

# Anatomical Structure of Sweet Cherry Rootstocks and their Influence on Growth and Development of Cultivars: A Review

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**Annotation:** This review summarizes current knowledge on the anatomical features of sweet cherry rootstocks, identifies key structural parameters, examines the mechanisms through which rootstocks affect tree growth and productivity, and outlines research perspectives and practical implications.

**Keywords:** rootstock, anatomy, structure, shoot, root, sweet cherry, cultivar, growth, development.

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## Introduction

Rootstocks are an integral component of both commercial and household sweet cherry (*Prunus avium*) production systems, significantly influencing tree vigor, fruiting capacity, tolerance to biotic and abiotic stresses, and the overall longevity and productivity of orchards. Over the past decades, the use of clonal and hybrid rootstocks adapted to diverse growing conditions has markedly improved orchard efficiency [7], [10].

Despite their wide practical use, the anatomical and physiological mechanisms through which the rootstock affects the scion remain insufficiently understood. Of particular interest are parameters such as the morphology and organization of the water-conducting system, xylem and phloem structure, spatial distribution of vessels, and the influence of root anatomy on above-ground physiological processes.

The aim of this review is to systematize and analyze current scientific data on the anatomical structure of sweet cherry rootstocks (including scion–rootstock interactions) and to determine how root and stem anatomy correlate with tree growth, development, productivity, and resilience under various agroecological conditions.

## 1. Classification and Significance of Sweet Cherry Rootstocks

### 1.1. Types and Genetic Origin of Rootstocks

Modern cherry production employs several groups of rootstocks:

- **Seedling rootstocks** (*Prunus mahaleb*, *P. avium*, *P. cerasus*) – traditional types characterized by high variability;
- **Clonal rootstocks** propagated vegetatively (e.g., *Gisela 5*, *Gisela 6*) – providing controlled vigor (moderate to weak);
- **Hybrid and interspecific rootstocks** developed to enhance adaptability to dense planting systems, adverse climates, drought, and pathogens.

For instance, Vasilev et al. [1] described novel hybrid forms “20 192” and “20 181,” which differ from *P. mahaleb* in several morphophysiological and anatomical traits.

### 1.2. Functional Roles of Rootstocks in the Agroecosystem

Rootstocks influence:

- ✓ scion vigor and vegetative growth,
- ✓ time to fruiting,
- ✓ yield and fruit quality,
- ✓ tolerance to abiotic and biotic stresses,
- ✓ compatibility with specific cultivars and adaptability to soil–climate conditions.

Pal et al. [4] demonstrated that rootstocks significantly affect tree height, shoot length, trunk cross-sectional area, and cumulative yield.

### 1.3. Importance of Anatomical Characteristics

Root and vascular anatomy play a key role in determining physiological function. Parameters such as xylem and phloem structure, vessel diameter and density, proportion of secondary wood, tissue porosity, and hydraulic conductivity are directly related to water transport, metabolic exchange, and hormonal signaling in the rootstock–scion system.

Understanding these anatomical mechanisms provides insights into size-controlling effects and facilitates more precise rootstock selection for intensive orchard systems.

## 2. Anatomical Structure of Roots and Basal Parts of Sweet Cherry Rootstocks

### 2.1. Key Anatomical Parameters

Rootstock anatomy directly affects the functional performance of root systems. Major morphometric indicators include:

**Root diameter:** varies among clones (2.76–5.69 mm; Narandžić & Ljubojević [2]), reflecting differences in primary and secondary development.

**Proportion of secondary xylem:** 27.9 %–52.2 % of root cross-sections [2].

**Xylem vessel classes by cross-sectional area:**

- ✓ Class I –  $\leq 700 \mu\text{m}^2$
- ✓ Class II – 700–2000  $\mu\text{m}^2$
- ✓ Class III –  $> 2000 \mu\text{m}^2$

A higher proportion of Class III vessels corresponds to greater hydraulic conductivity and thus more vigorous shoot growth.

Wood porosity and theoretical hydraulic conductivity strongly correlate with canopy volume ( $r \approx 0.96$ ; Narandžić et al. [3]).

**Root system architecture (depth, branching, and the ratio of fine to coarse roots):** although these parameters go beyond microscopic anatomy, they are closely related to the anatomical structure of tissues and determine the adaptive properties of the rootstock.

## 2.2. Anatomical Features of Rootstocks with Different Vigour Levels

Rootstocks inducing reduced scion vigor (dwarfing types) typically exhibit:

- **Lower proportion of large vessels ( $> 2000 \mu\text{m}^2$ )** and predominance of small ones; e.g., *Gisela 5* had ~88 % Class I vessels and virtually no Class III [2];
- **Low theoretical hydraulic conductivity**, caused by smaller vessel diameters and lower vessel density per unit area.
- **Reduced thickness of secondary xylem and a high proportion of bark.** For instance, in genotype PC\_06\_12, the proportion of secondary xylem was only 27.85%, while bark accounted for 64.74%.
- **Correlations between anatomical traits and growth:** fewer large vessels  $\rightarrow$  lower hydraulic conductivity  $\rightarrow$  reduced shoot and canopy growth.

At the same time, an excessive reduction in the proportion of large vessels may limit the plant's drought tolerance due to a decrease in its potential water-holding capacity.

Narandžić & Ljubojević [2] suggest an optimal vessel distribution:

~ 40–50 % Class I,

~ 40–50 % Class II,

$\leq 10$  % Class III.

Such a “**balanced vascular profile**” provides a compromise between growth control and resistance to water stress.

## 2.3. Anatomical Mechanisms Affecting Growth and Development

The anatomical organization of rootstock roots and vascular tissues influences several key physiological processes:

- **Water transport:** Vessel diameter and density directly determine hydraulic conductivity. Smaller vessels limit the supply of water and minerals, reducing photosynthetic intensity and restricting growth. Narandžić et al. [3] demonstrated a strong correlation ( $r$  up to 0.96) between trunk conductivity and crown volume.
- **Hormonal and resource exchange:** The rootstock affects the movement of auxins, cytokinins, abscisic acid, and other signaling molecules. Anatomical bottlenecks (e.g., a high proportion of phloem parenchyma combined with a small xylem volume) can restrict the movement of these substances.
- **Growth control (size-controlling effect):** Reduced hydraulic conductivity due to smaller vessel diameters or lower conducting tissue density suppresses vegetative growth, manifested by shorter shoots, decreased leaf area, and reduced increment.
- **Stress adaptation:** Rootstocks with large vessels have a high potential for water transport but are vulnerable to cavitation (air embolism in vessels) under drought conditions. Conversely, rootstocks dominated by small vessels exhibit greater resistance but may restrict growth under favorable conditions.

Narandžić & Ljubojević [2] emphasize that rootstocks with exclusively small vessels showed signs of stress during dry periods without irrigation, despite their apparent drought resistance.

### 3. Stem Anatomy and Rootstock–Scion Interaction

#### 3.1. Stem Anatomy and Hydraulic Conductivity

The anatomical structure of the trunk, including its basal (root) portion, reflects the specific interactions between rootstocks and scions and has a significant impact on the hydraulic properties of the tree.

In the study by Narandžić et al. [3], a detailed anatomical characterization of cross-sections of the cherry cultivar ‘Summit’ grafted onto different rootstocks was conducted. It was found that the trunk structure—particularly the area of conductive tissues, vessel density and diameter, as well as wood porosity—correlates directly with the intensity of water transport and the volume of aboveground biomass.

The key anatomical parameters of the trunk include:

- ✓ the area of xylem tissue in cross-section;
- ✓ the average diameter of xylem vessels;
- ✓ vessel density per unit area;
- ✓ theoretical hydraulic conductivity of the wood;
- ✓ overall trunk porosity, which affects the rate of water transport.

These parameters, determined both by the rootstock genotype and its interaction with the scion, can serve as indicators of tree vigor and potential productivity.

#### 3.2. Physiological Influence on the Scion

The root system of the rootstock exerts an indirect yet pronounced influence on the physiological processes within the scion tissues. Differences in the anatomy and functionality of rootstock roots are reflected in:

- ✓ the leaf water potential;
- ✓ the rate of transpiration;
- ✓ the intensity of photosynthesis;
- ✓ stomatal conductance;
- ✓ the anatomy of leaves and shoots.

For instance, sweet cherry trees grafted onto “vigorous” rootstocks exhibit higher water potential and enhanced photosynthetic activity compared to those grafted onto growth-restricting rootstocks (such as Gisela 5, Edabriz, etc.) [9].

These differences are primarily due to the varying ability of rootstocks to supply the scion with water and mineral nutrients, which in turn depends on the anatomical properties of the conductive tissues in the root and trunk.

Thus, the anatomy of the rootstock determines the physiological state of the scion, and this influence can be traced at the levels of morphology, anatomy, and overall tree productivity.

#### 3.3. Practical Examples of Rootstock Influence

The study by Pal et al. [4] demonstrated significant differences in growth, scaffold branch formation, and fruiting of sweet cherry trees when different rootstocks were used. The effect of the rootstock was evident not only in the intensity of vegetative growth but also in the initiation of generative organs, which is determined by anatomical and physiological characteristics.

Narandžić & Ljubojević [2] proposed a rootstock selection approach based on anatomical structure. According to their recommendations, the optimal rootstocks are those in which:

- ✓ class I and II vessels ( $\leq 2000 \mu\text{m}^2$ ) account for 80–90% of the total;
- ✓ class III vessels ( $> 2000 \mu\text{m}^2$ ) do not exceed 10%.

Such a vascular configuration ensures adequate conductivity while minimizing the risk of cavitation and increasing drought tolerance. The use of anatomical criteria in rootstock selection may improve the predictability of their performance under various growing conditions.

## **4. Influence of Rootstock Anatomy on Growth, Development, and Productivity of Sweet Cherry Cultivars**

### **4.1. Vegetative Growth**

The anatomical characteristics of rootstocks –primarily the vascular structure of roots and trunks – have a pronounced effect on the vegetative growth of cherry trees. Vessel diameter, distribution across classes, and overall hydraulic conductivity determine the volume and rate of water and nutrient transport, which are reflected in shoot growth intensity, branch length, and canopy size.

In the study by Pal et al. [4], the *Mahaleb* rootstock promoted more intensive shoot growth, with an average shoot length of about 111.7 cm, whereas on *Gisela 5* the average was approximately 93.3 cm. Similarly, Narandžić & Ljubojević [2] showed that rootstocks with a lower proportion of large vessels produced more limited growth, due to reduced hydraulic conductivity.

Thus, anatomical parameters of rootstocks can serve as predictors of tree growth and help forecast vigor under various cultivation conditions.

### **4.2. Yield and Fruit Quality**

Rootstocks also have a significant impact on the generative characteristics of sweet cherry trees, including the timing and intensity of fruiting, as well as fruit quality.

In Pal et al. [4], the yield of trees grafted on *Gisela 5* was nearly twice as high as that on *Mahaleb*, despite having less vegetative mass. This was attributed to earlier fruiting and a more balanced allocation of resources between growth and reproductive processes.

Studies of cultivars grafted on *Krymsk 5*, *Piku 1*, and *Gisela 6* showed that different rootstocks influence not only vegetative traits but also the morphological and biochemical properties of the fruit: on *Krymsk 5* trees produced larger fruits, while *Gisela 6* increased fruit firmness [8].

Anatomically, high hydraulic conductivity of the trunk and roots is closely related to canopy volume and yield, as confirmed by a strong correlation (up to 0.96) reported by Narandžić et al. [3].

### **4.3. Stress Tolerance and Longevity**

The anatomy of the root system and trunk has a substantial impact on the tolerance of sweet cherry trees to abiotic and biotic stresses, including drought, cold, and infectious diseases.

Rootstocks with smaller vessels often demonstrate higher resistance to cavitation – the breaking of water columns in the xylem – which is critical under water deficit conditions. For example, Végvári et al. [5] identified a correlation between rootstock stem anatomy and the manifestation of drought stress symptoms in cherry trees.

Furthermore, root anatomical characteristics affect pathogen spread and interactions with the soil microbiome. Recent studies show that the composition and quantity of root exudates, which depend on rootstock genotype, can modify soil microbiota, influencing resistance to diseases such as bacterial canker and root rot [6].

## **5. Synthesis: Mechanisms of Influence and Practical Applications**

### **5.1. Key Anatomical Mechanisms of Rootstock Influence**

Summarizing the available research, several key anatomical and functional mechanisms through

which rootstocks influence grafted sweet cherry cultivars can be identified:

### **Vascular structure of roots and trunk:**

Anatomical traits such as vessel diameter, density, and class distribution determine plant hydraulic conductivity. This directly affects the intensity of water transport, mineral uptake, and overall physiological activity of the tree.

### **Influence on aboveground physiology:**

The anatomical structure of the roots forms the foundation for photosynthesis, transpiration, and hormonal balance. The vascular system regulates the transport not only of water and nutrients but also of signaling molecules (auxins, cytokinins, abscisic acid) that govern the growth and development of aboveground organs.

### **Growth control (size-controlling effect):**

Rootstocks with narrower vascular systems and lower conductivity restrict resource flow to the scion, thereby reducing excessive vegetative growth. This is particularly important for developing compact, manageable canopies in intensive orchards.

### **Stress tolerance:**

Trees with predominantly small vessels exhibit greater cavitation resistance – critical in arid regions or under limited irrigation. However, overly reduced conductive tissue can negatively affect yield, making anatomical balance essential.

## **5.2. Practical Recommendations for Horticulture and Breeding**

Based on anatomical data analysis, the following practical recommendations can be made:

**When selecting rootstocks**, consider not only their origin and agronomic characteristics but also anatomical parameters, particularly:

- ✓ vessel class distribution (I–III),
- ✓ proportion of secondary wood,
- ✓ porosity and theoretical conductivity of roots and trunk.

**For intensive orchards**, rootstocks with moderate hydraulic conductivity are preferable, ensuring a balance between growth and productivity. The optimal vessel distribution proposed by Narandžić & Ljubojević [2] is:

- ✓ class I vessels ( $\leq 700 \mu\text{m}^2$ ): 40–50%;
- ✓ class II vessels (700–2000  $\mu\text{m}^2$ ): 40–50%;
- ✓ class III vessels ( $> 2000 \mu\text{m}^2$ ):  $\leq 10\%$ .

**Anatomical screening of young rootstocks** can be applied in breeding: cross-sectional analysis of roots at early stages allows for the selection of genotypes with promising vascular systems and a favorable proportion of secondary wood.

Excessively high conductivity can promote vigorous growth but reduce drought and pathogen resistance. Conversely, too low conductivity limits growth and may reduce yield. A balanced anatomical profile is essential.

A **combined approach** should be applied: rootstock choice must account for compatibility with a specific scion cultivar. Even an anatomically optimal rootstock may perform poorly if mismatched or grown under unsuitable environmental conditions.

**Planting techniques:** when establishing an orchard, proper planting depth, protection of the root collar, and optimal soil-root contact must be ensured – especially critical for rootstocks with fine or low-porosity root structures.

### 5.3. Future Research Perspectives

Current data open broad opportunities for further research, including:

- **expanding anatomical analyses** to a greater range of rootstocks, particularly new hybrid and clonal forms adapted to various climatic zones;
- **studying the age-related dynamics of anatomical traits** – how the vascular system of rootstocks and scions changes over the tree's lifespan under different orchard management systems (intensive, extensive, organic);
- **integrating anatomical, physiological, and molecular data** – combining studies of water status, photosynthesis, and hormone balance with morphometric analyses of vessels and secondary wood;
- **exploring the role of anatomy in pathogen resistance** – investigating links between vascular traits and the spread of root rots, bacterial infections, galls, and root-zone microbiome interactions;
- **developing rapid screening techniques for anatomical traits** in nurseries and breeding – using microscopic sections and digital morphometry for accelerated selection of promising rootstock genotypes.

### 6. Conclusion

The anatomical structure of sweet cherry rootstocks represents a key factor shaping the growth, development, productivity, and resilience of fruit trees. The review demonstrates that anatomical parameters – particularly vessel diameter, size-class distribution, proportion of secondary wood, hydraulic conductivity, and tissue porosity – exert both direct and indirect effects on plant physiological processes.

A strong relationship has been established between rootstock vascular systems and:

- intensity of vegetative growth (shoot length, canopy area),
- onset and volume of fruiting,
- fruit quality traits (mass, firmness, soluble solids content),
- tolerance to abiotic stresses (drought, water deficit),
- resistance to several phytopathogens [6].

Modern breeding approaches increasingly employ anatomical markers as tools for predicting cultivar performance under field conditions. It has been shown that a balanced anatomical organization – with a predominance of small and medium-diameter vessels and a limited number of large vessels – achieves an optimal ratio between productivity and stress tolerance.

In practical horticulture, the application of anatomical research can substantially improve orchard design efficiency, particularly under conditions of limited water resources, high planting density, and technological intensification.

Thus, further studies on rootstock anatomy and its interactions with different scion cultivars open up promising avenues for developing more productive, resilient, and resource-efficient sweet cherry agroecosystems.

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