposure to saline irrigation (≤ 6.5 dS m⁻¹) compared to those on B2-56 and 1613C with the latter two being effective in maintaining a lower Na⁺: K⁺ ratio and thus lesser injury to the shoot system. Flame seedless grapevines grafted on Paulson 1103 P rootstock can minimize the cell wall degradation enzyme activities of berry pedicles and alleviated the loss of berries due to berry shattering during storage period Banna and Loay (2019)^[34]. Dikilitas *et al.*, 2020 stated that foliar spray of exogenous proline applications showed more tolerant to environmental stresses.

Drought is one of the limiting factors and ultimately reduces the yield and quality. Some rootstocks already found tolerant to water stress is controlling and adjusting the water supply to shoot transpiration demand during stress condition. Both rootstock and scion genotypes can confer to the drought adaptability influencing respectively the capacity of water extraction from the soil and the sensitivity of the stomatal control. Rootstock 140Ru was showed high adaptation to water deficit condition (Tarmontini *et al.*, 2013)^[95]. 110R rootstock tolerates the drought stress by rapid reestablishment of root elongation and water uptake capacity Cuneo *et al.*, (2020)^[27]. Nimbolkar *et al.*, (2016)^[71], reported that grapevine rootstocks that increased the efficiency of stomatal closure by chemical (ABA) and hydraulic (aquaporins) signalling that act as a major tolerance to water stress. Hochberg *et al.*, (2013)^[48], reported that grapevine rootstocks that increased the efficiency of stomatal closure by Absciscic acid (ABA) and hydraulic (aquaporins) signalling that act as a major tolerance to water stress. Lu jinxing *et al.*, (2012)^[64] studied that cold hardiness in six grapes varieties resulted in relative conductivity significantly increased with the lowering of the temperature. The activity of the POD decreased as the temperature dropped down, while superoxide dismutase and catalase increased first and then declined. Among the six

rootstocks, Beta rootstock showed the highest tolerance to the cold.

Some rootstock showed resistance/tolerance to various pest and diseases. Cabernet Sauvignon grafted with 039-16 rootstock had the smallest degree of grapevine fanleaf virus (GFV) and 039-16 rootstock used for resistance to GFV. Ramsey and 1103 Paulsen are used as effective rootstocks for its tolerance capacity to phylloxera and nematodes infection in grapes (Nicholas *et al.*, 1997). Brooks and Olmo, (1997) [16]

founded that cultivars Harmony and Freedom are the first root-knot nematode resistant rootstocks derived from complex crosses among *V. champinii*, *V. longii*, *V. vinifera*, *V. riparia* and *V. labrusca*. Ferris *et al.*, (2013) [36] reported that *V. champinii* cultivars Ramsey and Dog Ridge emerged as exhibiting durable resistance to root-knot nematodes. The rootstocks UCD GRN1 and VR 039-16 used for resistance to the root lesion nematode.

Table 1: List of resistant/ tolerant rootstocks in fruit crops.

Crop	Rootstocks	Resistance/tolerance traits	References
	13-1	Tolerant to salinity	Gunjate, 2009 [45].
	Carabao, Pico Manga d Agua	Resistant to wilt	Ribeiro <i>et al.</i> , 1993 [84].
	IAC 103 Macoca & IAC 108 Pindorama	Resistant to <i>C. fimbriata</i>	Rossette <i>et al.</i> , 1996 [85].
	Gomera-1	Tolerant to salinity	Duran <i>et al.</i> , 2003 [32].
	13/3	Tolerant to salinity	Gunjate, 2009 [45].
	Kurukan	Tolerant to salinity	Dubey <i>et al.</i> , 2007 [31].
Guava	Olour and Bappakkai	Tolerant to salinity	Palaniappan, 2001, Dubey <i>et al.</i> , 2007 [74, 31].
	<i>Psidium friedrichsthalianum</i> P. <i>cattleianum</i> var. <i>lucidum</i>	Resistance to root-knot nematode	Freitas <i>et al.</i> (2014) [39].
	<i>Psidium guineense</i>	Resistance to root-knot nematode	Costa <i>et al.</i> , 2012 [23].
Grapes	Crioula	Tolerant to salinity	Souza <i>et al.</i> , 2016 [92].
	Dimple, Jonelle, GU 8	GWD resistance Nematode tolerance Salinity tolerance	Vos, 2000 [100]
	GU8 P. <i>longipes</i> and P. <i>arayan</i>	Root Knot Nematode resistant Root stock	Milan, (2007)
	Ramsey and Dog Ridge	Resistance to root-knot nematodes	Ferris <i>et al.</i> , 2013 [36].
	UCD GRN1 and VR 039-16	Resistance to the root lesion nematode	Ferris <i>et al.</i> , 2013 [36].
	Ramsey, Riparia Glorie, 5C	screened for salt tolerant	Kevin Fort and Andrew Walker, 2008 [58].
	Harmony and Freedom	Resistance to root-knot nematodes	Brooks and Olmo 1997 [16].
	Ramsey and 1103 Paulsen	Tolerance of phylloxera and nematodes	Nicholas <i>et al.</i> , 1997
	140Ru	Tolerance to water deficit condition	Tarmontini <i>et al.</i> , 2013 [95].
	Beta	Cold hardiness	Lu jinxing <i>et al.</i> , 2012 [64].
	3309C	Cold hardiness	Striegler <i>et al.</i> , 1991 [94].
	A15 and A17	Tolerance to alkalinity	Guo Shu-Hua <i>et al.</i> , 2018 [46].
	Hybrids of <i>V. berlandieri</i> x <i>V. riparia</i>	Tolerance to drought	Kocsis <i>et al.</i> , 1999 [59].
Avocado	196-17, CH-1, CH-2	Tolerance to salinity	Troncoso <i>et al.</i> , 1999 [96].
	G755C13-1	Salinity tolerance	Kadman, 1984 [54].
Loquat	Duke 7 and G6	Resistance to <i>P. cinnamomi</i>	Kellam <i>et al.</i> , 1985 [57].
	Anger	Tolerance to Saline conditions	Garcia-Legaz <i>et al.</i> , 2003
Citrus	<i>C. Macrophylla</i>	Resistance to salinity	Garcia legaz <i>et al.</i> , 1993
	Mandarin- Clemenules trees grafted on Carizo performed well	Resistance to salinity	Garcia-Legaz <i>et al.</i> , 2006 [40].
	Pearl, Mosambi x kinnow & mosambi x Nagpur	Resistant against citrus psylla	Sharma <i>et al.</i> , 2005 [89].
	Star ruby and ruby red	Resistant against citrus psylla	Sharma <i>et al.</i> , 2005 [89].
	F & A 418, #23, #24 Hybridization (<i>Troyer citrange</i> X <i>Cleopatra mandarin</i>)	Dwarfing rootstock	Ignacio-Iliso <i>et al.</i> , 2004 [52].
	US 852 Hybrid Selection	Phytophthora resistance	Bowman <i>et al.</i> , 1999 [14, 15]

Sapota (*Achras zapota* L.)

Sapota popularly known as ‘Sapodilla’ or ‘Chicku’, can flourish well on a wide range of soils like alluvial, sandy loam, red laterite and medium black type with temperature ranging from 11 °C to 34 °C. Commercial cultivation of sapota for better yield and fruit quality through grafted saplings. Species like *Achras zapota*, *Mimusops hexandra*, *Mimusops kauki*, *Madhuca latifolia*, *Bassia longifolia* and *Chrysophyllum cainito* have been reported as rootstocks for

sapota (Bose, 1985). Kalesh *et al.*, (2005) [13]. found that a new indigenous rootstock for sapota *C. lanceolatum* and it is wild species is rather sustainably disease resistant, profuse flowering, seed fertility over 95% and wide adaptability with different kinds of soils. Mohammadi *et al.*, (2018) [68, 69] reported that morphological and antioxidant enzymatic activity responses of sapodilla rootstock to salinity stress resulting in *Manilkara hexandra* showing very slow growth rate and there are no morphological changes during the stress

period. During the saline condition, the antioxidant enzymes increased strongly and peroxidase (POD) and catalase (CAT) activities were also increased.

Avocado (*Persea americana*)

Avocado is a new commercial fruit crop which is very sensitive to salinity and climatic factors prevailing in the subtropics, especially drought and extreme temperatures. Extreme temperatures result in low productivity and sometimes even in severe damage to the tree canopy. In Avocado, particularly Mexican race are extremely sensitive to salinity and found that trees grafted on West Indian rootstocks could survive the relatively saline condition but trees grafted on Mexican rootstocks suffered and finally died. And it is the first discovery of the West Indian avocado used as rootstock for resistance to salinity.

Under such condition, chloride toxicity is high include reductions in fruit yield and tree size, lowered leaf chlorophyll content, decreased photosynthesis, poor root growth and leaf scorching. West Indian race was found to be more resistant to salinity than Mexican race. Under saline condition, Mexican race induced greater accumulation of Cl in the leaves whereas West Indian race the Cl accumulation is very less. *Phytophthora* root rot is a major problem in avocado cultivation and it predominately occurs in saline soils. There are two Mexican avocado selections like Duke 7 and G 6 showed more tolerance to avocado root rot due to moderate horizontal resistance to *P.cinnamomi*. Whereas, susceptible rootstocks Walter Hole and Topa Topa to *P.cinnamomi*. Topa-Topa rootstock accumulated more Cl and Duke less Cl than other rootstocks. Under greenhouse, shoot biomass production was approximately one-half that observed for Duke 7 at all chloride concentrations and showed tolerance to root rot (David Crowley *et al.*, 1999)^[25].

Loquat (*Eriobotrya japonica* Lindl.)

Loquat is commercially grown in subtropical to mild temperate climate (Lin *et al.*, 2007). Commonly loquat plants are grafted onto anger (*Cydonia oblonga* Mill.) rootstock which is smaller hence have a lower cost of production (Burlo-Carbonell *et al.*, 1997). Under the saline condition, photosynthesis and dry matter production strongly affected and reduces the growth of the tree. However, the relationship between photosynthesis and salinity is influenced both by the rootstock and the scion. Loquat grafted onto anger had lower Na concentrations in their leaves than those grafted onto loquat and lower concentrations of Cl at the highest salinity. Anger rootstocks permitted some plant growth under saline conditions due to their ability to reduce the transport of Na and Cl to the shoots and leaves from roots (Garcia-Legaz *et al.*, 2008)^[42]. According to Lopez gomez *et al.*, (2007)^[62] loquat grafted on anger rootstock did not the affected growth of loquat plants under moderate (20mM) and high (35mM) concentration of NaCl in the nutritive solution. But loquat grafted on loquat rootstock under 20mM NaCl condition which leads to a 44% decrease in plant growth, whereas the higher NaCl concentration used produced a 65% of plant growth inhibition. Garcia-Legaz *et al.*, (2008)^[42] reported that salinity tolerance differences between the logan and anger were not due to ion uptake and translocation from roots to leaves or to the osmotic effect induced by salinity. Under the saline condition, anger rootstock showed higher tolerance to salinity due to higher capacity to compartmentalize toxic ions in vacuoles or to scavenge activated oxygen species.

Citrus (*Citrus spp*)

Citrus is one of the important major commercial fruit crops and occupies a prominent position in the fruit industry. Citrus growers are facing many problems viz., salinity, drought, different microorganisms (fungi, bacteria and viruses etc.), pests and nematodes affecting the quality and quantity of citrus. Choosing the right rootstocks is fundamental to the success of the citrus industry worldwide (Wheaton *et al.*, 1995)^[103]. In citriculture, the rootstocks are played a major role for the success of citrus cultivation for its resistance to various biotic and abiotic stresses and it has strongly influenced the tree canopy, vigour and yield Forner-Giner *et al.*, (2020)^[38]. Traditional sensing technologies in fruit crops field surveys and phenotyping are requiring more time and labour intensive. Nowadays UAV-based remote sensing and artificial intelligence are used for citrus rootstock evaluation by monitoring the phenotypic changes of plants (Ampatzidis *et al.*, 2019; Ampatzidis and Partel, 2019; Csillik *et al.*, 2018)^[6, 7, 26]. In 1842 the first rootstock was used in citriculture to control root rot caused by *Phytophthora* in Azores Islands through the use of resistant rootstocks. Citrus salt tolerance is associated with both the rootstock's ability to restrict the accumulation of chloride and/or sodium. *C. macrophylla* showed higher resistance to salinity than *C. volkameriana* and used as rootstock for tolerance to salinity in lemon. When the lemon budded on *C. volkameriana*, the increase in leaf sodium concentration would be the most influential factor affecting gas exchange rates. Whereas in lemon budded on *C. macrophylla* or sour orange leaf chloride concentration would be the main factor affecting the gas exchange rates. Cleopatra roots accumulated higher concentrations of Cl⁻ and Na than Carrizo roots but 'Sunburst' leaves on Cleopatra accumulated less Cl⁻ and Na and had higher CO₂ exchange rates than those on Carrizo (Garcia-Sanchez *et al.*, 2002). Raga *et al.*, (2014)^[43, 79] reported that salinity decreased yield and juice volume but improved the total soluble solids and rind thickness. The highest CO₂ assimilation was connected with best Na⁺ exclusion from the leaves. In other studies, Na⁺ and Cl⁻ contents in citrus leaves were mainly depended on scion and to a lesser degree depended on rootstock. Rao *et al.*, (2001)^[80] reported that Gal Gal, Kagzi lime and Karna khatta showed no psylla population were tolerant and used as rootstock for tolerance to Citrus psylla in Meghalaya areas. Under deficit-irrigation in semi-arid regions, Cleopatra mandarin can mitigate more the negative effects of drought stress and maintain better plant water status and higher gas-exchange activity than Carrizo citrange (Perez *et al.*, 2008)^[78]. Rootstocks like Pearl, mosambi x kinnow and mosambi x Nagpur showed resistance to whitefly while citranges such as Carrizo and troyer were highly susceptible. Kinnow and local mandarin showed resistant against citrus psylla and papeda and lemon were moderately resistant (Sharma *et al.*, 2005)^[89]. Javed *et al.*, (2008)^[53] found that citrus root stocks for resistance to citrus nematode (*Tylenchulus semipenetrans* Cobb.), Carrizo citrang, Citromela and Grapefruit were resistant. Savageage citrange and Sachton citrumelo were shown moderate resistant to citrus root nematode whereas some cultivars moderately susceptible like Gadi Dahi, Yuma citrange and Kharana khata. Sharma *et al.*, (2005)^[89] reported that grapefruit cv. Star Ruby and Ruby Red exhibited resistance to whitefly infection. Byrne *et al.*, (1995)^[18] found that Volkameriana and sour orange were tolerant Carrizo and Troyer citranges were intermediate, whereas the *Poncirus trifoliata* rootstock was more sensitive to iron chlorosis. Similar results were reported by Alvarez-Fernández *et al.*, (2006) and Castle *et al.*, (2009)^[5, 20].

Table 2: Characteristics of some resistance/tolerance citrus rootstocks (Chadha and Singh, 1990).

Rootstock	Reaction to					
	Root rot	Nematode	Tristeza	Exocortis	Salt	Drought
Rangpur lime	MT	S	R	S	R	R
Marmalade Orange	MT	MT	R	S	R	R
Rough lemon	S	S	R	R	T	T
Cleopatra mandarin	T	S	R	R	MT	S
Sour lime	R	T	HS	T	T	MT
Sweet lime	S	MT	S	S	S	S
Trifoliate orange	R	R	R	H	HS	HS
Troyer citrange	MT	T	MT	S	HS	HS
Carrizo orange	MT	T	MT	S	HS	HS
Sweet orange	HS	HS	MT	R	S	S
Karna khatta	S	MT	-	T	T	S
Nasanaran	S	MT	T	R	HT	S

M= Moderate, R= Resistant, T= Tolerant, MT= Moderately tolerant, S= Susceptible, HS= Highly susceptible,

Pomegranate (*Punica granatum* L.)

Pomegranate is a very interesting fruit for its adaptation to a wide range of climates and soil conditions. The climatic change affects proline accumulation in pomegranate fruits and hot and dry years, proline accumulation in fruits increases. (Hanim and Nesrin, 2009). Under deficient irrigation, pomegranate plants more tolerant to drought and use less water. Kaimi and Hassanpour, (2017) [56] reported that Tab-o-Larz rootstock restricts the uptake or transport of sodium and chloride from root to shoot. According to Hasanpour *et al.*, (2015) [47] selection of drought tolerant seedling by growing plants under water stress condition and resulted that Wonderful variety accumulated high values of proline content under water stress condition then Early 166 variety. Hence, the pomegranate variety Wonderful showed tolerant to drought condition when compared to Early 116 variety. ValizadehKaji *et al.*, (2020) [99] found that Daneshgah 13, Daneshgah 32 and Daneshgah 8 used as rootstocks showed maximum drought tolerance among the cultivars.

Fig (*Ficus carica*)

Plants under the saline condition which ultimately affect crop yield and quality depend on the crop species and cultivars, salinity level, the composition of salt, exposed period to salinity, the growth stage of plants, and several environmental factors Del Amor *et al.*, (1999); Carvajal *et al.*, (1998) [29, 19]. Masui Dauphine fig grafted on zidi, biter abiod, king and own rooted were grown in 6 different areas and among four rootstocks zidi performs well even in soil sickness condition and it is a suitable rootstock for tolerance to soil sickness (Hosomi *et al.*, 2002). Grattan and Grieve, (1999) [50, 44] stated that high concentrations of Na⁺ and Cl⁻ in the root depress nutrient ion activities and produce extreme ratios of Na⁺/Ca²⁺, Na⁺/K⁺, Ca²⁺/Mg²⁺, and Cl⁻/NO³⁻. Hence, the plants become nutritional deficiency, specific ion injury that may result in reduced yield and quality.

Papaya (*Carica papaya*)

Papaya is also known as wonder fruit of tropics which is grown in almost every part of the country. According to Noraisah Sarip *et al.*, (2018) [72] Viorica a promising rootstock in producing high tolerance against Papaya Dieback Disease by grafting method and more than 90% success rate was obtained and used in reducing the susceptibility of elite scions. Pecanha *et al.*, (2010) [76] reported that papaya rootstock Tainung1 perform better to provide water to the shoot and a good vascular connection between the scion and rootstock thereby maintaining high gas exchange and photochemical efficiency in the leaves and consequently a

greater carbon gain. Chlorophyll fluorescence was the highest (0.83) in Tainung 1 seedlings and the lowest (0.73) in Golden/Tainung 1 combination.

Conclusions

Both abiotic and biotic stress especially drought, salinity, temperature stress, fungal and other diseases of microbes in fruit crops have led to a reduction in yield and or crop failure. Hence, the use of different types of stress specific rootstocks in fruit crops would play a major role in increasing the productivity of fruit crops under various stressful conditions. Many challenges of the rootstock breeding programmer have been addressed effectively to some extent by combining the traditional rootstock breeding with modern breeding methods such as molecular breeding to save time and space. Although the source of rootstock, resistance to biotic and abiotic stresses has been reported by several workers, the research progress is very slow and needs to be hastened. Still, more efforts are needed to evaluate rootstocks with resistance to various traits and its use as rootstock directly or by introgression into commercial cultivars, compatibility of the tolerant/ resistant rootstock with various commercial cultivars. The trend in rootstock breeding is to incorporate more traits into the roster of ideotype features. Production trends are towards reduced chemical inputs, a fewer pass by hand labour crews, and higher production with more plants per unit area, more goals for breeding programmes will increase the intractability of rootstock improvement. It is visualizes and selecting suitable rootstock so that, the potential possibility of the scion variety could gain for sustainable production.

Conflict of interest

We hereby submit that there is no conflict of interest over this manuscript either among the authors or the sponsors.

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