AGRICULTURAL UNIVERSITY
FACULTY OF VITICULTURE AND HORTICULTURE
Department of Viticulture and Fruit growing

A B S T R A C T

For awarding of the educational and scientific degree of “Doctor”

Scientific specialty: Fruit growing

“STUDY OF SOME SCION–ROOTSTOCK COMBINATIONS FOR PLUMS AND APRICOTS”

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The studies related to the production of planting material were conducted in a commercial nursery located in the area of the village of Trud, Plovdiv Region. The investigations in plum and apricot orchards were carried out at the Training and Experimental Base of the Department of Viticulture and Fruit Growing, located near by village of Brestnik, Plovdiv Region. All experiments were implemented during the period 2022–2024.

The dissertation comprises 148 pages and contains 28 tables, 36 figures, and 7 pictures. The bibliography includes 342 references, of which 21 are in Cyrillic and 321 are in Latin script.

The defense of the dissertation will take place on 20.10.2026 at ….. in hall …… of the Faculty of Viticulture and Horticulture at Agricultural University – Plovdiv, at a meeting of the scientific jury appointed by the Rector of Agricultural University – Plovdiv by Order No. RD 16-777 of 23 June 2026, with the following members:

Reviews by: Prof. Valentin Iliev Lichev, PhD
Prof. Boryana Mincheva Stefanova, PhD

Opinions by: **Prof. Argir Todorov Zhivondov, PhD**
Assoc. Prof. Galya Stoeva Dobrevska (Ivanova), PhD
Assoc. Prof. Marieta Kostadinova Nesheva, PhD

All defense's materials are at the disposal of the interested stakeholders on the website of Agricultural University – Plovdiv: www.au-plovdiv.bg

INTRODUCTION

Plum cultivars belonging to *Prunus domestica* L. (European plum) occupy the largest area among fruit tree species cultivated in Bulgaria. According to the Ministry of Agriculture and Food (2023), plum orchards cover 12,316 hectares. Unfortunately, the orchards established throughout the country are predominantly of an extensive type, mainly due to the lack of irrigation and the fact that the harvested fruit is intended primarily for processing. The most widely used planting combination is the cultivar 'Stanley' grafted onto Myrobalan plum (*Prunus cerasifera*) seedling rootstock, planted at a density of approximately 500 trees per hectare. This production system has resulted in low yields per unit area and has compromised the economic viability of plum production. Consequently, there is a need to investigate the potential of growing different plum cultivars on alternative rootstocks that would enable intensive production systems, promote earlier bearing, and increase productivity per unit area. The results of such studies could provide an alternative to the currently adopted production technology and improve the profitability of plum cultivation in different regions of Bulgaria.

Apricot (*Prunus armeniaca* L.) is one of the traditional and economically important fruit tree species in Bulgaria. It is cultivated on approximately 3,500 hectares (Ministry of Agriculture and Food, 2023). The principal production areas are located in Northeastern Bulgaria (Silistra, Tutrakan, and Ruse regions), Southern Bulgaria (Plovdiv, Sliven, and Haskovo regions), as well as in smaller orchards distributed across other fruit-growing regions of the country. The harvested fruit is used mainly for processing, while a smaller proportion is marketed for fresh consumption and export. Average yields remain relatively low, one of the main reasons being the early flowering period, which makes apricot production highly susceptible to late spring frosts. Additional limiting factors include the establishment of extensive orchards with low planting densities, ranging from 330 to 500 trees per hectare, many of which are grown under rainfed conditions.

To meet the diverse requirements of fruit tree species under different soil and climatic conditions, while also satisfying the demands of modern production technologies aimed at increasing yield per unit area and establishing high-density orchards, contemporary fruit growing relies on plants composed of two distinct components: the rootstock, which forms the root system, and the scion, represented by the cultivar possessing the desired horticultural characteristics. The interaction between these two components, which together constitute a single biological organism, has been the subject of extensive research. In some cases, a third component—the interstock is incorporated to overcome graft incompatibility between the rootstock and the scion and/or to improve cultivar productivity or adaptation to unfavorable soil conditions. This approach also contributes to expanding the cultivation area of fruit tree species and mitigating the adverse effects of changing soil and climatic conditions. Despite the wide range of available rootstocks, an ideal rootstock has not yet been identified.

At present, apricot and plum orchards in Bulgaria are established predominantly on Myrobalan plum (*Prunus cerasifera*) seedling rootstock. Despite its adaptability and ease of propagation, this rootstock does not meet the current requirements for orchard intensification or for improving the productivity of grafted cultivars intended for the fresh fruit market. Its major disadvantages include genetic heterogeneity and the formation of root suckers, both of which increase orchard management costs.

Our investigations demonstrate that a wide range of rootstocks is available that can address many of the challenges associated with plum and apricot production. The results of these studies are presented in the present dissertation.

Aim and objectives of the study

The aim of the present study was to investigate the influence of the rootstocks **Wavit** and **Ishtara** on the performance of modern plum cultivars under orchard conditions, and to evaluate the effects of the rootstocks **GF677**, **GXN15 (Garnem)**, and the **'Stanley' interstock** on the apricot cultivar **'Hargrand'** under the prevailing soil and climatic conditions, in order to determine the most suitable rootstock/interstock combination.

- To evaluate the effects of the **Wavit** and **Ishtara** rootstocks on the vegetative growth characteristics of the modern plum cultivars **'Čačanska Lepotica'**, **'Stanley'**, and **'Jojo'** in the nursery.

- To evaluate the effects of the **GF677** and **GXN15 (Garnem)** rootstocks, and the **'Stanley' interstock**, on the vegetative growth characteristics of the apricot cultivar **'Hargrand'** in the nursery.
- To determine the influence of the **Wavit** and **Ishtara** rootstocks on the vegetative growth and reproductive performance of the modern plum cultivars **'Čačanska Lepotica'**, **'Stanley'**, and **'Jojo'** under orchard conditions.
- To determine the influence of the **GF677** and **GXN15 (Garnem)** rootstocks, and the **'Stanley' interstock**, on the vegetative growth and reproductive performance of the apricot cultivar **'Hargrand'** under orchard conditions.

MATERIAL AND METHODS

Experiment 1. Comparative study of the rootstocks Ishtara and Wavit grafted with three plum cultivars in the nursery.

The study was conducted during the period from 2022 to 2024 in a commercial nursery using the following European plum (*Prunus domestica* L.) cultivars: 'Čačanska Lepotica', 'Stanley', and 'Jojo', grafted onto the vegetative rootstocks Ishtara and Wavit, produced by the *in vitro* propagation method, as well as onto the traditionally used Myrobalan seedling rootstock (*Prunus cerasifera* Ehrh.). Budding was performed using the T-budding method with dormant buds during the period from 15 to 30 August. The *in vitro*-propagated rootstocks (Ishtara and Wavit) were planted in the nursery during the first year between 15 and 30 May, whereas the Myrobalan seedling rootstock used for the plum cultivars was produced in a seedbed and planted in the nursery between 15 and 30 March. Budding was carried out at a height of 20–25 cm above the soil surface.

All plants were grown under identical management conditions, including the removal of all lateral shoots up to 60 cm above the soil surface, drip irrigation, and individual support stakes.

The experiment was established according to the randomized block design without a standard control, with six replications of 15 plants each.

The following parameters were evaluated:

- Bud take (%)
- Rootstock diameter, measured 15 cm above the soil surface (mm)

- Scion diameter, measured 15 cm above the graft union (mm)
- Tree height (cm)
- Total shoot growth per tree (cm)
- Total growth of lateral shoots per tree (cm)
- Number of lateral shoots longer than 10 cm
- Average length of lateral shoots longer than 10 cm (cm)
- Percentage of the total shoot growth represented by the central leader
- Percentage of the total shoot growth represented by lateral shoots longer than 10 cm

All measurements were performed after leaf fall. The collected biometric data were averaged and statistically processed using Student's method (analysis of variance) at a 5% level of significance.

Experiment 2. Comparative study of the rootstocks GF677, GXN15 (Garnem), and Myrobalan seedling rootstock with the 'Stanley' plum cultivar used as an interstock, grafted with the apricot cultivar 'Hargrand' in the nursery.

The study was conducted during the period from 2022 to 2024 in a commercial nursery. The rootstocks Myrobalan seedling (*Prunus cerasifera* Ehrh.), GF677, and GXN15 (Garnem), with a one-year-old interstock of the plum cultivar 'Stanley' (*Prunus domestica* L.), were grafted with the apricot cultivar 'Hargrand' using the improved English whip grafting method during the period from 15 to 30 January. Grafting was performed at a height of 15–20 cm above the graft union. The apricot cultivar 'Hargrand' grafted onto the standard Myrobalan seedling rootstock (*Prunus cerasifera* Ehrh.) without an interstock served as the control treatment. All plants were planted between 20 and 30 March at a spacing of 120 × 30 cm. The experiment was established according to a randomized block design without a standard control, with six replications of 15 plants each. All trees were grown under identical management conditions, including drip irrigation, removal of all lateral shoots up to 60 cm above the soil surface, and individual support stakes.

The following parameters were evaluated:

- Bud take (%)

- Rootstock diameter, measured 15 cm above the soil surface (mm)
- Interstock diameter (measured at the midpoint of the interstock) (mm)
- Scion diameter, measured 15 cm above the graft union (mm)
- Tree height (cm)
- Total shoot growth per tree (cm)
- Total growth of lateral shoots per tree (cm)
- Number of lateral shoots longer than 10 cm
- Average length of lateral shoots longer than 10 cm (cm)
- Percentage of the total shoot growth represented by the central leader
- Percentage of the total shoot growth represented by lateral shoots longer than 10 cm

All measurements were performed after leaf fall. The collected biometric data were averaged and statistically processed using Student’s method (analysis of variance) at a 5% level of significance.

Experiment 3. Comparative study of the rootstocks Wavit and Ishtara in an orchard with three plum cultivars.

The European plum orchard was established in the spring of 2016 at a planting density of 500 trees ha^{-1} (5 × 4 m) and included the cultivars 'Čačanska Lepotica', 'Stanley', and 'Jojo', grafted onto the rootstocks Myrobalan seedling, Ishtara, and Wavit. The experiment was established according to a randomized block design without a standard control, with four replications of four trees each.

Experiment 4 - Comparative study of the rootstocks GF677, GXN15 (Garnem), and the 'Stanley' interstock grafted with the apricot cultivar 'Hargrand' in an orchard.

The experimental apricot orchard was established in the spring of 2018 at a planting density of 670 trees ha^{-1} (5 × 3 m). It consisted of the cultivar 'Hargrand' grafted onto the rootstocks GF677, GXN15 (Garnem), and Myrobalan seedling, all with the 'Stanley' interstock, as well as trees of the cultivar 'Hargrand' grafted onto Myrobalan seedling rootstock without an interstock. The experiment was established according to a randomized block design without a standard control, with four replications of four trees each.

The plum and apricot orchards are located in the area of the village of Brestnik, Plovdiv Region, at the Training and Experimental Base of the Agricultural University. The trees were managed using standard horticultural practices. The inter-row area was maintained under a grass–mulch system, while the in-row strip was kept as a herbicide-treated fallow. Fertilization was carried out in autumn (during the second half of October) with 20 kg NPK, followed by a second application of 30 kg of the same fertilizer at the end of February. The experiment was conducted under rainfed conditions. The trees were trained to a free-growing crown system. The following parameters were evaluated:

- **Trunk diameter, mm.** It was measured at 15 cm above the graft union – at the end of each vegetation period.
- **Trunk cross-sectional area,** cm^2, defined by the formula:

$$S = \left(\frac{d}{2}\right)^2 \cdot \pi$$

where:

d – trunk diameter, cm (average from both measured directions)

- **Height of trees** measured from the soil surface, cm.
- **Crown diameter, cm,** at the end of the vegetation period. Width was measured in two perpendicular directions – along the row and across.

- **Crown volume, m^3**. Estimated by the formula:

$$V = \frac{4}{3} \cdot \pi \cdot a \cdot в^2$$

where:

a - ½ of the crown diameter measured in both directions

в - ½ of crown height

• **Yield per tree, kg**. It was reported each year.

• **Total yield per tree for the period, kg**.

• **Yield per decare, kg**. It is calculated based on the yield per tree and their number per decare.

• **Average fruit weight, g**. Fifty fruits from each replicate were measured, taken from all parts of the crown at harvest period.

• **Productivity coefficient based on trunk cross-sectional area, kg/cm^2**. The amount of fruits per tree in kilograms is divided by the cross-sectional area of the stem in cm^2.

• **Productivity coefficient based on crown volume, kg/m^3**. The amount of fruits per tree is related to the volume of the crown (kg/m^3).

• **Crop Efficiency Coefficient based on trunk cross-sectional area, kg/cm^2**. The total yield for the period in kilograms was related to the trunk cross-sectional area in cm^2 at the end of the study period.

• **Crop Efficiency Coefficient based on crown volume, kg/m^3**.

The total yield for the period in kilograms was related to the crown volume, m^3 at the end of the study period.

The collected biometric data were mathematically processed by the *Student's Method* (dispersion analysis).

- **Phenology observations:**

The phases of flowering and ripening stages were evaluated in three consecutive years 2018 - 2020.

• Beginning of flowering was evaluated at 10% open flowers, beginning of full flowering – 25% open flowers, end of full flowering – 75% overblown flowers, end of full flowering – 10% not overblown flowers.

• The onset of fruit ripening was determined based on the change in the firmness of the fruit flesh measured with a penetrometer.

• The end of vegetation was considered at more than 75% fallen leaves. Frost damage was assessed two weeks after frost. Eighty flower buds of each cultivar were cut and frost damages of the pistil were assessed.

• Air temperature was measured with a Pessl Instruments® automatic weather station.

- **Evaluation of physiological activity**

Leaf gas exchange intensity – measured using a portable LC-4 gas exchange system (ADC).

Chlorophyll content – determined using a portable CCM-300 chlorophyll meter.

The measurements were carried out during the first week of July, after the cessation of intensive shoot growth, on leaves collected from the middle portion of shoots approximately 35 cm in length (Kerin et al., 2011).

RESULT AND DISCUSSION

Experiment 1.

The diameters of the rootstock and the scion are important indicators of the growth interaction between the two components that constitute the grafted tree (Tabakov and Yordanov, 2019). The results obtained for these two parameters are presented in Table 1. The data show that the Wavit rootstock produced trees with the greatest rootstock and scion diameters when combined with the cultivar 'Jojo'. A tendency towards the development of trees with similar diameters of both components across all three cultivars included in the study was observed under the influence of the Ishtara rootstock.

With the traditionally used Myrobalan seedling rootstock in Bulgaria, these parameters varied considerably, ranging from the greatest rootstock and scion diameters in the cultivar 'Stanley' to the smallest in the cultivar 'Jojo'. The heterogeneity of the Myrobalan seedling rootstock had a pronounced effect on the obtained results and was the main reason for the lack of consistent relationships and uniform trends.

A tendency towards the formation of trees with greater scion height was observed in all three cultivars grafted onto Myrobalan seedling rootstock. Scion height when using the Ishtara and Wavit rootstocks varied depending on the cultivar, which did not allow any clear relationships to be established. The growth characteristics of the trees were largely determined by the considerable influence of the rootstocks used. In addition to scion height, data on total shoot growth can also be used to assess tree vigour in the nursery.

Table 1. Growth characteristics induced by three rootstocks in three plum cultivars in the nursery (average for the period 2022–2024).

Rootstock	Rootstock diametre (mm)	Scion diametre (mm)	Scion height (m)
Chachanska leptoica			
Myrobalan	19,40	18,13	2,52
Ishtara	21,52	17,37	2,20
Wavit	20,65	17,96	1,93
LSD $_{0,05}$	**0,98**	**1,15**	**0,27**
Stanley			
Myrobalan	22,88	18,15	2,65
Ishtara	22,08	17,28	1,75
Wavit	23,14	16,90	1,90
LSD $_{0,05}$	**1,42**	**0,67**	**0,16**
Jojo			
Myrobalan	18,99	16,02	1,88
Ishtara	22,93	17,24	1,60
Wavit	25,14	19,40	1,55
LSD $_{0,05}$	**0,89**	**0,59**	**0,12**

Table 2. Branching characteristics induced by three rootstocks in three plum cultivars (average for the period 2022–2024).

Rootstock	Total scion growth (m)	Average number of lateral branches per tree	Average length of lateral branches (cm)
Chachanska lepotica			
Myrobalan	4,15	12,00	13,17
Ishtara	6,43	17,75	26,25
Wavit	4,28	13,75	19,03
$LSD_{0.05}$	**0,42**	**2,43**	**0,37**
Stanley			
Myrobalan	4,25	6,75	25,18
Ishtara	4,30	13,00	18,10
Wavit	4,07	8,50	23,95
$LSD_{0.05}$	**0,49**	**2,90**	**0,88**
Jojo			
Myrobalan	3,27	4,25	25,95
Ishtara	4,20	11,00	22,35
Wavit	3,65	8,25	25,88
$LSD_{0.05}$	**0,54**	**2,06**	**0,95**

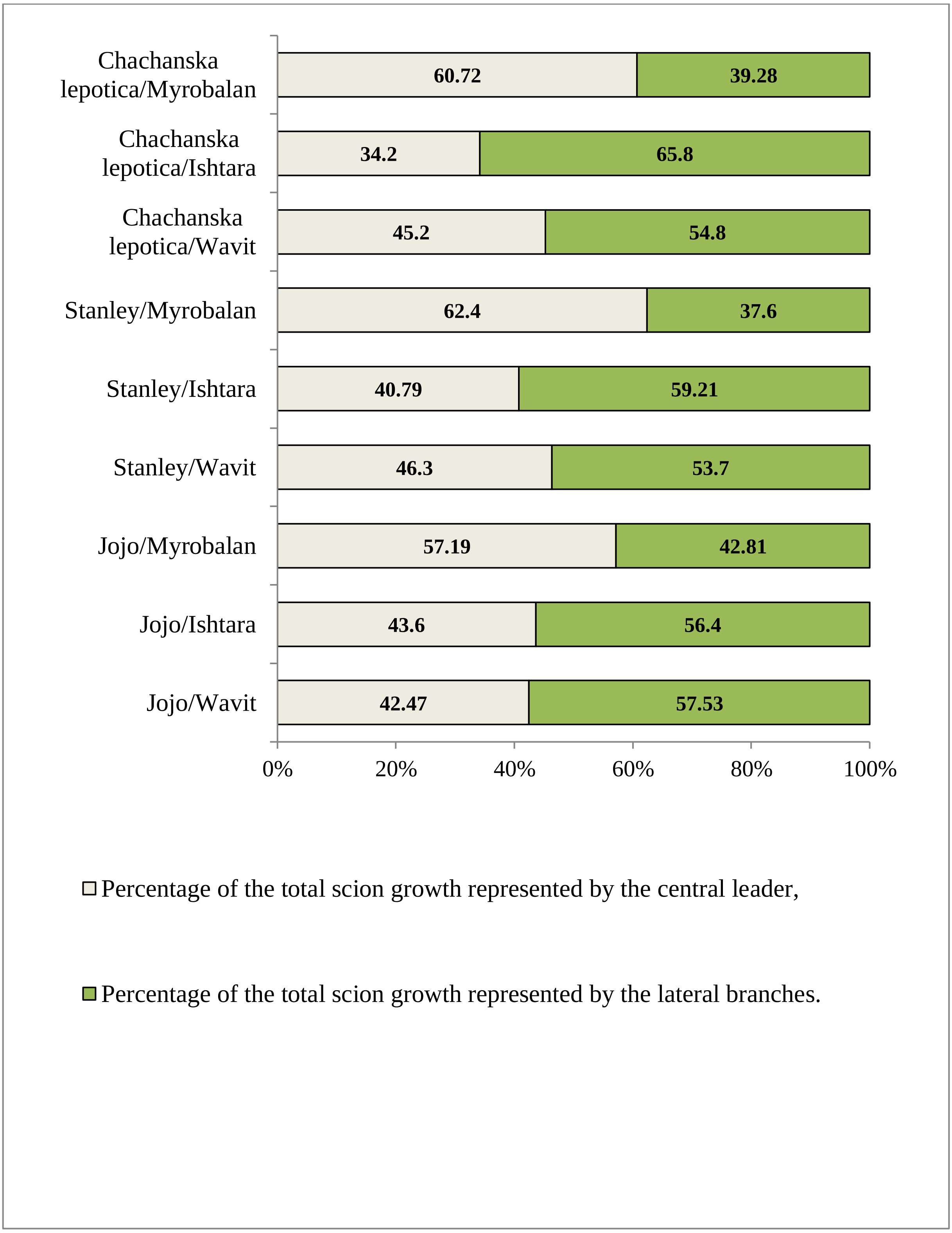

Figure 1. Percentage distribution of the total scion growth formed by the central leader and lateral branches of the studied cultivar–rootstock combinations (average for the period 2022–2024).

The average number of lateral branches indicates the natural tendency for branching of each cultivar–rootstock combination, which is an important characteristic of planting material quality in modern fruit growing (Tabakov and Yordanov, 2019). Lateral branching is closely related to the genetic characteristics of the cultivar (Licznar-Małańczuk and Sosna, 2006; Milošević and Milošević, 2010). In our experiment, the Myrobalan seedling rootstock induced the lowest number of lateral branches in all cultivars used, whereas trees on the clonal rootstocks Ishtara and Wavit formed a significantly higher number of lateral branches (Table 2).

With regard to the cultivar 'Stanley', despite the differences in the number of lateral branches, no significant difference was observed in the total scion growth induced by the studied rootstocks. The greatest total scion growth in the cultivar 'Chachanska Lepotica' was recorded in trees grafted onto the Ishtara rootstock, whereas the cultivar 'Jojo' exhibited the greatest total scion growth on the two vegetative rootstocks, Wavit and Ishtara, and the lowest on the Myrobalan seedling rootstock.

The results obtained in our study confirm the findings of Tabakov and Yordanov (2019) that the Ishtara rootstock promotes branching, with the major part of the total scion growth in all cultivars being formed by the lateral branches (Fig. 1). Conversely, slightly more than 60% of the total growth of trees grafted onto Myrobalan seedling rootstock was formed by the central leader.

The bud take percentage of grafted buds is a very important parameter for fruit tree producers, but at the same time it depends on many factors (Pedersen, 2010). The data presented in Table 3 show that a significantly lower bud take percentage was recorded for the Wavit rootstock compared with the other tested rootstocks, which confirms the finding of Tabakov and Yordanov (2019). With regard to this parameter, the obtained results also confirm the information reported by Yordanov et al. (2015) concerning the lower bud take percentage of the cultivar 'Jojo' on all rootstocks included in the study. We assume that this is probably due to its hard wood, which makes budding more difficult.

Table 3. Bud take percentage of the plum cultivars 'Stanley', 'Chachanska Lepotica', and 'Jojo' grafted onto three rootstocks (average for the period 2022–2024).

Rootstock/Cultivar	Chachanska Lepotica	Stanley	Jojo
Myrobalan	93,9	93,8	90,8
Ishtara	92,2	92,3	90,2
Wavit	79,6	80,4	79,2

Experiment 2.

The data presented in Table 4 show that there were no significant differences in rootstock diameter among the different treatments. The largest interstock diameter was recorded in the trees of the cultivar 'Hargrand' grafted onto Myrobalan seedling rootstock with the 'Stanley' interstock, with a statistically significant difference observed only in comparison with the combination of GF677 rootstock and 'Stanley' interstock. The smallest scion diameter was recorded in trees grafted onto the GF677 rootstock with the 'Stanley' interstock. The results for scion height revealed a tendency towards the formation of taller trees under the influence of the GF677 and Garnem rootstocks compared with the traditionally used Myrobalan seedling rootstock, regardless of the use of the interstock (Table 4).

Table 4. Growth characteristics of nursery trees of the apricot cultivar 'Hargrand' as affected by four rootstocks and an interstock (average for the period 2022–2024).

Rootstock/Interstock	Rootstock diameter, mm	Interstock diameter, mm	Scion diameter, mm	Scion height, cm
Myrobalan/Stanley	19,65	18,75	3,43	1,75
Garnem/Stanley	20,20	18,40	14,03	1,81
GF677/Stanley	19,06	17,43	12,41	1,78
Myrobalan seedling	19,97		13,90	1,71
$LSD_{0.05}/R_{0.05}$	**1,61**	**0,71**	**0,85**	**0,08**

Total scion growth is another important parameter that can be used to assess tree vigour in the nursery. The results of our study, presented in Table 5, show that the peach × almond hybrid rootstocks GF677 and Garnem with the 'Stanley' interstock produced trees with the greatest total scion growth, with statistically significant differences (Table 5). Another important parameter characterizing the quality of fruit tree planting material is the average number of lateral branches per tree. In their study, Tabakov and Yordanov (2019) reported that the use of the GF677 and Garnem rootstocks promoted branching in the plum cultivars 'Chachanska Lepotica', 'Stanley', and 'Jojo' in the nursery. Similar results were obtained in our experiment, where trees of the apricot cultivar 'Hargrand' formed a significantly higher average number of lateral branches per tree under the influence of the

GF677 and Garnem rootstocks with the 'Stanley' interstock compared with the other two treatments included in the study (Table 5).

Table 5. Branching characteristics of nursery trees of the apricot cultivar 'Hargrand' as affected by four rootstocks and an interstock (average for the period 2022–2024).

Rootstock/Interstock	Total scion growth (m)	Average number of lateral branches per tree	Average length of lateral branches (cm)
Myrobalan/Stanley	3,06	7,0	18,71
Garnem/Stanley	5,41	15,50	23,10
GF677/Stanley	5,23	14,75	23,39
Myrobalan seedling	2,73	5,75	18,01
$LSD_{0.05}/R_{0.05}$	**0,18**	**2,87**	**1,54**

Regarding the bud take percentage, presented in Table 6, it is noteworthy that better bud take in the cultivar 'Hargrand' was observed on the peach × almond hybrid rootstocks GF677 and Garnem with the 'Stanley' interstock, compared with the traditionally used Myrobalan seedling rootstock with and without an interstock.

Table 6. Bud take percentage of the apricot cultivar 'Hargrand' (average for the period 2022–2024).

Rootstock/Interstock	Bud take percentage
Myrobalan/Stanley	82,3
Garnem/Stanley	87,6
GF677/Stanley	88,2
Myrobalan seedling	78,1

Rootstocks have a significant influence on tree characteristics. Their effect on the branching process is determined primarily by the vigour they induce in the scion, as well as by the genetic characteristics of the cultivar (Licznar-Małańczuk and Sosna, 2006; Milošević and Milošević, 2010; Sitarek and Jakubowski, 2006; Bielicki and Pasko, 2013).

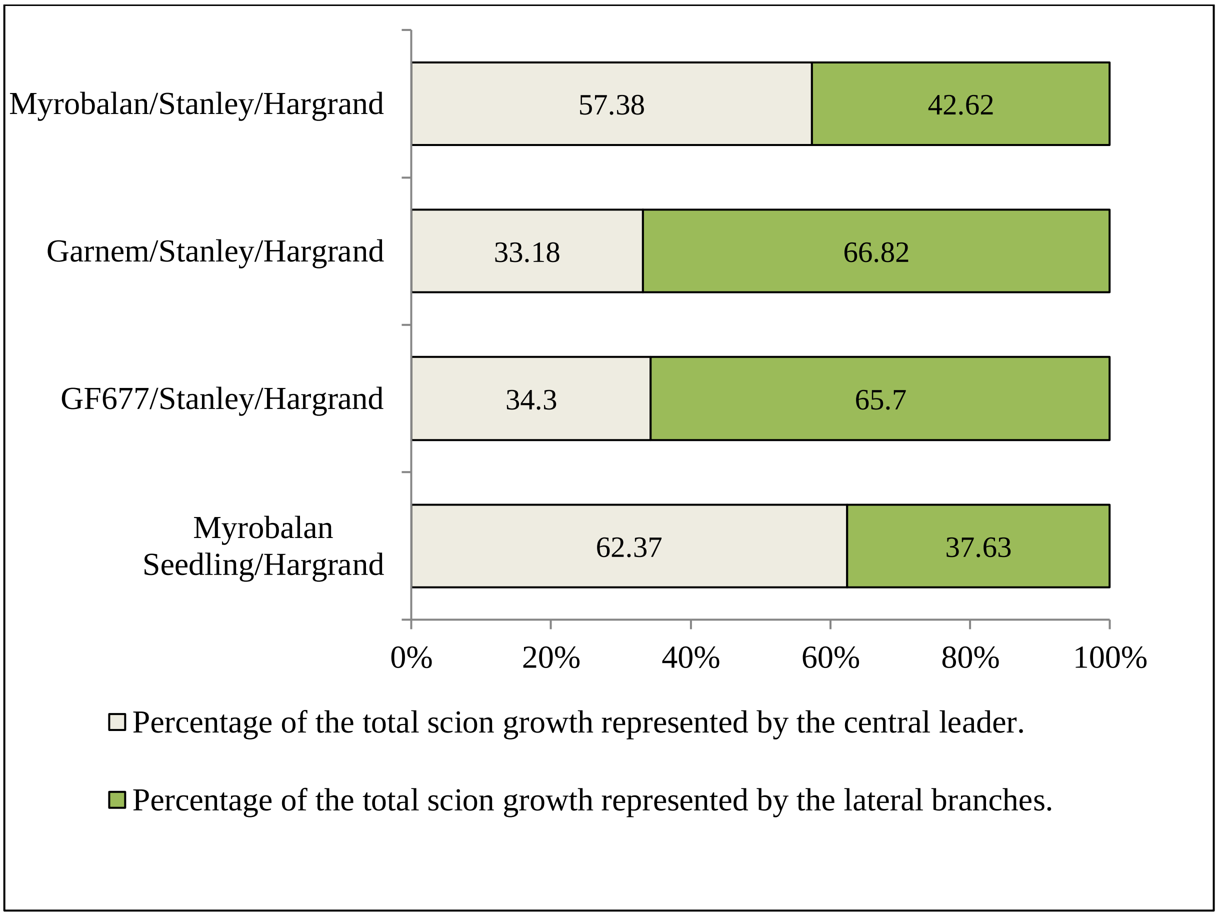

Figure 2. Percentage distribution of the total scion growth formed by the central leader and lateral branches of the studied cultivar–rootstock combinations (average for the period 2022–2024).

According to the results obtained in the present study, the peach–almond hybrid rootstocks GF 677 and Garnem with the interstock 'Stanley' induced the formation of more than 60% of the total annual shoot growth in the lateral branches of the tree. In contrast, the other two combinations included in the study exhibited the opposite tendency, with a greater proportion of the total annual shoot growth being formed by the central leader of the tree (Fig. 2).

Phenological observations

Knowledge of the effects of rootstocks on flowering time can be successfully applied in the selection of an appropriate rootstock for a specific growing area. Early-flowering fruit species such as almond, apricot, and peach are particularly susceptible to damage caused by late spring frosts (Mitov et al., 1993a; Karlidag and Ercisli, 2010).

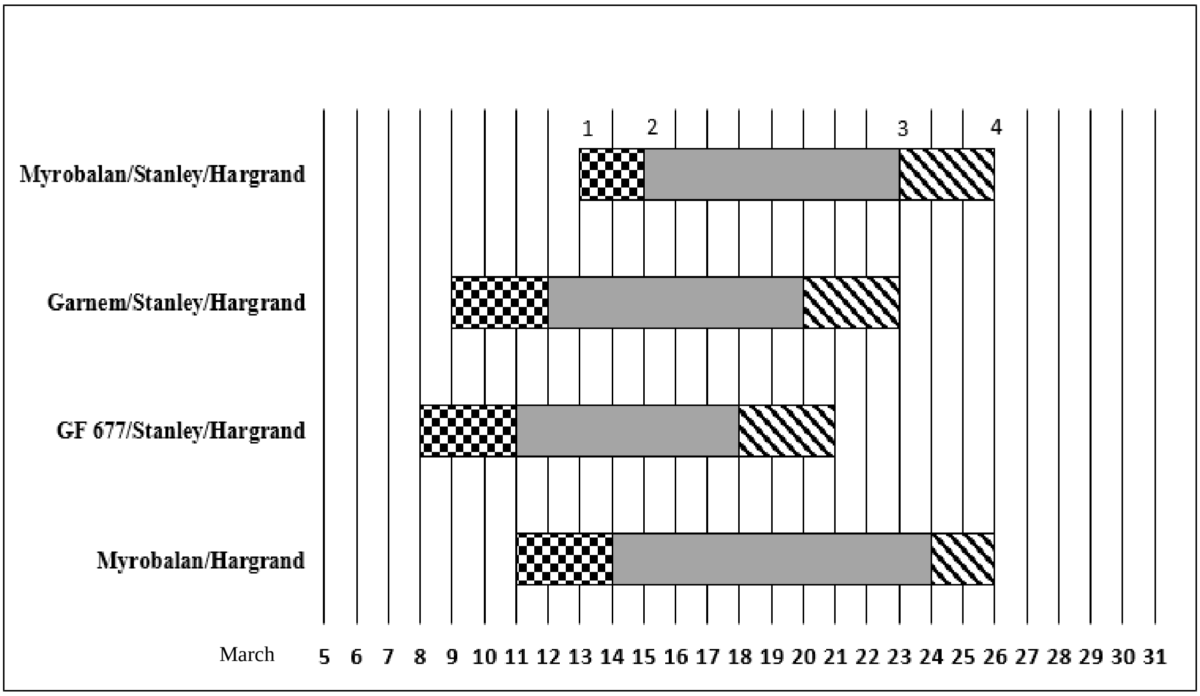

Figure 3. Date and duration of the flowering stages in 2022: 1. Beginning of flowering; 2. Beginning of full bloom; 3. End of full bloom; 4. End of flowering.

Differences in the onset and duration of flowering have been reported among apricot cultivars (Milatović, 2005; Mratinić et al., 2010). Ilić et al. (2026) reported differences of up to six days in the onset of flowering among the apricot cultivars included in their study. At the same time, the onset of this phenological stage may be influenced by the rootstock used (Egea et al., 2004; Ganji Moghadam and Mokhtarian, 2007).

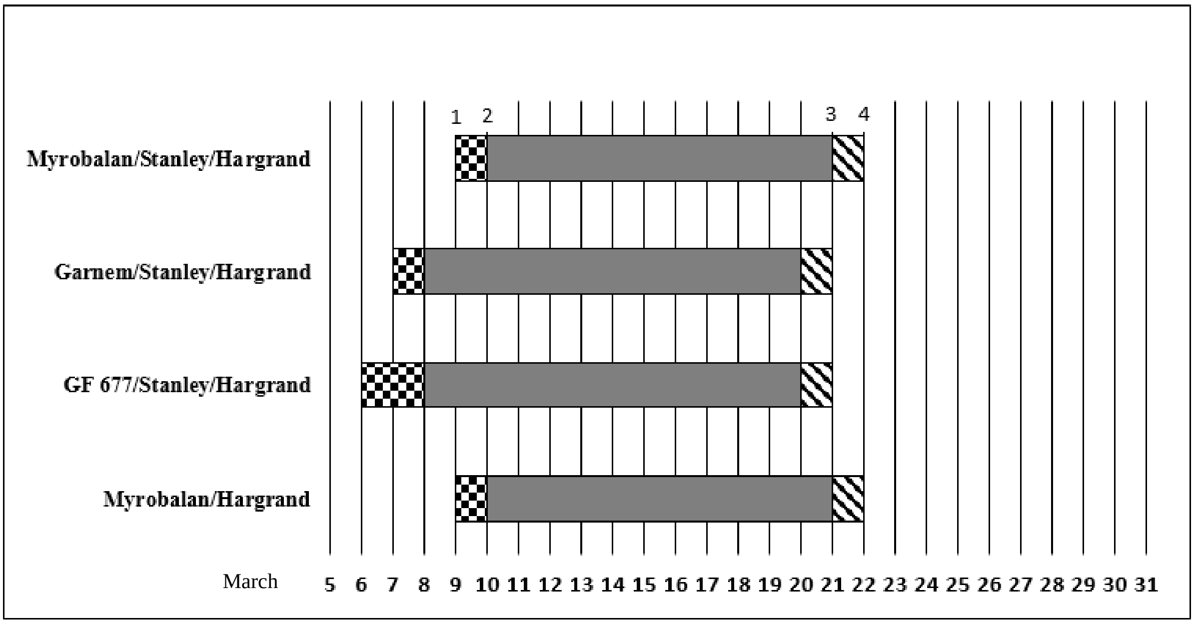

Figure 4. Date and duration of the flowering stages in 2023: 1. Beginning of flowering; 2. Beginning of full bloom; 3. End of full bloom; 4. End of flowering.

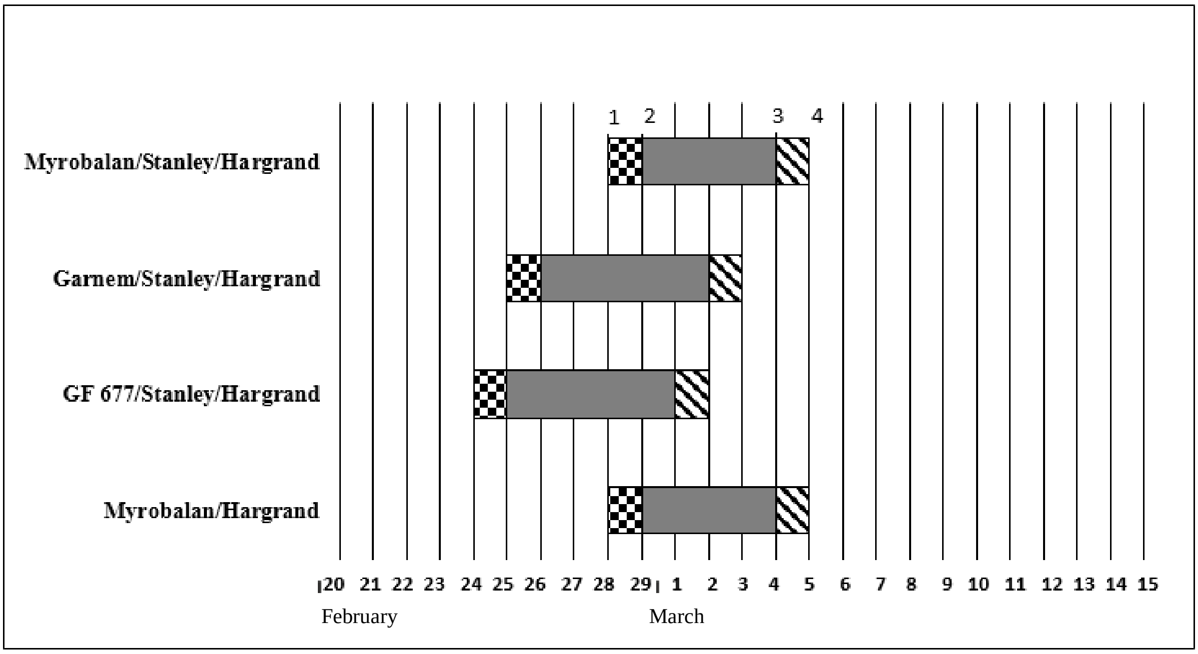

Figure 5. Date and duration of the flowering stages in 2024: 1. Beginning of flowering; 2. Beginning of full bloom; 3. End of full bloom; 4. End of flowering.

In some cases, even a one-day delay in flowering can substantially reduce the percentage of frost-damaged flower buds. Although the available literature contains reports on the influence of rootstocks on the flowering period of apricot cultivars (Egea et al., 2004; Ganji Moghadam and Mokhtarian, 2007; Yordanov et al., 2013), the effect of interstocks on the progression of this phenological stage has received relatively little attention. Ogašanović et al. (1991) reported changes in the flowering period of apricot cultivars when plum interstocks were used. Calderón et al. (2021) also reported a delay in flowering when the interstock was grafted at a greater height. Therefore, the aim of the present study was to evaluate the effects of the rootstocks Myrobalan seedling, the peach–almond hybrid rootstocks GF 677 and Garnem (G×N15) with the interstock 'Stanley', and the widely used Myrobalan seedling rootstock without an interstock on the flowering period of the apricot cultivar 'Hargrand'.

Flowering started earliest on trees grafted onto the peach–almond hybrid rootstocks, with GF 677 preceding Garnem by only one day. The use of Myrobalan seedling rootstock resulted in a later onset of flowering, while the combination with the 'Stanley' interstock flowered last. The cool weather prolonged the flowering period, making it possible to distinguish more clearly the individual flowering stages among the different treatments. On the other hand, the sub-zero temperatures caused frost injury to some of the open flowers. As these frost events occurred repeatedly rather than as a single event, the extent of frost damage could not be quantified. The prolonged flowering period under low-temperature conditions, together with the asynchronous opening of apricot flower buds depending on the type of fruiting shoot on which they were borne, allowed fruit set and subsequent fruit production despite the frost damage. Nevertheless, frost injury during flowering prevented the trees from expressing their full cropping potential. No significant rainfall was recorded during the flowering period that could have adversely affected pollination. In the second year of the study (2023), flowering followed a similar pattern, although no differences in the onset of this phenological stage were observed between the Myrobalan seedling rootstock with and without the 'Stanley' interstock (Fig. 4). In the final year of the study (2024), despite the earlier onset of flowering induced by the higher temperatures in February, the sequence of flowering among the different rootstock combinations remained unchanged (Fig. 5).

Throughout the three years of the study, flowering of trees grafted onto Myrobalan seedling rootstock began 3–5 days later than that of trees grafted onto the peach–almond hybrid rootstocks. This result does not confirm the findings of Bartolini et al. (2014), who reported that rootstock has no effect on the flowering period of the grafted cultivar, and further emphasizes the need to evaluate different scion–rootstock combinations under specific soil and climatic conditions to achieve a more comprehensive understanding of their performance. An important characteristic of the flowering period of any cultivar, particularly in early-flowering fruit species such as apricot, is the duration of full bloom. Overall, during the study period, the duration of full bloom of trees grafted onto the peach–almond hybrid rootstocks was either the same as or one day longer than that of trees grafted onto Myrobalan seedling rootstocks, which may promote more effective pollination and fertilization.

In recent years, climatic conditions, particularly temperatures during the flowering period of fruit species, have become increasingly unstable. Climatic factors, together with the genetic characteristics of the cultivar, directly influence the timing and duration of flowering, resulting in differences in the interval between the onset and the end of flowering even within the same cultivar (Cosmulescu et al., 2010). Under conditions of a variable and unstable climate, knowledge of the influence of rootstocks on the flowering period can be successfully applied in selecting the most appropriate scion–rootstock combination for a particular growing region (Lisandru et al., 2017). The selection of a suitable rootstock is an important aspect of fruit production, as it may affect not only fruit quality and tree longevity (Southwick and Weis, 1999; Dimitrova, 2001; Kaska, 2006; Sosna, 2006; Sosna and Licznar-Małańczuk, 2012), but also the onset and duration of certain phenological stages. Fruit species characterized by early flowering are more frequently exposed to damage caused by late spring frosts (Mitov et al., 1993a; Karlidag and Ercisli, 2010). Cultivars of the same fruit species may also differ in their flowering period (Mitov et al., 1993b; Milatović, 2005; Mratinić et al., 2010). Although European plum flowers later than almond, apricot, and peach, the risk of frost damage during flowering remains significant in this species. Therefore, it is worthwhile to investigate the influence of rootstocks on flowering time in European plum as well.

During the three years of the study, flowering of the plum cultivars 'Čačanska Lepotica', 'Stanley', and 'Jojo' occurred under different temperature conditions, which, in turn, affected the onset of this phenological stage in the individual years (Figs. 6, 7, and 8). These results confirm the findings of Badžak et al. (2021), who reported that the onset of flowering depends not only on the genetic characteristics of the cultivar but also on air temperature immediately preceding the beginning of this phenological stage and may therefore vary from year to year.

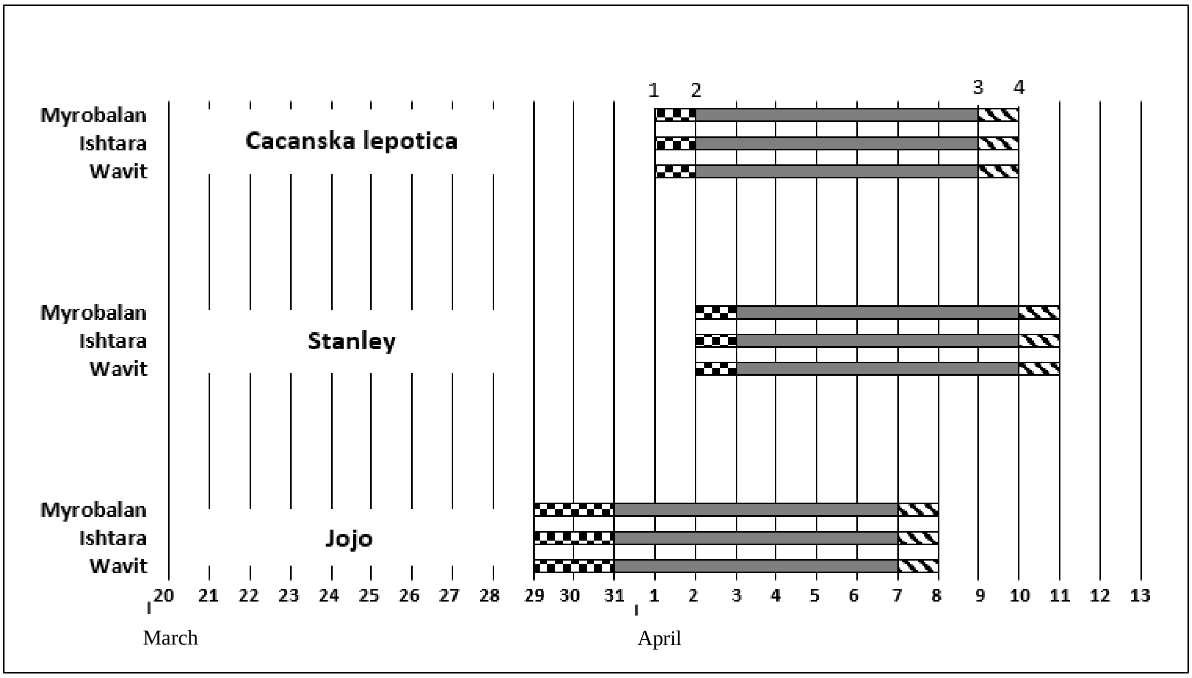

Figure 6. Date and duration of the flowering stages in 2022: 1. Beginning of flowering; 2. Beginning of full bloom; 3. End of full bloom; 4. End of flowering.

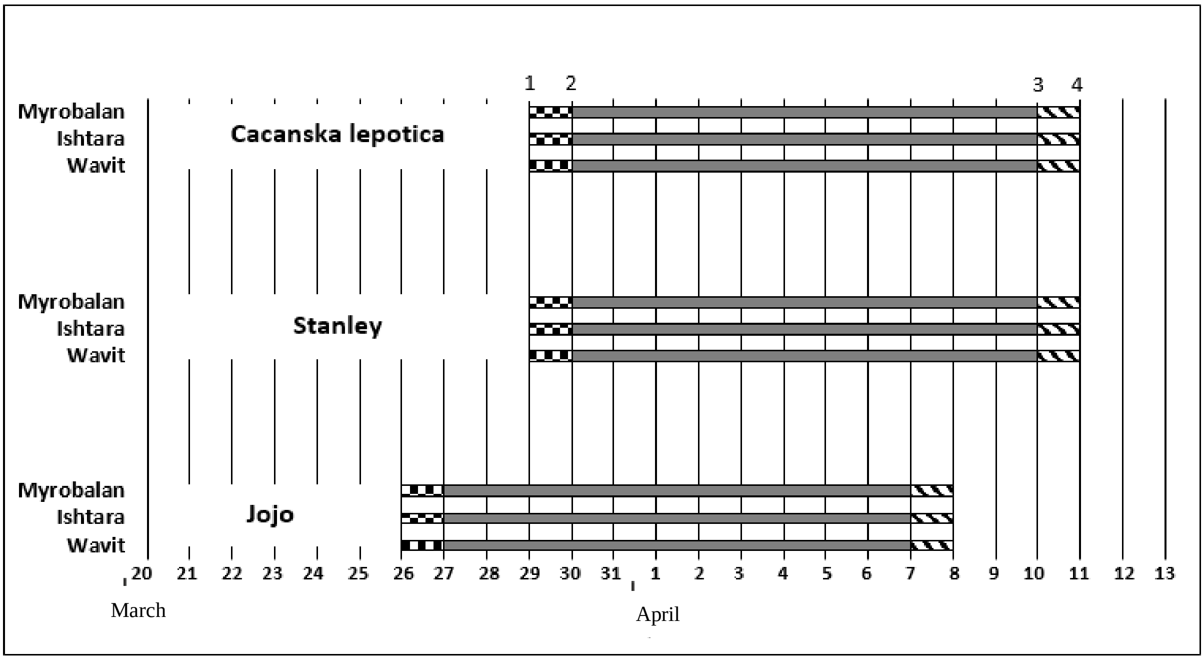

Figure 7. Date and duration of the flowering stages in 2023: 1. Beginning of flowering; 2. Beginning of full bloom; 3. End of full bloom; 4. End of flowering.

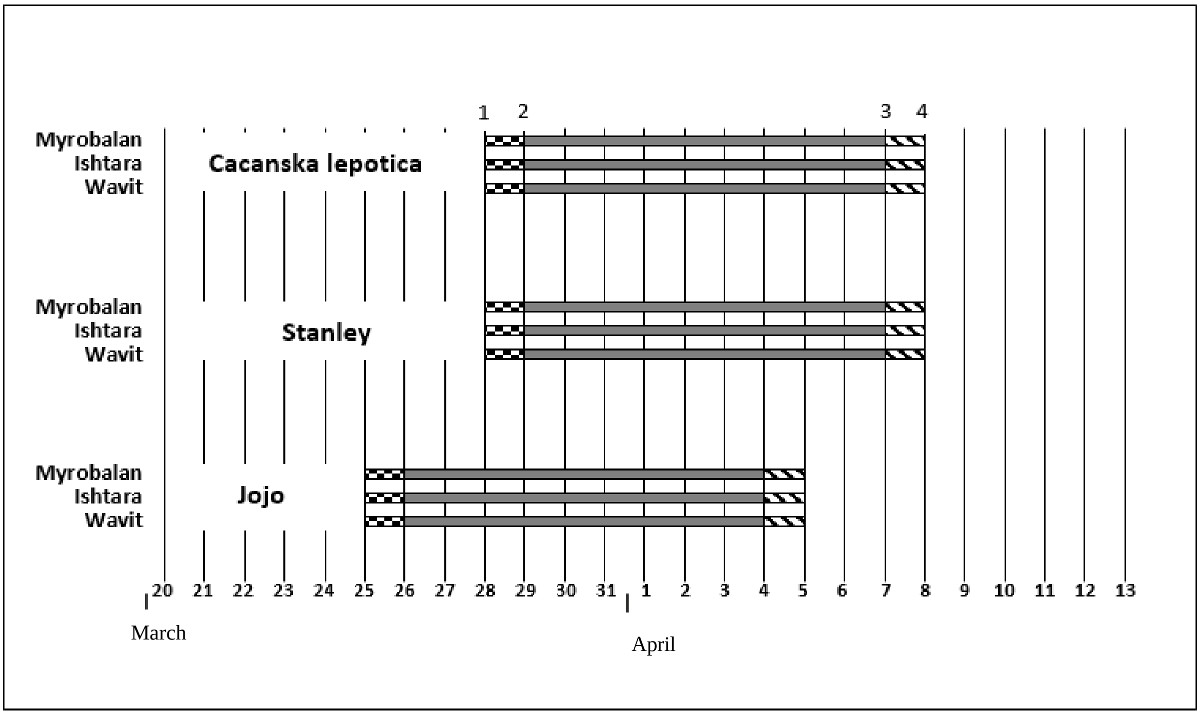

Figure 8. Date and duration of the flowering stages in 2024: 1. Beginning of flowering; 2. Beginning of full bloom; 3. End of full bloom; 4. End of flowering.

Throughout the study period, no differences in the onset of flowering attributable to the rootstocks were observed. This finding confirms the reports of Bartolini et al. (2014) and Zezulová et al. (2022), who concluded that rootstock does not affect the flowering period, but does not support the findings of Rozpara and Grzyb (1998), who reported earlier flowering induced by the rootstock. Trees of the cultivar 'Jojo' started flowering two to three days earlier than those of the other two cultivars, with no differences in flowering onset among the different rootstocks. During the three years of the study, only in 2022 did the cultivar 'Čačanska Lepotica' begin and complete flowering one day earlier than 'Stanley'. In 2022, the period preceding flowering was characterized by relatively lower-than-usual temperatures, which delayed the onset of this phenological stage. The duration of full bloom is an important characteristic of every cultivar. During the study period, it was similar among all scion–rootstock combinations, except in 2024, when the flowering period was characterized by relatively high temperatures, resulting in a shorter full bloom period (by two to four days) and, overall, a more rapid progression of the flowering phenophase compared with the other years of the study.

Experiment 3.

The principal indicators reflecting the vigour induced by rootstocks are trunk cross-sectional area and canopy volume. Scions grafted onto more vigorous rootstocks develop thicker trunks with a larger trunk cross-sectional area. The widely used Myrobalan seedling rootstock induced a significantly greater trunk cross-sectional area than the vegetative rootstocks Ishtara and Wavit (Fig. 9). At the end of the study, canopy volume of the cultivars 'Stanley' and 'Jojo' was also significantly greater on the Myrobalan seedling rootstock than on the other rootstocks (Fig. 10).

At the beginning of the study (the seventh growing season), the canopy volume of the cultivar 'Jojo' was greater than that of the other two cultivars. This was attributed to the absence of fruiting as a result of frost damage to the flowers during the two consecutive years preceding the study, which led to very vigorous vegetative growth. The differences in canopy volume recorded between the beginning and the end of the experiment were due to the pruning performed to limit tree size. The results obtained in the present study for the parameters presented in Figs. 9 and 10 confirm the findings of previous research (Stefanova and Popski, 2017), showing that the cultivar 'Jojo' grafted onto Wavit develops larger trees than 'Čačanska Lepotica' grafted onto the same rootstock.

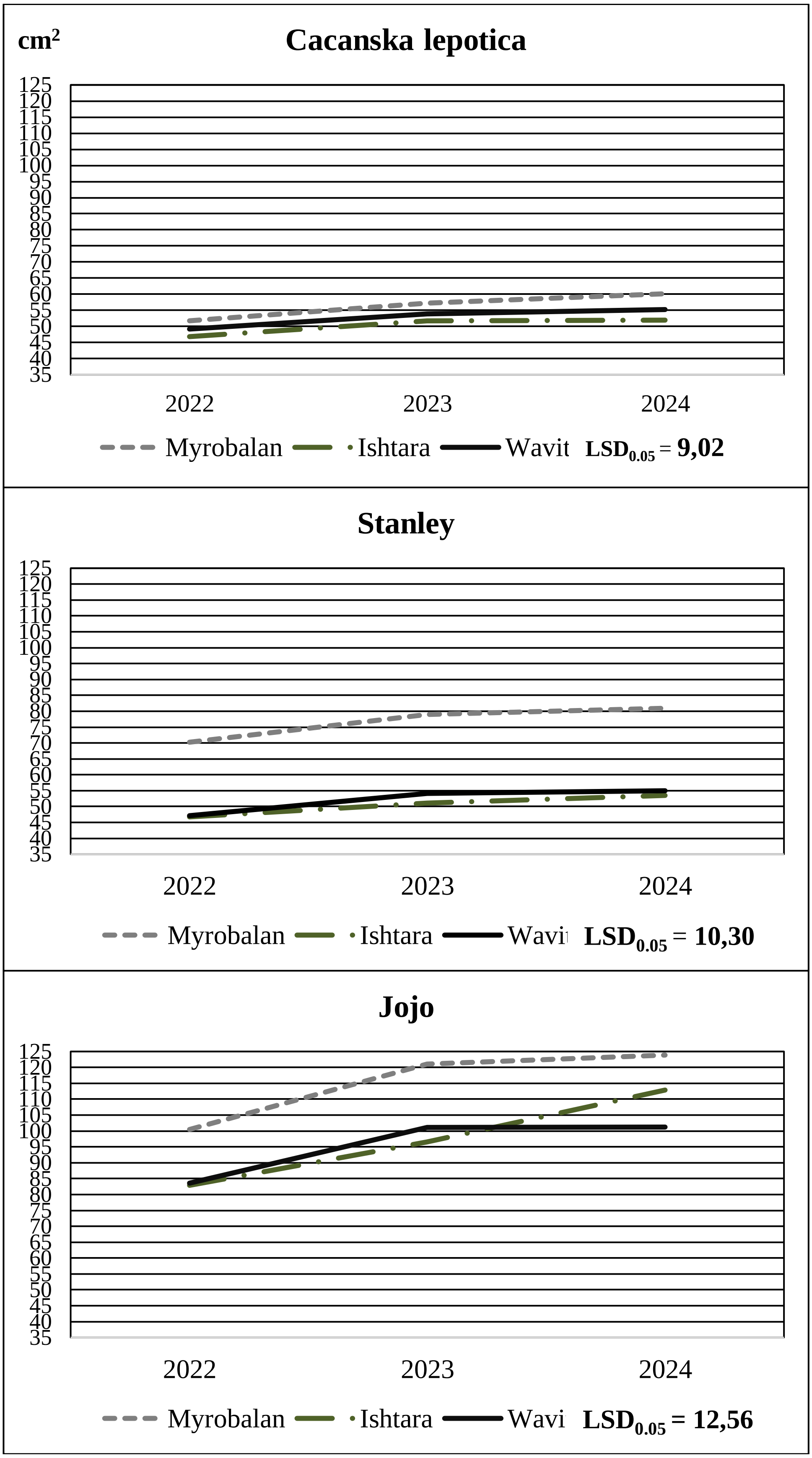

Figure 9. Increase in trunk cross-sectional area of three plum scion–rootstock combinations (cm²).

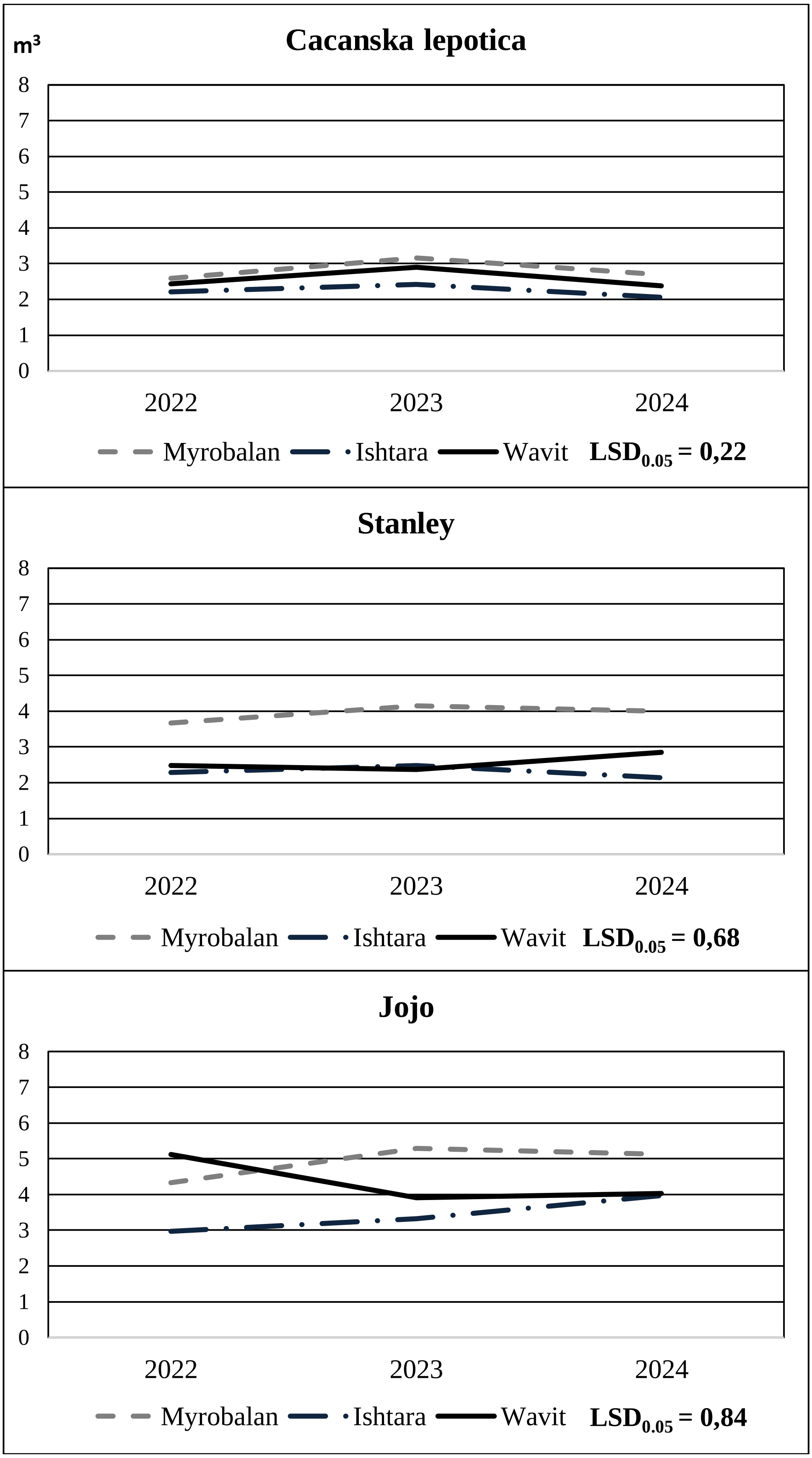

Figure 10. Increase in canopy volume of three plum scion–rootstock combinations (m^3).

Another indicator providing information on the vigour of scion–rootstock combinations is the rootstock stem diameter. Throughout the study period, the Myrobalan seedling rootstock developed the largest rootstock stem diameter in all three plum cultivars (Tables 7 and 8). A specific interaction between the Ishtara rootstock and the cultivars grafted onto it was observed throughout the three years of the study. This interaction was expressed by the formation of trees in which the rootstock stem diameter was smaller than that of the scion in all three cultivars included in the experiment (Photo 6).

Table 7. Rootstock stem diameter of three plum scion–rootstock combinations (mm).

Rootstock	Year		
	2022	2023	2024
Chachanska Lepotica			
Myrobalan	86,29	89,65	91,90
Ishtara	71,66	75,17	76,55
Wavit	83,93	88,28	90,19
$LSD_{0.05}/R_{0.05}$	**5,83**	**7,76**	**7,62**
Stanley			
Myrobalan	102,88	108,24	112,86
Ishtara	69,71	72,14	72,93
Wavit	77,43	94,27	96,22
$LSD_{0.05}/R_{0.05}$	**14,52**	**8,71**	**11,26**
Jojo			
Myrobalan	115,00	124,49	127,34
Ishtara	92,53	97,62	103,98
Wavit	100,23	110,23	114,88
$LSD_{0.05}/R_{0.05}$	**8,07**	**5,20**	**5,10**

Table 8. Scion diameter of three plum scion–rootstock combinations (mm).

Rootstock	Year		
	2022	2023	2024
Chachanska Lepotica			
Myrobalan	80,84	85,14	87,13
Ishtara	77,23	81,17	81,19
Wavit	79,14	82,79	83,21
$LSD_{0.05}/R_{0.05}$	**6,72**	**7,15**	**6,69**
Stanley			
Myrobalan	94,57	100,27	104,80
Ishtara	77,05	80,47	82,34
Wavit	77,39	82,76	83,66
$LSD_{0.05}/R_{0.05}$	**4,88**	**8,35**	**7,13**
Jojo			
Myrobalan	113,32	124,14	126,03
Ishtara	102,72	110,87	119,37
Wavit	104,50	108,77	133,35
$LSD_{0.05}/R_{0.05}$	**14,88**	**6,56**	**6,71**

As shown in Tables 9 and 10, at the end of the study the trees grafted onto the traditionally used Myrobalan seedling rootstock were significantly taller than those grafted onto the other two rootstocks included in the experiment. Trees of the cultivar 'Stanley' grafted onto the Myrobalan seedling rootstock also developed significantly larger canopy diameters than those grafted onto the other two rootstocks, whereas for the other two cultivars these differences were not consistently significant.

Table 9. Tree height of three plum scion–rootstock combinations (m).

Rootstock	Year		
	2022	2023	2024
Chachanska Lepotica			
Myrobalan	310,67	319,61	328,0
Ishtara	299,67	286,71	293,0
Wavit	297,33	285,67	306,5
$LSD_{0.05}/R_{0.05}$	**8,30**	**20,91**	**13,86**
Stanley			
Myrobalan	310,67	326,39	319,0
Ishtara	299,67	284,93	280,5
Wavit	297,33	306,44	287,75
$LSD_{0.05}/R_{0.05}$	**8,30**	**18,22**	**17,91**
Jojo			
Myrobalan	327,00	331,61	326,5
Ishtara	270,67	270,39	296,0
Wavit	298,00	307,60	311,75
$LSD_{0.05}/R_{0.05}$	**30,53**	**23,17**	**8,52**

Table 10. Canopy diameter of three plum scion–rootstock combinations (cm).

Rootstock	Year		
	2022	2023	2024
Chachanska Lepotica			
Myrobalan	194,25	211,0	193,5
Ishtara	186,25	207,67	175,75
Wavit	193,28	206,33	188,0
$LSD_{0.05}/R_{0.05}$	**16,43**	**18,22**	**7,89**
Stanley			
Myrobalan	220,83	237,0	227,25
Ishtara	192,78	198,33	176,0
Wavit	192,39	197,67	197,5
$LSD_{0.05}/R_{0.05}$	**8,73**	**28,54**	**18,77**
Jojo			
Myrobalan	242,08	265,33	261,75
Ishtara	225,70	239,33	245,5
Wavit	218,26	242,67	240,5
$LSD_{0.05}/R_{0.05}$	**11,26**	**9,22**	**20,30**

The within-row spacing of 4 m adopted under the experimental conditions proved to be excessively wide, as by the end of the study (the ninth growing season) none of the treatments had formed a continuous fruiting wall. Considering the absence of cropping in the cultivar 'Jojo' during the two years preceding the present study and the resulting vigorous vegetative growth, we consider it premature to propose recommended planting densities for this cultivar at this stage. In contrast, by the end of the study (the ninth growing season), the other two cultivars had reached full bearing, allowing recommended planting densities to be proposed for the soil and climatic conditions of the experimental site (Table 11).

Table 11. Recommended planting distances for two plum cultivars grafted onto three rootstocks (m).

Rootstock	Planting spacing, m	Number of trees per decare
Chachanska Lepotica		
Myrobalan	4,0 × 2,0	125
Ishtara	4,0 × 1,5	167
Wavit	4,0 × 1,5	167
Stanley		
Myrobalan	4,0 × 2,0	125
Ishtara	4,0 × 1,5	167
Wavit	4,0 × 1,5	167

The agronomic evaluation of different scion–rootstock combinations is based on a range of parameters. One of the indicators reflecting both labour requirements and the vigour of scion–rootstock combinations is the weight of pruned wood. The more severe the pruning required, the greater the associated labour costs (Petrov, 2024). The data presented in Table 12 show that more intensive pruning was required for trees grafted onto the widely used Myrobalan seedling rootstock. By the end of the study, the cumulative weight of pruned wood was significantly greater for trees on the Myrobalan seedling rootstock than for those grafted onto the other two rootstocks, between which no significant differences were observed for this parameter (Fig. 11).

Table 12. Weight of pruned wood from three plum cultivars grafted onto three rootstocks (kg).

Rootstock	Year		
	2022	2023	2024
Chachanska Lepotica			
Myrobalan	3,05	2,49	2,76
Ishtara	1,57	2,52	1,88
Wavit	2,05	2,21	2,12
$LSD_{0.05}$/$R_{0.05}$	**0,52**	**0,60**	**0,62**
Stanley			
Myrobalan	1,86	3,86	3,67
Ishtara	0,86	2,04	2,07
Wavit	1,67	1,44	2,44
$LSD_{0.05}$/$R_{0.05}$	**0,45**	**0,87**	**0,60**
Jojo			
Myrobalan	5,30	4,64	4,69
Ishtara	2,95	3,23	2,37
Wavit	2,45	4,4	2,54
$LSD_{0.05}$/$R_{0.05}$	**0,55**	**0,69**	**0,42**

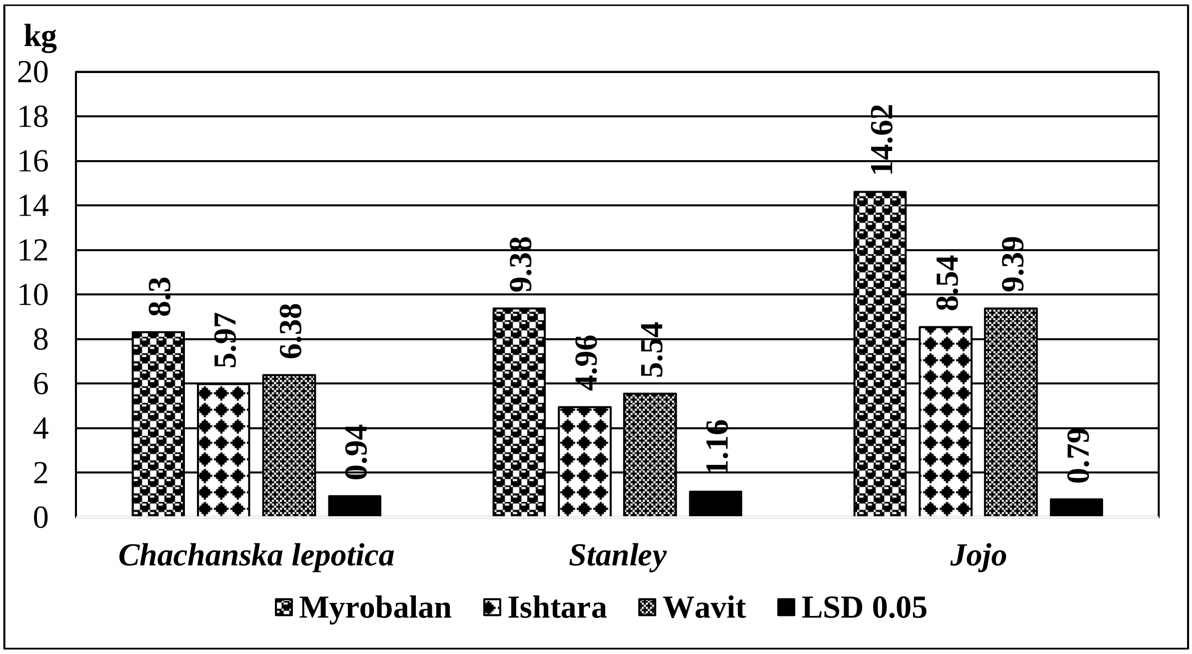

Figure 11. Cumulative weight of pruned wood per tree for three plum scion–rootstock combinations during the 7th–9th growing seasons.

The tendency to produce root suckers is considered an undesirable characteristic of rootstocks, as it increases orchard maintenance requirements. Throughout the study period, no root suckers were observed on trees grafted onto the vegetative rootstocks Ishtara and Wavit (Table 13). Of the three rootstocks evaluated, only the Myrobalan seedling rootstock produced root suckers, with the highest number consistently recorded in combination with the cultivar 'Čačanska Lepotica' during all three years of the study.

One of the most important indicators of the productivity induced by rootstocks is the yield per tree obtained from the grafted cultivars. During the seventh to the ninth growing seasons, the highest mean yield per tree was recorded for trees grafted onto the Myrobalan seedling rootstock in combination with all cultivars (Table 14). These results support the findings of Milošević et al. (2025), who reported that the Myrobalan seedling rootstock induced higher yields per tree in the cultivars 'Jojo' and 'Čačanska Lepotica' than the rootstocks Wavit, Weiwa, Docera 6, and Dospina 235. Among the cultivars evaluated, 'Stanley' was the most productive throughout the study period, whereas 'Čačanska Lepotica' produced the lowest yield. The cultivar 'Jojo' occupied an intermediate position for this parameter. The tendency to produce double fruits is considered an undesirable cultivar characteristic, as it complicates fruit processing. The results obtained for this trait were inconsistent, and therefore no particular rootstock could be identified as having a specific effect on the incidence of double fruits (Table 14). Nevertheless, a slightly higher percentage of double fruits was observed in the cultivar 'Jojo' compared with the other cultivars.

Table 13. Mean number of rootsuckers per tree.

Rootstock	Year		
	2022	2023	2024
Chachanska Lepotica			
Myrobalan	7,49	7,33	4,75
Ishtara	0	0	0
Wavit	0	0	0
$LSD_{0.05}/R_{0.05}$	**1,88**	**3,06**	**1,50**
Stanley			
Myrobalan	0,72	2,56	2,5
Ishtara	0	0	0
Wavit	0	0	0
$LSD_{0.05}/R_{0.05}$	**0,34**	**0,75**	**1,29**
Jojo			
Myrobalan	3,72	2,28	2,75
Ishtara	0	0	0
Wavit	0	0	0
$LSD_{0.05}/R_{0.05}$	**3,55**	**1,98**	**0,96**

Table 14. Mean yield per tree (kg) and percentage of double fruits in three plum cultivars.

Rootstock	Yield per tree, (kg)			Percentage of double fruits		
	2022	2023	2024	2022	2023	2024
Chachanska Lepotica						
Myrobalan	12,13	13,95	13,45	3,67	7,75	5,57
Ishtara	8,20	10,25	11,15	5,67	5,67	6,33
Wavit	7,92	10,53	11,78	4,57	6,33	5,67
$LSD_{0.05}/R_{0.05}$	**1,10**	**1,15**	**1,68**			
Stanley						
Myrobalan	15,88	25,45	25,7	5,67	4,57	5,67
Ishtara	11,5	13,53	14,03	4,57	3,33	3,20
Wavit	10,58	12,95	13,28	3,33	6,33	5,67
$LSD_{0.05}/R_{0.05}$	**1,29**	**1,82**	**1,88**			
Jojo						
Myrobalan	13,80	14,58	14,83	7,33	6,33	6,67
Ishtara	10,98	11,85	12,25	5,57	5,67	6,33
Wavit	9,83	13,72	14,08	6,33	5,57	7,75
$LSD_{0.05}/R_{0.05}$	**1,66**	**1,67**	**0,84**			

Cumulative yield over the entire study period provides a more comprehensive assessment of the productivity of scion–rootstock combinations. In all three cultivars included in the experiment, the highest cumulative yield per tree was obtained from trees grafted onto the traditionally used Myrobalan seedling rootstock (Fig. 12). No significant differences in cumulative yield were observed between the scion–rootstock combinations involving the low-vigour clonal rootstocks Ishtara and Wavit. The results obtained in the present study are not consistent with the findings of Popara et al. (2020), who reported that the vegetative rootstocks Wavit and Weiwa increased the cumulative yield per tree of the cultivar 'Čačanska Lepotica'.

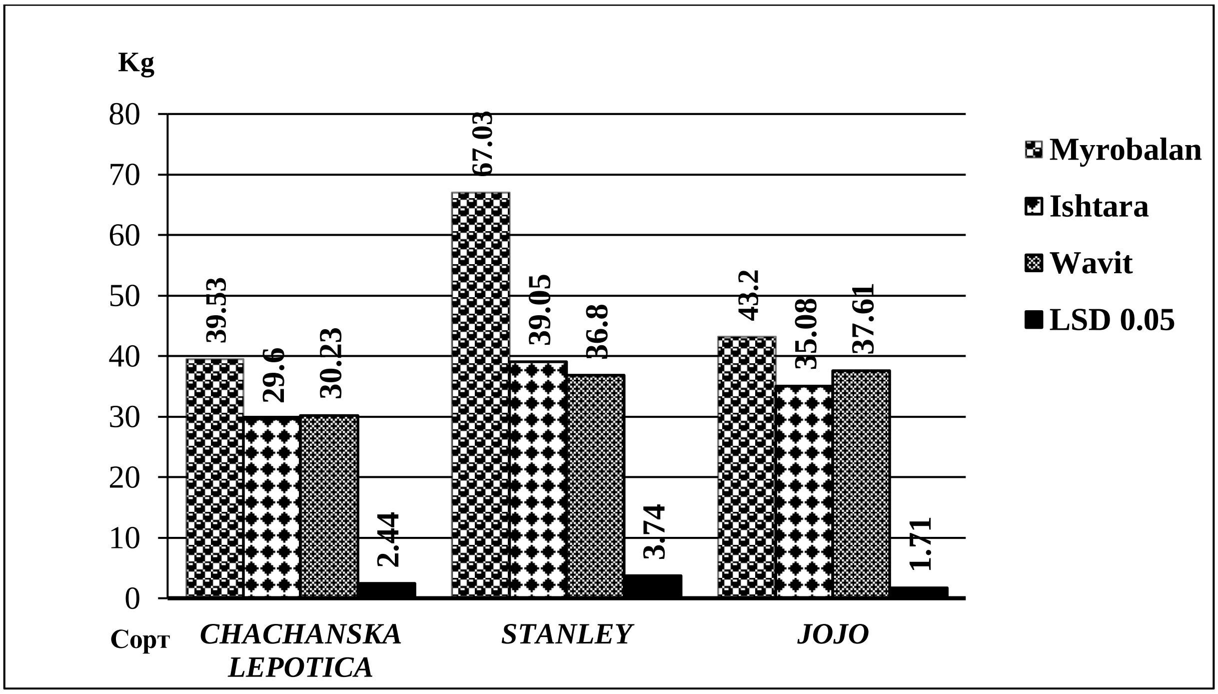

Figure 12. Cumulative yield per tree of three plum scion–rootstock combinations during the period 2022–2024 (7th–9th growing seasons).

Mean fruit weight is one of the main parameters determining fruit quality. Fruit size is generally related to crop load. Overall, during the three years of the study, the largest fruits were recorded for the cultivar 'Jojo' (Table 15); however, it should be taken into account that this cultivar carried a lighter crop load than 'Stanley'. With regard to the effect of rootstocks on fruit size, no consistent trend indicating a specific influence of any of the rootstocks was observed. The results of the present study confirm the findings of Zezulová et al. (2022), who reported that rootstock has no significant effect on fruit size in different plum cultivars. At the same time, they do not support the findings of Popara et al. (2020), who reported that the vegetative rootstocks Wavit and Weiwa increased fruit weight and fruit size in the cultivar 'Čačanska Lepotica'.

Table 15. Mean fruit weight of three plum cultivars (g).

Rootstock	Year		
	2022	2023	2024
Chachanska Lepotica			
Myrobalan	42,93	32,14	31,4
Ishtara	44,79	31,00	32,25
Wavit	40,83	33,60	26,5
$LSD_{0.05}/R_{0.05}$	**3,71**	**2,55**	**2,42**
Stanley			
Myrobalan	47,90	24,74	21,76
Ishtara	50,77	25,32	24,92
Wavit	39,06	29,48	28,44
$LSD_{0.05}/R_{0.05}$	**2,24**	**2,76**	**1,33**
Jojo			
Myrobalan	48,70	37,62	30,26
Ishtara	52,36	42,62	33,2
Wavit	45,78	26,38	34,6
$LSD_{0.05}/R_{0.05}$	**2,71**	**3,98**	**0,59**

Yield efficiency coefficients provide information on the productivity of cultivars as influenced by the rootstock, with yield most commonly expressed in relation to either the trunk cross-sectional area or the canopy volume at the end of the study. The highest yield efficiency relative to canopy volume at the end of the experimental period was recorded for the combination of the cultivar 'Stanley' grafted onto the Ishtara rootstock, followed by the cultivar 'Čačanska Lepotica' grafted onto

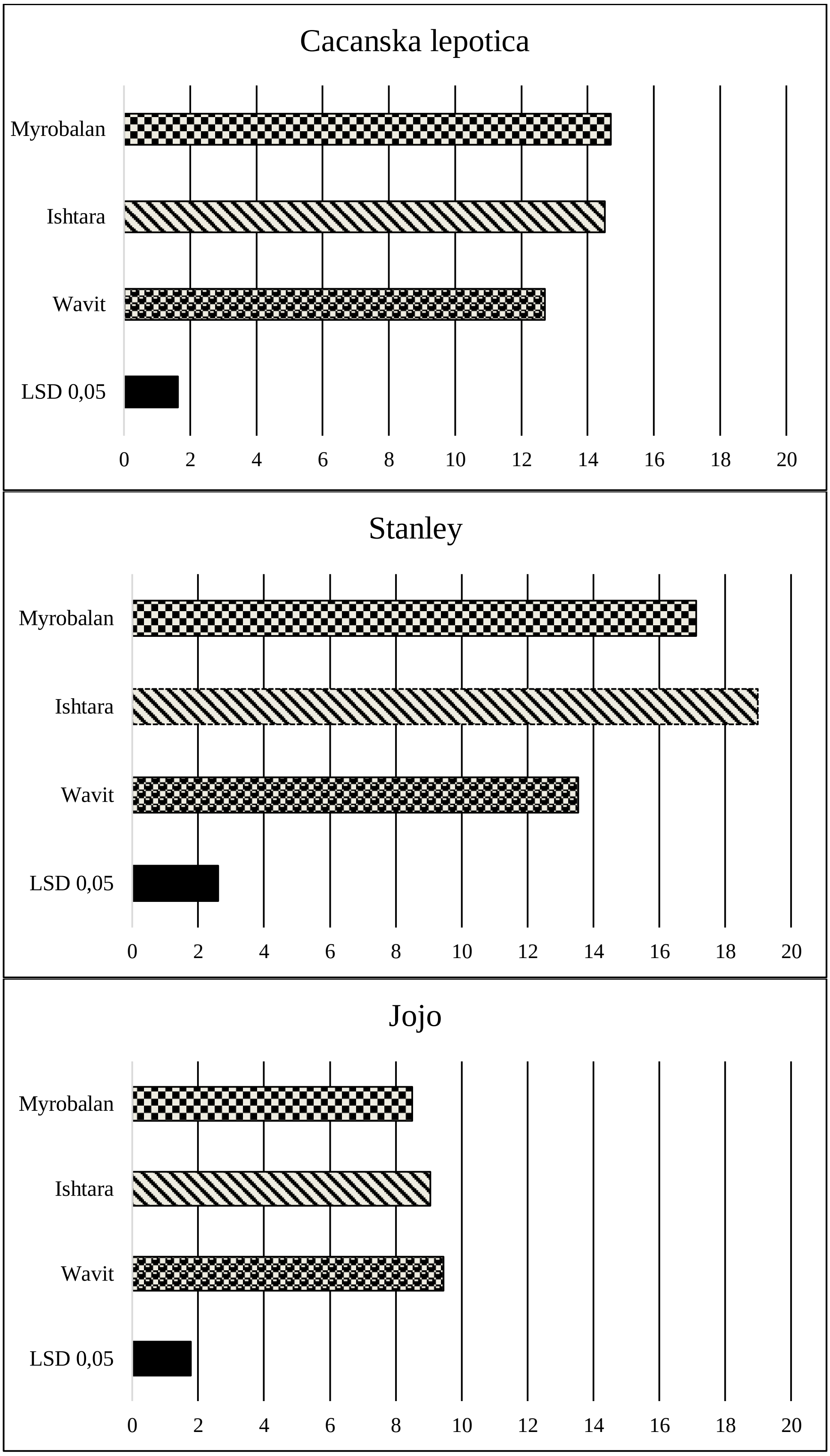

Figure 13. Yield efficiency relative to canopy volume (kg/m³).

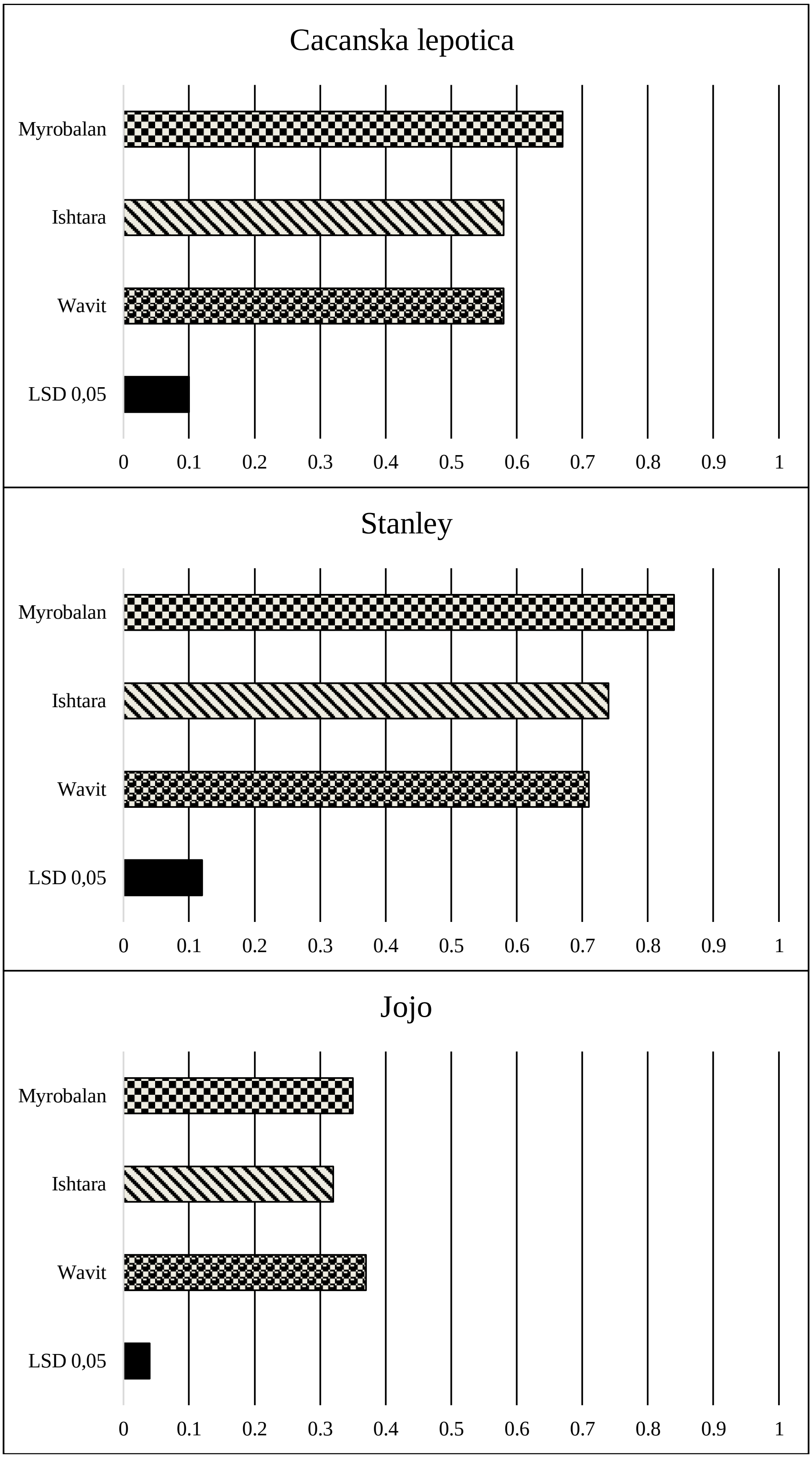

Figure 14. Yield efficiency relative to trunk cross-sectional area (kg/cm²).

the Myrobalan seedling rootstock, whereas the lowest values were recorded for the same two cultivars grafted onto the Wavit rootstock (Fig. 13). In the cultivar 'Jojo', the yield efficiency coefficients were lower than those of the other two cultivars because of its larger canopy volume. In this cultivar, the highest yield efficiency relative to canopy volume was recorded on the Wavit rootstock, while the lowest value was observed in combination with the widely used Myrobalan seedling rootstock.

Relating the cumulative yield per tree to the trunk cross-sectional area at the end of the study resulted in the highest yield efficiency values for the cultivar 'Stanley' grafted onto the Myrobalan seedling rootstock, whereas no significant differences were observed between the two low-vigour vegetative rootstocks in combination with the same cultivar (Fig. 14). The same trend was observed for the cultivar 'Čačanska Lepotica'. In the cultivar 'Jojo', this efficiency coefficient was again lower than in the other two cultivars because of its larger trunk cross-sectional area. The highest value was recorded for trees grafted onto Wavit, followed by the Myrobalan seedling rootstock, whereas the lowest value was observed for trees grafted onto Ishtara. The results obtained for the cultivars 'Čačanska Lepotica' and 'Stanley' do not agree with the findings of Popara et al. (2020), who reported that the Myrobalan seedling rootstock induced a lower yield efficiency relative to trunk cross-sectional area than Wavit in the cultivar 'Čačanska Lepotica'. Likewise, the results of the present study do not support the conclusions of Meland (2009) and Mészáros et al. (2015), who reported that trees grafted onto low-vigour rootstocks exhibit higher yield efficiency relative to trunk cross-sectional area. These findings once again emphasize that rootstock–scion interactions are expressed differently under the specific environmental conditions of each growing site.

Experiment 4

The vigour of scion–rootstock combinations is evaluated on the basis of several parameters. One of the principal indicators of tree vigour is the stem diameter of its individual components, namely the rootstock, the interstock (where present), and the scion. During the study period, more vigorous growth was recorded in the combinations grafted onto the peach–almond hybrid rootstocks GF 677 and Garnem than in those grafted onto Myrobalan rootstocks (Tables 16, 17, and 18). The combination of GF 677 with the 'Stanley' interstock produced trees with the largest rootstock stem diameter, whereas Garnem with the 'Stanley' interstock developed the largest stem diameter of the other two components, namely the interstock and the scion. A slightly larger stem diameter of the interstock than of the rootstock was observed only in the combination of Myrobalan rootstock with the 'Stanley' interstock.

Table 16. Rootstock diameter of the apricot cultivar 'Hargrand' grafted onto three different rootstocks with and without an interstock (mm).

Rootstock	Interstock	Year		
		2022	2023	2024
Myrobalan	Stanley	91,68	98,25	106,69
Garnem	Stanley	108,17	138,53	155,93
GF677	Stanley	119,57	143,91	153,34
Myrobalan		77,35	87,71	95,14
$LSD_{0.05}/R_{0.05}$		**14,43**	**9,16**	**10,67**

Table 17. Interstock stem diameter of the apricot cultivar 'Hargrand' grafted onto three different rootstocks with an interstock (mm).

Rootstock	Interstock	Year		
		2022	2023	2024
Myrobalan	Stanley	92,40	103,66	114,74
Garnem	Stanley	110,91	125,69	138,94
GF677	Stanley	113,07	121,87	129,10
Myrobalan				
$LSD_{0.05}/R_{0.05}$		**5,80**	**6,29**	**7,64**

The data obtained at the end of the study showed that trees of the apricot cultivar 'Hargrand' grafted onto the peach–almond hybrid rootstocks G×N15 (Garnem) and GF 677 with the 'Stanley' interstock had a significantly larger trunk cross-sectional area than trees grafted onto the widely used Myrobalan seedling rootstock, both with and without the interstock (Fig. 31). The traditional combination of the apricot cultivar 'Hargrand' grafted directly onto the Myrobalan seedling rootstock, without an interstock, exhibited the lowest vigour.

Table 18. Scion stem diameter of the apricot cultivar 'Hargrand' grafted onto three different rootstocks with and without an interstock (mm).

Rootstock	Interstock	Year		
		2022	2023	2024
Myrobalan	Stanley	67,57	76,67	80,75
Garnem	Stanley	79,57	98,68	101,53
GF677	Stanley	80,49	91,26	95,23
Myrobalan		64,09	67,9	80,33
$LSD_{0.05}/R_{0.05}$		**5,67**	**7,96**	**8,08**

A clearer assessment of the vigour induced by the rootstocks on the grafted cultivars is provided by the dynamics of trunk cross-sectional area development. In general, more vigorous rootstocks induce scions with a larger trunk cross-sectional area. The dynamics of trunk growth (measured at the graft union) of the apricot cultivar 'Hargrand' during the study period are presented in Fig. 15. Throughout the three years of the study, the largest trunk cross-sectional area was recorded for trees grafted onto the G×N15 (Garnem) rootstock with the 'Stanley' interstock, whereas the smallest was observed in the traditional combination of the apricot cultivar 'Hargrand' grafted directly onto the Myrobalan seedling rootstock.

Tree height and canopy size are important parameters for assessing the growth performance of scion–rootstock combinations. Throughout the three years of the study, the tallest trees were those grafted onto the G×N15 (Garnem) rootstock with the 'Stanley' interstock; however, the difference was statistically significant only in comparison with the Myrobalan seedling rootstock in 2023 and 2024 (Table 19). The use of the peach–almond hybrid rootstocks G×N15 (Garnem) and GF 677 accelerated canopy development of the apricot cultivar 'Hargrand' owing to the vigorous growth and abundant branching with wide branch crotch angles induced by these rootstocks. This was confirmed by the significantly greater canopy diameter and canopy volume, together with only small differences in tree height compared with the other two treatments (Tables 19 and 20; Fig. 32).

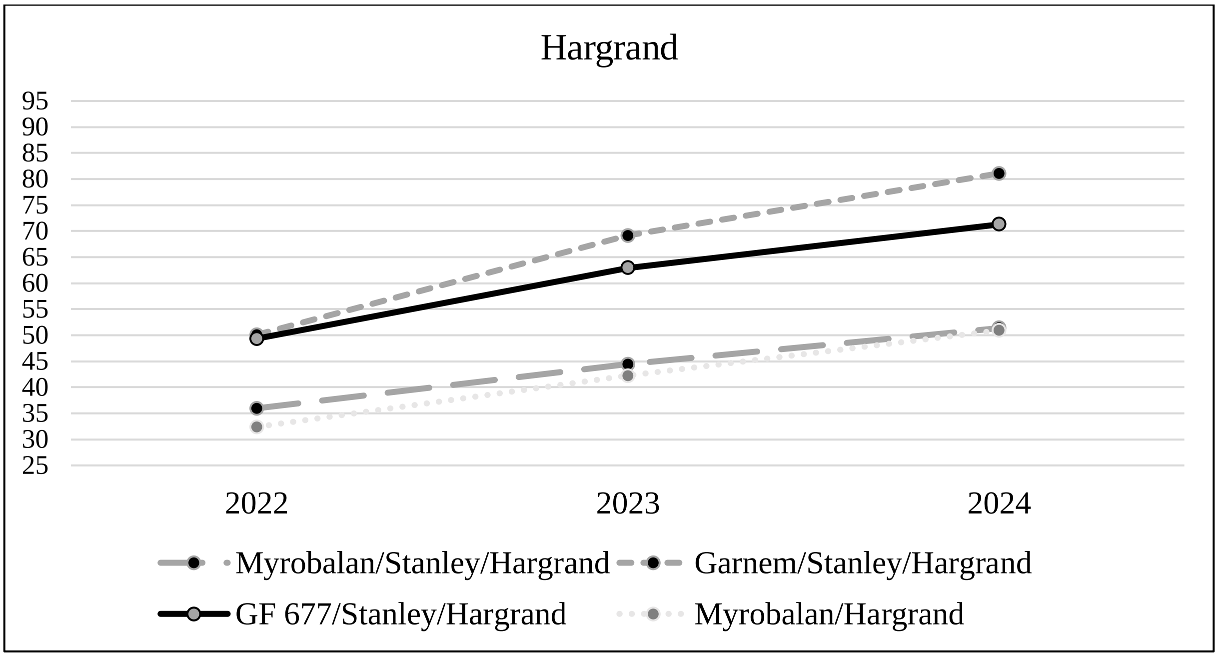

Figure 15. Increase in trunk cross-sectional area of the apricot cultivar 'Hargrand' grafted onto different rootstocks with and without an interstock (cm^2)

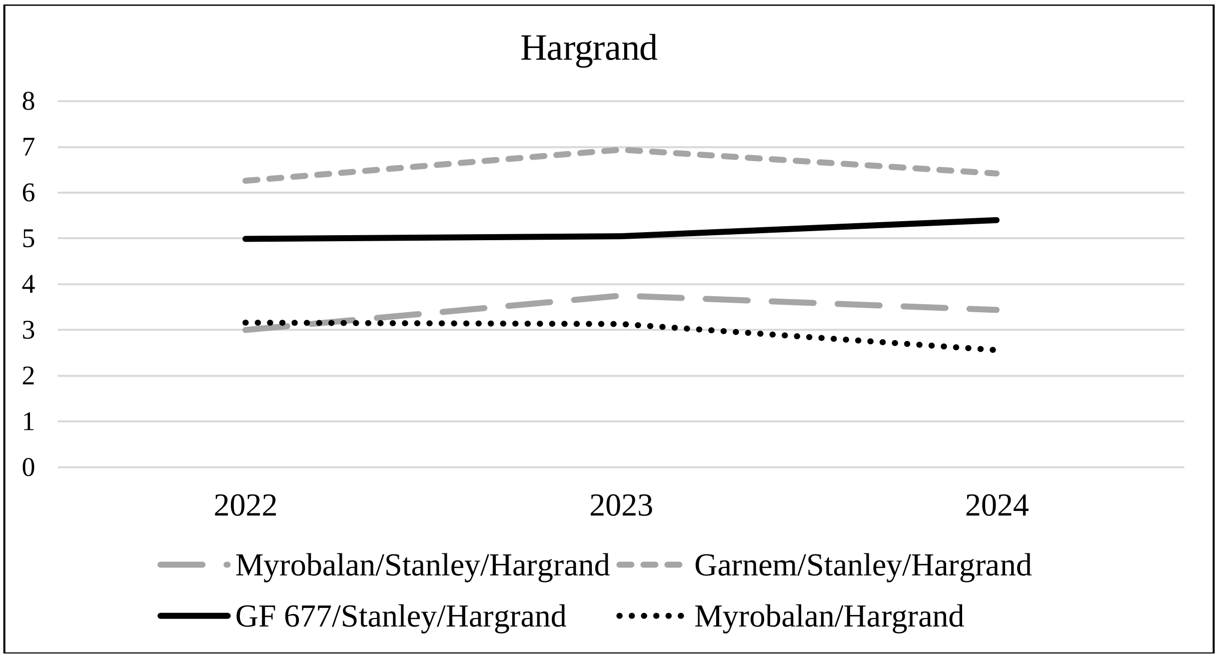

Figure 16. Increase in canopy volume of the apricot cultivar 'Hargrand' grafted onto different rootstocks with and without an interstock (m^3).

Canopy volume and canopy diameter are important parameters for characterizing the vigour of scion–rootstock combinations and for determining the optimum planting density for each combination (Petrov, 2024). The reduction in canopy volume recorded in 2024 was the result of the size-controlling pruning carried out during the previous year. At the end of the study, the largest canopy diameter and canopy volume were recorded for the apricot cultivar 'Hargrand' grafted onto the G×N15 (Garnem) rootstock with the 'Stanley' interstock (Table 20 and Fig. 16). The results obtained in the present study do not support the findings of Vachůn (1990), Rahnemoun et al. (2009), and Milošević et al. (2012), who reported that the use of an interstock reduces the vigour of the grafted cultivar, a discrepancy that is likely attributable to differences in the interstocks used.

Table 19. Tree height of the apricot cultivar 'Hargrand' grafted onto three different rootstocks with and without an interstock (cm).

Rootstock	Interstock	Year		
		2022	2023	2024
Myrobalan	Stanley	338,75	344,93	350,75
Garnem	Stanley	343,00	365,31	385,75
GF677	Stanley	321,00	341,49	377,00
Myrobalan		333,75	325,04	342,00
$LSD_{0.05}/R_{0.05}$		**27,16**	**37,08**	**24,90**

Table 20. Canopy diameter of the apricot cultivar 'Hargrand' grafted onto three different rootstocks with and without an interstock (cm).

Rootstock	Interstock	Year		
		2022	2023	2024
Myrobalan	Stanley	203,25	227,00	213,00
Garnem	Stanley	285,50	290,75	274,25
GF677	Stanley	270,50	265,75	262,5
Myrobalan		211,88	217,00	188,00
$LSD_{0.05}/R_{0.05}$		**21,77**	**21,37**	**24,89**

We consider that by the end of the present study (the seventh growing season), the scion–rootstock combinations had entered the full-bearing stage, allowing us to propose recommended planting densities under the soil and climatic conditions of the experimental site (Table 21). It should be noted that the recommended planting distances are based on the fact that the trial was conducted under rainfed conditions and that precipitation during the most critical stages of vegetative growth was extremely limited throughout the study period.

Table 21. Recommended planting densities for the apricot cultivar 'Hargrand' grafted onto three different rootstocks with and without an interstock.

Rootstock	Interstock	Planting spacing, m	Number of trees per decare
Myrobalan	Stanley	5,0 × 3,0	67
Garnem	Stanley	5,0 × 4,0	50
GF677	Stanley	5,0 × 4,0	50
Myrobalan		5,0 × 2,5	80

The data presented in Table 22 show the amount of pruned wood removed from the apricot trees during the study period. Throughout the three years of the experiment, the greatest amount of pruned wood was consistently recorded for trees grafted onto the peach–almond hybrid rootstock G×N15 (Garnem) with the 'Stanley' interstock, with the exception of 2023, when the difference between this combination and GF 677 with the 'Stanley' interstock was not statistically significant. A more comprehensive assessment of the labour required for pruning over the entire study period is provided in Fig. 17. The figure shows that the cumulative weight of pruned wood was significantly greatest for trees grafted onto the Garnem rootstock. Considerably less pruned wood was removed from trees grafted onto the Myrobalan rootstock with the 'Stanley' interstock, whereas no significant differences were observed between the traditional Myrobalan seedling rootstock (without an interstock) and the GF 677 rootstock with the 'Stanley' interstock, both of which occupied an intermediate position.

Table 22. Weight of pruned wood from the apricot cultivar 'Hargrand' grafted onto three different rootstocks with and without an interstock (kg).

Rootstock	Interstock	Year		
		2022	2023	2024
Myrobalan	Stanley	1,20	1,32	1,99
Garnem	Stanley	3,39	4,33	4,06
GF677	Stanley	2,21	3,56	1,98
Myrobalan		1,87	2,42	2,63
$LSD_{0.05}/R_{0.05}$		**0,42**	**0,99**	**0,64**

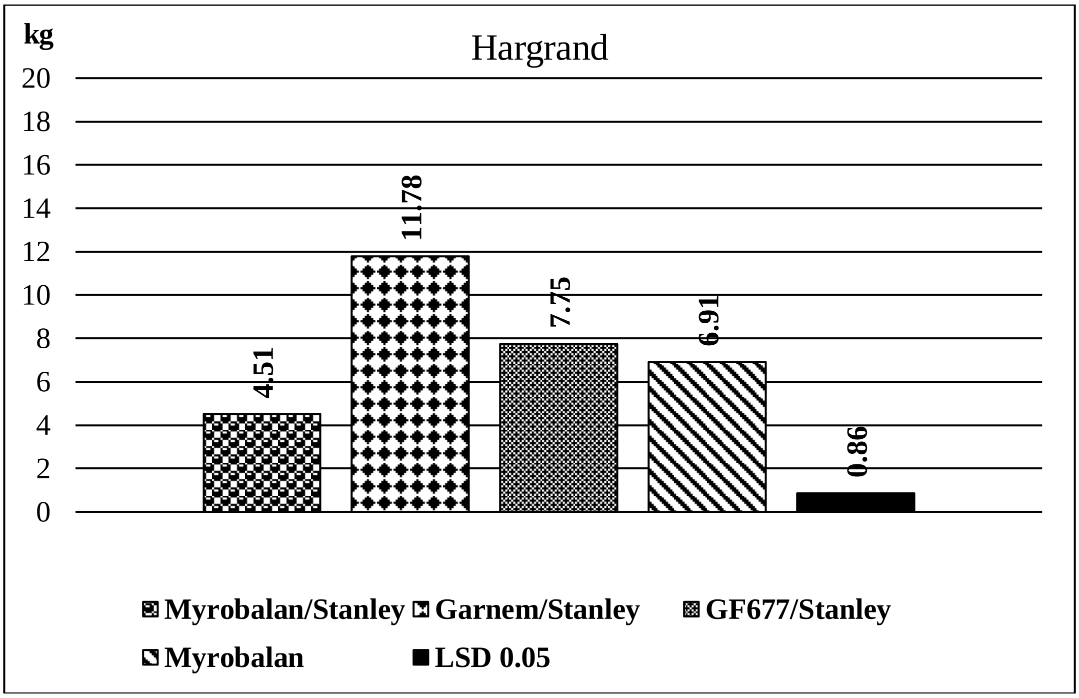

Figure 17. Cumulative weight of pruned wood per tree of the apricot cultivar 'Hargrand' grafted onto different rootstocks with and without an interstock during the period 2022–2024 (5th–7th growing seasons) (kg).

Table 23. Mean number of root suckers per tree of the apricot cultivar 'Hargrand' grafted onto different rootstocks with and without an interstock.

Rootstock	Interstock	Year		
		2022	2023	2024
Myrobalan	Stanley	2,96	4,12	3,75
Garnem	Stanley	0	0	0
GF677	Stanley	0	0	0
Myrobalan		2,75	4,83	6,75
$LSD_{0.05}/R_{0.05}$		**3,14**	**3,37**	**1,87**

The tendency of a rootstock to produce root suckers is considered an undesirable characteristic. Root sucker formation complicates weed control in the tree row by limiting the use of herbicides and increases orchard management costs because the suckers must be removed manually. Peach–almond hybrid rootstocks are known not to produce root suckers when grafted with peach cultivars (Petrov, 2024). This valuable characteristic was also confirmed when these rootstocks were combined with the 'Stanley' interstock and the apricot cultivar 'Hargrand' (Table 23). Throughout the three years of the study, root suckers were produced only by the Myrobalan seedling rootstock. In 2024, a significantly higher number of root suckers was recorded in the treatment without an interstock.

The number of flower buds per linear metre of one-year-old shoots is one of the parameters characterizing the potential productivity of the rootstock–interstock combinations under study. Throughout the three years of the experiment, the apricot cultivar 'Hargrand' grafted onto the peach–almond hybrid rootstock GF 677 with the 'Stanley' interstock consistently produced the highest number of flower buds per linear metre of one-year-old shoots (Table 24). The lowest number of flower buds was recorded on the traditional Myrobalan seedling rootstock without an interstock.

Table 24. Number of flower buds per linear metre of one-year-old shoot of the apricot cultivar 'Hargrand' grafted onto different rootstocks with and without an interstock.

Rootstock	Interstock	Year		
		2022	2023	2024
Myrobalan	Stanley	92,48	85,5	71
Garnem	Stanley	106,65	116,75	82
GF677	Stanley	184,45	151,5	110
Myrobalan		85,75	41	58
$LSD_{0.05}/R_{0.05}$		**51,72**	**7,60**	**8,13**

As a consequence of the above-mentioned characteristic, the highest mean yield per tree during the study period was recorded for trees grafted onto the GF 677 rootstock with the 'Stanley' interstock. The combination of the red-leaved peach–almond hybrid rootstock Garnem with the 'Stanley' interstock occupied an intermediate position for this parameter, whereas the lowest yields per tree were obtained from the widely used Myrobalan seedling rootstock, both with and without the interstock (Table 25).

Table 25. Mean yield per tree of the apricot cultivar 'Hargrand' grafted onto different rootstocks with and without an interstock (kg).

Rootstock	Interstock	Year		
		2022	2023	2024
Myrobalan	Stanley	3,64	2,10	2,99
Garnem	Stanley	3,91	3,46	4,62
GF677	Stanley	7,95	7,71	7,74
Myrobalan		2,95	1,31	2,3
$LSD_{0.05}/R_{0.05}$		**1.87**	**0.92**	**0,76**

Cumulative yield over the study period provides a more reliable assessment of the productivity induced by the rootstocks on the grafted cultivars. The highest cumulative yield was obtained from trees grafted onto the GF 677 rootstock with the 'Stanley' interstock, whereas the lowest cumulative yield was recorded for the widely used Myrobalan seedling rootstock without an interstock (Fig. 34). Overall, higher cumulative yields were obtained from trees grafted onto the peach–almond hybrid rootstocks GF 677 and Garnem with the 'Stanley' interstock than from the two treatments based on the Myrobalan seedling rootstock.

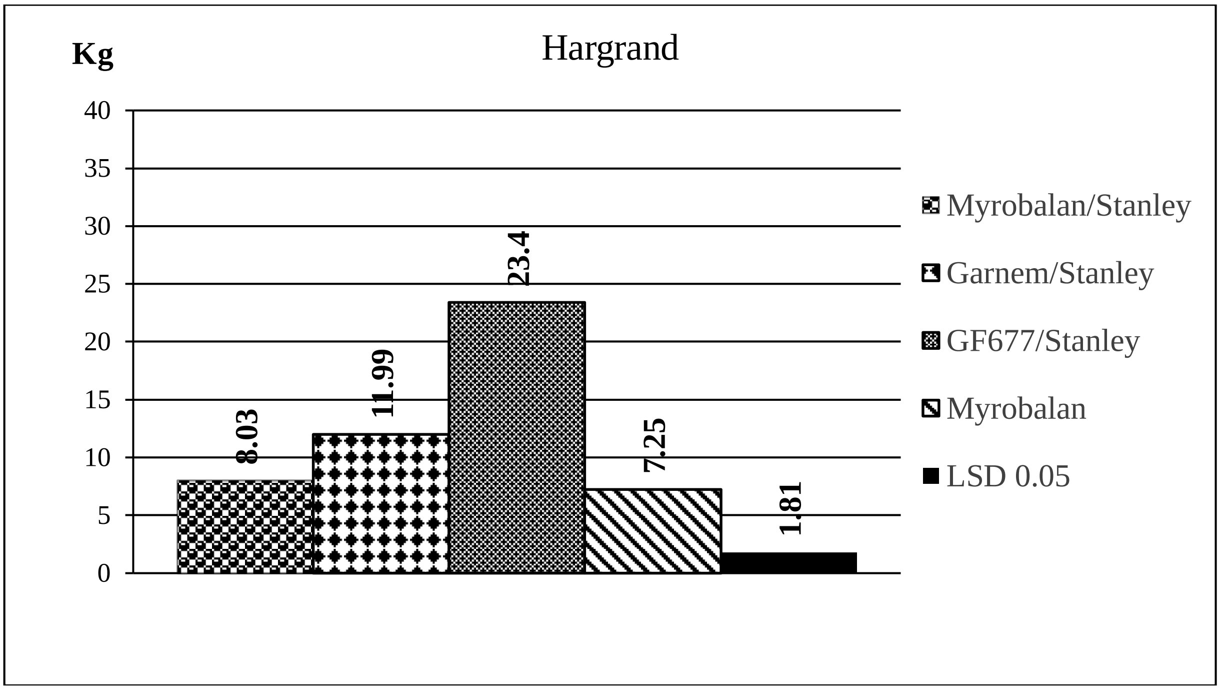

Figure 18. Cumulative yield per tree (kg) of the apricot cultivar 'Hargrand' grafted onto different rootstocks with and without an interstock during the 5th–7th growing seasons (2022–2024).

A reliable assessment of the economic efficiency of a given scion–rootstock combination should be based on the comparison of several parameters. The combination of the GF 677 rootstock with the 'Stanley' interstock produced the highest apricot yield. At the same time, this combination ranked second in terms of the cumulative weight of pruned wood (Fig. 18). This indicates the superior overall efficiency of this rootstock–interstock–cultivar combination.

Mean fruit weight is one of the characteristics determining fruit quality. During the study period, fruit size was significantly greater in the combinations GF 677 and G×N15 (Garnem) with the 'Stanley' interstock, whereas the smallest fruits were obtained from the traditional combination of Myrobalan seedling rootstock with the apricot cultivar without an interstock (Table 26). Photo 7 provides a visual representation of the fruit size of the apricot cultivar 'Hargrand' as influenced by the different rootstock–interstock combinations. The results obtained in the present study regarding the increase in mean fruit weight, mean yield per tree, and cumulative yield per tree are consistent with the findings of Milošević et al. (2015), who reported a positive effect of rootstock on these parameters.

Table 26. Mean fruit weight of the apricot cultivar 'Hargrand' (g).

Rootstock	Interstock	Year		
		2022	2023	2024
Myrobalan	Stanley	66,24	90,2	95,58
Garnem	Stanley	84,11	99,23	119,51
GF677	Stanley	93,98	114,43	116,63
Myrobalan		62,32	87,39	88,59
$LSD_{0.05}/R_{0.05}$		**13.93**	**7.14**	**5,04**

Over the past decades, yield efficiency coefficients (YEC) have been regarded as one of the most important indicators for evaluating the productivity of different rootstocks (Patzold, 1991). These coefficients are expressed as the cumulative yield per tree over the study period relative to the trunk cross-sectional area (kg/cm^2) and canopy volume (kg/m^3) measured at the end of the experiment. During the study period, the combination of the GF 677 rootstock with the 'Stanley' interstock exhibited the highest yield efficiency based on both trunk cross-sectional area and canopy volume, whereas the lowest values were recorded for the combination of the peach–almond hybrid Garnem with the 'Stanley' interstock (Figs. 19 and 20). In our opinion, these results are largely attributable to the greater trunk cross-sectional area and larger canopy volume of this scion–rootstock combination, as well as to the smaller canopy volumes observed in the treatments based on the traditionally used Myrobalan seedling rootstock, with and without an interstock.

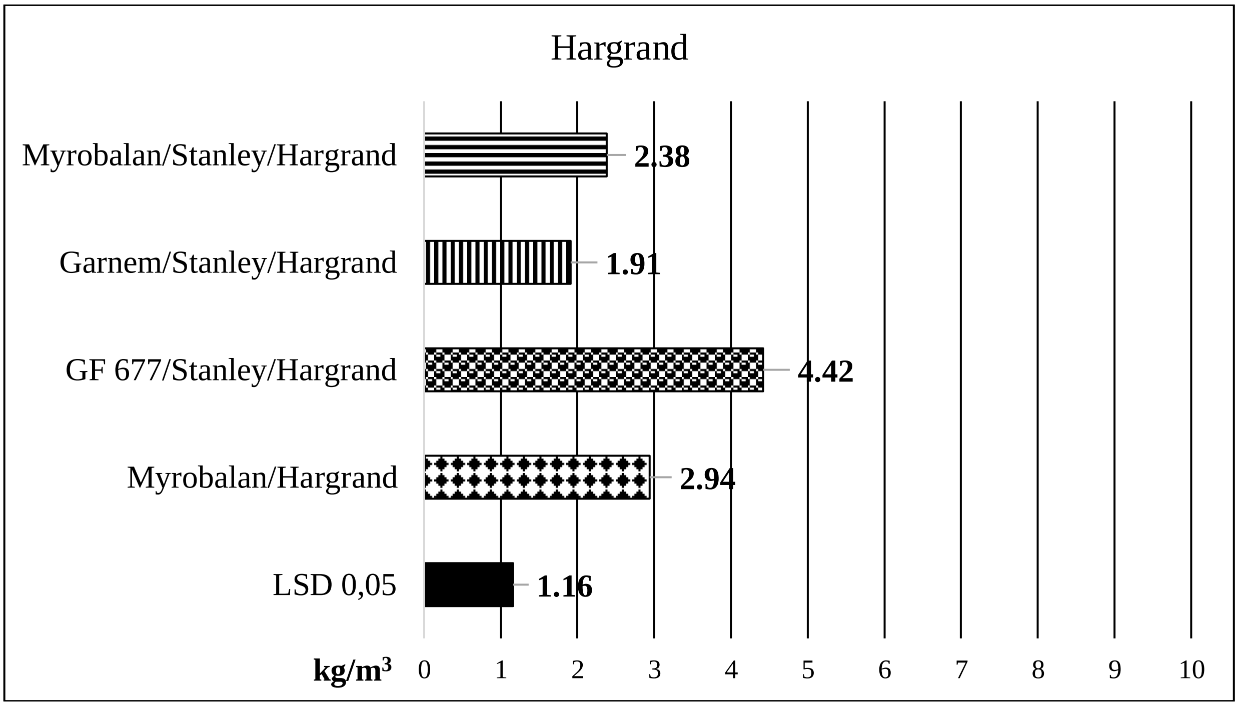

Figure 19. Yield efficiency coefficient of the apricot cultivar 'Hargrand' grafted onto different rootstocks with and without an interstock, expressed relative to canopy volume (kg/m³).

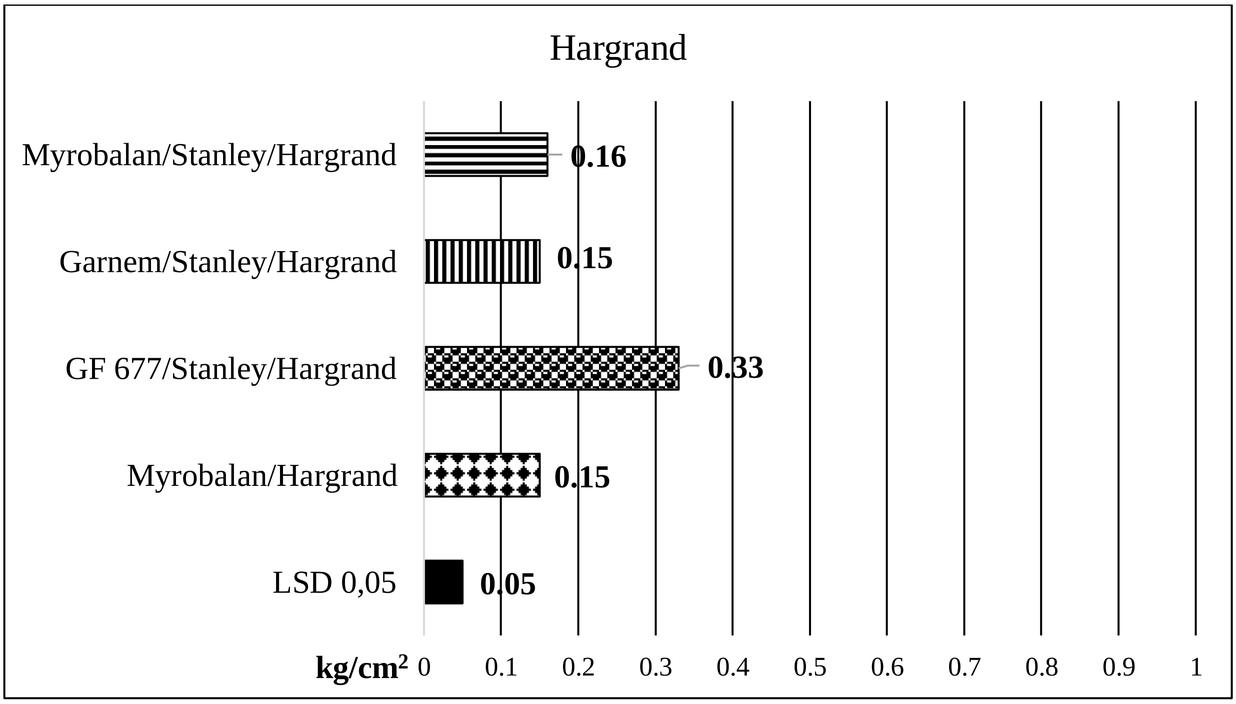

Figure 20. Yield efficiency coefficient of the apricot cultivar 'Hargrand' grafted onto different rootstocks with and without an interstock, expressed relative to trunk cross-sectional area (kg/cm²).

Physiological studies

Rootstocks play a very important role in maintaining the vigour of the grafted cultivars, as they influence factors such as nutrient uptake, water absorption, and the overall physiological status of the plants (Milošević et al., 2020). Photosynthesis is a key process for carbohydrate synthesis. In addition to affecting tree size, rootstocks also influence the rate of photosynthesis (Li et al., 2022). There are studies (An et al., 2017) reporting that photosynthetic intensity is not affected by the choice of rootstock or interstock. In a recent study on apricot, Banda et al. (2026) reported significantly higher rates of leaf gas exchange and transpiration in trees grafted onto plum rootstock ‘Marianna’ compared to those grafted onto apricot rootstock. Fruits obtained from trees on plum rootstock contained significantly higher levels of soluble solids compared to those on apricot rootstock, although the authors did not investigate interstock combinations. In other studies involving apple rootstocks of different vigour levels, Sotiropoulos (2008) and Zhang et al. (2021) reported lower photosynthetic rates in trees grafted onto dwarfing rootstocks compared to those grafted onto more vigorous rootstocks.

The parameters characterizing leaf gas exchange in three plum scion–rootstock combinations are presented in Table 27. Stomatal conductance and transpiration rate are among the indicators associated with the complex process of photosynthesis. The more open the stomata are, the more intensive transpiration and gas exchange become. In the present study, no significant differences were observed among the tested rootstocks. The highest transpiration rate was recorded in the cultivar 'Stanley', while the lowest was observed in 'Čačanska Lepotica'. The results obtained do not allow a clear trend to be established regarding the influence of rootstocks on stomatal conductance and transpiration rate. Regarding chlorophyll content and photosynthetic rate, the highest values were recorded in leaves of trees of the cultivar 'Stanley' grafted onto the Myrobalan seedling rootstock, whereas in the other two cultivars these parameters were highest under the influence of the Wavit rootstock.

According to Faizi et al. (2023), chlorophyll content in leaves increases in low-vigour scion–rootstock combinations. In our experiment, this was confirmed only in the cultivar 'Čačanska Lepotica', while in the other scion–rootstock combinations the differences were not significant. The results obtained in the present study are more consistent with those of Reig et al. (2018), who reported that leaf chlorophyll content varies depending on the specific scion–rootstock combination.

Table 27. Physiological parameters of three plum scion–rootstock combinations.

Rootstock	Chlorophyll content, mg/m^2	Transpiration rate, $mmol/m^2/s$	Stomatal conductance, $mol/m^2/s$	Photosynthesis rate, $\mu mol/m^2/s$
Chachanska Lepotica				
Myrobalan	379,67	1,50	0,04	15,47
Ishtara	415,67	1,55	0,04	14,92
Wavit	419,83	1,53	0,04	18,4
$LSD_{0.05}/R_{0.05}$	**21,77**	**0,07**	**0,00**	**6,87**
Stanley				
Myrobalan	433,5	1,78	0,04	19,11
Ishtara	412,5	1,81	0,05	18,68
Wavit	418,67	1,83	0,04	17,12
$LSD_{0.05}/R_{0.05}$	**44,31**	**0,12**	**0,00**	**2,83**
Jojo				
Myrobalan	376,5	1,67	0,03	16,34
Ishtara	370,75	1,57	0,03	16,79
Wavit	377,33	1,62	0,03	17,32
$LSD_{0.05}/R_{0.05}$	**25,79**	**0,13**	**0,01**	**1,31**

In the experiment involving different rootstocks and interstocks for the apricot cultivar 'Hargrand', trees grafted onto the more vigorous peach–almond hybrid rootstocks GF 677 and Garnem with the 'Stanley' interstock showed higher photosynthetic rate and transpiration rate compared to the Myrobalan seedling rootstock with the 'Stanley' interstock (Table 28). Regarding the other two parameters included in the study—chlorophyll content and stomatal conductance—the results indicate that there were no significant differences among the tested treatments.

Table 28. Physiological parameters of trees of the apricot cultivar 'Hargrand' grafted onto different rootstocks with an interstock.

Rootstock/ Interstock	Chlorophyll content, mg/m^2	Transpiration rate, $mmol/m^2/s$	Stomatal conductance, $mol/m^2/s$	Photosynthesis rate, $\mu mol/m^2/s$
Myrobalan/Stanley	322,50	1,11	0,03	15,27
Garnem/Stanley	336,33	1,72	0,04	20,85
GF677/Stanley	342,67	1,66	0,03	19,30
Myrobalan Seedling	332,17	1,48	0,02	18,84
$LSD_{0.05}/R_{0.05}$	**39,03**	**0,37**	**0,01**	**2,67**

CONCLUSIONS

From the conducted studies, extensive information was obtained regarding the interaction between modern rootstock and interstock combinations used for the production of apricot and plum cultivars in nursery and orchard conditions, which provides a basis for drawing the following conclusions:

A. From experiments with the European plum (*Prunus domestica*):

1. In the plum orchard, the highest cumulative yield per tree over the study period was obtained from trees grafted onto the Myrobalan seedling (*Prunus cerasifera*) rootstock for all three cultivars included in the experiment.

2. The highest yield efficiency coefficient relative to canopy volume was recorded in the combinations involving the rootstocks Ishtara and Myrobalan (*Prunus cerasifera*) with the cultivars ‘Stanley’ and ‘Čačanska Lepotica’, whereas Wavit showed the highest productivity with the cultivar ‘Jojo’. The yield efficiency coefficient relative to trunk

cross-sectional area was highest for the Myrobalan rootstock (*Prunus cerasifera*) in combination with ‘Stanley’ and ‘Čačanska Lepotica’, while in the cultivar ‘Jojo’ the highest coefficient was observed under the influence of the Wavit rootstock.

3. Under the experimental conditions, rootstocks did not influence fruit size in any of the three cultivars studied.

4. The rootstocks Ishtara, Wavit, and Myrobalan (*Prunus cerasifera*) did not affect the timing of flowering in any of the three plum cultivars.

5. The Myrobalan seedling rootstock (*Prunus cerasifera*) induced more vigorous vegetative growth in the studied cultivars, expressed as greater trunk cross-sectional area and larger canopy volume.

6. The rootstocks Ishtara and Wavit did not produce rootsuckers in combination with the three cultivars included in the study.

7. There were no consistent trends regarding the influence of rootstocks on the photosynthetic rate in the studied cultivars.

8. In the case of the Myrobalan seedling and Ishtara rootstocks, a high graft-take percentage (over 90%) was observed for all three plum cultivars. For the Wavit rootstock, the graft-take percentage during the study period was lower (below 80%).

9. In the nursery stage, the rootstocks Ishtara and Wavit promoted the formation of a greater number of lateral shoots, whereas the Myrobalan seedling rootstock (*Prunus cerasifera*) produced taller plants.

B. From the experiments with apricot:

10. The peach–almond hybrid rootstocks GF 677 and G×N15 (Garnem) with the 'Stanley' interstock induced higher productivity in the apricot cultivar 'Hargrand' compared to the traditionally used Myrobalan seedling rootstock (*Prunus cerasifera*), both with and without an interstock.

11. The present study shows that the combination of GF 677 rootstock with the 'Stanley' interstock and the cultivar 'Hargrand' exhibited the highest yield efficiency coefficients under the experimental conditions.

12. The use of the peach–almond hybrid rootstocks GF 677 and G×N15 (Garnem) with the 'Stanley' interstock significantly increased fruit size in the cultivar 'Hargrand'.

13. Rootstocks influenced the timing of flowering in the cultivar 'Hargrand'. Earlier flowering was observed when using the peach–almond hybrid rootstocks GF 677 and G×N15 (Garnem) with the 'Stanley' interstock.

14. The peach–almond hybrid rootstocks GF 677 and G×N15 (Garnem) with the 'Stanley' interstock induced more vigorous vegetative growth in the 'Hargrand' orchard compared to the widely used Myrobalan seedling rootstock (*Prunus cerasifera*).

15. Among the tested rootstocks, only the Myrobalan seedling rootstock (*Prunus cerasifera*) produced root suckers. The peach–almond hybrid rootstocks GF 677 and G×N15 (Garnem) with the 'Stanley' interstock, grafted with the apricot cultivar 'Hargrand', did not produce root suckers.

16. Trees of the apricot cultivar 'Hargrand' grafted onto the peach–almond hybrid rootstocks GF 677 and Garnem with the 'Stanley' interstock exhibited higher rates of photosynthesis and transpiration compared to the Myrobalan seedling rootstock (*Prunus cerasifera*) with the 'Stanley' interstock.

17. In nursery production, the peach–almond hybrid rootstocks GF 677 and G×N15 (Garnem) with the 'Stanley' interstock induced stronger growth and branching of the scion.

18. In the nursery, the apricot cultivar 'Hargrand', propagated by improved English grafting, showed a higher graft-take percentage when using the peach–almond hybrid rootstocks GF 677 and G×N15 (Garnem) with the 'Stanley' interstock compared to the Myrobalan seedling rootstock (Prunus cerasifera) and Myrobalan seedling rootstock with the 'Stanley' interstock.

STATEMENT OF CONTRIBUTIONS TO THE DISSERTATION

Original contributions

• As a result of the conducted study, for the first time in Bulgaria, comprehensive information has been obtained on the peach–almond hybrid rootstocks GF 677 and Garnem with the 'Stanley' interstock and the influence they exert on the growth and reproductive performance of the apricot cultivar 'Hargrand' in nursery and orchard conditions.

• As a result of the study, for the first time in Bulgaria, comprehensive information has been obtained on the peach–almond hybrid rootstocks GF 677 and Garnem with the 'Stanley' interstock and the influence they exert on the flowering phenophase of the apricot cultivar 'Hargrand'.

• As a result of the study, for the first time in Bulgaria, information has been obtained on the peach–almond hybrid rootstocks GF 677 and Garnem with the 'Stanley' interstock and the influence they exert on physiological parameters of plants of the apricot cultivar 'Hargrand'.

Scientific and applied contributions

- The studied peach–almond hybrid rootstocks GF 677 and Garnem with the 'Stanley' interstock ensure good compatibility with the apricot cultivar 'Hargrand'.
- The rootstocks Wavit and Ishtara show good compatibility with the plum cultivars included in the study.
- Peach–almond hybrids with the 'Stanley' interstock induce higher productivity in the apricot cultivar 'Hargrand' compared to the traditionally used Myrobalan seedling rootstock without an interstock.
- The peach–almond hybrid rootstocks GF 677 and Garnem with the 'Stanley' interstock in combination with the apricot cultivar 'Hargrand', as well as the rootstocks Ishtara and Wavit in combination with the studied plum cultivars, do not produce root suckers, unlike the traditionally used Myrobalan seedling rootstock.
- As a result of our study, the use of peach–almond hybrid rootstocks GF 677 and Garnem with the 'Stanley' interstock is recommended for apricot production as a good alternative to the traditionally used Myrobalan seedling rootstock (Prunus cerasifera).

Confirmatory contributions

- The rootstocks Ishtara and Wavit induce weak vigour in the grafted European plum cultivars.
- The flowering of the cultivar ‘Jojo’ begins and ends 2–3 days earlier compared to the other two plum cultivars, while the rootstocks do not affect the timing or duration of flowering in the studied plum cultivars.

LIST OF PUBLICATIONS RELATED TO THE DISSERTATION

1. Tabakov S., Yordanov A. Donkov T. 2024. Effect of Different Rootstocks and Interstocks on Flowering of Apricot Cultivar Hargrand. Journal of Mountain Agriculture on the Balkans, 27 (4), 310-319 ISSN1311-0489 (Print) Research Institute of Mountain Stockbreeding and Agriculture, Troyan ISSN 2367-8364 (Online) https://jmabonline.com/en/article/k8BZDLAiizqJ13gGAjBq

2. Yordanov A., Tabakov S., Donkov T. 2025. Influence of different rootstocks on the growth performance of plum cultivars Chachanska Lepotitsa, Stenley and Jojo. Journal of Mountain Agriculture on the Balkans, 28 (2), 336-349. ISSN 1311-0489 (Print) Research Institute of Mountain Stockbreeding and Agriculture, Troyan ISSN 2367-8364 (Online) https://jmabonline.com/en/article/9tQp8cZvHkUUqD05gieW

3. Yordanov A., Tabakov S., Donkov T. 2025. Influence of different rootstocks and interstocks on the growth and productivity performance of the apricot cultivar Hargrand. Journal of Mountain Agriculture on the Balkans, 28 (6), 358-371 ISSN1311-0489 (Print) Research Institute of Mountain Stockbreeding and Agriculture, Troyan ISSN 2367-8364 (Online)
https://jmabonline.com/en/article/cVQmPzw6Swa7nE7DrlCo