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RESEARCH ARTICLE

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Tree performances of eight rootstocks grafted with 'Šumadinka' sour cherry

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Abstract

Aim of study: To evaluate the suitability of seven clonal rootstocks and one seedling rootstocks for grafting the sour cherry cv. 'Šumadinka' based on early tree development, precocity, productivity and fruit quality.

Area of study: A sour cherry orchard in village Prislonica, Serbia, near Čačak city.

Material and methods: The sour cherry cultivar 'Šumadinka' was grafted onto Colt, MaxMa 14, Krymsk 6, Adara, Cigančica, Gisela 5, Gisela 6 and Myrobalan rootstocks. Standard and validated procedures were used to measure tree growth, productivity (from 2017 to 2020), leaf area, fruit physical properties and fruit chemical composition (from 2019 to 2020).

Main results: Significant differences were observed among rootstocks in leaf and petiole dimensions, leaf area, tree vigour, yield, fruit size, soluble solids content, titratable acidity, sugars and vitamin C contents, ripening and sweetness indexes. Trees grafted on Adara exhibited the highest tree vigour, while those on Gisela 6 produced the largest fruit size. On the other hand, Colt trees generally displayed the highest sugar content and sweetness index. Adara also showed improvements in fruit quality characteristics, whereas the properties associated with Myrobalan received the lowest evaluation scores.

Research highlights: Adara rootstock demonstrated good adaptability to heavy and acidic soil conditions in Serbia, even though it was originally selected for cherry cultivation in heavy, waterlogged, and calcareous soils in Spain. This adaptability likely contributed to its higher vigour, yield, yield efficiency and good fruit quality.

Additional key words: clonal rootstocks; fruit quality attributes; leaf size; *Prunus cerasus*; tree vigour; yield performance

Abbreviations used: CY (cumulative yield); D_g (geometric mean diameter); FRa (flesh rate); fw (fresh weight); FW (fruit weight); IS (invert sugars); L (fruit length); LA (leaf area); Ll (leaf length); Lw (leaf width); R_a (aspect ratio); RI (ripening index); SI (sweetness index); SL (stem length); SSC (soluble solids content); SU (sucrose); SW (stone weight); T (fruit thickness); TA (titratable acidity); TCSA (trunk cross-sectional area; TS (total sugars); W (fruit width); Y (yield per tree); YE (yield efficiency).

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Introduction

Sour cherry (*Prunus cerasus* L., Rosaceae, $2n = 4x = 32$) alongside with sweet cherry (*P. avium* L., Rosaceae, $2n = 2x = 16$) originated around the Black and Caspian Seas and have been cultivated in temperate and cool regions. According to Pliny Elder (1st century AD), cherries were brought to Ancient Rome from the coasts of the Black Sea in 69 BC by Lucius Lucullus, a colonel in the Roman army. However, some sources suggest that cherries were cultivated in ancient Greece a long time before Lucius Lucullus and spread slowly from their origin to other regions through to human and animal migrations (Moreno & Manzano, 2002).

The sour cherry is cultivated for its sharp tasting and succulent fruit, which is primarily used for various industrial preserves such as jam, juice, puree, concentrate, alcoholic drink, frozen, dried or canned fruit, marmalade, jelly, juice concentrates and confectionery items such as pralines, candies, chocolates and other uses (Milošević et al., 2020). Sour cherry is also used as a rootstock for sweet cherry (Moreno et al., 2001).

By 2021, the world production of sour cherry reached 1.15 million tons (http://faostat3.fao.org). Russian Federation, Ukraine, Turkey, Poland, USA and Serbia are the most important producing countries of sour cherry, accounting for approximately ~72% of the world sour cherry production. In 2021, Serbia produced 155,137 tons of sour cherries (http://faostat3.fao.org). The main sour cherry producing areas in Serbia include the Danube River valley, North Bačka, Toplica and Nišava regions (Milošević, 1997). The area of focus in this study is part of a large fruit growing area known as the Čačak region.

In Serbia, sour cherry is a traditional fruit type with great economic and social importance. It is cultivated across 19,551 ha, primarily on small family farms. The predominant cultivar in Serbian orchards is 'Oblačinska' (over 55%), followed by 'Cigančica' (also called 'CigányMeggy' or 'Cigány') (Milošević & Milošević, 2012). These cultivars are propagated by suckers (without grafting) and produce "morello" type fruits, characterized by small to medium size, and dark red and thin skin. Fruits of 'Oblačinska' are exported to the EU, especially to Germany, often in a frozen state (Milošević et al., 2020). 'Oblačinska' is also utilized as a rootstock and/or interstock for sweet cherry to manage tree vigour inducing approximately 50% less vigorous trees compared to standard sour cherry genotypes (Milošević, 1997). International large-fruit sour cherry cultivars such as 'Rexelle', 'Kelleris 14', 'Kelleris 16', 'Heimanns Konservenkirsche', 'Újfehértói Fürtös', 'Érdi Bőtermő' along with Serbian cultivars such as 'Čačanski Rubin', 'Šumadinka', 'Lara' and 'Sofija' are grown to a lesser extent. Unlike 'Oblačinska' and 'Cigančica', these cultivars are typically grafted onto Mazzard and/or Mahaleb seedlings and occasionally on the clonal 'Colt' rootstock in commercial orchards.

Modern fruit trees consist of two essential components: the rootstock and the cultivar. Therefore, continuous improvement of cultivars must be complemented by the rootstocks that confer optimal horticultural characteristics. While the cultivar plays a major role in determining productivity, fruit quality and economic value, selecting a quality rootstock is equally crucial and often contributes up to 50% of the profitability of a particular fruit type in orchards (Milošević et al., 2018). Similar to other fruit species, rootstocks in cherries affect tree vigour, precocity, yield (Wocior, 2008; Magyar & Hrotkó, 2013; Milošević et al., 2014), fruit quality (Kopytowski & Markuszewski, 2010; Milošević et al., 2020), phenological (San Martino et al., 2008) and physiological properties (Gonçalves et al., 2006; Sarisu et al., 2022), leaf nutrient status (Jiménez et al., 2007; Milošević et al., 2014), response to pest and disease attacks (Calabro et al., 2009) and tolerance/resistance to different abiotic and biotic stresses (Mestre et al., 2017).

The previously cited rootstock effects on the scion are crucial for fruit growing practice since they provide the base for selecting the best rootstock-cultivar combination tailored to specific edaphic-climatic conditions (Cantín et al., 2010). Today, growers and breeders of sour cherry prioritize not only yield, but also better fruit quality, characterized by balanced sugar/acid ratio (Schuster, 2019). Enhanced external and internal fruit quality, coupled with a high number of bioactive compounds, are crucial parameters for consumer acceptance of fresh sour cherries (Siddiq et al., 2011; Milošević et al., 2020). However, it is unlikely that a single rootstock to possess all desired qualities (Hajagos et al., 2012), as specific scion properties may be improved while others may be compromised by a particular rootstock.

The experiences of Serbian farmers with new international, dwarfing and semi-dwarfing clonal rootstocks, as well as intensive growing technologies for sour cherry cultivation are very modest. Additionally, the heavy and acidic soils in this country present challenges for cultivating this fruit tree species (Milošević et al., 2023).

Given the limited experience with new international clonal rootstocks and their influence on sour cherry performance, this study aims to investigate the effectiveness of eight rootstocks grafted with the Serbian large-fruited cultivar 'Šumadinka'.

Material and methods

Plant material and trial layout

In spring 2015, the sour cherry cv. 'Šumadinka' was budded onto seven clonal rootstocks [Colt, MaxMa 14 (syn.: Brokforest, MaxMa Delbard 14), Krymsk 6, Adara, Cigančica (syn.: CigányMeggy), Gisela 5 and Gisela 6] and one generative selection of Myrobalan (seedlings), which were then planted in the field in Spring 2016. 'Šumadinka' was chosen for this experiment due to its large fruits, good cropping and commercial importance in the Serbian sour cherry industry. It was named and released by the Fruit Research Institute, Čačak (Serbia).

The sour cherry trial was located at Prislonica (near Čačak city, western Serbia, 43°33'N and 16°21'E, 300 m above sea level) on heavy, shallow and acidic soil. In this area (moderate climate), the average annual temperature from 2016 to 2020 was 12.9°C and the total annual rainfall was 810.9 mm. The orchard had a clay-loam soil texture with 1.62% organic matter and low soil pH (4.86) in 0-30 cm soil depth. Contents of total N, available P_2O_5 and K_2O, CaO and MgO were 0.16%, 178 mg g^{-1}, 220 mg g^{-1}, 0.39% and 6.2 mg g^{-1} on a dry matter basis, respectively.

Horticultural management practices such as fertilization, training, pruning and weed control were conducted as in a commercial orchard. Fungicides and insecticides were applied as necessary for pest and disease control, following industry standards. Irrigation was not applied.

The experiment was established in a randomized block design with five trees for each rootstock-scion combination in four replicates (n = 20). Guard rows were used to avoid edge effects. Trees were trained to a high-density central leader system - modified Brunner-spindle (4.0 m × 2.0 m or 1,250 trees ha^{-1}).

Measurements

Tree growth, precocity, yield, leaf and stem properties and the primary fruit quality attributes were all observed during the research period.

Tree growth and yield properties

Trunk diameter at 10 cm above the graft union was measured every year at the end of October from 2017 to 2020 using the calliper gauge Starrett 727 (Athol, MA, USA) and was used to estimate tree vigour by trunk cross-sectional area (TCSA, cm^2). Yield per tree (Y, kg) and cumulative yield (CY, kg) of each rootstock-cultivar combination were measured from the harvest data using an ACS System Electronic Scale (Zhejiang, China). The yield efficiency (YE, kg cm^{-2}) was calculated as the ratio of the total CY per final TCSA. Measurements were performed every year.

Leaf and stem properties

Leaf sampling was conducted at mid-summer, i.e. approximately 120 days after full bloom from the middle part of moderate long, (30-40 cm in average) 1-year-old non-bearing shoots of each rootstock-cultivar combination. Twenty-five leaves free of any disease symptoms and defects from four replicates were harvested (n = 100) in 2019 and 2020. The two-year data were averaged. The stem length (SL) was measured using a ruler (cm). The maximum leaf length (Ll, cm) without petiole and leaf width (Lw, cm) of all leaves were measured using a ruler. Leaf area (LA, cm^2) was determined for intact leaves using the L-W method for cherries proposed by Cittadini & Peri (2006). The equation used for calculating leaf area is as follows:

$$LA = K \times (Ll \times Lw) \quad (1)$$

where K is the leaf (constant) factor, which is 0.6612 according to Cittadini & Peri (2006).

Fruit quality properties

During the harvest period, 20 fruits per each individual tree of each rootstock-cultivar combination (n = 100) were randomly picked at commercial harvest by a single person to maintain consistency of maturity grade each season for the period of 2019 to 2020. The two-year data were averaged. Fruits were considered ripe when they no longer grew and exhibited the ground color representative for the 'Šumadinka' cultivar.

The fruit weight (FW) and stone weight (SW) were measured using the digital balance FCB 6K (Kern & Sohn GmbH, Balingen, Germany). The flesh content (%) was calculated by subtracting the SW from the whole FW. Fruit linear dimensions including length [L (mm)], and suture [W (mm)] and equatorial [T (mm)] diameters for each fruit were measured using the calliper gauge Starrett 727 (Athol, MA, USA). The D_g (geometric mean diameter, mm) and R_a (aspect ratio, %) were calculated using formulas proposed by Mohsenin (1980):

$$D_g = (LWT)^{1/3} \quad (2)$$

$$R_a = W/L \times 100 \quad (3)$$

The SSC (°Brix) of fruit juice was measured with the hand refractometer Milwaukee MR 200 (ATC, Rocky Mount, USA) at 20°C. The TA (% of malic acid) was analyzed in juices by titration with 0.1 mol L^{-1} NaOH, up to pH 8.1 using the automatic titration system Metrohm 719S (Titrino, Herisau, Switzerland). The ripening index (RI) was calculated based on the SSC/TA ratio.

The total sugars (TS) and invert sugars (IS) were determined by the official volumetric procedure of Luff-Schoorl (Schneider, 1979). The sucrose (SU) content was calculated according to the relationship: SU = (TS – IS) × 0.95. The results were expressed in % of fresh weight (fw). The SI was based on the TS/TA ratio. Vitamin C was estimated by the Tillmans' method and results were expressed as mg/100 g of fw.

Data analysis

All data obtained in the present study were subjected to analysis of variance (ANOVA) using the Microsoft Office Excel software (Microsoft Corporation, Redmond, WA, USA) and means were separated by the LSD test at $p \leq 0.05$.

Results and discussion

Tree growth, precocity and productivity

In the environmental conditions of the Čačak region, tree growth, as assessed by TCSA, was significantly influenced by rootstock starting from the third year after planting, with different increasing rates of TCSA (Fig. 1). Other authors also reported that rootstocks significantly influenced tree vigour of sour cherries (Hrotkó et al., 1996; Bujdosó et al., 2004). By the fifth (final) year after planting, trees on Adara exhibited the highest TCSA value. In contrast, the lowest TCSA was observed on Myrobalan, although no significant differences were found with the semi-dwarfing Gisela 6 and Krymsk 6 rootstocks. Adara's increased vigour is consistent with findings by Moreno et al. (1995, 1996). Adara was initially selected as a rootstock for sweet cherries, but Moreno et al. (1995) reported good graft compatibility with some sour cherry cultivars both in nursery and orchard conditions. Moreover, in the present trial, this rootstock demonstrated good adaptation capacity to growing conditions, particularly shallow, heavy and acidic soil. As previously suggested by Sorce et al. (2002) in *Prunus* rootstocks, greater growth features may lead to higher TCSA in the 'Šumadinka' scion by enhancing the availability of specific cytokinins (e.g. zeatin riboside) to the shoot.

Currently, the selection and breeding of Myrobalan as rootstock for cherries is the main target of research in some countries (Moreno, 2004; De Salvador et al., 2019). However, in the present experiment, Myrobalan seedlings caused the smallest tree vigour. The trees of cv. 'Šumadinka' on Myrobalan seedlings exhibited visual symptoms such as small, pale or yellow leaves and a large thickening at the graft union, indicating potential graft incompatibility with the 'Šumadinka' sour cherry. Consequently, Myrobalan seedling should not be recommended for production practice. On Gisela 6, the trees also displayed low vigour and unexpectedly smaller size compared to those on Gisela 5. These results contradicted the findings of Bujdosó et al. (2004), who stated that the Gisela 5 rootstock appeared to induce excessive dwarfing. It is possible that Gisela 6 and Krymsk 6 require a longer period of adaptation to shallow, heavy and acidic soils. Similarly, Wociór (2008) reported that trees of 'Łutówka' sour cherry grafted on Colt rootstock exhibited stronger growth than those on Mazzard seedlings in the first years after planting, despite Colt being considered a less vigorous rootstock. However, on fertile soils with vigorous scion cultivars, a reduction in tree size is often desirable for reduced pruning, thinning and picking costs. Additionally, lower vigour and increased tree density in the orchard allow the possibility of establishing pedestrian orchards leading to reduced labour costs (Jiménez et al., 2007). Agricultural economists have have also demonstrated that it takes eight years to recover the investment for

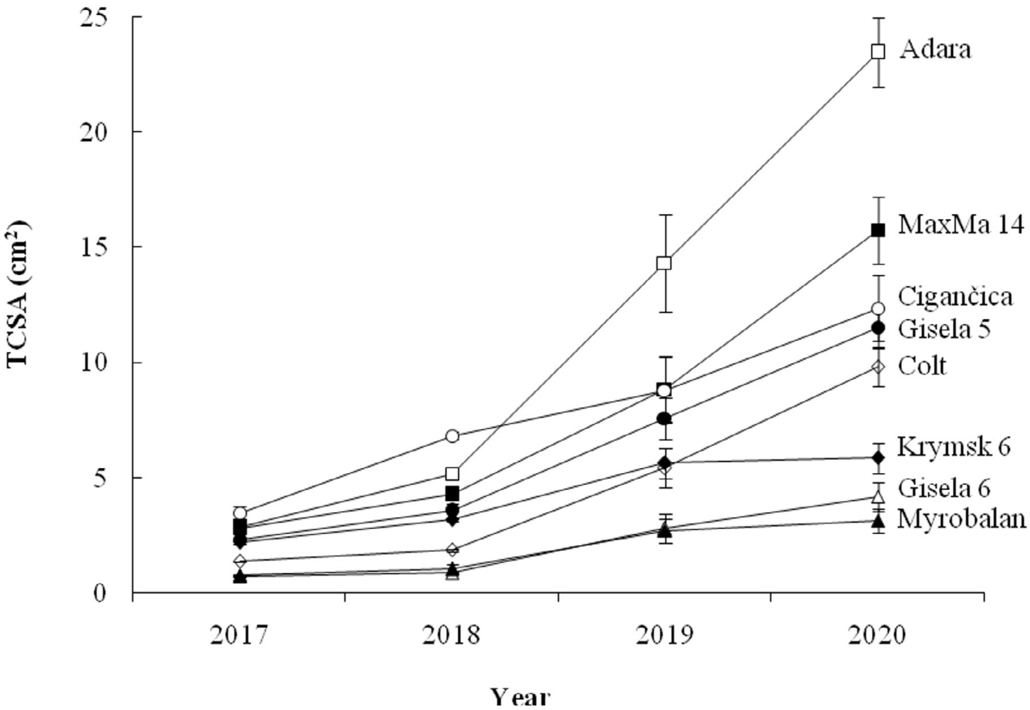

Figure 1. Effect of rootstock on trunk cross-sectional area (TCSA) of 'Šumadinka' sour cherry cultivar from the second (2017) to the fifth (2020) year after grafting.

moderately dense planting on Gisela rootstocks, compared to up to 15 years for an orchard with standard trees on Mazzard rootstock.

In the first two bearing years (2018-2019), yields were very low, and there were no significant differences observed among rootstocks (data not shown). However, 'Šumadinka' began to produce fruit in the second year after planting, consistent with our earlier findings regarding this cultivar (Milošević, 1997). Significant differences among rootstocks became evident in the last cropping year (2020) (Table 1). The highest average yield per tree (Y) on heavy, shallow and acidic soil was induced by the invigorating Adara, the semi-vigorous MaxMa 14 and the dwarfing Gisela 5 rootstocks with no significant differences among them. However, sour cherry trees on Gisela 5 in intensive orchards yielded less than more vigorous clonal rootstocks, as reported by Bujdosó et al. (2004). Possible reasons for discrepancias between our results and those of other authors for that rootstock include tree age, training system, cultural practices and site conditions.

Colt, Gisela 6 and the Myrobalan seedlings induced the lowest and statistically similar yields. These rootstocks also promoted the lowest and similar CY for the last two years of the trial, whereas the highest CY was observed with Adara and Gisela 5, respectively. Other authors have also reported that rootstocks significantly affected the yield of sour cherry (Hrotkó et al., 1996; Bujdosó et al., 2004; Kopytowski & Markuszewski, 2010; Magyar & Hrotkó, 2013). In a study of Anderson et al. (1996), MaxMa 14 induced the heaviest yield in comparison with other clonal rootstocks, whereas Wocior (2008) reported that Colt induced moderate productivity, which partially confirmed our results. Krymsk 6 and Cigančica exhibited an intermediate level of yield per tree. Nevertheless, Long et al. (2019) noted that Krymsk 6 rootstock produced sufficient cherry yields for growers to exceed all costs of production. The low Y and CY values observed with Myrobalan in the current study are likely due to the rootstock's incompatibility with the cv. 'Šumadinka' which significantly restricts its application in the production of sour cherries.

The YE is a complex index that accounts the relationship between production and tree growth. Gisela 5 trees outperformed trees on other rootstocks in terms of YE, with Krymsk 6 trees coming in second (Table 2). Jadczuk et al. (1998) found that smaller sour cherry trees on dwarf rootstocks prompted higher YE compared to more vigorous trees or invigorating rootstocks. The lowest YE were observed in Colt trees, probably due to their low CY and relatively high tree vigour as assessed by TCSA. Similar findings were reported by Bujdosó et al. (2004) for the same rootstocks.

Leaf and stem properties

Determination of leaf dimensions and its area is an important criterion in understanding various physiological processes such as respiration, transpiration, photosynthesis, light interception, water and nutrient use, flowering, fruit set, crop growth, yield, and fruit quality (Barlow, 1980; Picchioni & Weinbaum, 1995). The trees on Adara, Colt and MaxMa 14 had the largest Ll in this investigation (Table 2). Myrobalan and Gisela 5 induced the lowest values with no significant differences between them. Rootstocks such as MaxMa 14, Colt, Myrobalan, Adara and Cigančica induced the highest and statistically similar leaf width (Lw), whereas the smallest was observed in trees on Krymsk 6. In the study of Pérez-Sánchez et al. (2008), Ll and Lw of sour cherries were between 8.96-11.19 cm and 4.47-6.78 cm respectively, which is consistent with our results.

Table 1. Impact of rootstocks on yield performance of 'Šumadinka' sour cherry grafted on eight rootstocks at the fifth year after planting.

Rootstock	Yield, kg tree^{-1} (Year 2020)	Cumulative yield, kg tree^{-1} (2018-2020)	Yield efficiency, kg cm^{-2} (Year 2020)
Colt	0.89 ± 0.07 c	1.05 ± 0.07 e	0.117 ± 0.01 e
MaxMa 14	4.11 ± 0.36 a	6.04 ± 0.36 b	0.481 ± 0.07 bc
Krymsk 6	2.16 ± 0.15 b	2.40 ± 0.15 d	0.507 ± 0.06 b
Adara	4.61 ± 0.32 a	6.72 ± 0.32 a	0.342 ± 0.04 cd
Cigančica	2.47 ± 0.36 b	3.15 ± 0.36 c	0.311 ± 0.05 d
Gisela 5	4.51 ± 0.37 a	7.39 ± 0.37 a	0.761 ± 0.11 a
Gisela 6	1.14 ± 0.12 c	1.38 ± 0.12 e	0.441 ± 0.06 bcd
Myrobalan	0.69 ± 0.10 c	0.83 ± 0.10 e	0.425 ± 0.08 bcd

For each rootstock, cumulative yield and yield efficiency correspond to the first three bearing years of trees in the rootstock trial. Values are the mean ± standard error. Data with the same letter within a column are not significantly different at $p \leq 0.05$ level as determined by LSD test.

Regarding LA, significant differences among rootstocks were observed (Table 2). The more vigorous rootstocks such as Colt, MaxMa 14, Adara and Cigančica promoted the highest and statistically similar values, while the semi-dwarf Krymsk 6 induced the lowest LA. These findings align closely with those proposed by Cittadini & Peri (2006) who, suggested estimating LA for cherry trees by multiplying the product of Ll and Lw with a coefficient usually between 0.67 and 0.75, i.e. 0.6612. In our previous study on pear (Milošević et al., 2015), we also found significant effect of rootstocks on leaf dimensions and LA. As noted by Rouphael et al. (2010), it can generally be inferred that leaves of 'Šumadinka' on Colt, MaxMa 14, Adara and Cigančica may receive more sunlight and thus be more photosynthetically active, leading to increased carbohydrate production available for enhanced vegetative growth. However, it's important to consider that fruit trees with higher LA may be more susceptible to pest and disease colonization, and have higher transpiration (Vanneste et al., 2004).

For centuries, stems of cherries have been used in traditional medicine as a diuretic and for the treatment of urinary tract infections, the prevention of cardiovascular diseases, and lowering blood pressure and cholesterol probably due to its wider availability (Švarc-Gajić et al., 2018). In fruit trees, they represent the connection between fruit and bearing shoots. Fresh fruits for markets are picked with the stalk. As depicted in Table 2, the ANOVA showed that rootstock significantly affected the SL. Adara induced the highest value, whereas the lowest and statistically similar values were produced by Myrobalan and Gisela 6, respectively. To the best of our knowledge, no research has previously examined the impact of rootstock on cherry stems.

According to Vercier (1934), sour cherries can be classified into three groups based on the length of the stalk: short (less than 35 mm), medium-long (35-50 mm) and long (greater than 50 mm). Therefore, it can be stated that 'Šumadinka' belongs to the group of cultivars with a short stalk, which is a desirable feature in the trade of fresh fruits. In the studies of Pérez-Sánchez et al. (2008), SL of commercial sour cherries varied between 3.34 and 4.81 cm. Conversely, Radičević et al. (2012) reported values ranging from 4.26 to 5.01 cm, respectively, for promising genotypes of wild sour cherry populations. From all these studies, it is evident that the scion genotype exerts a strong influence on this trait.

Fruit physical properties

Fruit physical properties evaluated during the last cropping year (2020) were significantly affected by rootstocks (Tables 3 and 4), consistent with findings of previous cherry rootstock studies (Cantín et al., 2010; Long et al., 2019; Milošević et al., 2020). Gisela 6 induced the highest FW of 'Šumadinka', followed by Adara and Gisela 5, while Myrobalan resulted in the lowest FW (Table 3), with a reduction of ~33% compared to Gisela 6. Rootstocks such as Cigančica, Colt, MaxMa 14 and Krymsk 6 induced statistically similar FW, suggesting comparable potential to enhance FW under heavy and acidic soil conditions. Higher fruit weight is advantageous from the processing stendpoint, as it reduces solid waste (mainly pits) per ton of processed cherries (Siddiq et al., 2011). Generally, FW is influenced by crop load, with a noted relationship between lower yields in some years and higher FW and vice versa (Moreno et al., 2001). In addition, Blagojević et al. (2006) and Nenadović Mratinić et al. (2006) reported average FW for 'Šumadinka' of 7.40 g and 7.57 g, respectively, consistent with our data. Although most sour cherries are processed, a small portion of the 'morello' fruit in Europe is sold at a premium on the fresh market. According to Iezzoni (1996), fruits weighing 6-8 g are preferred, aligning with the FW observed in our trial.

Significant differences were observed among rootstocks, despite the typically stable and genetically regulated nature

Table 2. Leaf linear dimensions, leaf area and fruit stem length of 'Šumadinka' sour cherry cultivar grafted on eight rootstocks at the fifth year after planting.

Rootstock	Leaf length (cm)	Leaf width (cm)	Leaf area (cm^2)	Stem length (cm)
Colt	10.23 ± 0.15 a	5.33 ± 0.14 a	36.23 ± 1.34 a	3.19 ± 0.07 c
MaxMa 14	9.99 ± 0.11 a	5.48 ± 0.07 a	36.29 ± 0.78 a	3.46 ± 0.09 b
Krymsk 6	8.00 ± 0.11 d	4.24 ± 0.08 c	22.51 ± 0.63 d	3.40 ± 0.08 b
Adara	10.24 ± 0.19 a	5.31 ± 0.07 a	36.11 ± 1.09 a	3.68 ± 0.09 a
Cigančica	9.65 ± 0.26 b	5.07 ± 0.14 ab	32.79 ± 1.79 ab	3.18 ± 0.07 c
Gisela 5	8.96 ± 0.20 c	4.70 ± 0.08 b	28.03 ± 1.00 c	3.43 ± 0.08 b
Gisela 6	9.52 ± 0.16 b	4.75 ± 0.10 b	29.98 ± 0.95 bc	2.86 ± 0.08 d
Myrobalan	8.55 ± 0.15 c	5.33 ± 0.18 a	30.43 ± 1.42 bc	2.84 ± 0.07 d

For each rootstock, values are the mean ± standard error, with data correspond to the years 2019 and 2020. Data with the same letter within a column are not significantly different at $p \leq 0.05$ level as determined by LSD test.

of SW in *Prunus* spp. Stones of 'Šumadinka' grafted onto Adara and Gisela 5 showed the highest values, whereas the lowest SW was induced by Krymsk 6. A previous study by Milošević et al. (2014) confirmed the rootstock influence on this trait.

The flesh rate (FRa) or fruit flesh percentage represents the edible part of the fruit (mesocarp and skin) in the total FW and is an important parameter for the processing industry due to lower losses of raw material and desirable properties for consumers (Milošević et al., 2014, 2020). Đorović & Živaljević (1980) declared that if the percentage of stone in sour cherry is less than 10%, it can be used as a raw material for processing.

In the present trial, trees on Krymsk 6 and Gisela 6 produced the highest and similar FRa, followed by Colt, whereas the lowest value was observed on Myrobalan. One possible explanation is that Krymsk 6 had a smaller SW than Colt, Myrobalan, and Cigančica. Milutinovic et al. (2008) also found a significant rootstock influence on the fruit flesh percentage but reported smaller values than those observed in the present study.

Fruit shape and size are determined by fruit dimensions. Trees of 'Šumadinka' grafted on Gisela 6, Gisela 5 and Adara were statistically similar with the highest fruit length (L), whereas on Gisela 6 and Adara were similar with the highest fruit width (W) (Table 4). Gisela 6 promoted the highest fruit thickness (T). The lowest values of all three dimensions were produced by Myrobalan. For example, the reduction in T was 14% on Myrobalan compared to Gisela 6. Overall, Gisela 6 was the best rootstock in improving fruit size. In other studies on sour cherries, rootstocks also significantly affected fruit dimensions (Kopytowski & Markuszewski, 2010). In our trial, Gisela 6, Gisela 5 and Adara induced fruit diameters >24 mm. This is the minimal accepted limit for the diameter of sweet cherries in Serbia intended for export to the foreign market (Milošević et al., 2014). Lower average fruit diameter of sour cherry on clonal rootstocks than those obtained in this study was recorded by Bujdosó et al. (2004) and Milošević et al. (2020) for the same cultivar. Adequate fruit size and fruit equatorial diameter (thickness) is absolutely essential for good commercial cherry market value (Whiting et al., 2005). Consumers and retailers prefer 'morello' type sour cherries that have large and sweeter fruits with short, green stems (Iezzoni, 1996; Schuster, 2019).

Knowledge related to the D_g would be valuable in designing the grading process as the R_a relates the W to the L of the fruit, indicating its tendency toward an oblong shape (Mohsenin, 1980). Data summarized in Table 4 revealed that Gisela 6 and Adara rootstocks induced similar and the highest values of both D_g and R_a. The lowest D_g value was observed in trees on Myrobalan, whereas the lowest and statistically similar R_a was produced by Myrobalan and Cigančica. Pérez-Sánchez et al. (2008) reported that the average D_g of sour cherries evaluated in their study varied between 16.57 mm and 20.49 mm, whereas Milinović et al. (2012) noted values between 18.37 mm and 22.75 mm. Hence, fruits from trees of 'Šumadinka' on Myrobalan and Cigančica rootstocks had more elongated (heart-shaped) fruits compared to other rootstocks. In all the other rootstocks, fruits were oblate in shape and had a relatively uniform shape factor.

Fruit chemical properties

Regarding the SSC, fruits of 'Šumadinka' on Krymsk 6 had the highest values, while those on Gisela 5 had the lowest average values (Table 5). Fruits on Cigančica had the highest average TA, while the lowest TA value was found on Colt. In contrast, fruits of 'Šumadinka' on Colt had the highest RI mean value, with the lowest value observed for Cigančica. The effect of different rootstocks on SSC, TA and RI in sour cherries has also been found to

Table 3. Fruit and stone weight and flesh rate of 'Šumadinka' sour cherry cultivar grafted on eight rootstocks at the fifth year after planting.

Rootstock	Fruit weight (g)	Stone weight (g)	Flesh rate (%)
Colt	7.25 ± 0.12 cd	0.57 ± 0.01 c	92.05 ± 0.17 bc
MaxMa 14	6.94 ± 0.11 d	0.60 ± 0.01 bc	91.35 ± 0.19 d
Krymsk 6	7.16 ± 0.20 d	0.51 ± 0.02 d	92.76 ± 0.32 a
Adara	7.95 ± 0.11 b	0.69 ± 0.02 a	91.29 ± 0.31 d
Cigančica	7.17 ± 0.11 cd	0.59 ± 0.01 bc	91.67 ± 0.23 cd
Gisela 5	7.62 ± 0.12 bc	0.66 ± 0.01 a	91.32 ± 0.23 d
Gisela 6	8.48 ± 0.20 a	0.62 ± 0.01 b	92.56 ± 0.26 ab
Myrobalan	6.10 ± 0.12 e	0.58 ± 0.01 c	90.47 ± 0.28 e

For each rootstock, values are the mean ± standard error, with data correspond to the years 2019 and 2020. Data with the same letter within a column are not significantly different at p ≤ 0.05 level as determined by LSD test.

be significant by other authors (Kopytowski & Markuszewski, 2010). However, Milutinovic et al. (2008) reported that rootstock did not significantly influence SSC and TA. These discrepancies may be due to the different cultivars and rootstock used, as well as factors such as season, crop load, training system, cultural practices and edapho-climatic conditions (Kopytowski & Markuszewski, 2010; Lakatos et al., 2014). The variations in SSC and acidity are commonly observed. Pérez-Sánchez et al. (2008) noted that SSC and TA varied from 15.34 to 17.52 °Brix and 0.62 to 1.37%, respectively, whereas Siddiq et al. (2011) reported values of 13.7 to 20.2 °Brix and 1.13 to 1.41%, respectively. Grafe & Schuster (2014) reported that TA in sour cherry varied from 1.3-3.1 g malic acid per 100 g fresh weight. All these studies indicate that the above compounds mostly depend on the cultivar, rootstock, fruit maturity stage and climatic conditions during fruit ripening. Higher SSC have been shown to provide processing benefits, particularly when making cherry juice concentrate, according to Siddiq et al. (2011). Namely, the cherry juice with a higher soluble solid level as a starting material would save time and energy, resulting in lower processing costs for the cherry concentrate industry. In the present study, the SSC values were much lower compared to other studies, whereas the contents of TA were within the limits of them. The main reason could be that rainy and cold weather was common during the fruit ripening period (data not shown). Otherwise, SSC, TA and RI (SSC/TA ratio) are key factors in determining the consumer's acceptability in stone fruits, including cherries (Crisosto et al., 2003). These authors also reported that sour cherry is a fruit characterized by exceptionally sour taste with intense overall aroma. In sour cherry fruit sourness is primarily affected by the presence of organic acids,mainly malic acid. In general, consumers usually prefer cherries with higher SSC/TA ratios and visual skin colour. Papp et al. (2010) and Wojdyło et al. (2014) noted that RI in sour cherries varied from 9.6 to 15.8 and/or from 5.8 to 15.3, respectively, which confirms our results. In addition, sour cherries with RI ≥ 11.0 have a balanced flavour and are suitable for fresh consumption, although which this was not case in this study. However, fruit of 'Šumadinka' could be recommended for this purpose in certain cases (Milošević, 1997).

The data in Table 6 revealed that rootstocks significantly affected the sugar content in fruits of 'Šumadinka' sour cherry, which agrees with earlier studies on this fruit type (Milutinovic et al., 2008; Kopytowski & Markuszewski, 2010). The highest IS and TS values were induced by Colt, whereas the lowest values were found with Cigančica. Comparing Cigančica to Colt, the decrease in IS and TS content was 36% and 35%, respectively.

Sweetness in cherry fruit is mainly influenced by IS (glucose and fructose), while sourness is primarily caused by the presence of organic acids (Proietti et al., 2019).

Krymsk 6 induced the highest SU content in fruits of cv. 'Šumadinka', followed by Colt and Myrobalan. Nevertheless, sucrose content in cherries is not as abundant as the fructose and glucose individual soluble sugars. In this trial, MaxMa 14 produced the lowest sucrose content although it did not significantly differ from Adara, Gisela 5 and Gisela 6. In the study of Kopytowski & Markuszewski (2010), TS content significantly varied among cultivars and rootstocks ranging from 5.4% in fruits of 'English Morello' on Mazzard to 7.6% in 'Újfehértói Fürtös' on Mahaleb. Similar tendencies were found by Milutinovic et al. (2008) who noted that on the Oblačinska clonal rootstock, TS and IS in fruits of 10 promising clones of 'Oblačinska' genotype varied from 6.5% to 10.6% and from 3.7% to 6.0%, respectively. On Mahaleb seedlings those traits ranged from 6.2% to 10.3% and 4.4% to 5.9%, respectively. Our sugar content values were comparable to those obtained by Nenadović Mratinić et al. (2006) for cv. 'Šumadinka' and by Radičević et al. (2012) for other commercial sour cherries grown under Serbian conditions.

A high and balanced sugar-acid ratio is imposed as an imperative goal in many sour cherry breeding programs

Table 4. Fruit linear dimensions, size and shape of 'Šumadinka' sour cherry cultivar grafted on eight different rootstocks at the fifth year after planting.

Rootstock	Fruit length (mm)	Fruit width (mm)	Fruit thickness (mm)	Geometric mean diameter (mm)	Aspect ratio (%)
Colt	21.18 ± 0.15 cde	21.03 ± 0.19 c	23.63 ± 0.14 d	21.91 ± 0.13 c	99.30 ± 0.78 c
MaxMa 14	20.89 ± 0.16 e	20.96 ± 0.18 c	23.69 ± 0.15 d	21.80 ± 0.13 c	100.41 ± 0.79 bc
Krymsk 6	21.14 ± 0.22 de	20.98 ± 0.23 c	23.32 ± 0.27 e	21.78 ± 0.22 c	99.31 ± 1.00 c
Adara	21.50 ± 0.19 abc	22.06 ± 0.20 a	24.71 ± 0.14 b	22.71 ± 0.13 ab	102.73 ± 1.13 a
Cigančica	21.31 ± 0.15 bcd	20.71 ± 0.20 c	23.37 ± 0.18 e	21.77 ± 0.15 c	97.17 ± 0.70 d
Gisela 5	21.62 ± 0.14 ab	21.66 ± 0.19 b	24.24 ± 0.13 c	22.50 ± 0.12 b	100.19 ± 0.89 c
Gisela 6	21.70 ± 0.19 a	22.05 ± 0.22 a	25.16 ± 0.25 a	22.92 ± 0.18 a	101.67 ± 1.02 ab
Myrobalan	20.31 ± 0.18 f	19.68 ± 0.17 d	21.60 ± 0.19 f	20.51 ± 0.13 d	97.01 ± 1.17 d

For each rootstock, values are the mean ± standard error, with data correspond to the years 2019 and 2020. Data with the same letter within a column are not significantly different at $p \leq 0.05$ level as determined by LSD test.

around the world. Due to their high acidity and the low sugar content as well as the small fruit size of most cultivated cultivars, sour cherry is mainly used in fruit processing (Schuster, 2019). In our trial, SI or sugar/acid ratio was highest in the trees on Colt, followed by Myrobalan and Gisela 6. Consumers acceptance appears to be dependent on the ratio between sugar and acid contents in stone fruits including cherries (Crisosto et al., 2003). Interestingly, Myrobalan was the rootstock that generally produced the poorest agronomical and pomological properties evaluated in this study with the exception of SI value, which may be attributed to lower fruit acid content. Therefore, while some rootstocks may be a good choice for improving certain traits, they may negatively impact others (Hajagos et al., 2012).

The lowest SI value was produced by Cigančica due to its low TS content and high acidity. Fruits of 'Šumadinka' on this rootstock are more suitable for juice and other processing industries, as acidity is one of the major contributors to the flavour of products (Siddiq et al., 2011). In addition, high sugar content and, to a lesser extent, high acid content seem to increase fruit quality as evaluated by consumers (Callahan, 2003; Crisosto et al., 2003). Otherwise, Radičević et al. (2012) reported SI values between 10.30 and 14.11, which are much higher than those obtained in our study.

Fruit of sour cherries is a rich source of primary and secondary compounds that possess many biological activities with high health benefits (Ferretti et al., 2010). Among others, total anthocyanins and hydrosoluble (C, B) and liposoluble (A, E and K) vitamins play an important role as constituents of these phytochemicals. In this trial, trees on Cigančica rootstock produced the highest vitamin C content, followed by MaxMa 14 and Krymsk 6 rootstocks. The lowest content of this compound was promoted by Colt rootstock. On Colt, the reduction in vitamin C was 22% less than on Cigančica. Kopytowski & Markuszewski (2010) also reported a significant effect of rootstock and cultivar on the vitamin C

Table 5. Soluble solids content, acidity and ripening (maturity) index of 'Šumadinka' sour cherry grafted on eight different rootstocks at the fifth year after planting.

Rootstock	Soluble solids content (°Brix)	Titratable acidity (%)	Ripening index
Colt	11.95 ± 0.03 b	1.44 ± 0.01 h	8.30 ± 0.03 a
MaxMa 14	11.66 ± 0.03 c	1.82 ± 0.00 b	6.41 ± 0.02 g
Krymsk 6	12.32 ± 0.22 a	1.76 ± 0.00 c	7.00 ± 0.14 e
Adara	11.10 ± 0.08 d	1.54 ± 0.01 e	7.21 ± 0.07 d
Cigančica	11.77 ± 0.13 c	1.93 ± 0.00 a	6.09 ± 0.07 h
Gisela 5	10.77 ± 0.06 e	1.59 ± 0.01 d	6.79 ± 0.06 f
Gisela 6	11.17 ± 0.09 d	1.51 ± 0.01 f	7.40 ± 0.08 c
Myrobalan	11.18 ± 0.10 d	1.48 ± 0.01 g	7.70 ± 0.10 b

For each rootstock, values are the mean ± standard error, with data correspond to the years 2019 and 2020. Means followed by the same letter in each column are not significantly different at $p \leq 0.05$ according to LSD test

Table 6. Sugars content, sweetness index and vitamin C content of 'Šumadinka' sour cherry cultivar grafted on eight rootstocks at the fifth year after planting.

Rootstock	Invert sugars (%)	Sucrose (%)	Total sugars (%)	Sweetness index	Vitamin C (mg / 100 g)
Colt	10.52 ± 0.08 a	0.58 ± 0.02 b	11.32 ± 0.10 a	7.86 ± 0.08 a	10.91 ± 0.07 h
MaxMa 14	7.45 ± 0.02 e	0.44 ± 0.03 d	8.02 ± 0.07 g	4.41 ± 0.04 g	13.70 ± 0.02 b
Krymsk 6	7.70 ± 0.37 e	1.00 ± 0.04 a	8.80 ± 0.14 f	5.00 ± 0.09 f	12.73 ± 0.01 c
Adara	9.27 ± 0.20 c	0.49 ± 0.01 cd	10.00 ± 0.02 d	6.50 ± 0.03 d	11.73 ± 0.01 e
Cigančica	6.75 ± 0.01 f	0.51 ± 0.03 c	7.35 ± 0.14 h	3.80 ± 0.07 h	14.07 ± 0.02 a
Gisela 5	8.33 ± 0.03 d	0.47 ± 0.02 cd	9.12 ± 0.02 e	5.75 ± 0.04 e	12.08 ± 0.00 d
Gisela 6	9.50 ± 0.16 bc	0.47 ± 0.02 cd	10.20 ± 0.02 c	6.76 ± 0.03 c	11.48 ± 0.01 f
Myrobalan	9.62 ± 0.04 b	0.61 ± 0.01 b	10.40 ± 0.02 b	7.16 ± 0.07 b	11.36 ± 0.03 g

For each rootstock, values are the mean ± standard error, with data correspond to the years 2019 and 2020. Data with the same letter within a column are not significantly different at $p \leq 0.05$ level as determined by LSD test.

content in sour cherry. In their study, vitamin C was higher in fruits from trees on F12/1 clonal rootstock compared to Mazzard and Mahaleb seedlings. Our range of values for the vitamin C content was much higher than those obtained by Kopytowski & Markuszewski (2010) and Ferretti et al. (2010) and much smaller than the data found by Wojdyło et al. (2014) and Borowy et al. (2017). This variation may be attributed to differences in cultivars,rootstocks, maturity stage, season, cultural practices and environmental conditions (Lakatos et al., 2014; Proietti et al., 2019).

The results of this study showed that under shallow, heavy and acidic soil growing conditions, trees grafted on the semi-dwarfing Gisela 6 rootstock and the invigorating Myrobalan seedlings tended to exhibit excessive dwarfing and low yields. Trees of 'Šumadinka' on Myrobalan were to be too small in size, unhealthy, displaying visual symptoms of graft incompatibility and were consequently not recommended for usage in commercial orchards. Also, tree growth, yield performance and fruit physical properties on Krymsk 6 were found to be unsatisfactory for the fruit industryAs expected, better tree growth was found on the invigorating Adara and the intermediate vigorous MaxMa 14 and Cigančica rootstocks. The best productivity and fruit size were obtained from Adara and the dwarfing Gisela 5 rootstocks. Adara initially selected for cherry growing on heavy, calcareous soils, demonstrated good adaptation to heavy, acidic soils resulting in higher yield, vigour, yield efficiency and good fruit quality. This rootstock also exhibited the best leaf physical traits. While MaxMa 14 and Cigančica rootstocks showed good yield and some fruit quality properties of further examination is needed to fully understand their potential for growers in similar pedo-climatic conditions. However, 'Šumadinka' cultivar grafted on Gisela 5 and Gisela 6 exhibited better fruit physical properties but possessed the poorest fruit chemical composition.Additionally, the inconsistent and unstable behaviour of 'Šumadinka' grafted on several rootstocks, especially on Gisela 5, Gisela 6 and Colt, requires further examination in future trials to determine the underlying causes and potential solutions.

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