horticulturae

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Evaluation of Nursery Traits in Japanese Plums on Five Different Rootstocks

Tomáš Nečas *, Jan Wolf, Eliška Zezulová and Ivo Ondrášek

Department of Fruit Science, Faculty of Horticulture in Lednice, Mendel University in Brno, Valtická 337, 691 44 Lednice, Czech Republic
* Correspondence: tomas.necas@mendelu.cz

Abstract: Climate change has a negative effect on the environment in which traditional fruit species are grown and, at the same time, offers the potential for cultivation of new species. Japanese plums derived from *P. salicina* Lindley are a fruit species that is slowly being introduced to the Czech Republic. Therefore, there are efforts to find ways to grow these varieties. In our experiment, selected nursery traits that are important for the production of Japanese plum saplings in the region of the Czech Republic were evaluated. The main evaluation criteria were scion affinity, sapling yield, and selected growth characteristics. The results show that the best affinity was achieved with the Adesoto (92.0%) and the Torinel (90.0%) rootstocks. Moderate levels of affinity were found for Brompton (84.2%) and St. Julien A (80.0%) rootstocks. Weak affinity was found only for the rootstock Wavit (52.7%). The economically significant trait is the yield of saplings; here, the highest yields were obtained with the Adesoto rootstock (88.4%) and the Japanese plum variety 'Black Star' (89.3%). Generally, the Adesoto and Torinel rootstocks proved to be the most suitable for use with Japanese plum varieties.

Keywords: *P. salicina* Lindley; Japanese plums; affinity; chip budding; nursery traits

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Citation: Nečas, T.; Wolf, J.; Zezulová, E.; Ondrášek, I. Evaluation of Nursery Traits in Japanese Plums on Five Different Rootstocks. *Horticulturae* **2023**, *9*, 318. https://doi.org/10.3390/horticulturae9030318

Academic Editor: Károly Hrotkó

Received: 19 January 2023
Revised: 21 February 2023
Accepted: 24 February 2023
Published: 28 February 2023

1. Introduction

Japanese (*Prunus salicina* Lindley) and European plums (*P. domestica* L.) are taxonomically classified in the same section, but they differ in adaptability, origin, and method of domestication. Their fruit is also very different, along with their ripening periods and methods of use [1]. Japanese plums are highly adaptive and are grown in subtropical and mild climates. Their adaptability to temperatures is so high that they are able to survive in temperatures as low as −40 °C [2]. They are mainly used for direct consumption, but some varieties may be stored for various periods of time [3].

Under the conditions of the Czech Republic, Japanese plums are used both as rootstocks for a wider range of plum varieties and as a fruit species grown for their fruit. In both cases, they can be studied and evaluated for their suitability as a rootstock or as a recommendation for cultivation. Current practice uses a number of rootstocks derived from Japanese plums (*P. salicina*). Nowadays, the affinity of many types of interspecific hybrid rootstocks with different *Prunus* scions has been studied [4,5]; however, some of the rootstocks show problems with affinity when combined with some varieties [5] and different conclusions concerning the affinity of the rootstock groups and varieties of Japanese plums can be found in the literature [6–9]. The most widely used rootstock in Europe is myrobalan seedling (*P. cerasifera*), but apart from the high vigor of these trees, they have might have many undesirable effects, such as grafting incompatibility, delayed precocity, etc. [9]. Andersen et al. [6] describe Japanese plums such as 'Shiro' and 'Methley' being incompatible with the myrobalan rootstocks. On the contrary, Mezzetti and Sottile [7] showed that European and Japanese plums are equally successful on myrobalan rootstocks, and Reig et al. [4] confirmed the compatibility of four Japanese plums with Myrobalan B. In addition, *P. insititia* L. was confirmed as a good source of rootstocks for the plum industry as well as several interspecific *Prunus* hybrids [4].

Of course, when evaluating the suitability of rootstocks for fruit planting, it is necessary to think not only about the affinity properties of the rootstock, i.e., the scion survival rate, but also about the growth characteristics and especially about the properties influenced by the environment, such as resistance to asphyxia, water stress, different pH values, salinity, high or low calcium values, and also overall soil fatigue [9–13].

The aim of our experiment was to evaluate selected nursery traits in a group of rootstocks derived from *P. domestica* a *P. insititia*, which are frequently used and widely available in the Czech Republic and are suitable for use in most of the plum growing areas, but their influence on Japanese plums has never been studied in our climatic conditions.

2. Materials and Methods

The experiment took place from 2019–2021 in a nursery of the Faculty of Horticulture in Lednice, South Moravian Region. The planting site is situated at an altitude of 164 m.a.s.l. and is one of the warmest places in the Czech Republic. The annual average temperature is 9.1 °C and the average annual rainfall is 422 mm (1960–1991). The growing season for the area is from 19th April to 19th October, which is 178 days [14]. In 2019, the average growing season temperature was 17.7 °C (11.5 °C year-round), the annual precipitation was 528.1 mm, and the sunshine duration was 1982.9 h. In 2020, the average growing season temperature was 16.8 °C (11.0 °C year-round), the annual precipitation was 574.0 mm, and the sunshine duration was 1872.1 h. In 2021, the average growing season temperature was 16.5 °C (10.0 °C year-round), the annual precipitation was 472.7 mm, and the sunshine duration was 2013.6 h [15].

The experiment was carried out in field nursery conditions on 5 different rootstocks (Wavit, Torinel, St. Julien A, Adesoto, Brompton), whose influences were studied for 10 different Japanese plum varieties (Table 1). For each rootstock–variety combination, the evaluation was carried out on 15 saplings in 3 repetitions (one repetition produced each year from 2019 to 2021), totaling 45 saplings of each rootstock–variety combination. In total, 750 saplings were produced and evaluated every year, 2250 saplings in the period of 3 years. The scions were grafted using a T-budding system on a rootstock at a height of 150–200 mm. The grafted saplings were treated according to standard nursery procedures: in early spring, the rootstock above the grafted scion was removed; in June, the annual shoots of varieties were secured to bamboo supporting poles; and in August, the side shoots growing from trunks and rootstocks were removed. During the year, the vegetation in the nursery was treated with additional large-area irrigation (irrigation drum) at 2–3-week intervals. As a fertilizer, the Czech multi-component fertilizer Cererit wa applied at the beginning of vegetation before sprouting. Weeds were removed manually within the rows and by mechanization between the rows. Phytohormones were not used, and the saplings were grown in a natural way. Pesticides against aphids were applied as needed.

Table 1. Selected plum varieties used for conducting experimental evaluations of nursery traits.

Varieties of Plums	Botanical Origin	Geographical Origin
Pink Saturn	*P. salicina*	Italy
T.C. Sun	*P. salicina*	USA
Flavor Queen	Pluot *P. salicina* × *P. armeniaca*	USA
Aphrodite	*P. salicina*	USA
October Sun	*P. salicina*	USA
Golden Japan	*P. salicina*	USA
Autumn Giant	*P. salicina*	USA
Black Star	*P. salicina*	USA
Stanley	*P. domestica*	USA
Chrudimská	*P. domestica*	Czech Republic

The evaluations in the nursery were carried out at monthly intervals, from the time of the removal of rootstock above the grafted scion to the final training of the sapling crown. Selected nursery tree characteristics were evaluated during the experiment: affinity between the scion and the rootstock (%, evaluated subjectively as the state of the plant when the sapling did not show any growth abnormalities, e.g., no leaf color changes, growth depression, or graft breakage during growth in the nursery until defoliation); root suckering (number of suckers growing from the root neck or roots); growth intensity of saplings (measured as height in mm with a standard tape measure); root collar diameter (mm, measured with a caliper); and the intensity of branching, which was scored on a point scale: 3 very slightly branched (number of shoots lower than 3), 5 moderately branched (number of shoots 4–6), 7 strongly branched (number of shoots 7–9), 9 very strongly branched (number of shoots more than 9). The yield of saplings (nursery plants) in the nursery was calculated as a percentage of successfully uprooted and prepared saplings for expedition by the grower. Unlike affinity, the yield counts also with other factors, like saplings broken or damaged by machinery, animals, people, or the weather, thus giving the real estimation of sapling production. Evaluations of the aforesaid characteristics were carried out according to the "Methodology of state examination of varieties—fruit crops" [16].

The distribution of experimental plants, variants and repetitions in the nursery was organized by the method of random blocks in all years of the experiment. For the statistical evaluation of the obtained data, a 3-factor analysis of variance and subsequent multiple comparisons with the division of data into homogeneous subgroups using the Tukey-HSD method were used. Statistical analyses were performed in the software Statistica ver.14.

Plant Material-Rootstocks

'Wavit': (origin: Schreiber Nursery, Poysdorf, Austria) a new rootstock for plums and apricots derived from a clonal selection from the "Wangenheim plum" (*P. domestica* L.). It weakens the growth of the grafted variety by 40%. It is propagated exclusively using the in vitro method because the success rate of propagation from woody and herbaceous cuttings is low. It is suitable for deep and fertile soils with the possibility of irrigation. Due to the poor growth of the grafted varieties, it is aimed for intensive cultivation systems with 1000 or more trees per hectare. It accelerates the fruit's onset, which is usually high. It does not form root suckers. It is not suitable for sandy or dry soils [17].

'Torinel': (origin: C.A.V. Agri Obtentions S.A, France) a hybrid of 'Reine Claude P 99' × 'Reine Claude de Bavay' (*P. domestica* L. subsp. *italica* Borkhausen). It is a poorly growing rootstock that weakens the growth of grafted varieties by 15–20% compared to other plum rootstocks. It is suitable for intensive production systems and for vigorous varieties. The varieties grafted on the rootstock have an earlier fruit onset. This rootstock has a good affinity with most varieties. It is particularly suitable for heavy and wet soils. It is propagated by herbaceous and woody cuttings or by in vitro methods [18].

'St. Julien A': (origin: East Malling Station, UK) is currently the most widely used medium-strong-growth vegetative rootstock for plums. Botanically, it belongs to *Prunus insititia* L. Bullace. It forms very few root suckers. It is propagated by woody and herbaceous cuttings. The shallow root system is suitable for wetter soils. It suffers on dry soils. Compared to myrobalan, it weakens growth by about 20–30%. Plums on this rootstock perform earlier fruit-onset than on myrobalan and have very good fruit size. It is very sensitive to the plum pox virus (sharka). It is suitable for almost all stone fruits [18].

'Adesoto': (origin: Estación Experimental de Aula Dei, Zaragoza, Spain) a vigorously growing plum rootstock originating from the selection of *Prunus insititia* L. Bullace. It is intended not only for plums but also for apricots, peaches, and almonds. It has a strong root system, which makes it drought-resistant. It adapts well to highly alkaline and heavy soils and is resistant to root asphyxia and chlorosis caused by iron deficiency. It accelerates ripening by up to 7 days. The rootstock is resistant to *Meloidogyne arenaria*, *M. incognita* and *M. javanica* nematodes. However, it can be infected by the endoparasitic *Pratylenchus vulnus* nematode. It is propagated by woody cuttings [19].

'Brompton': (origin: East Malling Station Selection, UK) derives from *P. domestica* L. It is a vigorously growing rootstock (grows more vigorously than apricot seedlings) suitable for both plums and apricots. It is propagated by herbaceous and woody cuttings, but also by seed. The rootstock is suitable for heavy calcareous soils; it does not suffer from root asphyxia, and it produces almost no root suckers. A poorer affinity with some plum and apricot varieties was found. It shows late intolerance, which may end in breakage in the 8th to 10th years after planting [18].

Scions for budding were collected from varieties of the following species: *Prunus salicina* Lindley, *Prunus domestica* L., and *P. salicina* Lindley × *P. armeniaca* L. (Table 1). Two European plums, ′Stanley′ and ′Chrudimská′ were used as control varieties. The Stanley variety was chosen because it is a well-known and widespread variety in Europe and is very popular and commonly grown in the Czech Republic. It is characterized by weaker growth on most of the rootstocks.

Variety Chrudimská is an older local variety characterized by excellent affinity, yield of saplings, strong growth, and overall high vitality in the nursery. Varieties listed in Table 1 budded on the rootstocks in the summers of 2018, 2019, and 2020.

3. Results

3.1. Evaluation of the Effect of Rootstock on Selected Nursery Traits

In terms of the possibility of using a rootstock in a nursery, it is important to know several nursery traits of the rootstock. The key ones include affinity, i.e., the percentage of successfully growing scions on a rootstock (Figure 1). In our experiment, the highest affinity was shown for the Adesoto rootstock (at a level as high as 92.0%) and the Torinel rootstock (90.0%). The other rootstocks showed an average affinity of about 76.2–83.3%. The average affinity value for the entire group was 84.3%. In terms of the rootstock–variety interaction (Figure S1), the highest affinity, in all cases 100%, was found for Torinel–October Sun, Torinel–Stanley, and Adesoto–Black Star (Table 2). By contrast, the worst combination in terms of affinity was St. Julien A–October Sun at a mere 60.0%. Statistical multiple factor analysis using Tukey's HSD test found significant differences ($p < 0.01$) in affinity within the rootstocks and varieties that were classified into seven homogeneous subgroups. Overall, the results show that the affinity of the Brompton rootstock was significantly different ($p < 0.01$) in 2019 compared to other rootstocks.

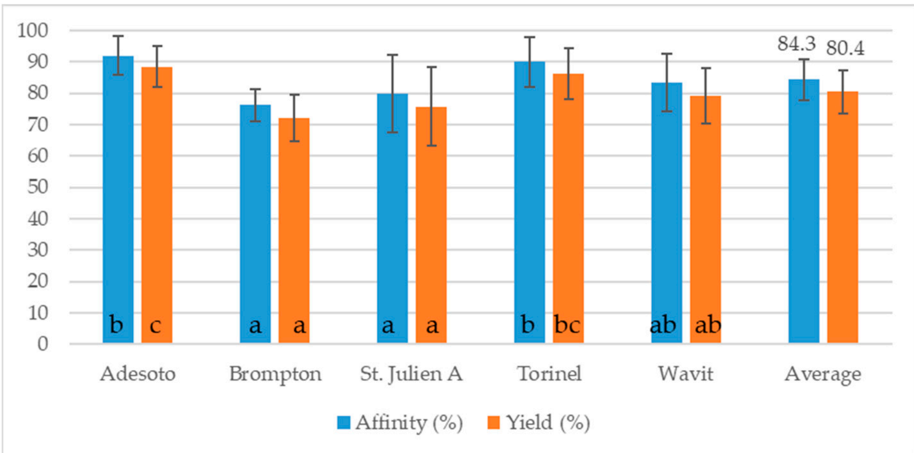

Figure 1. A comparison of the average affinity and yield of saplings, by rootstock. Scale bars refer ± standard deviations. Letters refer to statistical grouping according to the Tukey HSD test. Small letters indicate statistically different homogeneous subgroups.

Table 2. Average trait values for rootstock–variety interactions and statistical significance regardless of year.

Rootstocks	Varieties	Affinity of Saplings (%)	Yield of Saplings (%)	Height of Saplings (mm) **	Thickness of Saplings (mm)	Number of Suckers (Pieces) **	Intensity of Branching (Points)
Adesoto	Aphrodite	82.2 $^{b–g/8.01}$ *	77.8 $^{a–j/6.69}$	**1450.0**	**18.0** $^{a/0.42}$	**0.0**	5.3 $^{a–d/0.88}$
	Autumn Giant	86.7 $^{b–g/3.85}$	86.7 $^{d–j/3.85}$	1580.0	19.3 $^{a–d/0.33}$	**0.3**	6.3 $^{a–d/0.67}$
	Black Star	**100.0** $^{g/3.67}$	**100.0** $^{j/3.83}$	1546.7	19.7 $^{a–e/0.33}$	1.0	6.3 $^{a–d/1.33}$
	Flavor Queen	88.9 $^{b–g/4.44}$	84.4 $^{a–d/4.44}$	1633.3	**18.0** $^{a/0.42}$	**0.3**	7.0 $^{a–d/0.71}$
	Golden Japan	95.6 $^{e–g/4.44}$	86.7 $^{d–j/7.70}$	**1373.3**	**18.3** $^{ab/0.33}$	1.0	6.3 $^{a–d/1.33}$
	Chrudimská	**97.8** $^{fg/2.22}$	93.3 $^{g–j/6.67}$	**1863.3**	22.7 $^{g–k/0.33}$	0.7	**4.3** $^{a–c/0.67}$
	October Sun	93.3 $^{d–g/3.85}$	88.9 $^{e–j/5.88}$	**1480.0**	**18.3** $^{ab/0.42}$	**0.0**	7.7 $^{a–d/0.71}$
	Saturn	93.3 $^{d–g/3.85}$	88.9 $^{e–j/5.88}$	1496.7	20.0 $^{a–f/0.42}$	**0.0**	7.0 $^{a–d/0.71}$
	Stanley	**97.8** $^{fg/2.22}$	**95.6** $^{h–j/2.22}$	1620.0	20.0 $^{a–f/0.58}$	**0.0**	**3.7** $^{ab/0.33}$
	Te Sun	84.4 $^{b–g/5.88}$	82.2 $^{a–d/4.44}$	**1256.7**	19.0 $^{a–d/0.42}$	**0.3**	5.0 $^{a–d/0.71}$
	Average	*92.0* ^{c}	*88.5* ^{c}	*1530.0* ^{ab}	*19.3* ^{a}	*0.4* ^{a}	*6.0* ^{b}
Brompton	Aphrodite	82.2 $^{b–g/4.44}$	77.8 $^{a–j/5.88}$	**1956.7**	22.3 $^{f–k/0.33}$	1.3	**7.7** $^{b–d/0.67}$
	Autumn Giant	80.0 $^{a–g/3.85}$	80.0 $^{a–j/3.85}$	1810.0	22.3 $^{f–k/1.20}$	1.3	**9.0** $^{d/0.71}$
	Black Star	84.4 $^{b–g/5.88}$	82.2 $^{b–j/4.44}$	**1860.0**	21.3 $^{d–i/0.67}$	1.3	**8.3** $^{cd/0.67}$
	Flavor Queen	73.3 $^{a–d/13.33}$	73.3 $^{c–j/13.33}$	**1836.7**	20.7 $^{b–g/0.33}$	**1.7**	7.0 $^{a–d/0.71}$
	Golden Japan	77.8 $^{a–f/8.89}$	77.8 $^{a–j/8.89}$	1466.7	20.7 $^{b–g/0.33}$	1.0	**7.7** $^{b–d/0.67}$
	Chrudimská	68.9 $^{ab/11.76}$	**60.0** $^{ab/6.67}$	**2143.3**	**24.3** $^{j–l/0.67}$	**2.0**	**4.3** $^{a–c/0.33}$
	October Sun	75.6 $^{a–e/8.01}$	68. $^{a–f/4.44}$	**2043.3**	22.0 $^{e–j/0.42}$	1.0	**7.0** $^{b–d/0.67}$
	Saturn	68.9 $^{ab/5.88}$	**62.2** $^{a–c/8.01}$	**1903.3**	23.7 $^{i–l/0.33}$	1.3	7.0 $^{a–d/0.71}$
	Stanley	75.6 $^{a–e/14.57}$	71.1 $^{a–g/12.37}$	1500.0	23.3 $^{h–l/0.33}$	1.0	5.0 $^{a–d/0.71}$
	Te Sun	75.6 $^{a–e/5.88}$	68.9 $^{b–j/8.89}$	1436.7	21.0 $^{c–h/0.42}$	1.0	**8.3** $^{cd/0.67}$
	Average	*76.2* a	*72.1* a	*1795.7* c	*22.2* c	*1.3* b	*7* c
St. Julien A	Aphrodite	73.3 $^{a–d/7.70}$	71.1 $^{a–g/8.01}$	1490.0	19.0 $^{a–d/0.58}$	**0.3**	5.3 $^{a–d/0.88}$
	Autumn Giant	95.6 $^{e–g/2.22}$	93.3 $^{g–j/3.85}$	**1436.7**	19.7 $^{a–e/0.33}$	**0.0**	5.0 $^{a–d/0.71}$
	Black Star	93.3 $^{d–g/3.85}$	84.4 $^{c–j/4.44}$	1560.0	20.3 $^{a–g/0.33}$	0.7	**4.3** $^{a–c/0.67}$
	Flavor Queen	71.1 $^{a–c/5.88}$	68.9 $^{a–f/4.44}$	**1456.7**	20.3 $^{a–g/0.33}$	**0.0**	**4.3** $^{a–c/0.67}$
	Golden Japan	73.3 $^{a–d/6.67}$	66.7 $^{a–e/6.67}$	**1350.0**	**18.7** $^{a–c/0.33}$	**0.0**	5.7 $^{a–d/1.33}$
	Chrudimská	75.6 $^{a–e/5.88}$	73.3 $^{a–h/6.67}$	1780.0	**24.3** $^{j–l/0.33}$	**0.3**	**4.0** $^{ab/0.71}$
	October Sun	**60.0** $^{a/6.67}$	**57.8** $^{a/5.88}$	**1323.3**	20.0 $^{a–f/0.42}$	**0.3**	**3.7** $^{ab/0.67}$
	Saturn	73.3 $^{a–d/6.67}$	64.4 $^{a–d/2.22}$	**1383.3**	22.3 $^{f–k/0.33}$	**0.3**	**3.0** $^{a/0.71}$
	Stanley	95.6 $^{e–g/4.44}$	93.3 $^{g–j/3.85}$	**1283.3**	22.3 $^{f–k/0.33}$	**0.0**	**4.7** $^{a–c/1.20}$
	Te Sun	88.9 $^{b–g/5.88}$	84.4 $^{c–j/5.88}$	**1156.7**	18.7 $^{a–c/0.33}$	**0.0**	5.0 $^{a–d/0.71}$
	Average	*80.0* ab	*75.8* ab	*1422.0* a	*20.6* b	*0.2* a	*5* a
Torinel	Aphrodite	88.9 $^{b–g/5.88}$	84.4 $^{c–j/8.1}$	1773.3	**24.0** $^{j–l/0.58}$	**0.3**	7.0 $^{a–d/1.15}$
	Autumn Giant	91.1 $^{c–g/5.88}$	86.7 $^{d–j/3.85}$	1543.3	23.67 $^{i–l/0.67}$	0.7	**9.0** $^{d/0.71}$
	Black Star	**97.8** $^{fg/2.22}$	88.9 $^{e–j/2.22}$	**1880.0**	**24.7** $^{kl/0.33}$	0.7	**8.3** $^{cd/0.67}$
	Flavor Queen	80.0 $^{a–g/10.18}$	77.8 $^{a–j/9.69}$	1760.0	22.0 $^{e–j/1.00}$	**0.0**	**7.7** $^{b–d/0.67}$
	Golden Japan	91.1 c–g/4.44	91.1 $^{f–j/4.44}$	**1340.0**	20.3 $^{a–g/0.33}$	0.7	**8.3** $^{cd/0.67}$
	Chrudimská	91.1 $^{c–g/4.44}$	91.1 $^{f–j/4.44}$	**1993.3**	**25.7** $^{l/0.33}$	0.7	**4.7** $^{a–c/0.33}$
	October Sun	**100.0** $^{g/3.67}$	**97.8** $^{ij/2.22}$	1650.0	22.3 $^{f–k/0.58}$	**0.3**	5.7 $^{a–d/0.67}$
	Saturn	82.2 $^{b–g/2.22}$	80.0 $^{a–j/3.85}$	1696.7	**24.7** $^{kl/0.33}$	0.7	6.33 $^{a–d/0.67}$
	Stanley	**100.0** $^{g/3.67}$	93.3 $^{g–j/3.83}$	1693.3	**24.0** $^{j–l/0.42}$	1.0	5.7 $^{a–d/0.67}$

Table 2. *Cont.*

Rootstocks	Varieties	Affinity of Saplings (%)	Yield of Saplings (%)	Height of Saplings (mm) **	Thickness of Saplings (mm)	Number of Suckers (Pieces) **	Intensity of Branching (Points)
	Te Sun	77.8 $^{a–f/8.89}$	71.1 $^{a–g/9.69}$	**1360.0**	22.0 $^{e–j/0.58}$	**0.3**	7.0 $^{a–d/0.71}$
	Average	*90.0* c	*86.2* c	*1669.0* bc	*23.3* d	*0.5* a	*7* c
Wavit	Aphrodite	80.0 $^{a–g/7.70}$	75.6 $^{a–i/5.88}$	1500.0	19.0 $^{a–d/0.42}$	0.7	5.0 $^{a–d/1.15}$
	Autumn Giant	82.2 $^{b–g/8.01}$	80.0 $^{a–j/6.67}$	**1390.0**	20.0 $^{a–f/0.42}$	**0.0**	**4.7 $^{a–c/0.33}$**
	Black Star	**97.8 $^{fg/2.22}$**	91.1 $^{f–j/4.44}$	1560.0	19.0 $^{a–d/0.42}$	0.7	5.0 $^{a–d/1.15}$
	Flavor Queen	77.8 $^{a–f/5.88}$	71.1 $^{a–g/5.88}$	1523.3	19.3 $^{a–d/0.33}$	**0.0**	**7.7 $^{b–d/1.33}$**
	Golden Japan	93.3 $^{d–g/3.85}$	88.9 $^{e–j/5.88}$	**1220.0**	19.3 $^{a–d/0.88}$	**0.0**	**3.0 $^{a/0.71}$**
	Chrudimská	88.8 $^{b–g/5.88}$	86.7 $^{c–j/6.67}$	**2023.3**	**24.0 $^{j–l/0.58}$**	0.7	**4.3 $^{a/0.33}$**
	October Sun	91.1 $^{c–g/5.88}$	86.7 $^{d–j/7.70}$	1606.7	18.7 $^{a–c/0.67}$	**0.0**	5.0 $^{a–d/0.71}$
	Saturn	75.6 $^{ab/5.88}$	71.1 $^{a–g/4.44}$	1610.0	21.0 $^{c–h/0.42}$	0.7	5.7 $^{a–d/0.67}$
	Stanley	77.8 $^{a–f/9.69}$	73.3 $^{a–h/6.67}$	1646.7	22.0 $^{e–j/0.42}$	**0.3**	**4.7 $^{a–c/0.33}$**
	Te Sun	68.9 $^{a–e/5.88}$	66.7 $^{a–e/3.85}$	**1176.7**	20.3 $^{a–g/0.33}$	**0.0**	5.7 $^{a–d/0.67}$
	Average	*83.3* b	*79.1* b	*1525.7* ab	*20.3* ab	*0.3* ab	*5* ab

* letters indicate homogeneous subgroups, letters in italics refer to homogenous subgroups within average values, numbers indicate standard errors; ** inconclusive differences in the interaction (however, the differences between rootstocks and varieties individually are highly statistically significant-data not published).

Another criterion is growth intensity, which is of course influenced not only by the rootstock but also by the grafted variety, the soil conditions (nutrients, water) and the weather conditions (temperature, sunshine). The Brompton rootstock proved to have the strongest impact on growth intensity with an average plant height of 1796 mm, followed by the Torinel rootstock with an average plant height of 1670 mm (Table 2). Saplings on the St. Julien A rootstock were the shortest, averaging 1422.0 mm. In terms of the rootstocks, the average plant height was 1588.5 mm. In terms of rootstock–variety combinations, the tallest plants were obtained at the Brompton–Chrudimská (2143.3 mm), Brompton–October Sun (2043.3 mm), and Wavit–Chrudimská (2023.3 mm) combinations (Figure S2). By contrast, the shortest saplings were obtained at the St. Julien A–Te Sun (1156.7 mm), Wavit–Te Sun (1176.7 mm), and Wavit–Golden Japan (1220.0 mm) combinations. Statistical multiple factor analysis using Tukey's HSD test did not prove significant differences ($p > 0.05$) in height for the rootstock and variety factors. Statistical analysis found significant interactions ($p < 0.05$) between rootstocks and years of evaluation.

The second growth intensity factor, which is related to height, is root collar diameter (Table 2). Here, the order of rootstocks was reversed, with the thickest saplings (nursery plants) being obtained on the Torinel rootstock (an average thickness of 23.3 mm) followed by the Brompton rootstock, where the thickness of the saplings was 22.2 mm. The thickness of the other saplings ranged from 19.3 to 20.3 mm; the average thickness in the evaluated rootstock population was 21.1 mm. When evaluating the rootstock–variety combinations, the Torinel–Chrudimská combination showed the greatest thickness (25.7 mm), followed by the Torinel–Saturn and Torinel–Black Star combinations, both with a thickness of 24.7 mm. By contrast, the thinnest saplings were obtained in the Adesoto–Aphrodite and Adesoto–Flavor Queen combinations, both with a thickness of 18.0 mm (Figure S3). Statistical multiple factor analysis using Tukey's HSD test found significant differences ($p < 0.01$) in root collar diameter for the rootstock and variety factors, which were classified into twelve homogeneous subgroups. Statistical analysis did not prove significant interactions ($p > 0.05$) between rootstocks and years of evaluation.

Root suckering of the rootstock is an important trait that also affects the grafting itself (Table 2). The greater the number of root suckers, the more difficult it is to graft and to work with such a rootstock in a nursery in general. In this case, the Brompton rootstock showed relatively strong root suckering, producing 1.3 suckers per sapling. The other rootstocks produced 0.2–0.5 suckers per sapling (Figure 2). In general, the average root suckering values were 0.5 suckers per sapling. In terms of rootstock–variety combinations, the greatest undesirable root suckering were observed in the Brompton–Chrudimská combination (2.0 suckers per sapling) and the Brompton–Flavor Queen combination (1.7 suckers per sapling) (Figure S4). Statistical multiple factor analysis using Tukey's HSD test did not prove significant differences ($p > 0.05$) in the production of suckers for the rootstock and variety factors. Statistical analysis did not prove significant interactions ($p > 0.05$) between rootstocks and years of evaluation.

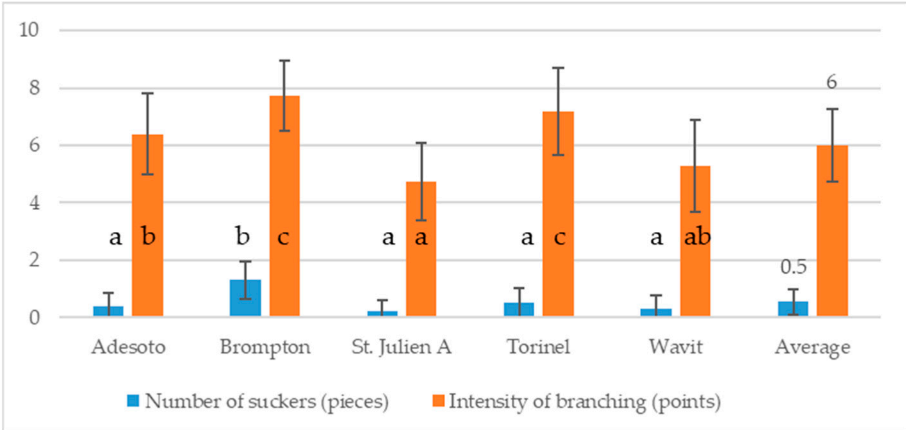

Figure 2. A comparison of the average values for root suckering and shoot formation on the stem of the saplings, by rootstock. Scale bars refer ± standard deviations. Letters refer to statistical grouping according to the Tukey HSD test. Small letters indicate statistically different homogeneous subgroups.

The intensity of branching is more or less a varietal issue, but the influence of the rootstock is also not entirely negligible, especially in relation to growth intensity (Table 2). This theory is supported by the obtained results, which show that the largest number of naturally formed side shoots (at saplings without shortened terminals) that are needed to form a crown are produced by saplings in combination with vigorously growing rootstocks. Therefore, saplings on Brompton–Torinel rootstocks were the most branched (Figure S5). By contrast, the least branched were the saplings on the St. Julien A rootstock. The average branching score for the rootstocks was 6 points, which corresponds to 6–7 shoots/sapling. When evaluating the rootstock–variety interaction, the Brompton–Autumn Giant and Torinel–Autumn Giant combinations were the most branched, with a score of 9 points (i.e., producing 9 or more shoots/sapling). By contrast, St. Julien A–Saturn and Wavit–Golden Japan were the least branched combinations, both scoring 3 points (fewer than 3 shoots/sapling). Statistical multiple factor analysis using Tukey's HSD test found significant differences ($p < 0.01$) in the number of produced shoots for rootstock and variety factors, which were classified into four homogeneous subgroups. Statistical analysis did not prove significant interactions ($p > 0.05$) between rootstocks and years of evaluation.

The last, economically crucial criterion is the yield of saplings at the nursery (Table 2). As before, this trait is determined not only by the rootstock–variety combination but also, for example, by the agricultural equipment used during the cultivation and uprooting of the saplings (nursery plants broken or damaged by machinery, animals, people, etc.), the weather, etc. In our experiment, the highest sapling yield was obtained with the Adesoto (88.5%) and Torinel (86.2%) rootstocks. By contrast, the lowest yield (72.1%) was obtained with the Brompton rootstock (Figure 1). The average rootstock-dependent yield was 80.3%. When evaluating the highest yielding combinations, the Adesoto–Black Star (100%), Torinel–October Sun (98.0%) and Adesoto–Stanley (97.8%) combinations yielded the highest number of saplings (Figure S6). By contrast, the lowest yield was obtained in the St. Julien A–October Sun (57.8%) and Brompton–Chrudimská (60.0%) combinations. Statistical multiple factor analysis using Tukey's HSD test found significant differences ($p < 0.01$) in the yield of saplings for rootstock and variety factors, which were classified into three homogeneous subgroups. Statistical analysis found significant interactions ($p < 0.01$) between rootstocks and years of evaluation.

3.2. Evaluation of the Effect of Varieties on Selected Nursery Traits

As aforementioned, the evaluation of the nursery traits of saplings (nursery plants) is based on rootstock–variety combinations. Just as the rootstock influences the grafted part, the variety also influences the rootstock in a certain way.

The evaluation of average affinity relationships between rootstocks and varieties has shown that the Japanese 'Black Star' variety had the best average affinity (94.7%) followed by the European plum 'Stanley' (89.3%) control variety. 'Autumn Giant' (87.1%) and 'Golden Japan' (86.2%) also had relatively high affinity values. On the other hand, the lowest affinity values were obtained with the 'Flavor Queen' (78.2%) and 'Saturn' (78.7%) varieties (Figure 3). The average affinity value for the entire population of varieties was 84.3%. Statistical multiple factor analysis using Tukey's HSD test found significant differences ($p < 0.01$) between varieties, which were classified into five homogeneous subgroups according to affinity. Statistical analysis found significant interactions ($p < 0.05$) between varieties and years of evaluation.

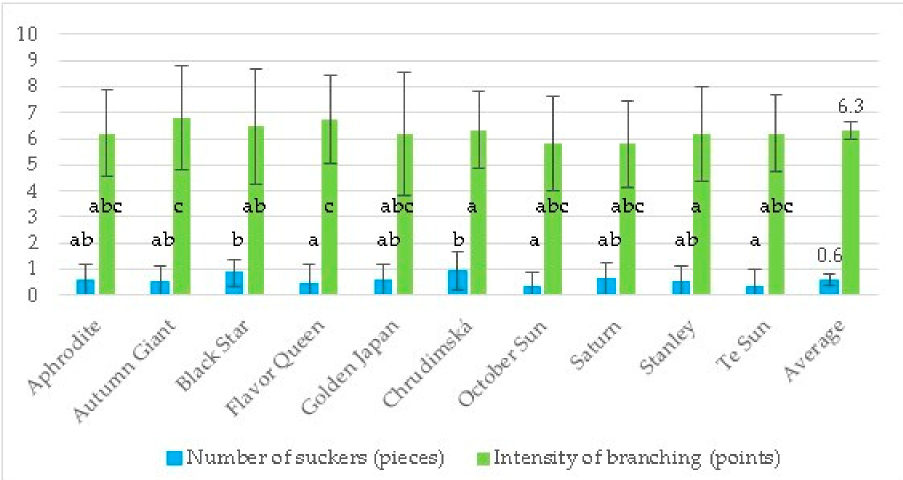

Figure 3. A comparison of the average affinity and yield of saplings, by variety used. Small letters indicate statistically different homogeneous subgroups.

Among varieties, the average highest saplings were obtained with the vigorously growing European 'Chrudimská' (1960.7 mm) as the control variety and the Japanese plum 'Black Star' (1681.3 mm) variety. On the other hand, the lowest growth intensity was recorded at the 'Flavor Queen' (1277.3 mm) and 'Golden Japan' (1350.0 mm) varieties. Statistical multiple factor analysis using Tukey's HSD test found significant differences ($p < 0.01$) between varieties, which were classified into four homogeneous subgroups according to height of saplings. Statistical analysis did not prove significant interactions ($p > 0.05$) between varieties and years of evaluation.

The root collar diameter of the saplings according to variety was the greatest in the European plum 'Chrudimská' (24.2 mm) and 'Stanley' (22.3 mm) control varieties and in the Japanese plum 'Saturn' (22.3 mm) variety (Table 3). The smallest thickness was recorded for the Japanese 'Golden Japan' variety (19.5 mm). Statistical multiple factor analysis using Tukey's HSD test found significant differences ($p < 0.01$) between varieties, which were classified into five homogeneous subgroups according to root neck thickness. Statistical analysis did not prove significant interactions ($p > 0.05$) between varieties and years of evaluation.

When evaluating the effect of the variety on average root suckering (Table 3), the highest number of suckers were produced by nursery plants with the 'Black Star' variety and 'Chrudimská' control variety, with almost 1 sucker per sapling (0.9 sucker per sapling, respectively). By contrast, combinations with the 'Te Sun' and 'October Sun' varieties produced the lowest number of suckers (0.3 suckers per sapling). Statistical multiple factor analysis using Tukey's HSD test found significant differences ($p < 0.05$) between varieties, which were classified into two homogeneous subgroups according to root suckering. Statistical analysis did not prove significant interactions ($p > 0.05$) between varieties and years of evaluation.

Table 3. Average trait values for variety and statistical significance (2019–2021).

Varieties	Affinity of Saplings (%)	Yield of Saplings (%)	Height of Saplings (mm)	Thickness of Saplings (mm)	Number of Suckers (Pieces)	Intensity of Branching (Points)
Saturn	78.7 ^{ab} *	73.3 ^{a}	1618.0 ^{c}	22.3 ^{d}	0.6 ^{ab}	6 ^{bc}
Te Sun	79.1 ^{ab}	74.7 ^{ab}	1277.3 ^{a}	20.2 $^{a–c}$	0.3 ^{a}	6 ^{c}
Flavor Queen	78.2 ^{a}	75.1 ^{ab}	1642.0 ^{c}	20.1 ^{ab}	0.4 ^{a}	7 ^{c}
Aphrodite	81.3 $^{a–c}$	77.3 ^{ab}	1634.0 ^{c}	20.5 $^{a–c}$	0.5 ^{ab}	6 ^{bc}
October Sun	84.0 $^{a–d}$	80. 0 $^{a–c}$	1620.7 ^{c}	20.3 $^{a–c}$	0.3 ^{a}	6 ^{bc}
Chrudimská	84.4 $^{a–d}$	80.9 $^{a–c}$	1960.7 ^{d}	24.2 ^{e}	0.9 ^{b}	4 ^{a}
Golden Japan	86.2 $^{b–d}$	82.2 $^{b–d}$	1350.0 ^{ab}	19.5 ^{a}	0.5 ^{ab}	6 ^{c}
Autumn Giant	87.1 $^{c–e}$	85.3 ^{cd}	1552.0 ^{bc}	21.0 ^{c}	0.5 ^{a}	7 ^{c}
Stanley	89.3 ^{de}	85.3 ^{cd}	1548.7 ^{bc}	22.3 ^{d}	0.5 ^{a}	5 ^{ab}
Black Star	94.7 ^{e}	89.3 ^{d}	1681.3 ^{c}	21.0 ^{c}	0.9 ^{b}	6 ^{c}

letters indicate homogeneous subgroups.

Average branching of the saplings (Table 3) was the strongest at the 'Autumn Giant' and 'Flavor Queen' varieties, both scoring 7 points (7–9 shoots/sapling). By contrast, the two European control varieties, 'Stanley' and 'Chrudimská', were the least branched with an average of 4 points (which corresponds to 3–4 shoots/sapling). Overall, the average branching score was 6 points, which corresponds to the production of 6–7 shoots/sapling (Figure 4). Statistical multiple factor analysis using Tukey's HSD test found significant differences ($p < 0.01$) between varieties, which were classified into three homogeneous subgroups according to trunk branching. Statistical analysis did not prove significant interactions ($p > 0.05$) between varieties and years of evaluation.

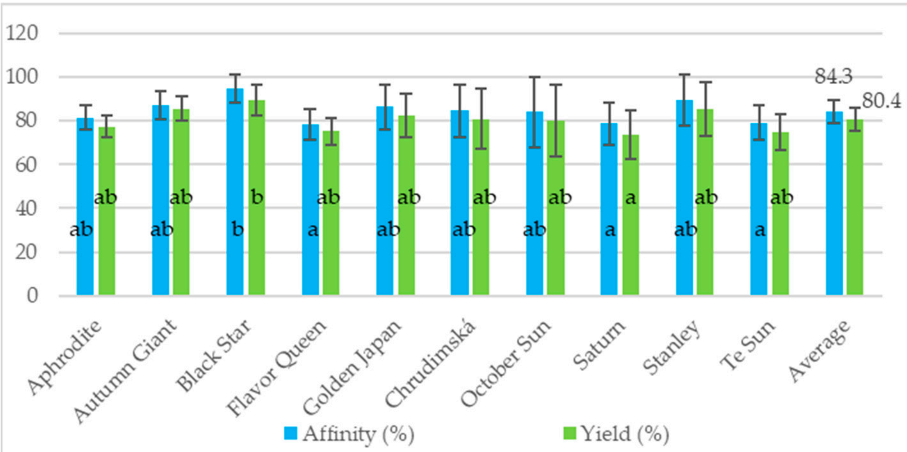

Figure 4. A comparison of the average values for root suckering and shoot formation on the stem of the saplings, by variety used. Small letters indicate statistically different homogeneous subgroups. Statistical analysis revealed that some of the analyzed traits were significantly influenced by the year of evaluation (Table 4). These traits were affinity ($p < 0.01$) and yield of saplings ($p < 0.01$). However, due to significant differences in rootstock–variety combinations at affinity and yield of saplings, the evaluation of interactions between year–rootstock–variety would be complicated and extensive. For this reason, only the annual average values of traits with classification to homogenous subgroups are shown in Table 4.

Table 4. Average trait values in individual years and statistical significance.

Years	Affinity of Saplings (%)	Yield of Saplings (%)	Height of Saplings (mm)	Thickness of Saplings (mm)	Number of Suckers (Pieces)	Intensity of Branching (Points)
Year 2019	72.2 [a]	71.6 [a]	1523.0 [a]	21.2 [a]	0.54 [a]	6 [a]
Year 2020	91.7 [b]	87.5 [b]	1598.0 [a]	21.1 [a]	0.52 [a]	6 [a]
Year 2021	86.0 [c]	82.0 [b]	1644.4 [a]	21.1 [a]	0.56 [a]	6 [a]

* letters indicate homogeneous subgroups.

As stated above, the average yield of saplings is influenced mainly by the rootstock and other agricultural engineering activities at the nursery, but on average it varied from variety to variety (Table 3). The highest yields were obtained with the 'Black Star' (89.3%) variety, followed by the European plum 'Stanley' (85.3%) as the control variety and the 'Autumn Giant' variety. By contrast, the lowest yields were recorded at the 'Saturn' (73.3%) and 'Te Sun' (74.7%) varieties. The average value of the yield of saplings was 80.4% for the entire population of varieties. Statistical multiple factor analysis using Tukey's HSD test found significant differences ($p < 0.01$) between varieties, which were classified into five homogeneous subgroups according to yield. Statistical analysis found significant interactions ($p < 0.05$) between varieties and years of evaluation.

4. Discussion

As with the introduction of new rootstocks into practice, the introduction of new varieties and species in fruit-growing regions requires an initial evaluation that targets many characteristics and that, in turn, will pave the way for their smooth commercial cultivation. In the case of the Czech Republic, this is currently relevant to the slowly expanding cultivation of Japanese plum varieties and possibly various interspecific hybrids.

Evaluations of various characteristics of different types of rootstocks and varieties are a relatively frequent topic of publications. The point is that, in terms of fruit species, variety, location, site conditions, and other such evaluations have an infinite range of results that are suitable exactly for specific combinations of varieties and rootstocks at specific growing sites. In other words, in many cases, what is true for plums growing in Spain may not be true in more northern countries, etc.

Many other studies dealt with improving the qualitative properties of *Prunus* varieties using suitable rootstocks; for example, visual symptoms of 'translocated' incompatibility were only found in the Japanese plum variety. 'Golden Japan' budded on the plum–apricot hybrid AP-45. In the case of the European plum varieties, 'President' and 'Reine Claude Tardive of Chambourcy' exhibited good graft compatibility with all the tested rootstocks, with the exception of 'President' budded on the pentaploid plum hybrid rootstock Damas GF 1869. 'Reine Claude Verte' variety showed localized incompatibility with Myrobalan B and Myrobalan GF 3-1 from the second year after budding. 'Stanley' variety showed localized incompatibility with the six evaluated peach–almond hybrid rootstocks, although it was compatible with all plum-based rootstocks [4]. For example, the affinity of rootstock INRA GF 31, which was bred in France by crossing the east Japanese *P. salicina* with myrobalan, is good with apricots and plums of any species but is not perfect with 'Raineclaude'. Rootstock MRS 2/5 from Italy and another interspecific hybrid (*P. cerasifera* × *P. salicina*) is not recommended for non-irrigated sites. Rootstock Myram is produced in France as a triple hybrid of *P. cerasifera* × *P. salicina* × 'Yunnan' peach and as a rootstock suitable for almond, peach, and plum. Rootstock Citation is also a hybrid of *P. salicina* × *P. persica*. Rootstock Ishtara, a hybrid of *P. cerasifera* × *P. salicina*, which appeared in France, is used mainly for European plums (*P. domestica* L.), but Japanese plums, apricots, peaches, and almond varieties also grow well on this rootstock. Rootstock Fereley Jaspy® (*P. salicina* × *P. spinosa*) is an interspecific hybrid for heavy soils with poor aeration [5].

In the case of Japanese plums, four varieties (Angeleno, Black Amber, Delbarazur and Songold) did not show graft incompatibility, but 'Friar' showed localized incompatibility on Myrobalan B [4]. The effect of two widely used rootstocks, Myrobalan 29C and Montclare, on growth, yield and fruit quality of nine Japanese plum varieties (Sorriso di Primavera, Early Golden, Black Amber, Shiro, Red Beaut, Angeleno, Obilnaya, Black Star a Friar) and 3 European varieties (Stanley, Grossa di Felisio a President) was investigated by Ferlito et al. [8]. As for rootstocks, both Myrobalan 29C and Montclare proved satisfactory for plum cultivation and did not show any limitations. At the time of this evaluation, no apparent graft incompatibility has been recorded. The trunk cross-sectional area measured in the pre-growing season of saplings on Myrobalan 29C was the highest for 'Shiro' and 'Angeleno' and the lowest for 'Grossa di Felisio'. 'Red Beaut' and 'Shiro' on Montclare had the greatest trunk cross-sectional area. The Myrobalan variety 'Obilnaya' and Japanese plum 'Shiro' showed the highest yield on both rootstocks. Total soluble solids values were always higher at plants grafted on Myrobalan 29C, although this difference was significant only for 'Obilnaya' and 'Shiro'.

Within similar studies, interesting results were presented in a paper by Zarrouk et al. [20] that examined the compatibility of peach grafts with a wider group of rootstocks from the genus *Prunus* and their hybrids. In the experiment, 32 rootstocks were evaluated. The results show that no significant incompatibility between the tested rootstocks and peach varieties was found. The variation between growth traits was significant and depended on the specific rootstock–variety combination as shown in our experiment. In contrast, in a study by Rodrigues das Neves et al. [21], plum rootstocks such as Myrobalan 29C and Marianna showed translocated graft incompatibility with peach varieties BRS-Kampai, Jade, and Maciel, and plant death was preceded by a reduction in SPAD index values five months after field planting. The SPAD index can be used as a predictive method to assess graft incompatibility in *Prunus* spp., as long as it is supported by other methods. A study by Jalal et al. [22] investigated the grafting of the European-type Afghani Fazal-e-Manani variety and the Japanese-type Santa Rosa variety on "Swat local" peach seedlings. The results show that the affinity of the Santa Rosa variety was 76.4%, and no significant differences in growth intensity were found between the European-type and Japanese-type varieties. In our study, the differences in growth intensity were significant for both rootstocks and varieties. The differences in growth, i.e., height, were in the range of 150–210 mm for rootstocks and 310–370 mm for varieties. Similar results were obtained in a previous study by Nečas and Lébl [23], which was aimed at evaluating rootstock–variety interactions in pears. The study of Thomidis and Tsipouridis [24] showed highly significant differences in growth characteristics such as height and width, including fertility, within different pear varieties rootstock combinations. It is well proven that affinity-related growth defects are manifest at different stages of graft-rootstock joining and graft development. Adhikari et al. [25] list four stages of graft development at which affinity defects manifest: (1) incision; (2) mechanical adhesion of graft partners; necrotic layer formation at the graft interface; (3) callogenesis and bridge establishment; and (4) cellular redifferentiation and vascular continuity. This means that at different stages of development, different causes of scion-rootstock affinity defects, or disaffinity, may occur. According to Errea et al. [26] no differences were found either in the process of healing or in its kinetics. Thus, callus proliferation, callus differentiation, and vascular connections are established in the same way and at the same time in both compatible and incompatible grafts. However, clear differences exist in the level of differentiation of the callus produced. While in compatible grafts, callus quickly differentiates into cambium and vascular tissue, in incompatible grafts this differentiation is not complete, and a portion of the tissue evolves into a parenchymatous tissue that coexists with the differentiated vascular tissue. Several studies are available to explain incompatibility in woody plants. In these studies, it is reported that various phenolic compounds are known to affect cell division, development, and differentiation at the graft union. Flavonol (catechins and proanthocyanidins) concentrations increase shortly after grafting and, as a result of the stress induced during the healing response, vacuolar membrane disruption occurs, resulting in the escape of phenols from the vacuole into the cytoplasmic matrix, causing dysfunctions in the growth of certain tissues (xylem and phloem), interference with the synthesis of lignin, or inducing hormonal imbalances [27,28].

These factors may of course affect both affinity at the nursery and, above all, affinity at the permanent site.

The results of our study did not indicate that the combinations under evaluation had any internal metabolic changes affecting the affinity of the scions and rootstocks. A study by Reig et al. [29] dealt with the characterization of affinity relationships between apricot varieties and plum-based rootstocks. Their research shows that Marianna and diploid myrobalan (Myrobalan 29C, Miral 3278 AD) rootstocks have poorer affinity with apricots than hexaploid plum rootstocks derived from *P. insititia* and *P. domestica*. In our study, all types of these rootstocks proved to be more or less suitable for Japanese plums. In rootstock versus variety experiments, it is also important to bear in mind that the results of the evaluation of nursery traits may be affected by various external factors, the most important of which include health conditions, such as the associated presence of viral pathogens [30].

5. Conclusions

According to the results, the best performing rootstocks tested for plum cultivars were Adesoto and Torinel, which had the highest affinity (more than 90%, $p < 0.01$) and yield (more than 85%, $p < 0.01$). Next, Wavit gave good results too, with 83.3% ($p < 0.01$) affinity and 79.1% ($p < 0.01$) yield. Saplings were the highest on Brompton (1795.7 mm, $p > 0.05$) and Torinel (1669.0 mm, $p > 0.05$) rootstocks, and varieties grafted on these rootstocks were also the most branched, reaching 7 branches/sapling ($p < 0.01$) for both rootstocks. On the other hand, the least branched saplings were those on St. Julien A and Wavit rootstocks (5.0 branch/saplings, $p < 0.01$). Suckering, a negative characteristic, was the highest at Brompton rootstock (1.3 suckers per saplings, $p > 0.05$), while the lowest was at St. Julien A (0.2 suckers per saplings, $p > 0.05$). When focused on varieties, the highest affinity was reached at combinations 'Black Star'–Adesoto, 'October Sun'–Torinel, 'Stanley'–Torinel (in all cases 100%, $p < 0.01$) and the lowest in general at 'Flavor Queen' (75.1%, $p < 0.01$); however, here, focus should be kept on the interactions between rootstocks and varieties, where the lowest affinity was observed at 'October Sun' grafted on the St. Julien A rootstock (60.0%, $p < 0.01$).

Overall, due to high values of affinity and yield, adequate branching, and low amount of suckering, the Adesoto, Torinel, and Wavit rootstocks could be used as suitable rootstocks for a wider group of Japanese plum varieties that may become increasingly common among the European varieties planted in the Czech Republic.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/horticulturae9030318/s1, Figure S1:mean affinity (%) values across all rootstock/variety combinations; Figure S2: mean highest of saplings (mm) values across all rootstock/variety combinations, Figure S3: mean root collar diameter of saplings(mm) values across all rootstock/variety combinations, Figure S4: mean number of suckers in sapling (pieces) values across all rootstock/variety combinations, Figure S5: mean intensity of branching in sapling (points) values across all rootstock/variety combinations, Figure S6: mean yield of saplings (%) values across all rootstock/variety combinations.

Author Contributions: Conceptualization, T.N. and J.W.; methodology, T.N. and J.W.; formal analysis, T.N., J.W. and I.O.; investigation, I.O.; E.Z. and T.N.; resources, T.N.; data curation, T.N.; writing—original draft preparation, T.N., E.Z. and I.O.; writing—review and editing, E.Z. and T.N.; supervision, T.N.; project administration, T.N.; funding acquisition, T.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research received external funding from projects NAZV-MZe QK1910137.

Data Availability Statement: Not applicable.

Acknowledgments: This research used the infrastructure acquired by project CZ.02.1.01/0.0/0.0/16_017/0002334, the Research Infrastructure for Young Scientists, which is co-financed by the Operational Program of Research, Development, and Education.

Conflicts of Interest: The authors declare no conflict of interest.

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