Available online at
http://agrospheresmagazine.vitalbiotech.org/

ISSN (E): 2582 – 7022

Agrospheres:e- Newsletter, (2025) *6*(5), 35-39

Article ID: 717

Rootstock Research in Fruit Crops: Status and Future Directions

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Article History
Received: 03. 05.2025
Revised: 07. 05.2025
Accepted: 12. 05.2025

INTRODUCTION

Rootstocks are the root systems to which fruit tree scions (the top part of the tree that bears the fruit) are joined. Choosing rootstocks is essential in deciding the general performance of fruit trees, growth, yield, and longevity. Rootstocks influence a variety of physiological processes in fruit trees, such as water and nutrient uptake, resistance to disease, and reaction to environmental stresses. With the global demand for fruits continuing to rise, maintaining sustainable and efficient production mechanisms is crucial, and rootstock improvement is a major strategy that can help make this possible.

Over the last few decades, rootstock research has been increasing in importance because of its ability to counteract challenges associated with climate change, soil erosion, and pests. By enhancing rootstock characteristics, scientists strive to come up with more tolerant fruit crops that can perform well even under adverse conditions while having better or same quality fruits.

Grafting a rootstock with a compatible cultivar (scion) in fruit crops is a standard horticultural practice. Rootstocks yield several advantages, including enhanced adaptation to soil and climatic environments, increased tolerance to biotic and abiotic stresses, management of plant vigor, and homogeneity in production. The rootstock-scion interaction has also gained increased focus due to concerns over climate change, soil salinity, and high-density plant cultivation systems.

Current Status of Rootstock Research

1. Apple (*Malus domestica*)

- ✓ **Key Rootstocks**: M9, M26, MM106, MM111
- ✓ **Focus**: Dwarfing rootstocks like M9 and M26 are widely used in high-density orchards for early bearing and ease of harvesting. MM106 provides better drought tolerance.
- ✓ **Challenges**: Susceptibility to fire blight and woolly apple aphid in some clonal rootstocks.

2. Citrus (Citrus spp.)

- ✓ **Key Rootstocks**: Rough lemon, Carrizo citrange, Rangpur lime, Swingle citrumelo
- ✓ **Focus**: Enhancing tolerance to citrus tristeza virus (CTV), Phytophthora root rot, salinity, and drought.
- ✓ **Trends**: Shift towards rootstocks with resistance to Huanglongbing (HLB) or citrus greening disease.

3. Mango (*Mangifera indica*)

- ✓ **Key Rootstocks**: Olour, Vellaikolamban, Bappakai
- ✓ **Focus**: Dwarfing, salinity and drought tolerance, and early bearing.
- ✓ **Emerging Research**: Evaluation of polyembryonic genotypes for uniformity and vigor control.

4. Grapes (*Vitis vinifera*)

- ✓ **Key Rootstocks**: Dog Ridge, St. George, 110R, 99R
- ✓ **Focus**: Resistance to nematodes, salinity, drought, and phylloxera.
- ✓ **Current Approach**: Use of rootstocks to manage vine vigor and improve fruit quality under varying agro-climatic zones.

5. Guava (*Psidium guajava*)

- ✓ **Key Rootstocks**: *P. cattleianum, P. molle*, Aneuploid-82
- ✓ **Focus**: Wilt resistance, dwarfing, and fruit yield improvement.
- ✓ **Observation**: Aneuploid-82 rootstock has shown promising results in controlling guava wilt.

6. Sapota, Ber, Litchi, and Other Minor Fruits

- ✓ Research in crops like ber (Ziziphus spp.), litchi (Litchi chinensis), and sapota (Manilkara zapota) is gaining momentum, focusing on drought tolerance and improving productivity under marginal conditions.

Different work of Rootstock in Fruit Crops

Rootstock-Scion Interactions

The interaction between rootstocks and scions is multifaceted, affecting plant growth, nutrient acquisition, and fruiting traits. Rootstocks affect scion vigor, and some rootstocks induce vigorous growth while others regulate the size and canopy of the tree. Rootstocks have been reported to modulate scion reactions to water stress, nutrient, and temperature stresses and thus provide a potential tool for enhancing productivity under conditions of environmental change.

Disease Resistance

Rootstocks have the ability to impart improved resistance to diseases, especially soil-borne pathogens, nematodes, and root diseases. Research has been an area of emphasis for developing resistant rootstocks for crops such as citrus, apple, and grapevine, which are prone to several diseases. For instance, some citrus rootstocks have been found to be resistant to the citrus greening disease, which has ruined orchards globally.

Abiotic Stress Tolerance

Rootstocks also have an important role in improving fruit tree tolerance to abiotic stresses like drought, salinity, and extreme temperatures. With the ongoing effects of climate change on world agriculture, the creation of rootstocks with tolerance to these stresses becomes more and more important. Certain rootstocks have been found to enhance water use efficiency and improve drought tolerance, thus minimizing irrigation requirements in water-scarce areas.

Nutrient and Water Uptake

Rootstocks have an impact on the effectiveness of nutrient and water absorption in fruit trees. Rootstocks that optimize the efficiency of nutrient uptake can result in better fruit quality and higher yields. Further, rootstocks that optimize water absorption and retention are especially useful in regions where there is limited water availability.

Rootstock-Specific Characteristics

Research has also addressed rootstocks having certain qualities like compact habit of growth, dwarfing, or resistance to disease. These factors can prove particularly useful in systems of high-density planting, now increasingly found on modern fruit farms to ensure highest land utilization and productivity.

Directions for the Future in Rootstock Research

Precision Breeding to Improve Rootstock

Advancements in genomics and molecular breeding provide promising prospects for the improvement of rootstocks. Gene editing systems such as CRISPR-Cas9, and genomic selection can help bring about the improvement of rootstocks with targeted characteristics, including disease resistance, abiotic stress, and enhanced nutrient acquisition. In the future, breeders could develop rootstocks that are individually designed to meet targeted environmental conditions and scion cultivars.

Molecular Breeding and Genomics

The use of molecular markers and genomic technology has greatly transformed the breeding of rootstocks as it has made it possible to identify such genes that play a critical role in determining key traits, i.e., disease resistance, stress tolerance, and scion compatibility.

Marker-assisted selection (MAS) is capable of speeding up the screening process for roots with favorable traits, shortening breeding cycles and enhancing the efficiency of selection. Such markers can identify rootstocks having potential for increased resistance to biotic and abiotic stresses, enhanced nutrient acquisition, and quality of the fruit. The application of genomic tools (such as next-generation sequencing, genome-wide association studies) will allow scientists to identify specific genes responsible for rootstock traits. This will translate to more specific breeding techniques, making sure that future rootstocks are more attuned to both environmental and market needs.

Biotechnology and CRISPR Applications

The use of modern biotechnology tools, including CRISPR-Cas9, offers promising avenues for targeted rootstock improvement. Genome editing tools can be employed to specifically target genes involved in desirable characteristics such as disease resistance, stress tolerance, and vigor regulation for efficient and faster rootstock development. Furthermore, genetic transformation technology can be employed to introduce wild species traits or to increase the disease resistance of rootstocks, such as imparting resistance to soil-borne diseases or increasing root growth.

Emphasize Root Characteristics and Rhizosphere Interactions

Although most research has emphasized the aboveground aspects of the tree, increasing attention is being paid to the role of root characteristics in governing fruit tree performance. Research on the rhizosphere of roots the region of soil affected by root activity seeks to unravel how root-associated microorganisms contribute to disease resistance, nutrient acquisition, and tolerance to stress. Increased knowledge will no doubt continue to explore further these interactions and the optimization of rootstocks to maximize the presence of beneficial soil microorganisms.

Grafting of Rootstocks with Sustainable Farming Practices

With the future world agricultural scene heading towards sustainability, incorporating rootstock research into sustainable agriculture will be essential. Rootstocks that enhance soil fertility, enhance organic production systems, and minimize use of synthetic fertilizers and pesticides will be sought after. The future of rootstock research might include finding rootstocks that enhance soil biodiversity, enhance soil structure, and minimize external inputs.

Adaptation to Climate Change

Climate change is posing new threats to fruit crop production, such as changed precipitation patterns, warmer temperatures, and increased frequency of extreme weather. Rootstocks with resilience to such changes will be essential for fruit production systems of the future. Research will have to be geared towards finding and developing rootstocks that are heat stress-tolerant, drought-tolerant, and saline soil-tolerant.

Global Collaboration and Knowledge Sharing

Rootstock research gains from international cooperation, especially against common threats such as climate change and pest pressure. Cooperative activities among researchers, farmers, and policy-makers will speed up the development and use of better rootstocks. Global research networks and open-access databases will be critical in supporting knowledge and resource sharing.

Rootstock-Scion Interaction Studies

A greater comprehension of rootstock-scion interaction is essential to maximize the performance of fruit trees. This includes an investigation into the effect of rootstocks on the growth and development of the scion via hormonal, physiological, and molecular processes. Exploring hormonal rootstock-scion interaction, e.g., the effect of auxins, cytokinins, and gibberellins, will assist in refining the growth and fruiting behavior of the scion. In addition, research on how rootstocks affect nutrient acquisition, water use efficiency, and secondary metabolite production will enhance scion vigor, fruit quality, and tolerance to environmental stresses.

Climate-Resilient Rootstock Development

With changing climate patterns, the need for climate-resilient rootstocks is increasing. Rootstocks with tolerance to extreme

ISSN (E): 2582 – 7022

temperatures, drought, and salinity will play a crucial role in maintaining stable fruit yields. Rootstocks must be chosen and developed for characteristics like heat resistance, drought tolerance, and salinity tolerance to counter the impacts of climate change. Research will aim at the identification of rootstocks that can perform well under adverse conditions, which will minimize the threats of water shortages and weather extremes. Screening of wild and native species for their possible rootstock characters can yield important information on the genetic variability available for use in breeding climate-resistant rootstocks. These plants may have naturally developed characteristics that enable them to cope with stressful environmental conditions, which can be utilized for transfer into commercial rootstocks.

Biotic Stress Management

Rootstocks have an important function in controlling biotic stresses like pathogens and pests. With the development of new diseases and pest species, there is a need to create rootstocks that are resistant to these pathogens and pests. Rootstocks can be genetically improved to be resistant to pathogens such as Phytophthora or nematodes, and pests such as the fruit fly, so that fruit trees continue to be productive even with growing biotic stress. Furthermore, the application of rootstocks in integrated pest and disease management (IPM) also needs to be investigated. Rootstocks that induce systemic resistance or attract beneficial agents may be integrated in sustainable pest management and can lower the dependency on chemical interventions.

Rootstocks in High-Density and Meadow Orchards

The movement towards high-density orchards and meadow-type plantings calls for the generation of rootstocks that enable more effective land utilization.

Ultra-dwarf rootstocks that limit tree size will allow increased planting densities, optimizing space and maximising yield/hectare. Such rootstocks will also favour early fruiting, hence the time to market.For mechanical harvesting, rootstocks that produce consistent tree sizes and dense growth habits will simplify the design of harvesting machines capable of collecting fruits without damage. This can be very cost-saving in terms of labor and can increase the efficiency of harvest.

CONCLUSION

Rootstocks play a critical part in contemporary fruit crop cultivation, affecting a variety of traits that determine fruit yields and quality. Research has advanced substantially in rootstock-scions interactions, resistance to diseases, abiotic stress tolerance, and nutrient acquisition. Many possibilities still exist for improvement, particularly in precision breeding, sustainability, and adaptation to climate change.

With increasingly complex global challenges, rootstock research will be an essential part of the effort to guarantee future success and sustainability of fruit production. New technologies in genomics, breeding methods, and environmentally friendly farming practices have immense potential for the creation of the next generation of rootstocks that will propel the productivity and resilience of fruit crops across the globe.

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ISSN (E): 2582 – 7022

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