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EARLY PERFORMANCE OF FOUR SWEET CHERRY CULTIVARS GRAFTED ON GISELA 5 AND COLT ROOTSTOCKS IN A HIGH DENSITY GROWING SYSTEM

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ABSTRACT

Growing the sweet cherry on different vigor rootstocks, such as Colt and Gisela 5, in a high-density orchard, causes differences in growth and productivity and later imposes the need to change the growing system including pruning, flower and fruit thinning, irrigation and fertilization. In the present research, four sweet cherry cultivars (Summit, Kordia, Lapins and Regina) grafted on Colt and Gisela 5 rootstocks were assessed for morphological traits and productivity. The parameters investigated were: vegetative growth, bearing potential, fruit set, precocity, productivity, fruit growth habit and quality attributes. Compared to Colt, the trees on Gisela 5 had smaller TCSA and the length of two-year-old branches, in the fifth season after planting. Trees on Gisela 5 had a higher number of flower buds per may bouquet compared to Colt, which confirms that bearing potential is highly affected by the rootstock. Growing the sweet cherries on Gisela 5 induced a higher fruit setting in all cultivars except in Kordia. Fruit physical attributes were affected by the cultivar, growing system and experimental year. For all tested cultivars, the yield per tree was significantly lower on Colt compared to Gisela 5. Gisela 5 performed better than Colt, which suggests that Gisela 5 should be used as a rootstock in high density sweet cherry production systems.

Key words: vegetative growth, two-year-old branch, bearing potential, fruit set, yield, productivity

INTRODUCTION

The most important factors that should be considered before choosing the right rootstock for growing sweet cherries (*Prunus avium* L.) are rootstock adaptability, precocity and productivity [Gyeviki et al. 2008]. Precocity and high productivity are characteristics commonly related to dwarf rootstocks such as Gisela 5 and 6 [Neilsen et al. 2016]. Introduction of dwarfing rootstocks imposes the need to change sweet cherry growing system including pruning, flower and fruit thinning, irrigation and fertilization [Gyeviki et al. 2008, Milić et al. 2015]. Dwarfing and semi-dwarfing rootstocks showed proper results only with irrigation or very good site conditions. A strong negative relationship was found between fruit-to-leaf area ratio and quality of fruits in sweet cherry [Whiting and Lang 2004], meaning that high yields on dwarfing rootstocks often result in a small fruit size.

Low-density growing systems with generative vigorous rootstocks are still common in Serbia. Mazzard seedlings (*Prunus avium* L.) are used on heavy

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and acidic soils [Milošević et al. 2014], while mahaleb (*Prunus mahaleb* L.) is mostly used on calcareous soils in northern areas of the country [Keserović et al. 2011]. Vegetative rootstock Colt (*P. avium* L. × *P. pseudocerasus* Lindl.), is commonly used in Serbia for sweet cherry growing along with mazzard (*P. avium* L.) and mahaleb (*P. mahaleb* L.) seedling rootstocks. Colt was found to be less vigorous than mazzard seedling after 9 growing seasons [Wociór 2008]. Traditional growing systems on vigorous rootstocks with 330−450 trees ha^{-1} are nowadays being replaced with high-density orchards with 1100–2500 trees ha^{-1} on dwarfing rootstocks. However, there are opinions based on long-term research results that a high-density orchard with 1250 trees ha^{-1} could be efficient in the long term on vigorous vegetative rootstocks such as Colt [Milošević et al. 2015] or vigorous and semi-vigorous mahaleb clonal rootstocks [Bujdosó and Hrotkó 2016].

The present research was carried out with four sweet cherry cultivars grafted on two rootstocks, including vigorous Colt with 1250 trees ha^{-1} and dwarfing Gisela 5 with 1666 trees ha^{-1}. It was assumed that sweet cherry grafted on Gisela 5 would have a higher early productivity compared to Colt as a consequence of differences in morphological characteristics of bearing wood influenced by the rootstock, planting density and tree age. The objective was to evaluate vegetative growth, bearing potential, fruit set, precocity, productivity, fruit growth habit and quality attributes of four sweet cherry cultivars grown on two rootstocks within high-density growing systems.

MATERIAL AND METHODS

The experiment was conducted during the period 2013–2016 at the experimental field for fruit growing of the Faculty of Agriculture situated at Rimski Šančevi (45°20'N and 19°50'E, 80 m above sea level), Novi Sad, Serbia. The climate conditions at the experimental site, including mean monthly air temperatures (°C), mean precipitation (mm) and mean relative humidity (%), for the period 2012–2016 are presented in Table 1. The soil, on which the field experiment was set up was degraded chernozem of medium deep form, containing 4.24% $CaCO_3$, 2.63% organic matter, 0.13% total nitrogen, 4.58 mg 100 g^{-1} P_2O_5 and 21.03 mg 100 g^{-1} K_2O. Four sweet cherry cultivars, Summit, Kordia, Lapins and Regina, grafted on two vegetative rootstocks Colt (*P. avium* L. × *P. pseudocerasus* Lindl.) and Gisela 5 (*P. cerasus* L. × *P. canescens* B.) were assessed. The trees on both rootstocks were planted in 2012 and trained to a central leader canopy. Planting distance differed in accordance with the vigor of the rootstock. The trees of sweet cherry cultivars grafted on Colt rootstock were planted at 4 × 2 m distance (1250 tree ha^{-1}), while the trees on Gisela 5 were planted at 4 × 1.5 m (1666 tree ha^{-1}). Sweet cherry cultivars on Colt rootstock were planted as unbranched one-year-old maiden trees, while on Gisela 5, they were planted as two-year-old knip-boom trees with a one-year-old feathered crown with 5 or more feathers, which is a standard practice when establishing the new orchards. The use of different type planting material and uneven planting distances makes this research a comparison between two growing systems of sweet cherries rather than a comparison between performances of two rootstocks.

The orchard was set up under hail nets and drip irrigation system. The average amount of 70 kg N, 35 kg P and 50 kg K per hectare was applied along the tree rows each year, starting from 2013. The lanes were covered with grass cover, while herbicides were used to maintain space within rows. Standard agrotechnical procedures were applied during the season including dormant pruning, branch bending and standard pest management. After harvest in 2015, a summer pruning was performed on Colt rootstock in order to avoid excessive tree height and hail net damage.

The experiment was designed as a randomized complete block, in which a total of 12 trees of each scion/rootstock combination were grouped into 3 blocks of 4 trees of similar growth vigor and bloom density. During the dormant season of each experimental year (2013–2016), the trunk circumference was measured 20 cm above graft union and trunk cross-sectional area (TCSA) was calculated. Blossoming dates were determined according to the BBCH scale as beginning, full and end of flowering (61, 65 and 69 BBCH, respectively). In 2016, on each tree, a single two-year-old branch was selected on the basis of flower abundance and marked for assessment. Each scion/rootstock combination was represented by 4 branches/replicates within a block. Branch length and diameter at the basal part were measured on a two-year-old branch and a one-year-old extending shoot. The total number of may bouquets per two-year-old branch, flower buds per may bouquet, flower buds per one-year-old extending shoot and flowers per bud were counted.

Fruit set (% of flower set) was determined twice, at the end of flowering and prior to the harvest, on 4 branches/replicates within each block of trees. Fruit diameter was measured at weekly intervals from the end of flowering until harvest.

The fruit quality (involved 2015–2016) was assessed based on the weight of the fruits and pomological characteristics. The analyses were performed on 10 fruits picked from each selected branch (120 fruits in total). Fruit shape index was calculated using the following equation: length × length/width × thickness. Fruit volume was calculated using the formula $4\pi r^3/3$, where $r = [L + W + T]/6$, and fruit sphericity (ϕ) was calculated using the following equation: $\phi = ([LWT])^{0.333})/L$ [Pérez-Sánchez et al. 2010]. The yield was determined by weighing the harvested fruits and expressed as kg $tree^{-1}$. The yield efficiency (kg cm^{-2}) was calculated as the ratio of the total cumulative yield per final TCSA.

The obtained data were processed by factorial ANOVA using Statistica 12 software [StatSoft Inc., Tulsa, USA]. Duncan's multiple range test was used to compare the means at $P < 0.05$.

RESULTS AND DISCUSSION

Phenological stages, including flowering and fruit maturity differed among cultivars (Tab. 2). However, the growing system did not affect the flowering and fruit maturity time, therefore fruits from both rootstocks were picked at the same time. The earliest to flower was cv. Lapins, meaning the longest period of fruit growth and ripening until harvest. The shortest period of fruit growth was recorded in cv. Summit, that has the earliest harvest date. Rötzer and Chmielewski [2001] described the dependence of tree phenological phases on latitude and altitude in Europe. In wild cherry (*Prunus avium* L.), flowering begins 2.9 days later per 100 m altitude and 3.7 days later per 100 km from south to north, while ripening begins 3.7 days later per 100 m altitude and 3.2 days later per 100 km from south to north. According to Gjamovski et al. [2016], sweet cherry cultivars began to flower 4 (Kordia) to 10 (Regina) days later in southwestern Macedonia, while the same cultivars began to ripen about two weeks later. The later onset of phenological phases in the present research compared to those from southwestern Macedonia is caused by geographical distance of more than 800 m in altitude and more than 4° in latitude between the two experimental sites. The present experimental site is characterized by higher mean air temperatures and seasonal precipitation as well (Tab. 1).

Starting from the second growing season, in 2013, TCSA varied among sweet cherry cultivars and growing systems (Fig. 1). Among the four sweet cherry cultivars grown on Gisela 5, Regina had the smallest TCSA in all four experimental years, while on Colt, trunk growth of cv. Regina was similar to that of Kordia and Lapins. On the other hand, cv. Lapins had the highest TCSA on Gisela 5. TCSA of cv. Summit grafted on Colt rootstock was smaller compared to other cultivars in the first three years of the experiment. However, the differences became insignificant in 2016. In the fifth season after planting, TCSA became significantly larger on Colt compared to Gisela 5 rootstock in each sweet cherry cultivar. Gisela 5 is a vigor-controlling rootstock, known to reduce TCSA up to 50–65% of Mazzard-rooted trees, while according to Lang [2000] and Whiting et al. [2005], Colt is very vigorous, reaching 100–120% tree size relative to Mazzard-rooted trees. Among 21 vegetatively propagated rootstocks, trees of cv. Lapins on Colt rootstock were among the most vigorous [Gyeviki et al. 2008]. Milošević et al. [2014] reported that final TCSA was higher in Mazzard than in Colt by 20.55%, explaining that Colt might be suitable for higher planting distances (4 × 2 m) when grown on heavy soils. Besides genetically related size-controlling properties of rootstocks, another factor that is negatively correlated with tree vigor is tree density [Meland 1998], being 1.5 × 4 m for Gisela 5 and 2 × 4 m for Colt. In the present research, trees on Gisela 5 reached only 52% of the final tree size on Colt in Regina, while in Lapins, trees on two rootstocks were of almost equal size. The variable cultivar response on rootstocks with different vigor was previously reported by Milošević et al. [2014]. Tree size of investigated sweet cherry cultivars was in accordance with results obtained by Gjamovski et al. [2016], with Kordia and Summit being more vigorous on Gisela 5 than Regina.

Table 1. Climate conditions at Rimski Šančevi (average 2012–2016)

	Months													
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year	Veg
Mean air temperature (°C)	0.8	4.6	7.9	12.8	17.1	21.1	23.0	22.4	17.1	12.0	17.4	2.1	12.4	16.7
Precipitation (mm)	48.0	53.4	67.9	51.7	132.7	80.7	44.6	49.3	71.0	65.8	59.4	31.8	756.3	497.9
Mean relative humidity (%)	94.0	90.6	80.1	69.7	77.9	77.9	74.9	75.0	82.6	89.3	93.3	96.5	83.5	78.4

Table 2. Flowering period and date of harvest of sweet cherry fruits (average for 2014–2016 years and two rootstocks)

Cultivar	April																		Harvest date
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Summit																			10.06.
Kordia																			14.06.
Lapins																			21.06.
Regina																			22.06.

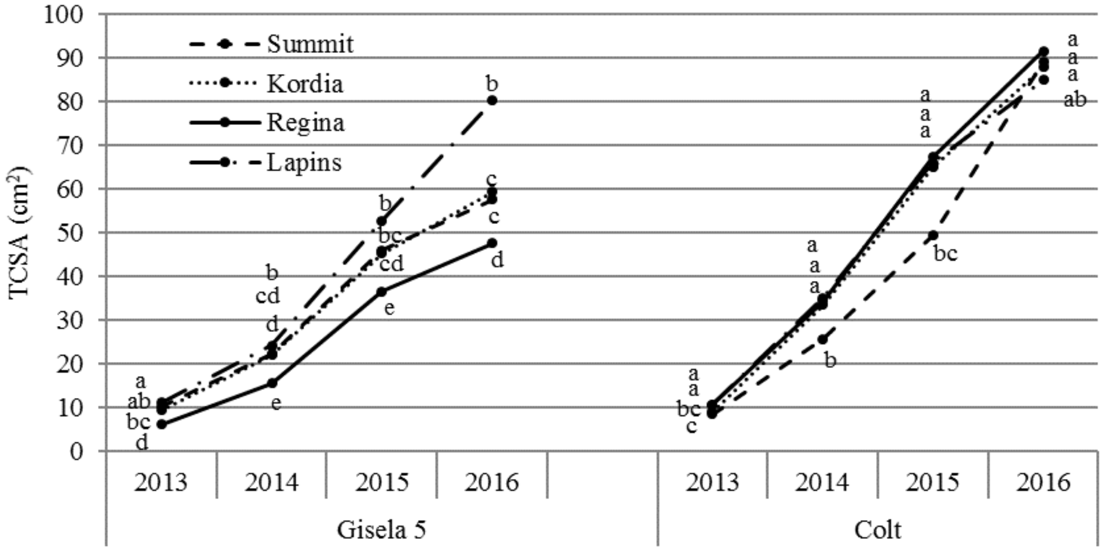

Fig. 1. Trunk cross-sectional area (TCSA cm^2) of sweet cherry trees of four cultivars. Different letters indicate significant differences according to Duncan's Multiple Range Test at P < 0.05 within a single experimental year

The length and basal diameter of two-year-old branches were larger in sweet cherry cultivars Summit, Kordia and Regina grafted on Colt than those grafted on Gisela 5 (Tab. 3). This was not the case in cv. Lapins, where the differences were not significant between two growing systems. Differences in length of one-year-old shoots of cultivars Kordia and Lapins were not significant between rootstocks. One-year shoots were longer on Colt rootstock in Summit, while shorter in Regina compared to Gisela 5. Although two tested rootstocks differ in vigor control, some inconsistencies were noticed regarding the growth of one- and two-year old fruit-bearing branches of sweet cherry cultivars (Tab. 3). Two-year-old branches were longer in tested sweet cherry cultivars grafted on Colt than on Gisela 5, except for Lapins, where the difference was statistically not significant; as was the case with TCSA in Lapins at the end of observation period in 2016, as well. On the other hand, one-year-shoots were longer on Colt than on Gisela 5 in Summit only. The possible reason for the decrease in shoot growth might be the summer pruning performed in 2015 in Colt only, due to its excessive growth. This is in accordance with Guimond et al. [1998], who found that summer pruning 45 days after full bloom reduces vegetative growth and increases flower buds formation regardless of the severity of pruning.

Table 3. Length and diameter of one- and two-year-old branches of sweet cherry trees in the fifth growing season (2016)

Cultivar	Rootstock	Two-year-old branch		One-year-old shoot	
		length (cm)	basal diameter (mm)	length (cm)	basal diameter (mm)
Summit	Colt	60.2 ^{b}	9.5 ^{bc}	18.2 ^{ab}	4.8 ^{b}
	Gisela 5	37.8 ^{c}	6.8 ^{d}	6.0 ^{c}	4.1 ^{b}
Kordia	Colt	85.3 ^{a}	12.3 ^{a}	19.0 ^{ab}	4.6 ^{b}
	Gisela 5	59.5 ^{b}	9.1 ^{bcd}	19.5 ^{ab}	5.4 ^{ab}
Lapins	Colt	46.2 ^{c}	9.6 ^{bc}	21.3 ^{ab}	6.4 ^{a}
	Gisela 5	49.6 ^{bc}	11.3 ^{ab}	22.2 ^{ab}	6.5 ^{a}
Regina	Colt	81.6 ^{a}	10.1 ^{abc}	11.8 ^{bc}	5.1 ^{b}
	Gizela 5	47.5 ^{bc}	8.4 ^{cd}	25.4 ^{a}	4.6 ^{b}

Different letters indicate significant differences according to Duncan's Multiple Range Test at $P < 0.05$ within a column

Table 4. Number of flower buds per two- and one year-old fruiting branches of sweet cherry trees in the fifth growing season (2016)

Cultivar	Rootstock	Two-year-old branch				One-year-old shoot	
		total no. of may bouquets	no. of flower buds per may bouquet	total no. of flower buds	no. of may bouquets cm^{-1}	total no. of flower buds	no. of flower buds cm^{-1}
Summit	Colt	7.9 ^{bcd}	2.3 ^{c}	21.2 ^{c}	0.14 ^{b}	5.7 ^{cd}	0.37 ^{b}
	Gisela 5	5.0 ^{de}	4.6 ^{b}	22.7 ^{c}	0.13 ^{b}	7.4 ^{bc}	1.32 ^{a}
Kordia	Colt	13.1 ^{a}	2.8 ^{c}	37.7 ^{ab}	0.15 ^{b}	6.1 ^{cd}	0.48 ^{b}
	Gisela 5	8.8 ^{bc}	5.1 ^{ab}	46.0 ^{ab}	0.15 ^{b}	8.7 ^{ab}	0.53 ^{b}
Lapins	Colt	2.2 ^{e}	2.3 ^{c}	6.3 ^{d}	0.05 ^{c}	5.6 ^{cd}	0.37 ^{b}
	Gisela 5	10.6 ^{ab}	4.7 ^{b}	49.9 ^{a}	0.21 ^{a}	10.5 ^{a}	0.91 ^{ab}
Regina	Colt	13.0 ^{a}	2.4 ^{c}	32.2 ^{bc}	0.16 ^{b}	5.1 ^{d}	0.61 ^{b}
	Gisela 5	6.6 ^{cd}	5.7 ^{a}	38.2 ^{ab}	0.14 ^{b}	8.5 ^{ab}	0.35 ^{b}

Different letters indicate significant differences according to Duncan's Multiple Range Test at $P < 0.05$ within a column

Variations in growth of fruit-bearing branches among cultivars and growing systems caused the differences in the formation of flower buds of sweet cherry trees (Tab. 4). The total number of may bouquets per two-year-old branch was higher in sweet cherries grafted on Colt than on Gisela 5 as a consequence of higher branch length on Colt, except for the cv. Lapins, that formed more may bouquets per branch on Gisela 5. On the other hand, the number of flower buds per may bouquet and per one-year-old shoot was higher in sweet cherry cultivars on dwarfing Gisela 5 rootstock than on standard-size Colt (Tab. 4). According to Webster [1995], the choice of rootstock can influence the tree productivity in many ways such as floral and yield precocity, abundance of flowering or the ability of the flowers to set fruits (flower quality). In stone fruit, rootstock may increase the proportion of axillary buds on 1-year-old wood, the production of floral spurs on 2-year or older wood, the number of floral buds per spur or the number of flowers in each floral bud.

The total number of flowers per two- and one-year-old branch was significantly higher in sweet cherry cultivars Kordia, Lapins and Regina on Gisela 5 compared to Colt rootstock, while the differences were not significant in Summit (Fig. 2). The highest number of flowers was recorded in Kordia and Lapins on Gisela 5, whereas fruit set at harvest was the highest in Lapins on Gisela 5. Very poor fruit set at harvest was recorded in sweet cherry cultivars on Colt rootstock. The highest variation in fruit set among two rootstocks was observed in cv. Lapins. Similar observations were reported by Kappel and Lichou [1994], who found that branches on dwarfing rootstock (Edabriz) had more flowers, more flowers per spur and more spurs compared to the standard rootstock (F12/1). However, growth-reducing rootstock Edabriz had lower fruit set compared to F12/1, while in the present research, Colt rootstock was characterized by very weak fruit set.

Variations in flower bud density (number of flower buds per cm branch length) were not dependent on cultivar in sweet cherry [Garcia-Montiel et al. 2010]. In the present research, cv. Summit had significantly higher flower bud density on one-year-old shoots compared to Kordia and Regina on Gisela 5, while differences among cultivars were not significant on Colt (Tab. 4). On the other hand, fruit set was affected by the cultivar both on Gisela 5 and Colt rootstocks, which is in accordance with results obtained by Garcia-Montiel et al. [2010], claiming that fruit set was strongly influenced by the cultivar.

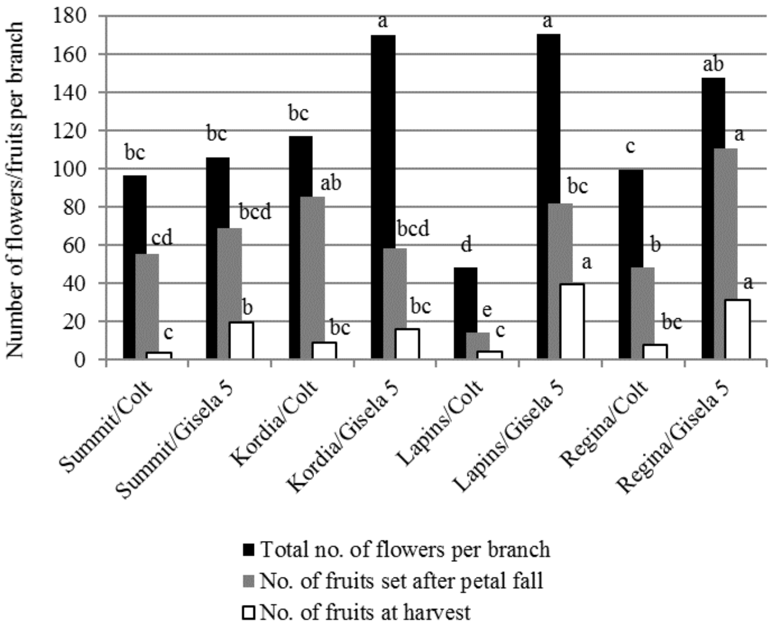

Fig. 2. The total number of flowers and fruits per two- and one-year old branch of sweet cherry trees of four cultivars in the fifth growing season (2016). Bars representing the same trait marked with the same letter do not differ significantly according to Duncan's Multiple Range Test at P < 0.05

Table 5. Physical fruit attributes of sweet cherry fruits of four cultivars (2015–2016)

Fruit physical attributes	Cultivar	Rootstock	Year		
			2015	2016	2015–2016 average
Fruit weight (g)	Summit	Colt	10.4 [a]	10.0 [d]	10.2 [b]
		Gisela 5	10.4 [a]	10.1 [d]	10.2 [b]
	Kordia	Colt	10.5 [a]	11.5 [bc]	11.0 [a]
		Gisela 5	9.0 [b]	12.8 [a]	10.9 [a]
	Lapins	Colt	10.8 [a]	11.1 [c]	10.9 [a]
		Gisela 5	8.7 [b]	10.2 [d]	9.5 [c]
	Regina	Colt	10.8 [a]	11.9 [b]	11.3 [a]
		Gisela 5	10.5 [a]	12.1 [b]	11.3 [a]
Fruit diameter (mm)	Summit	Colt	25.4 [c]	25.8 [d]	25.6 [d]
		Gisela 5	26.2 [ab]	27.1 [bc]	26.6 [c]
	Kordia	Colt	26.6 [b]	27.7 [b]	27.1 [b]
		Gisela 5	24.4 [d]	28.6 [a]	26.5 [c]
	Lapins	Colt	27.7 [a]	26.8 [c]	27.2 [b]
		Gisela5	25.3 [c]	25.4 [d]	25.3 [d]
	Regina	Colt	27.9 [a]	27.7 [b]	27.8 [a]
		Gisela 5	26.8 [b]	27.7 [b]	27.2 [b]
Fruit stalk length (mm)	Summit	Colt	37.9 [de]	38.4 [d]	38.1 [e]
		Gisela 5	41.2 [d]	43.3 [c]	42.3 [c]
	Kordia	Colt	54.1 [b]	53.1 [b]	53.6 [b]
		Gisela 5	57.9 [a]	55.8 [ab]	56.8 [a]
	Lapins	Colt	37.6 [e]	41.5 [c]	39.6 [d]
		Gisela 5	37.1 [e]	41.2 [c]	39.2 [d]
	Regina	Colt	49.2 [c]	55.0 [ab]	52.1 [b]
		Gisela 5	54.4 [b]	57.2 [a]	55.8 [a]
Fruit volume (cm)	Summit	Colt	6.7 [d]	6.8 [c]	6.8 [d]
		Gisela 5	7.4 [c]	7.9 [b]	7.6 [c]
	Kordia	Colt	7.5 [c]	8.9 [b]	8.2 [ab]
		Gisela 5	6.2 [e]	9.9 [a]	7.9 [bc]
	Lapins	Colt	8.5 [ab]	8.4 [b]	8.4 [a]
		Gisela 5	6.7 [d]	6.5 [c]	6.6 [d]
	Regina	Colt	8.8 [a]	8.2 [b]	8.5 [a]
		Gisela 5	8.1 [b]	8.3 [b]	8.2 [b]
Fruit sphericity (%)	Summit	Colt	96.2 [d]	98.0 [c]	97.1 [c]
		Gisela 5	98.2 [c]	99.5 [c]	98.8 [c]
	Kordia	Colt	99.7 [b]	96.6 [c]	98.3 [c]
		Gisela 5	98.7 [b]	98.0 [c]	98.3 [c]
	Lapins	Colt	101.3 [a]	107.3 [a]	104.3 [a]
		Gisela 5	99.7 [b]	103.4 [b]	101.5 [b]
	Regina	Colt	101.3 [a]	104.3 [b]	102.8 [ab]
		Gisela 5	101.6 [a]	103.6 [b]	102.6 [ab]

Different letters indicate significant differences according to Duncan's Multiple Range Test at $P < 0.05$ within a column for each of the assessed fruit physical attributes

Table 6. Yield and yield efficacy of sweet cherry trees of four cultivars (2015–2016)

Productivity	Cultivar	Rootstock	Year 2015	Year 2016	Year 2015–2016 average
Yield (kg tree^{-1})	Summit	Colt	0.2 ^{c}	0.3 ^{c}	0.2 ^{d}
		Gisela 5	8.4 ^{b}	7.8 ^{a}	8.1 ^{a}
	Kordia	Colt	1.4 ^{c}	1.3 ^{bc}	1.3 ^{cd}
		Gisela 5	10.1 ^{a}	2.9 ^{b}	6.5 ^{b}
	Lapins	Colt	0.6 ^{c}	2.6 ^{b}	1.6 ^{c}
		Gisela 5	10.0 ^{a}	7.9 ^{a}	9.0 ^{a}
	Regina	Colt	1.4 ^{c}	1.2 ^{bc}	1.3 ^{cd}
		Gisela 5	10.2 ^{a}	6.8 ^{a}	8.5 ^{a}
Yield efficacy (kg cm^{-1})	Summit	Colt	0.004 ^{d}	0.003 ^{e}	0.0037 ^{d}
		Gisela 5	0.18 ^{c}	0.13 ^{a}	0.15 ^{b}
	Kordia	Colt	0.05 ^{d}	0.01 ^{de}	0.02 ^{d}
		Gisela 5	0.22 ^{b}	0.05 ^{c}	0.13 ^{c}
	Lapins	Colt	0.01 ^{d}	0.03 ^{cd}	0.02 ^{d}
		Gisela5	0.19 ^{c}	0.10 ^{b}	0.14 ^{bc}
	Regina	Colt	0.01 ^{d}	0.01 ^{de}	0.01 ^{d}
		Gisela 5	0.27 ^{a}	0.14 ^{a}	0.20 ^{a}

Different letters indicate significant differences according to Duncan's Multiple Range Test at $P < 0.05$ within a column for each productivity parameter

Cultivated sweet cherries produce fruit that weigh from 6 g to over 13 g for recently bred cultivars [Olmstead et al. 2007]. Fruit weight and size are the most important physical traits determining the value of fruits [Pérez-Sánchez et al. 2010]. According to EU standards of quality, cherries with 25 mm of diameter belong to "Extra" category. According to the sensory panel, the preferable size of sweet cherry fruits for the North American market would be within a range of 11 to 13 g [Kappel et al. 1996]. Sweet cherry fruit growth is divided into three stages: stage I is characterized by rapid and exponential mesocarp growth by both cell division and cell enlargement; stage II, endocarp hardening and embryo development; and stage III defined by the second growth period through the cell expansion. Both cell number and cell size contribute to the final fruit size [Olmstead et al. 2007]. However, cell number is unaffected by neither growing location nor physiological factors, while cell size is significantly influenced by the environment. Thus, the final fruit size is a variable trait as a result of genetics and the environment, crop load [Gonçalves et al. 2006], cultural practices [Whiting et al. 2005], and fruit maturity stage [Serrano et al. 2009]. The greatest variations in generative potential, the number of flowers and fruits set between two sweet cherry growing systems tested were detected in cv. Lapins. Therefore, as expected, fruit weight and diameter recorded in cv. Lapins on Colt were significantly higher than on Gisela growing system (Tab. 5). Growing the self-fertile sweet cherry cultivars (such as Lapins), which provides high and regular yields, may result in over-cropping and therefore small fruit size [Whiting et al. 2006]. According to Whiting et al. [2005], fruit weight was about 16% lower from trees on Gisela 5 and Gisela 6 than on Mazzard, especially in heavy cropping years. Among other tested vegetative rootstocks, Gisela 5 confirmed the tendency to produce the smallest fruits [Cantín et al. 2010, Lanauskas et al. 2012]. Regulating the crop load on Gisela-rooted trees by heading shoots back to about 45 to 50 cm during the dormant period leads to improved fruit quality and good fruit size. Chemical thinning with a surfactant Silwet was found to be an efficient method to reduce fruit set and increase fruit weight in self-fertile sweet cherry cultivars Alex and Sunburst [Milić et al. 2015]. On the other hand, fruits on Colt rootstock grown with the planting distance 4 × 2 m, as it was done in the present research, were significantly larger than on Mazzard [Milošević et al. 2014]. Other three sweet cherry cultivars included in the trial did not show consistent differences in fruit size when grown within two growing systems. Among them, Kordia and Regina had the highest fruit weight, on average (Tab. 5).

The length of the fruit stalk is an important parameter for determination of sweet cherry cultivars, and has a practical significance. Fruits with longer stalk are easier to harvest and less susceptible to fruit rot [Fotirić-Akšić and Nikolić 2013]. The longest stalk was recorded in fruits of cv. Kordia/Gisela 5 (56.8 mm), followed by Regina/Gisela 5 (55.8 mm). Sweet cherry cultivars had longer stalks when grafted on Gisela 5 compared to Colt, except for the cv. Lapins where the differences were not significant.

Fruit volume is a parameter that is calculated using three dimensions of fruits, and thus it represents the fruit size better than fruit width itself. The highest fruit volume was recorded in cv. Regina, having significantly larger fruits on Colt than on Gisela 5. On average, all four sweet cherry cultivars had higher fruit volume on Colt than on Gisela 5 (Tab. 5). According to Pérez-Sánchez et al. [2010], fruit volume is not always correlated with fruit weight, as it was in the case of Summit and Regina in the present research. The reason for this might lie in differences in flesh/stone ratio or mesocarp cell size affected by the rootstock [Olmstead et al., 2007] causing higher specific weight and smaller volume of fruits from Gisela 5.

Regarding the fruit sphericity (%), elongated (heart-shaped) fruits were recorded in cv. Summit and Kordia, which is in accordance with Gjamovski et al. [2016], while Lapins and Regina had flattened fruits. The effect of growing system on fruit sphericity was variable between the two experimental years and among cultivars. A consistent effect was only recorded in Lapins, each year having more elongated fruits on Gisela 5 than on Colt.

Sweet cherry precocity and productivity are highly influenced by rootstock [Whiting et al. 2005, Milošević et al. 2014, Neilsen et al. 2016] and planting distance [Meland 1998] as well as the scion cultivar [Milošević et al. 2014, Gjamovski et al. 2016]. As a result of differences in vegetative growth, fruiting wood morphology, fruit set and fruit growth of sweet cherries between two growing systems (which include rootstock, planting distance and tree age), significant differences were detected in yield and yield efficacy (Tab. 6). In the first three bearing years, yields were very small on both rootstocks, harvesting the first economically significant crop on Gisela 5 in the 4th season (2015), while at the same time, crop on Colt had still not reached its full economic potential (Tab. 6), which is in accordance with Lang [2000]. Yield and yield efficacy for each of the four sweet cherry cultivars were several-fold higher on Gisela 5 than on Colt rootstock. Yields of sweet cherry cultivars on Colt with the planting distance of 2 m between trees in a row in the 5th growing season (2016) were low and similar to the ones recorded by Milošević et al. [2014]. Planted at a greater planting distance (5 × 3 m), cv. Kordia gave higher yields on Colt [Wociór 2008] compared to the present research. This might be due to the improved light distribution through the canopy at greater planting distances and more favorable conditions for flower bud induction even in the lower parts of the canopy [Whiting et al., 2005]. Varietal differences were significant as well, whereas cv. Summit on Colt had the lowest yields. The inconsistent yields were recorded in cv. Kordia on Gisela 5, being significantly decreased in 2016 (2.9 kg tree^{-1}) compared to 2015 (10.1 kg tree^{-1}). This was probably due to the weak fruit set, recorded in 2016 (Fig. 2). Inconsistent yielding makes cv. Kordia grown on Gisela 5 rootstock the weakest yield-efficient combination. The highest yield efficacy was calculated for cv. Regina on Gisela 5 as a result of combining characteristics of a high productivity scion cultivar and vigor-reducing rootstock.

CONCLUSIONS

The results show that the growing system (which include rootstock, planting distance and tree age) had a direct influence on vegetative growth, bearing potential, fruit set, precocity, productivity, fruit growth habit and quality attributes of sweet cherry cultivars. Colt rootstock stimulated vegetative growth, while trees grafted on Gisela 5 had generally higher bearing potential, fruit set and particularly higher yield per tree. Fruits' physical attributes were highly variable and affected by the cultivar, growing system and year. Gisela 5 performed better compared to Colt, which suggests that Gisela 5 should be used as a rootstock in high density sweet cherry production systems.

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