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Contribution of Dwarfing Rootstocks to the Establishment of Stable and High-Yielding Tomato Cultivation Systems

Wenzhong Huang [1], Xingzhu Feng [2], Dandan Huang [2]
1 Hainan Provincial Key Laboratory of Crop Molecular Breeding, Sanya, 572025, Hainan, China
2 Hainan Institute of Biotechnology, Haikou, 570206, Hainan, China
Corresponding email: dandan.huang@hibio.org
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Abstract This study mainly introduces the role of dwarfing rootstocks in tomato cultivation. They can help regulate the growth intensity of plants, enhance their stress resistance, and make the utilization of water and nutrients more efficient. It also explores the impact of dwarfing rootstocks on yield stability, fruit quality and management efficiency under different planting environments, and analyzes the commonly used dwarfing rootstocks in the current market. Their genetic origins, hormone regulation methods, and how they interact with scions were evaluated. The performance of dwarfing rootstocks in the face of difficult environments such as drought, salinity and alkalinity, and high temperature was examined through actual cases to see if they could maintain yield and quality under these conditions. This study aims to provide some theoretical support and technical references for the establishment of an efficient, stable and climate-adaptive tomato cultivation system in the future.
Keywords Dwarfing rootstocks; Tomatoes; Stress resistance; High-density cultivation; Yield and quality

1 Introduction

During the process of growing tomatoes, many problems are often encountered, such as drought, high temperature, salinity and alkalinity, as well as pests and diseases. These problems will lead to a decline in output, a deterioration in fruit quality, and farmers will also suffer economic losses as a result (Alqardaeai et al., 2025). Nowadays, the weather is becoming increasingly extreme, water resources are tight, and the duration of high temperatures is getting longer, which also makes tomato cultivation more difficult (Khapte et al., 2022; Davis et al., 2024; Hashem et al., 2024). In addition, growing tomatoes on the same plot of land for consecutive years can also lead to “continuous cropping obstacles”. Coupled with diseases, it also affects the stable yield of tomatoes (Lee et al., 2020; Latifah et al., 2023).

To address these issues, people began to employ grafting techniques, especially dwarfing rootstocks. This method can control the plant from growing too vigorously, making it suitable for a denser planting style. It can also enhance the stress resistance of the plant and help it absorb water and nutrients better (Aydin, 2024). If tomatoes are grafted onto rootstocks with different genetic backgrounds, they can be more drought-resistant, salt-tolerant, heat-resistant, disease-resistant, and at the same time, the yield and quality will not be poor, and may even be better (Hashem et al., 2024). In recent years, more and more attention has been paid to the molecular mechanisms of dwarfing rootstocks, hormonal regulation patterns, and how they affect fruit quality and stress resistance (Hayat et al., 2021; Gomes et al., 2022; Ormazabal et al., 2024).

This study aims to explore the extent to which dwarfing rootstocks can enhance tomato yield, quality and stress resistance, analyze their ability to adjust plant structure, evaluate their application effects under different environmental conditions, and also make some discussions on future development directions. This study hopes to provide some theoretical and technical references for establishing an efficient and stable-yielding tomato cultivation method.

2 Rootstock Technology in Tomato Cultivation

2.1 Historical development and adoption of rootstock use in tomato

Tomato grafting technology was initially developed to address soil-borne diseases and environmental stress issues. Later, with the development of greenhouse cultivation and soilless cultivation, the use of rootstocks became increasingly common. Nowadays, rootstocks can not only resist diseases, but also help tomatoes better cope with adverse environments such as saline-alkali, drought and high temperature, and at the same time increase yield and fruit quality (Lee et al., 2023; Mohamed et al., 2024). This technique is particularly common in greenhouse and saline-alkali land cultivation and is also regarded as an important means for stable yield increase (Singh et al., 2020; Fu et al., 2022; Alqardaeai et al., 2024).

2.2 Types of rootstocks: vigorous, disease-resistant, and dwarfing

Some "strong rootstocks", such as Maxifort and GFS-16, perform well in high-temperature or saline-alkali environments. They can make tomatoes grow more vigorously, produce more fruits and have a higher yield (Balliu et al., 2024; Hashem et al., 2024; Mohamed et al., 2024). There is also a kind of "disease-resistant rootstock", usually wild tomatoes or other solanaceae plants, such as wild tomatoes *S. pimpinellifolium*, *S. habrochaites* or eggplants. These rootstocks can effectively prevent soilborne diseases and viral infections (Singh et al., 2020; De Moura Guerra and Da Silva Rodrigues, 2024). In recent years, dwarfing rootstocks have also become increasingly popular. Its main advantages are that it can control the height of the plant, is suitable for close planting, is convenient for management, and is more suitable for mechanized operation. At the same time, it can also ensure yield and fruit quality. Many studies have found that dwarfing rootstocks perform well when cultivated at high density in greenhouses.

2.3 Grafting techniques and compatibility issues

When grafting tomatoes, the commonly used methods include "split grafting" and "insertion grafting". The survival and subsequent growth after grafting are related to the "affinity" between the rootstock and the scion (Latifah et al., 2023). If the affinity is good, tomatoes will grow fast, have strong absorption capacity and good stress resistance (Balliu et al., 2024). However, if the affinity is poor, not only is the grafting not likely to succeed, but there may also be problems such as the plant not growing and even dying prematurely (De Moura Guerra and Da Silva Rodrigues, 2024). Therefore, selecting a suitable combination of rootstocks and scions with complementary traits is a crucial step in achieving high-yield and high-quality tomato cultivation (Fu et al., 2022; Lee et al., 2023).

3 Characteristics and Classification of Dwarfing Rootstocks

3.1 Definition and physiological features of dwarfing rootstocks

Dwarfing rootstocks are a type of rootstock that can make tomatoes grow shorter and more compact. They can regulate the growth of scions, making tomatoes mature earlier, with better fruit quality, and also more drought-resistant and disease-resistant. This type of rootstock is often used for close planting and also helps to increase yield (Figure 1) (Hayat et al., 2021; Hayat et al., 2023a). This effect is mainly due to the fact that they can affect the hormones within plants, such as auxin, cytokinin, abscisic acid, gibberellin and brassinolide, etc. In addition, dwarfing rootstocks can also alter the efficiency of photosynthesis, the transport efficiency of water and nutrients, as well as the structure of the root system and stems. Through the "mutual cooperation" with the scion, they regulate the growth rhythm and plant structure of tomatoes, thereby enabling tomatoes to grow normally and bear more fruits even when planted closely.

3.2 Genetic background and breeding sources

The genetic background of these rootstocks is rather complex. Some come from the dwarfism variations of tomatoes themselves, and many are from wild relatives, such as *Solanum pennellii* or *Solanum torvum*. These wild plants usually have stronger drought resistance and root vitality. If they are hybridized with tomatoes, these advantages can be "passed on" to tomatoes. For instance, the offspring of tomatoes and *S. pennellii*, "RF4A", can retain water better and grow more robustly in arid environments (Khapte et al., 2022). Furthermore, there are currently many studies looking for genes and molecular markers related to "dwarfism", which can help breeders screen out good dwarfing rootstocks more quickly (Hayat et al., 2021; Hayat et al., 2023a).

3.3 Classification by species and commercial availability

In terms of types, dwarfing rootstocks can be divided into two categories. One type is “allogeneic rootstock”, which means using tomatoes themselves or their dwarfing mutants as rootstocks. Another category is “heterologous rootstocks”, such as eggplant (*S. melongena*) or wild tomato relatives (*S. pennellii*, *S. torvum*). The latter is usually more adaptable to harsh environments and more disease-resistant (Khapte et al., 2022; Latifah et al., 2023). At present, there are already many commercial dwarfing rootstock varieties on the market, such as ‘Powerguard’, ‘T1’, ‘L1’ and ‘B.Locking’. These rootstocks can maintain the balanced growth of tomatoes and have a good yield under greenhouse or long-term cultivation conditions (Lee et al., 2020). There are also some rootstocks, such as ‘DRO141TX’ and ‘Fortamino’, which perform better in drought or other adverse conditions. Not only do they have more fruits, but they also taste better (Davis et al., 2024).

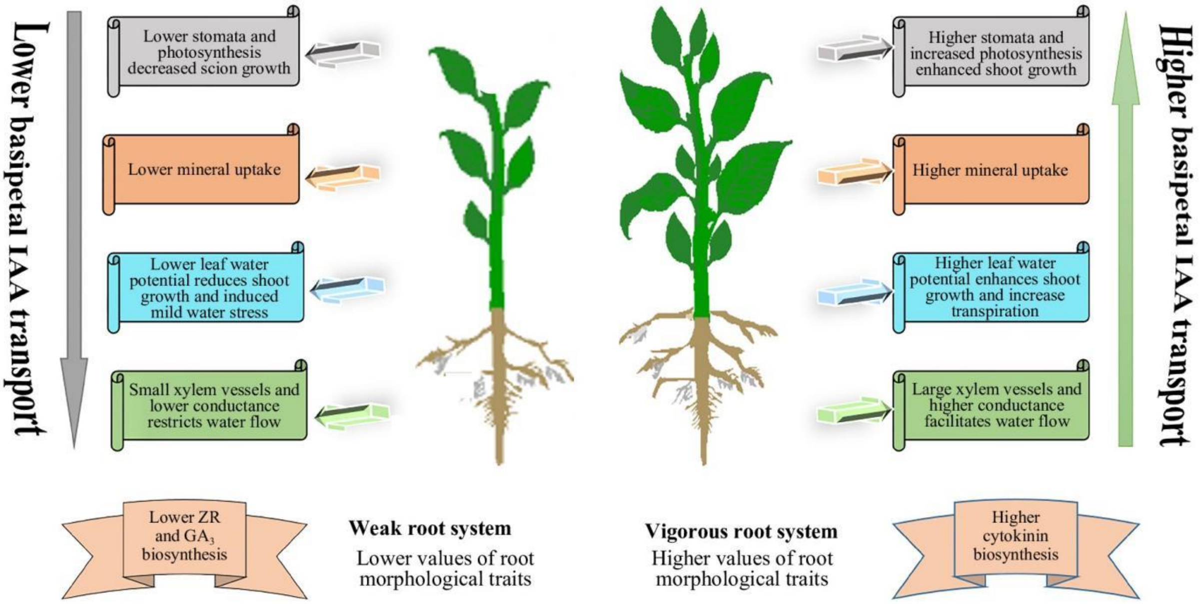

Figure 1 Schematic diagram of rootstock control scion vigour (Adopted from Hayat et al., 2021)

4 Physiological Mechanisms Behind Dwarfing Effects

4.1 Hormonal regulation: auxin, cytokinin, gibberellins

Dwarfing rootstocks can affect the synthesis, transport and signal transduction of various plant hormones, thereby exerting a significant effect on the growth of tomatoes. Studies have found that when dwarfing rootstocks are used, the transport of auxin (IAA) is hindered, and the expression of some transport proteins (such as AUX1 and LAX2) decreases, which makes the aboveground parts of the plants grow more slowly (Zhou and Underhill, 2021; Verma et al., 2024). In addition, the contents of cytokinin (CK) and gibberellin (GA) in dwarfing rootstocks are usually low, or the signal transduction of these two hormones is inhibited, which leads to shorter internodes and shorter plants (Hayat et al., 2022b; Gu et al., 2023; Hayat et al., 2023a). There are also some transcription factors, such as WRKY, which can inhibit the synthesis genes of hormones like gibberellin and brassinolide (BR), thereby making the dwarfing effect more obvious (Hayat et al., 2023b).

4.2 Modulation of nutrient uptake and transport

After using dwarfing rootstocks, the plant’s ability to absorb nutrients such as nitrogen and phosphorus will be weakened. Studies have found that the root system of this type of rootstock absorbs nutrients at a slower rate, and the growth of the upper part is also restricted (Hayat et al., 2021; Hayat et al., 2022a). When there is insufficient nitrogen or phosphorus in the soil, dwarfing rootstocks will cause the roots to grow more branches and expand the root area. Although this can better absorb the limited nutrients, the above-ground parts still do not grow very fast (Xie et al., 2023). In addition, dwarfing rootstocks often also affects water transportation. The water absorption and transportation capacity of the roots weakens, resulting in water deficiency in the upper part of the plant and thus affecting the yield (Biasuz and Kalcsits, 2022; Biasuz and Kalcsits, 2023).

4.3 Influence on plant architecture and root-to-shoot ratio

Dwarfing rootstocks can alter the structure of the entire plant. It enables more resources to be focused on the roots and prevents the above-ground parts from growing too fast (Anthony and Musacchi, 2021; Verma et al., 2024). In terms of manifestation, the volume of roots, branches and surface area have all increased, but the plant height, internodes and leaf area have all decreased. In this way, the ratio of roots to stems increases, which helps the plant survive under conditions with little fertilizer and water, and also facilitates dense planting management (Xie et al., 2023). Other studies have found that dwarfting rootstocks can affect the structure of stems, such as reducing cell wall synthesis and changing lignin and cellulose metabolism. As a result, the stems become shorter and their strength decreases (Zhou and Underhill, 2021; Gu et al., 2023).

5 Contribution to Cultivation System Stability

5.1 Consistency of vegetative growth across environments

Dwarfing rootstocks can regulate the transportation of hormones, nutrients and water in plants. It helps tomatoes grow more consistently in various environments. Many experiments have found that tomatoes grafted with dwarfing or strong rootstocks perform very stably under high temperature, low temperature or drought conditions, and their yields are not prone to fluctuations. For instance, rootstocks such as 'Maxifort' and 'KFS-16' can significantly enhance plant growth and yield under high-temperature conditions (Hashem et al., 2024). In different planting environments (such as high tunnel, open field or different regions), the yield and fruit quantity of some grafting combinations (such as HM/MU, HM/ES) are very stable and less affected by environmental changes (Djidonou et al., 2020). Moreover, grafting can also extend the growth period of tomatoes, making them more vigorous in the later growth stage, which is suitable for situations that require long-term cultivation (Lee et al., 2020; Lee et al., 2022).

5.2 Resistance to biotic and abiotic stressors

Dwarfing rootstocks can enhance the resistance of tomatoes. Whether it is biological stress (such as soil-borne diseases, nematodes) or abiotic stress (such as saline-alkali, drought or low temperature), the grafted tomatoes performed better, with higher yield and quality (Alqardaeai et al., 2024; Hashem et al., 2024). This is mainly attributed to the enhanced vitality of the rootstock roots, which have a stronger ability to absorb mineral nutrients and can also promote the accumulation of stress-related enzymes and antioxidant substances (Hayat et al., 2021; Fu et al., 2022). Some commercial rootstocks have strong resistance to more than seven common soil-borne diseases and can reduce the use of pesticides. In addition, grafting can also reduce the occurrence of physiological disorders such as blossom-end rot (Davis et al., 2024).

5.3 Reduction in lodging and improved plant manageability

In terms of plant structure, dwarfing rootstocks also have advantages. It can make tomatoes grow less tall but stronger, with more developed roots and less prone to lodging (Gong et al., 2022c). The plants are of moderate height, which is conducive to dense planting and also convenient for field management by mechanical or manual means (Gong et al., 2022b). Meanwhile, after grafting, the plants are more compact, the fruit distribution is more even, and harvesting and pest and disease inspection are more convenient (Bayindir and Kandemir, 2022).

6 Impact on Tomato Yield and Fruit Quality

6.1 Yield performance under different planting densities

In high-density planting, people often use dwarfing or low-vitality rootstocks to increase the yield per unit area. Many studies have found that as long as the right dwarfing rootstock is selected, the total yield and commercial fruit yield of tomatoes can be significantly increased, with the increase ranging from 30% to 119%. Sometimes, the yield-increasing effect is more obvious in high-temperature or arid weather (Lang et al., 2020; Jenkins et al., 2022). High-vitality rootstocks such as 'Maxifort', 'DRO141TX', and 'Estamino' can also increase the yield per plant and total yield when planted in greenhouses or high-density (Gong et al., 2022b; Ingram et al., 2022; Hashem et al., 2024). Some wild solanaceous plants can maintain good yield and water use efficiency when used as rootstocks under water shortage conditions (Tejada-Alvarado et al., 2022).

6.2 Effect on fruit size, shape, sugar content, and shelf life

Rootstocks also have an impact on the size and quality of fruits. Most studies suggest that using appropriate rootstocks can increase fruit weight, fruit diameter and fruit length (Gomes et al., 2022). However, there are also some rootstock combinations that can reduce the dry matter, sugar, vitamin C and soluble solids of the fruit. Especially overly vigorous rootstocks may produce a “dilution effect” (Mauro et al., 2020; Gong et al., 2022a). However, in most cases, the rootstock has little effect on the color, pH, lycopene, beta-carotene and other nutrients of tomatoes, nor does it deteriorate the taste or nutritional quality (Jenkins et al., 2022). There are also some rootstocks that can make the fruit more resistant to diseases and less likely to spoil after being stored for a long time (Kabas and Kucukaydin, 2023).

6.3 Trade-offs between vigor reduction and yield optimization

Dwarfing rootstocks can regulate plant hormones, nutrient transport and photosynthesis, reduce vegetative growth, and allow plants to focus more on fruit growth, thereby achieving high yield even when planted closely. However, if the vitality of the rootstock is too weak, it will instead lead to a decrease in yield, smaller fruits, and a possible decline in quality (Mauro et al., 2020). Therefore, a balance must be struck between “controlling growth” and “ensuring output”. It is best to choose the rootstock that can suppress excessive growth without affecting yield and fruit quality (Jenkins et al., 2022). In addition, the combination of rootstocks and scions, planting season, climatic conditions, etc. will also affect the final performance (Figure 2) (Gong et al., 2022a).

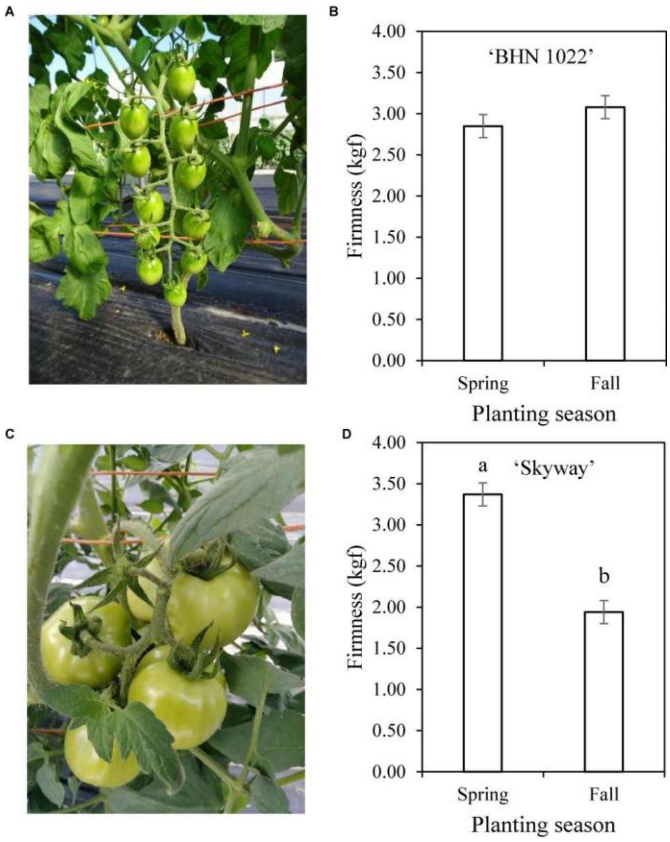

Figure 2 Tomato fruit firmness as affected by scion × planting season interaction (Adopted from Gong et al., 2022a)

Image caption: (A) ‘BHN 1022’ grape tomato scion. (B) Fruit firmness of ‘BHN 1022’. (C) ‘Skyway’ beefsteak tomato scion. (D) Fruit firmness of ‘Skyway’. Error bars represent standard errors. Means followed by the same letter are not significantly different at $p \leq 0.05$ according to Fisher’s LSD test (Adopted from Gong et al., 2022a)

7 Integration with Modern Cultivation Practices

7.1 Suitability for protected and high-density systems

Dwarfing rootstocks can control the growth of scions and the shape of plants, making tomatoes grow more compact. This structure is suitable for close planting and helps to increase the yield per unit area (Zheng et al., 2018). In greenhouses, this type of rootstock can also make the plant structure more balanced, the fruiting period longer, and the final yield and fruit quality better (Lee et al., 2020). In addition, dwarfing rootstocks can also enhance the adaptability of plants to adverse environments such as salt, drought and high temperature, and are suitable for long-term cultivation in high-density and protected areas (Khapte et al., 2022).

7.2 Compatibility with mechanical harvesting and pruning

Dwarfing rootstocks can help control the height and branching pattern of the plants, making the plants grow neatly and easier for mechanical harvesting and pruning (Hayat et al., 2021). Because of its compact plant shape, manual pruning and fruit picking are much easier. After selecting the dwarfing rootstock, the fruit distribution on the plant is more uniform and concentrated, which is convenient for machine harvesting (Lee et al., 2020).

7.3 Role in labor and resource efficiency

In addition to the plant type advantage, dwarfing rootstocks can also reduce the chance of pest and disease occurrence and make management simpler (Hayat et al., 2021). In terms of the use of water and fertilizer, it can enable roots to absorb more efficiently, especially in soilless cultivation or environments with tight water and fertilizer, the effect is more obvious (Khapte et al., 2022). Moreover, after using dwarfing rootstocks, the fruit ripening was more uniform, the harvest period was longer, the number of harvests could be reduced, the grading cost could be lowered, and overall more manpower and resources could be saved (Lee et al., 2020).

8 Case Study: Successful Application of a Dwarfing Rootstock in Commercial Tomato Farming

8.1 Location and environmental conditions of the case study

This case is selected from the Willamette Valley, Oregon, USA. Most of the tomatoes here are grown under dryland conditions, meaning they are not irrigated throughout the entire growing season. This place has a temperate climate. It is dry and hot in summer with little rainfall. Tomatoes often face the problem of water shortage and are prone to physiological problems such as blossom-end rot (BER) (Davis et al., 2024).

8.2 Description of rootstock- scion combination and management practices

In the experiment, two dwarfing rootstocks, ‘DRO141TX’ and ‘Fortamino’, were used and grafted onto multiple tomato varieties, such as ‘Azoychka’, ‘Astrakhanskie’, ‘BHN 871’, ‘Big Beef’, etc. In terms of management, a unified grafting process was adopted, and a field management method without irrigation was used. At the same time, the yield, quality and disease conditions were regularly recorded. All grafting groups and control groups were planted in the same plot, and comparative experiments were conducted under the same management standards for three years (Davis et al., 2024).

8.3 Outcomes: yield stability, fruit quality, economic return

The total yield and the number of large fruits of tomatoes grafted with dwarfing rootstocks were both higher than those of the control group over the past three years. Both ‘DRO141TX’ and ‘Fortamino’ can increase the yield per plant and the average fruit weight, and the incidence of blossom-end rot has decreased significantly. Some varieties have reduced the disease by 69% to 93% (Davis et al., 2024). Grafted fruits are not only larger, have a better appearance, and a higher proportion of commercial fruits, but also have fewer problems. Overall, they are more competitive in the market. More importantly, due to the improved yield and appearance, the economic benefits of tomato cultivation after grafting are far higher than those of tomatoes without grafting. Under drought and adverse conditions, this approach brings more stable and higher income security to growers.

9 Current Limitations and Research Gaps

9.1 Limited availability of elite dwarfing rootstock varieties

At present, the number of high-quality dwarfing rootstocks available on the market is still limited, and in many cases, they cannot meet the needs of different regions and planting conditions. Although some dwarfing rootstocks have been relatively maturely applied to fruit trees such as apples and citrus fruits, for other crops like tomatoes, there are still very few dwarfing rootstocks that are truly suitable for different environments. This is mainly due to the long breeding cycle, complex genetic background and slow speed of new variety development (Hayat et al., 2022a). In addition, many existing dwarfing rootstocks have a single source and a narrow genetic basis. As a result, they are more prone to pests and diseases and also more likely to experience a decline in adaptability (Ling et al., 2025)

9.2 Inconsistent performance across environments

The performance of dwarfing rootstocks varies greatly in different regions. In some places, the effect is very good, which can increase the yield and quality. However, in other places, there may be poor growth or decreased resistance (Yakushiji et al., 2021). This "instability" makes it difficult for them to be promoted and used nationwide or in more regions. Therefore, it is necessary to have an in-depth understanding of how they respond to the environment and to enhance their stability through methods such as molecular breeding (Anthony and Musacchi, 2021; Hayat et al., 2023b).

9.3 Need for integration with root microbiome and stress signaling research

At present, most of the research on dwarfing rootstocks focuses on physiological mechanisms such as hormone regulation and carbohydrate distribution. However, there is insufficient research on their relationship with root microorganisms and how to regulate signals under adverse conditions (Hayat et al., 2022a; Gu et al., 2023). In fact, rhizosphere microorganisms are very important for plant health and stress resistance. In the future, more research should be conducted on the interaction between dwarfing rootstocks and these microorganisms, as well as their signal response mechanisms under stress such as drought and saline-alkali conditions. Combining multiple omics approaches is expected to better improve and utilize dwarfing rootstocks (Ling et al., 2025).

10 Concluding Remarks

Dwarfing rootstocks can regulate the growth vigor, fruit quality and stress resistance of tomato plants, and are an important foundation for achieving high-density planting and high-yield cultivation. Many studies have found that after grafting with dwarfing rootstocks, the fruit weight, flesh thickness, fruit length and diameter of tomatoes are significantly improved, and their pest resistance and nutritional value can also be enhanced. The rootstock and scion interact with each other. Together, they regulate hormone signals, photosynthesis, and the transport of nutrients and water, thereby altering the plant structure and growth performance, and helping to increase yield and quality. Especially in adverse environments such as saline-alkali, high temperature and drought, dwarfing rootstocks can make the yield more stable and the resistance stronger.

In the future, research should pay more attention to the molecular mechanisms of dwarfing rootstocks. Gene editing tools like CRISPR-Cas9 can be used to rapidly cultivate new varieties suitable for large-scale production while retaining the original good traits. Functional genomics research can also help us identify the key genes and signaling pathways that regulate growth, stress resistance and quality improvement in rootstocks. In the design of production systems, it is best to integrate high-throughput phenotypic technology, precise irrigation and high-density cultivation methods, and optimize the combination of rootstocks and scions, so as to achieve more efficient resource utilization and better environmental adaptability.

In the face of various challenges brought about by climate change, such as high temperatures, droughts and soil salinization, dwarfing rootstocks have played a significant role. It can enhance water utilization efficiency, increase nutrient absorption capacity, and improve stress resistance, ensuring stable production and quality of tomatoes even under extreme weather conditions. Meanwhile, dwarfing rootstocks are also suitable for facility agriculture, high-density planting and organic production, providing a new direction for future sustainable, efficient and climate-risk-resistant tomato cultivation methods.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

References

Alqardaeai T., Alharbi A., Alenazi M., Alomran A., Alghamdi A., Obadi A., Elfeky A., and Osman M., 2025, Effectiveness of grafting in enhancing salinity tolerance of tomato (*Solanum lycopersicum* L.) using novel and commercial rootstocks in soilless systems, Sustainability, 17(10): 4333.
https://doi.org/10.3390/su17104333

Alqardaeai T., Alharbi A., Alenazi M., Alomran A., Elfeky A., Osman M., Obadi A., Aldubai A., Ortiz N., Melino V., Tester M., and Pailles Y., 2024, Effect of tomato grafting onto novel and commercial rootstocks on improved salinity tolerance and enhanced growth, physiology, and yield in soilless culture, Agronomy, 14(7): 1526.
https://doi.org/10.3390/agronomy14071526

Anthony B., and Musacchi S., 2021, Dwarfing mechanisms and rootstock-scion relationships in apple, Italus Hortus, 28(2): 22-36.
https://doi.org/10.26353/j.itahort/2021.2.2236

Aydin A., 2024, Effects of grafting with wild tomato (*Solanum pimpinellifolium* and *Solanum habrochaites*) rootstocks on growth and leaf mineral accumulation in salt stress, Horticulture, Environment, and Biotechnology, 65: 785-801.
https://doi.org/10.1007/s13580-024-00607-5

Balliu A., Babaj I., and Sallaku G., 2024, Root morphology parameters and nutrient acquisition capabilities of grafted tomato plants in root-restricted conditions are subject to salinity and rootstock characteristics, International Journal of Vegetable Science, 30(5): 503-526.
https://doi.org/10.1080/19315260.2024.2383847

Bayindir S., and Kandemir D., 2022, Root system architecture of interspecific rootstocks and its relationship with yield components in grafted tomato, Gesunde Pflanzen, 75: 329-341.
https://doi.org/10.1007/s10343-022-00704-4

Biasuz C., and Kalcsits L., 2022, Apple rootstocks affect functional leaf traits with consequential effects on carbon isotope composition and vegetative vigour, AoB Plants, 14(4): plac020.
https://doi.org/10.1093/aobpla/plac020

Biasuz E., and Kalcsits L., 2023, Rootstock effects on leaf function and isotope composition in apple occurred on both scion grafted and ungrafted rootstocks under hydroponic conditions, Frontiers in Plant Science, 14: 1274195.
https://doi.org/10.3389/fpls.2023.1274195

Davis M., Stone A., Selman L., Merscher P., and Garrett A., 2024, Grafting onto tomato rootstocks improves outcomes for dry-farmed tomato, HortTechnology, 34(4): 313-321.
https://doi.org/10.21273/horttech05412-24

De Moura Guerra A., and Da Silva Rodrigues Í., 2024, Compatibility of wild rootstocks in the production of cherry tomato seedlings, Comunicata Scientiae, 15: e3937.
https://doi.org/10.14295/cs.v15.3937

Djidonou D., Leskovar D., Joshi M., Jifon J., Avila C., Masabni J., Wallace R., and Crosby K., 2020, Stability of yield and its components in grafted tomato tested across multiple environments in Texas, Scientific Reports, 10: 13535.
https://doi.org/10.1038/s41598-020-70548-3

Fu S., Chen J., Wu X., Gao H., and Lü G., 2022, Comprehensive evaluation of low temperature and salt tolerance in grafted and rootstock seedlings combined with yield and quality of grafted tomato, Horticulturae, 8(7): 595.
https://doi.org/10.3390/horticulturae8070595

Gomes D., Machado T., Maciel G., Siquieroli A., De Oliveira C., De Sousa L., and Da Silva H., 2022, Dwarf tomato plants allow for managing agronomic yield gains with fruit quality and pest resistance through backcrossing, Agronomy, 12(12): 3087.
https://doi.org/10.3390/agronomy12123087

Gong T., Brecht J., Hutton S., Koch K., and Zhao X., 2022a, Tomato fruit quality is more strongly affected by scion type and planting season than by rootstock type, Frontiers in Plant Science, 13: 948556.
https://doi.org/10.3389/fpls.2022.948556

Gong T., Brecht J., Koch K., Hutton S., and Zhao X., 2022b, A systematic assessment of how rootstock growth characteristics impact grafted tomato plant biomass, resource partitioning, yield, and fruit mineral composition, Frontiers in Plant Science, 13: 948656.
https://doi.org/10.3389/fpls.2022.948656

Gong T., Zhang X., Brecht J., Black Z., and Zhao X., 2022c, Grape tomato growth, yield, and fruit mineral content as affected by rootstocks in a high tunnel organic production system, HortScience, 57(10): 1267-1277.
https://doi.org/10.21273/hortsci16553-22

Gu Q., Wei Q., Hu Y., Chen M., Chen Z., Zheng S., Ma Q., and Luo Z., 2023, Physiological and full-length transcriptome analyses reveal the dwarfing regulation in Trifoliate orange (*Poncirus trifoliata* L.), Plants, 12(2): 271.
https://doi.org/10.3390/plants12020271

Hashem A., Bayoumi Y., El-Zawily A., Tester M., and Rakha M., 2024, Interspecific hybrid rootstocks improve productivity of tomato grown under high-temperature stress, HortScience, 59(1): 129-137.
https://doi.org/10.21273/hortsci17482-23

Hayat F., Iqbal S., Coulibaly D., Razzaq M., Nawaz M., Jiang W., Shi T., and Gao Z., 2021, An insight into dwarfing mechanism: contribution of scion-rootstock interactions toward fruit crop improvement, Fruit Research, 1: 3.
https://doi.org/10.48130/frures-2021-0003

Hayat F., Li J., Iqbal S., Khan U., Ali N., Peng Y., Hong L., Asghar S., Javed H., Li C., Song W., Tu P., Chen J., and Shahid M., 2023a, Hormonal interactions underlying rootstock-induced vigor control in horticultural crops, Applied Sciences, 13(3): 1237. https://doi.org/10.3390/app13031237

Hayat F., Li J., Iqbal S., Peng Y., Hong L., Balal R., Khan M., Nawaz M., Khan U., Farhan M., Li C., Song W., Tu P., and Chen J., 2022a, A mini review of citrus rootstocks and their role in high-density orchards, Plants, 11(21): 2876. https://doi.org/10.3390/plants11212876

Hayat F., Li J., Liu W., Li C., Song W., Iqbal S., Khan U., Javed H., Altaf M., Tu P., Chen J., and Liu J., 2022b, Influence of citrus rootstocks on scion growth, hormone levels, and metabolites profile of 'Shatangu' mandarin (*Citrus reticulata* Blanco), Horticulturae, 8(7): 608. https://doi.org/10.3390/horticulturae8070608

Hayat F., Ma C., Iqbal S., Ma Y., Khanum F., Tariq R., Altaf M., Khan U., Coulibaly D., Huang X., Shi T., and Gao Z., 2023b, Comprehensive transcriptome profiling and hormonal signaling reveals important mechanism related to dwarfing effect of rootstocks on scion in Japanese apricot (*Prunus mume*), Scientia Horticulturae, 321: 112267. https://doi.org/10.1016/j.scienta.2023.112267

Ingram T., Sharpe S., Trandel M., Perkins-Veazie P., Louws F., and Meadows I., 2022, Vigorous rootstocks improve yields and increase fruit sizes in grafted fresh market tomatoes, Front. Hortic., 1: 1091342. https://doi.org/10.3389/fhort.2022.1091342

Jenkins T., Cowan J., Rivard C., and Pliakoni E., 2022, Effect of rootstock on 'Tasti-Lee' tomato yield and fruit quality in a high tunnel production system, HortScience, 57(10): 1235-1241. https://doi.org/10.21273/hortsci16634-22

Kabas A., and Kucukaydin H., 2023, Effect of tomato interspecific hybrid (F1) rootstocks on yield and fruit quality traits, Gesunde Pflanzen, 75: 603-612. https://doi.org/10.1007/s10343-022-00725-z

Khapte P., Kumar P., Wakchaure G., Jangid K., Colla G., Cardarelli M., and Rane J., 2022, Application of Phenomics to elucidate the influence of rootstocks on drought response of tomato, Agronomy, 12(7): 1529. https://doi.org/10.3390/agronomy12071529

Lang K., Nair A., and Moore K., 2020, The impact of eight hybrid tomato rootstocks on 'BHN 589' scion yield, fruit quality, and plant growth traits in a midwest high tunnel production system, HortScience, 55(6): 936-944. https://doi.org/10.21273/hortsci14713-20

Latifah E., Antarlina S., Sugiono S., Handayati W., and Mariyono J., 2023, Grafting technology with locally selected eggplant rootstocks for improvement in tomato performance, Sustainability, 15(1): 855. https://doi.org/10.3390/su15010855

Lee H., Hong K., Kwon D., Cho M., Lee J., Hwang I., and Ahn Y., 2020, Changes of growth and yield by using rootstocks in tomato, Journal of Bio-Environment Control, 29(4): 456-463. https://doi.org/10.12791/ksbec.2020.29.4.456

Lee H., Jeong H., Lee J., Hwang I., Kwon D., and Ahn Y., 2023, Evaluation of grafted tomatoes with different levels of resistance of rootstocks to TYLCV by analyzing the growth characteristics, leaf-macronutrient content, and chlorophyll fluorescence, Horticultural Science and Technology, 41(5): 571-583. https://doi.org/10.7235/hort.20230049

Lee H., Lee J., Cho M., Hwang I., Hong K., Kwon D., and Ahn Y., 2022, Rootstock performance of cherry tomatoes grown in soil cultivation: evaluation of growth, yield, and photosynthesis, Horticultural Science and Technology, 40(4): 376-387. https://doi.org/10.7235/hort.20220034

Ling J., Yu W., Yang L., Zhang J., Jiang F., Zhang M., Wang Y., and Sun H., 2025, Rootstock breeding of stone fruits under modern cultivation regime: current status and perspectives, Plants, 14(9): 1320. https://doi.org/10.3390/plants14091320

Mauro R., Agnello M., Onofri A., Leonardi C., and Giuffrida F., 2020, Scion and rootstock differently influence growth, yield and quality characteristics of cherry tomato, Plants, 9(12): 1725. https://doi.org/10.3390/plants9121725

Mohamed A., Glala A., and Saleh S., 2024, Rootstock-scion combinations affect chemical contents of tomato and its productivity, Egyptian Journal of Chemistry, 68(2): 349-360.

Ormazabal M., Prudencio Á., Martínez-Melgarejo P., Martín-Rodríguez J., Ruiz-Pérez L., Martínez-Andújar C., Jiménez A., and Pérez-Alfocea F., 2024, Rootstock effects on tomato fruit composition and pollinator preferences in tomato, Horticulturae, 10(9): 992. https://doi.org/10.3390/horticulturae10090992

Singh H., Kumar P., Kumar A., Kyriacou M., Colla G., and Rouphael Y., 2020, Grafting tomato as a tool to improve salt tolerance, Agronomy, 10(2): 263. https://doi.org/10.3390/agronomy10020263

Tejada-Alvarado J., Meléndez-Mori J., Vilca-Valqui N., Neri J., Ayala-Tocto R., Huaman-Huaman E., Gill E., Oliva M., and Goñas M., 2022, Impact of wild solanaceae rootstocks on morphological and physiological response, yield, and fruit quality of tomato (*Solanum lycopersicum* L.) grown under deficit irrigation conditions, Heliyon, 9(1): e12755. https://doi.org/10.1016/j.heliyon.2022.e12755

Verma P., Sharma N., Sharma D., Kumar P., Chand K., and Thakur H., 2024, Dwarfism mechanism in *Malus* clonal rootstocks, Planta, 260: 133. https://doi.org/10.1007/s00425-024-04561-5

Xie B., Chen Y., Zhang Y., An X., Li X., Yang A., Kang G., Zhou J., and Cheng C., 2023, Comparative physiological, metabolomic, and transcriptomic analyses reveal mechanisms of apple dwarfing rootstock root morphogenesis under nitrogen and/or phosphorus deficient conditions, Frontiers in Plant Science, 14: 1120777.
https://doi.org/10.3389/fpls.2023.1120777

Yakushiji H., Sugiura H., Yamasaki A., Azuma A., and Koshita Y., 2021, Tree growth, productivity, and fruit quality of 'Fuyu' persimmon trees onto different dwarfing rootstocks, Scientia Horticulturae, 278: 109869.
https://doi.org/10.1016/j.scienta.2020.109869

Zheng X., Zhao Y., Shan D., Shi K., Wang L., Li Q., Wang N., Zhou J., Yao J., Xue Y., Fang S., Chu J., Guo Y., and Kong J., 2018, *MdWRKY9* overexpression confers intensive dwarfing in the M26 rootstock of apple by directly inhibiting brassinosteroid synthetase *MdDWF4* expression, New Phytologist, 217(3): 1086-1098.
https://doi.org/10.1111/nph.14891

Zhou Y., and Underhill S., 2021, Differential transcription pathways associated with rootstock-induced dwarfing in breadfruit (*Artocarpus altilis*) scions, BMC Plant Biology, 21: 261.
https://doi.org/10.1186/s12870-021-03013-6