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INFLUENCE OF THE PROPAGATION METHOD OF THREE SEMIDWARF ROOTSTOCKS ON THE GROWTH AND ACTIVITY OF THE PHYSIOLOGICAL PROCESSES OF MAIDEN SWEET CHERRY TREES IN A NURSERY

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ABSTRACT

Rootstocks that reduce the vigor of sweet cherry trees are currently in high demand in orchard production. However, their suitability for nursery production is not fully verified. There are also difficulties in the method of their obtaining, mainly through *in vitro* cultures, which is associated with high prices. The experiment compared the growth of maiden trees of four sweet cherry varieties on rootstocks that reduce their vigor, 'Gisela 5', 'Krymsk 5;, and 'Pi-ku 1'. In addition, rootstocks produced by cheaper means using shoot cuttings were evaluated compared with those from *in vitr*o. The lower efficiency of maiden trees was obtained on the 'Krymsk 5' rootstock than on the other two rootstocks. In contrast, the vigor of maiden trees on this rootstock was significantly more potent. Generally, rootstocks derived from *in vitro* yielded a higher percentage of maiden trees. Additionally, for most of the varieties and years tested, the rootstocks obtained in this way improved the growth of the trees as determined by their diameter and length of the lateral shoots. The activity of the physiological processes of the maiden trees varied with the rootstock used. Maiden trees on the 'Krymsk 5' rootstock were most often characterized by the lowest levels of the three tested parameters (E, C, and I CO2). Meanwhile, the net photosynthetic intensity was lowest on the 'Pi-ku 1' rootstock.

Key words: shoot cuttings, *in vitro*, efficiency of maiden trees, growth parameters

INTRODUCTION

A steady improvement in the intensification of production has characterized the cultivation of sweet cherries in Poland over the last two decades. The sweet cherry fruit harvest oscillates from approximately 90 000 tons, depending on weather conditions, to just 20 000 in 2019. This fact does not discourage producers from growing trees of this species. This is because the price obtained for sweet cherries is several times higher than that for apples. The dominant rootstock is 'Colt', whose qualified maiden tree production share was 88% in 2020. There are also changes in the selection of rootstocks for the production of maiden sweet cherry trees in favor of those reducing the vigor of sweet cherry trees, of which 'Colt' is not one. Many studies have confirmed the influence of rootstocks on the growth characteristics of sweet cherry trees [Baryła and Kapłan 2005, Gonçalves et al. 2005, Jimenez et al. 2007, Sitarek and Grzyb 2010, Cantín et al. 2010, Sitarek and Bartosiewicz 2012, Baryła et al. 2014, Zec et al. 2017].

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In a nursery study [Baryła and Kapłan 2005], rootstocks with different vigor (‘PHL-A’, ‘PHL-C’, ‘Colt’, ‘F12/1’, *Prunus mahaleb*, *Prunus avium*) had a significant effect on the growth parameters of maiden trees. The reduction in tree vigor using the ‘GiSelA 5’ rootstock was confirmed by Papachatzis [2006]. In a study by Sitarek and Grzyb [2010], trees of ‘Kordia’ grew significantly less strongly on semidwarf and dwarf rootstocks than on vigorously growing ‘F12/1’. Biško et al. [2017] also indicated a reduction in the vigor of six-year-old sweet cherry trees on ‘GiSelA 5’ and ‘Pi-ku 1’ rootstocks compared to trees grown on ‘PHL-C’ and ‘GiSelA 6’ rootstocks. In addition, they indicated slightly stronger tree growth on the ‘Pi-ku 1’ rootstock compared to ‘GiSelA 5’ while pointing out the lack of differences after the first year in the orchard. In another experiment, Bielicki and Rozpara [2010] also pointed to the ‘GiSelA 5’ rootstock as being of great value due to the abundant yield of the trees relative to other rootstocks. Hrotkó et al. [2009] also found higher tree parameters on ‘Pi-ku 1’ rootstock than on ‘GiSelA 5’, with no significant differences in the trunk cross-sectional area of trees in the orchard.

According to some researchers [Lang 2000, Long and Kaiser 2010], semidwarf rootstocks, which include ‘GiSelA 5’ or ‘Krymsk 5’, perform best in orchard production with a high tree planting density in combination with strongly growing sweet cherry varieties. However, they require fertile soils and suitable climatic conditions, so planting them on shallow and low -fertility soils is discouraged. Appropriate rootstocks influence earlier and more abundant flowering of fruit trees [Atkinson and Else 2001, Long and Kaiser 2010]. As reported by Atkinson and Else [2001], this influence is mainly well known for rootstocks that reduce tree vigor, significantly impacting the economic aspect of large-scale orchard production [Lang 2000, Long and Kaiser 2010].

MATERIAL AND METHODS

The nursery experiment comprised two cycles of production (2018–2020) of one-year-old maiden trees of four sweet cherry varieties (‘Bellise’, ‘Earlise’, ‘Lapins’, ‘Vanda’) on rootstocks obtained from propagation by shoot cuttings and the in vitro method. The number of combinations was 24 (four varieties, three rootstocks, two propagation methods). Each combination was represented by 20 maiden trees in four replications. On rootstocks planted in a nursery in spring at a spacing of 90 × 30 cm, the “letter T” method of shield budding was applied. The plants were grown in a nursery on podzolic soil, bonitation class IVb. The mineral content of the soil was as follows: phosphorus-107, potassium-145, calcium-520, and magnesium 96. The soil had a pH of 6.5. Before nursery establishment, the following fertilization was applied at the following pure nutrient doses: 40 $kg \cdot ha^{-1}$ phosphorus and 140 $kg \cdot ha^{-1}$ of potassium. Nitrogen fertilization at a rate of 120 $kg \cdot ha^{-1}$ was applied in three split doses. To prevent weed growth, the soil herbicide Sencor 80 WG was applied once immediately after planting the rootstocks at a dosage of 0.25 $kg \cdot ha^{-1}$. Preventively, from mid-May to mid-August, plants were sprayed every fortnight against cherry leaf spots. For this purpose, the following preparations were applied alternately: Zato 50 WG, Score 250 EC, Syllit 65 WP, and Topsin M 500SC in recommended doses. The nursery was not irrigated in all years of experience. The rainfall in individual years was 2018 – 320 mm, 2019 – 409 mm, and 2020 – 443 mm.

After the completion of maiden tree growth, measurements and observations of maiden tree growth were carried out on 15 randomly selected maiden trees in 4 replications. They were measured for height (cm), trunk diameter (mm) at 20 cm above the shield budding site, and length of lateral shoots (cm). At the end of the growing season, the maiden trees were dug out of the nursery, and the number of first-order roots was determined. In addition, the percentage of the maiden trees obtained concerning the shield-budded rootstocks was calculated.

In 2020, the following parameters were measured with a CI-340 aa Handheld Photosynthesis device (CID Bio-Science Inc., USA): net photosynthetic rate (Pn, $\mu mol\ CO_2 \cdot m^{-2} \cdot s^{-1}$), transpiration rate (E, $\mu mol\ H_2O \cdot m^{-2} \cdot s^{-1}$), stomatal conductance (C, $mol\ H_2O \cdot m^{-2} \cdot s^{-1}$), and intracellular CO_2 (I CO_2, $mol\ CO_2 \cdot mol^{-1}$). The research was conducted at a constant intensity of photosynthetically active radiation (PAR; 1000 $\mu mol \cdot m^{-2} \cdot s^{-1}$) supplied to the plants and at a constant concentration of carbon dioxide (CO_2; 390 $\mu mol\ CO_2 \cdot mol^{-1}$ of air). Mature, healthy leaves growing on the middle part of the long shoots from the illuminated part of the crown of four randomly selected plants for each combination were selected for measurements.

Statistical calculations were performed using ‘Statistica 13.1’. The Duncan test was used to perform the analyses at a significance level of α = 0.05. The results were subjected to a two-factor analysis of variance (rootstocks, method of propagation) separately for each variety and year (growth parameters).

RESULTS

A higher percentage of maiden sweet cherry trees of the tested varieties was obtained for the ‘Pi-ku 1’ and ‘GiSelA 5’ rootstocks than for ‘Krymsk 5’ (Tab. 1). Four times the best values were obtained for the ‘Pi-ku 1’ rootstock. For ‘Bellise’, the average for the propagation methods was not significantly different. For ‘Earlise’, the in vitro method only gave a better result in the study’s first year. For the other two varieties, a higher percentage of maiden trees was confirmed for the in vitro method in both series.

Two years after the experiment, the maiden trees of the first three considered varieties grown on ‘Krymsk 5’ rootstock were characterized by greater height (Tab. 2). Moreover, those varieties produced on rootstocks from shoot cuttings were significantly higher in one series. Only in one year of research were higher maiden trees ‘Vanda’ obtained on ‘Krymsk 5’ rootstock and for rootstocks propagated in vitro.

Only the ‘Krymsk 5’ rootstock for ‘Bellise’ and ‘Lapins’ produced a larger trunk diameter in one series (Tab. 3). More frequently, the method of propagation by in vitro (four times) produced better diameter results than the second method (two times).

Table 1. Percentage of obtained sweet cherry maiden trees depending on the method of rootstock propagation in 2019–2020

Year	Rootstock (factor A)	Way of propagation (factor B)	Influence of factors A ×B	Average for A factor	Average for B factor
		‘Bellise’			
2019	GiSelA 5	stem cuttings	84.08 b	85.05 b	76.57 a
		in vitro	85.99 b		78.49 a
	Krymsk 5	stem cuttings	57.78 a	59.82 a	–
		in vitro	61.84 a		
	Pi-ku 1	stem cuttings	84.96 b	84.99 b	
		in vitro	85.03 b		
2020	GiSelA 5	stem cuttings	60.80 ab	62.94 b	64.09 a
		in vitro	65.05 b		66.48 a
	Krymsk 5	stem cuttings	56.40 a	57.52 a	–
		in vitro	58.64 a		
	Pi-ku 1	stem cuttings	74.44 c	74.83 c	
		in vitro	75.22 c		
		‘Earlise’			
2019	GiSelA 5	stem cuttings	78.76 c	80.96 b	72.95 a
		in vitro	83.07 c		78.94 b
	Krymsk 5	stem cuttings	54.95 a	60.62 a	–
		in vitro	66.16 b		
	Pi-ku 1	stem cuttings	82.92 c	84.42 b	
		in vitro	85.87 c		

Table 1 - continued.

2020	GiSelA 5	stem cuttings	59.14 ab	60.29 a	62.14 a
		in vitro	61.42 b		65.07 a
	Krymsk 5	stem cuttings	55.51 a	57.19 a	–
		in vitro	58.87 ab		
	Pi-ku 1	stem cuttings	71.37 c	72.89 b	
		in vitro	74.38 c		
‘Lapins’					
2019	GiSelA 5	stem cuttings	75.16 b	78.96 b	70.08 a
		in vitro	82.53 c		74.30 b
	Krymsk 5	stem cuttings	56.40 a	58.12 a	–
		in vitro	59.84 a		
	Pi-ku 1	stem cuttings	77.59 bc	78.24 b	
		in vitro	78.88 bc		
2020	GiSelA 5	stem cuttings	56.30 a	59.63 b	57.46 a
		in vitro	62.91 b		62.52 b
	Krymsk 5	stem cuttings	52.80 a	53.54 a	–
		in vitro	54.27 a		
	Pi-ku 1	stem cuttings	63.19 b	66.65 c	
		in vitro	70.04 c		
‘Vanda’					
2019	GiSelA 5	stem cuttings	75.16 b	78.96 b	70.08 a
		in vitro	82.53 c		74.30 b
	Krymsk 5	stem cuttings	56.40 a	58.12 a	–
		in vitro	59.84 a		
	Pi-ku 1	stem cuttings	77.59 bc	78.24 b	
		in vitro	78.88 bc		
2020	GiSelA 5	stem cuttings	56.30 a	59.63 b	57.46 a
		in vitro	62.91 b		62.52 b
	Krymsk 5	stem cuttings	52.80 a	53.54 a	–
		in vitro	54.27 a		
	Pi-ku 1	stem cuttings	63.19 b	66.65 c	
		in vitro	70.04 c		

According to Duncan's test, data followed by the same letters separately for each variety and year do not differ significantly at p = 0.05

Table 2. Height (cm) of sweet cherry maiden trees depending on the method of rootstock propagation in 2019–2020

Year	Rootstock (factor A)	Way of propagation (factor B)	Influence of factors A ×B	Average for A factor	Average for B factor
		‘Bellise’			
2019	GiSelA 5	stem cuttings	134.45 a	133.97 a	148.00 a
		in vitro	133.50 a		143.98 a
	Krymsk 5	stem cuttings	170.55 b	170.87 b	–
		in vitro	171.20 b		
	Pi-ku 1	stem cuttings	139.00 a	133.12 a	–
		in vitro	127.25 a		
2020	GiSelA 5	stem cuttings	137.85 ab	140.75 a	156.23 b
		in vitro	143.65 b		143.25 a
	Krymsk 5	stem cuttings	171.35 c	164.85 b	–
		in vitro	158.35 c		
	Pi-ku 1	stem cuttings	159.50 c	143.62 a	–
		in vitro	127.75 a		
		‘Earlise’			
2019	GiSelA 5	stem cuttings	140.15 a	143.92 a	148.35 a
		in vitro	147.70 ab		151.15 a
	Krymsk 5	stem cuttings	160.40 bc	163.75 b	–
		in vitro	167.10 c		
	Pi-ku 1	stem cuttings	144.50 a	141.57 a	–
		in vitro	138.65 a		
2020	GiSelA 5	stem cuttings	146.70 a	143.05 a	164.17 b
		in vitro	139.40 a		144.73 a
	Krymsk 5	stem cuttings	189.05 b	166.17 b	–
		in vitro	143.30 a		
	Pi-ku 1	stem cuttings	156.75 a	154.12 ab	–
		in vitro	151.50 a		
		‘Lapins’			
2019	GiSelA 5	stem cuttings	127.25 a	123.60 a	138.60 b
		in vitro	119.95 a		129.30 a
	Krymsk 5	stem cuttings	159.85 c	152.12 b	–
		in vitro	144.40 b		
	Pi-ku 1	stem cuttings	128.70 a	126.12 a	–
		in vitro	123.55 a		
2020	GiSelA 5	stem cuttings	133.40 a	128.87 a	138.73 a
		in vitro	124.35 a		136.72 a
	Krymsk 5	stem cuttings	150.30 b	152.80 b	–
		in vitro	155.30 b		
	Pi-ku 1	stem cuttings	132.50 a	131.50 a	–
		in vitro	130.50 a		
		‘Vanda’			
2019	GiSelA 5	stem cuttings	135.05 ab	134.70 a	145.83 a
		in vitro	134.35 ab		142.17 a
	Krymsk 5	stem cuttings	149.45 bc	156.20 a	–
		in vitro	162.95 c		
	Pi-ku 1	stem cuttings	153.00 c	141.10 a	–
		in vitro	129.20 a		
2020	GiSelA 5	stem cuttings	143.15 bc	140.85 a	141.75 a
		in vitro	138.55 ab		150.10 a
	Krymsk 5	stem cuttings	126.60 a	145.55 a	–
		in vitro	164.50 d		
	Pi-ku 1	stem cuttings	155.50 cd	151.37 a	–
		in vitro	147.25 bc		

According to Duncan's test, data followed by the same letters separately for each variety and year do not differ significantly at p = 0.05.

Table. 3. Diameter (mm) of sweet cherry maiden trees depending on the method of rootstock propagation in 2019-2020

Year	Rootstock (factor A)	Way of propagation (factor B)	Influence of factors A × B	Average for A factor	Average for B factor
		‘Bellise’			
2019	GiSelA 5	stem cuttings	16.60 a	16.35 a	17.60 a
		in vitro	16.10 a		17.69 a
	Krymsk 5	stem cuttings	20.02 b	20.21 b	–
		in vitro	20.40 b		
	Pi-ku 1	stem cuttings	16.19 a	16.38 a	–
		in vitro	16.56 a		
2020	GiSelA 5	stem cuttings	14.93 a	15.51 a	16.75 b
		in vitro	16.08 a		15.14 a
	Krymsk 5	stem cuttings	19.36 b	17.17 a	–
		in vitro	14.97 a		
	Pi-ku 1	stem cuttings	15.94 a	15.16 a	–
		in vitro	14.37 a		
		‘Earlise’			
2019	GiSelA 5	stem cuttings	17.52 a	17.98 a	17.14 a
		in vitro	18.45 a		18.53 b
	Krymsk 5	stem cuttings	16.74 a	18.75 a	–
		in vitro	20.77 b		
	Pi-ku 1	stem cuttings	17.16 a	16.77 a	–
		in vitro	16.37 a		
2020	GiSelA 5	stem cuttings	15.59 ab	15.26 a	17.91 b
		in vitro	14.93 ab		15.06 a
	Krymsk 5	stem cuttings	20.97 c	17.35 a	–
		in vitro	13.72 a		
	Pi-ku 1	stem cuttings	17.17 b	16.85 a	–
		in vitro	16.52 b		
		‘Lapins’			
2019	GiSelA 5	stem cuttings	15.51 ab	15.66 a	16.39 a
		in vitro	15.80 ab		18.12 b
	Krymsk 5	stem cuttings	15.33 a	18.35 a	–
		in vitro	21.37 d		
	Pi-ku 1	stem cuttings	18.33 c	17.75 a	–
		in vitro	17.18 bc		

2020	GiSelA 5	stem cuttings	15.74 a	15.67 a	16.33 a
		in vitro	15.59 a		18.24 b
	Krymsk 5	stem cuttings	16.68 a	19.50 b	–
		in vitro	22.32 b		
	Pi-ku 1	stem cuttings	16.56 a	16.68 a	–
		in vitro	16.79 a		
‘Vanda’					
2019	GiSelA 5	stem cuttings	15.66 a	16.88 a	16,.60 a
		in vitro	18.09 b		18.73 b
	Krymsk 5	stem cuttings	16.36 ab	18.64 a	–
		in vitro	20.91 c		
	Pi-ku 1	stem cuttings	17.79 ab	17.48 a	–
		in vitro	17.18 ab		
2020	GiSelA 5	stem cuttings	15.78 ab	15.71 a	15.95 a
		in vitro	15.64 ab		16.35 a
	Krymsk 5	stem cuttings	14.51 a	15.46 a	–
		in vitro	16.42 ab		
	Pi-ku 1	stem cuttings	17.54 b	17.27 a	–
		in vitro	16.99 b		

According to Duncan's test, data followed by the same letters separately for each variety and year do not differ significantly at p = 0.05.

The sum of shoot lengths for the two varieties ‘Bellise’ and ‘Lapins’ was more remarkable for the ‘Krymsk 5’ rootstock (Tab. 4), while for ‘Bellise’, this was the case only in the first year. The ‘Earlise’ maiden trees on the ‘Pi-ku 1’ rootstock had longer lateral shoots in both years and ‘Vanda’ and ‘Bellise’ had longer lateral shoots only in the second year. The in vitro propagation method gave better results in half of the combinations considered than the other shoot-cutting methods.

For the three varieties, the number of roots on the ‘Krymsk 5’ and ‘Pi-ku 1’ rootstocks was higher than that on the ‘GiSelA 5’ rootstock (Tab. 5). The ‘Lapins’ tended to have more roots on the ‚Pi-ku 1’ rootstock and the ‘GiSelA 5’ rootstock in the first year of the experiment. The rootstock propagation method did not affect the number of roots.

The net photosynthetic rate (Pn) of the ‘Bellise’ and ‘Earlise’ maiden trees had a better average value for the ‘GiSelA 5’ and ‘Krymsk 5’ rootstocks (Tab. 6). Different propagation methods were applied, in favor of the in vitro method for the first variety and in favor of shoot cuttings for the second. The highest average value of Pn for the ‘Lapins’ was obtained for the ‘Krymsk 5’ rootstock, and the lowest was for ‘Pi-ku 1’. Meanwhile, for the last variety, the best value was obtained for the ‘GiSelA 5’ rootstock and the worst for ‘Pi-ku 1’. The two rootstock propagation methods did not differ in the average Pn for these varieties.

The average value of the transpiration rate (E) of the ‘Bellise’ and the ‘GiSelA 5’ rootstock was the best, while the ‘Krymsk 5’ rootstock was the worst (Tab. 7). ‘Earlise’ had the highest E for the ‘Pi-ku 1’ rootstock and the lowest for ‘Krymsk 5’. For the ‘Lapins’, only the average for the ‘GiSelA 5’ rootstock had a significantly higher E value than the other two. With the in vitro method, a higher transpiration rate of the maiden trees was found for ‘Earlise’ and ‘Lapins’. For the last

Table 4. A sum of lateral shoots (cm) of sweet cherry maiden trees depending on the method of rootstock propagation in 2019-2020

Year	Rootstock (factor A)	Way of propagation (factor B)	Influence of factors A × B	Average for A factor	Average for B factor
		‘Bellise’			
2019	GiSelA 5	stem cuttings	64.25 a	109.15 a	143.52 a
		in vitro	154.05 b		243.72 b
	Krymsk 5	stem cuttings	158.65 b	275.60 b	–
		in vitro	392.55 c		
	Pi-ku 1	stem cuttings	207.65 b	196.10 ab	–
		in vitro	184.55 b		
2020	GiSelA 5	stem cuttings	79.80 a	106.00 a	127.22 a
		in vitro	132.20 ab		139.50 a
	Krymsk 5	stem cuttings	73.15 a	83.65 a	–
		in vitro	94.15 a		
	Pi-ku 1	stem cuttings	228.70 c	210.42 b	–
		in vitro	192.15 bc		
		‘Earlise’			
2019	GiSelA 5	stem cuttings	85.80 b	93.37 a	115.17 a
		in vitro	100.95 bc		188.52 b
	Krymsk 5	stem cuttings	9.10 a	156.12 ab	–
		in vitro	303.15 d		
	Pi-ku 1	stem cuttings	250.60 d	206.02 b	–
		in vitro	161.45 c		
2020	GiSelA 5	stem cuttings	121.05 ab	135.72 a	139.18 a
		in vitro	150.40 b		257.20 b
	Krymsk 5	stem cuttings	39.15 a	204.15 ab	–
		in vitro	369.15 d		
	Pi-ku 1	stem cuttings	257.35 c	254.70 b	–
		in vitro	252.05 c		
		‘Lapins’			
2019	GiSelA 5	stem cuttings	123.5 a	121.22 a	149.82 a
		in vitro	118.95 a		206.28 a
	Krymsk 5	stem cuttings	229.95 b	316.02 b	–
		in vitro	402.10 c		
	Pi-ku 1	stem cuttings	96.00 a	96.90 a	–
		in vitro	97.80 a		

2020	GiSelA 5	stem cuttings	31.55 a	78.62 a	172.68 a
		in vitro	125.70 ab		117.12 a
	Krymsk 5	stem cuttings	279.60 c	231.07 b	–
		in vitro	182.55 b		
	Pi-ku 1	stem cuttings	206.90 bc	125.00 a	–
		in vitro	43.10 a		
‘Vanda’					
2019	GiSelA 5	stem cuttings	221.55 bc	269.60 b	147.78 a
		in vitro	317.65 c		348.78 b
	Krymsk 5	stem cuttings	103.70 ab	371.20 b	–
		in vitro	638.70 d		
	Pi-ku 1	stem cuttings	118.10 ab	104.05 a	–
		in vitro	90.00 a		
2020	GiSelA 5	stem cuttings	2.00 a	65.47 a	185.45 a
		in vitro	128.95 b		199.75 a
	Krymsk 5	stem cuttings	221.25 bc	185.75 b	–
		in vitro	150.25 b		
	Pi-ku 1	stem cuttings	333.10 d	326.57 c	–
		in vitro	320,.5 cd		

According to Duncan's test, data followed by the same letters separately for each variety and year do not differ significantly at p = 0.05.

Table 5. Number of roots of maiden sweet cherry trees depending on the method of rootstock propagation in 2019–2020

Year	Rootstock (factor A)	Way of propagation (factor B)	Influence of factors A × B	Average for A factor	Average for B factor
‘Bellise’					
2019	GiSelA 5	stem cuttings	12.70 a	12.50 a	15.75 a
		in vitro	11.80 a		17.07 a
	Krymsk 5	stem cuttings	15.85 b	18.78 b	–
		in vitro	21.70 d		
	Pi-ku 1	stem cuttings	18.70 c	18.20 b	–
		in vitro	17.70 bc		
2020	GiSelA 5	stem cuttings	15.70 a	15.25 a	16.85 a
		in vitro	14.80 a		18.43 a
	Krymsk 5	stem cuttings	15.10 a	17.95 ab	–
		in vitro	20.80 b		
	Pi-ku 1	stem cuttings	19.75 b	19.72 b	–
		in vitro	19.70 b		

Table 5 - continued.

‘Earlise’					
2019	GiSelA 5	stem cuttings	12.60 a	12,10 a	15,45 a
		in vitro	11.60 a		16,28 a
	Krymsk 5	stem cuttings	17.85 c	20,10 c	–
		in vitro	22.35 d		
	Pi-ku 1	stem cuttings	15.90 b	15,40 b	–
		in vitro	14.90 b		
2020	GiSelA 5	stem cuttings	17.60 b	15.35 a	18.62 b
		in vitro	13.10 a		16.93 a
	Krymsk 5	stem cuttings	20.25 c	18.77 b	—
		in vitro	17.30 b		
	Pi-ku 1	stem cuttings	18.00 bc	19.20 b	—
		in vitro	20.40 c		
‘Lapins’					
2019	GiSelA 5	stem cuttings	11.90 a	11.15 a	14.05 a
		in vitro	10.40 a		14.73 a
	Krymsk 5	stem cuttings	14.55 b	16.72 b	–
		in vitro	18.90 c		
	Pi-ku 1	stem cuttings	15.70 b	15.30 b	–
		in vitro	14.90 b		
2020	GiSelA 5	stem cuttings	17.80 bc	16.85 a	17.28 a
		in vitro	15.90 ab		18.27 a
	Krymsk 5	stem cuttings	13.90 a	16.87 a	—
		in vitro	19.85 c		
	Pi-ku 1	stem cuttings	20.15 c	19.60 b	—
		in vitro	19.05 c		
‘Vanda’					
2019	GiSelA 5	stem cuttings	10.75 a	1157 a	14.72 a
		in vitro	12.40 ab		14.63 a
	Krymsk 5	stem cuttings	18.40 d	17.95 b	–
		in vitro	17.50 d		
	Pi-ku 1	stem cuttings	15.00 c	14.50 ab	–
		in vitro	14.00 bc		
2020	GiSelA 5	stem cuttings	16.30 b	14.80 a	17.83 a
		in vitro	13.30 a		16.47 a
	Krymsk 5	stem cuttings	18.00 b	17.95 ab	—
		in vitro	17.90 b		
	Pi-ku 1	stem cuttings	19.20 b	18.70 b	—
		in vitro	18.20 b		

According to Duncan’s test, data followed by the same letters separately for each variety and year do not differ significantly at p = 0.05.

Table. 6. Net photosynthetic rate (Pn, μmol $CO2 \cdot m^{-2} \cdot s^{-1}$) of maiden sweet cherry trees in 2020

Rootstock (factor A)	Methods of propagation (factor B)	Interaction between AxB	Average for factor A	Average for factor B
		'Bellise'		
GiSelA 5	stem cuttings	16.44 a	20.27 b	18.21 a
	in vitro	23.4 e		21.24 b
Krymsk 5	stem cuttings	19.66 c	20.90 b	–
	in vitro	22.40 d		
Pi-ku 1	stem cuttings	17.96 b	18.21 a	–
	in vitro	18.39 b		
		'Earlise'		
GiSelA 5	stem cuttings	20.31 d	18.73 b	18.37 b
	in vitro	16.70 b		16.57 a
Krymsk 5	stem cuttings	19.54 cd	19.33 b	–
	in vitro	19.12 c		
Pi-ku 1	stem cuttings	14.73 a	14.85 a	–
	in vitro	14.91 a		
		'Lapins'		
GiSelA 5	stem cuttings	19.68 d	18.56 b	18.04 a
	in vitro	17.77 c		17.82 a
Krymsk 5	stem cuttings	19.14 d	19.81 c	–
	in vitro	20.55 e		
Pi-ku 1	stem cuttings	15.90 b	15.54 a	–
	in vitro	15.14 a		
		'Vanda'		
GiSelA 5	stem cuttings	17.69 d	18.49 c	16.11 a
	in vitro	19.09 e		15.94 a
Krymsk 5	stem cuttings	16.78 c	17.52 b	–
	in vitro	18.26 de		
Pi-ku 1	stem cuttings	13.59 b	12.43 a	–
	in vitro	11.76 a		

According to Duncan's test, data followed by the same letters separately for each variety do not differ significantly at p = 0.05

Table 7. Transpiration rate (E, µmol $H_2O \cdot m^{-2} \cdot s^{-1}$) of maiden sweet cherry trees in 2020

Rootstock (factor A)	Methods of propagation (factor B)	Interaction between AxB	Average for factor A	Average for factor B
		'Bellise'		
GiSelA 5	stem cuttings	1.78 d	1.82 c	1.54 a
	in vitro	1.86 d		1.46 a
Krymsk 5	stem cuttings	1.13 b	1.04 a	
	in vitro	0.94 a		
Pi-ku 1	stem cuttings	1.85 d	1.67 b	
	in vitro	1.53 c		
		'Earlise'		
GiSelA 5	stem cuttings	1.38 d	1.31 b	1.26 a
	in vitro	1.22 c		1.53 b
Krymsk 5	stem cuttings	1.12 b	0.98 a	
	in vitro	0.85 a		
Pi-ku 1	stem cuttings	1.32 cd	1.83 c	
	in vitro	2.09 e		
		'Lapins'		
GiSelA 5	stem cuttings	1.47 d	1.92 b	1.20 a
	in vitro	2.24 e		1.43 b
Krymsk 5	stem cuttings	1.07 b	1.03 a	
	in vitro	1.00 a		
Pi-ku 1	stem cuttings	1.16 c	1.11 a	
	in vitro	1.05 ab		
		'Vanda'		
GiSelA 5	stem cuttings	2.02 e	2.26 c	1.66 a
	in vitro	2.44 f		1.64 a
Krymsk 5	stem cuttings	1.67 d	1.52 b	
	in vitro	1.37 c		
Pi-ku 1	stem cuttings	1.26 b	1.18 a	
	in vitro	1.14 a		

According to Duncan's test, data followed by the same letters separately for each variety do not differ significantly at p = 0.05

Table 8. Stomatal conductance (C, mol $H_2O \cdot m^{-2} \cdot s^{-1}$) of maiden sweet cherry trees in 2020

Rootstock (factor A)	Methods of propagation (factor B)	Interaction between AxB	Average for factor A	Average for factor B
		'Bellise'		
GiSelA 5	stem cuttings	92.02 c	109.14 b	98.15 a
	in vitro	122.84 e		96.24 a
Krymsk 5	stem cuttings	83.43 b	74.20 a	
	in vitro	62.92 a		
Pi-ku 1	stem cuttings	124.53 e	109.94 b	
	in vitro	99.33 d		
		'Earlise'		
GiSelA 5	stem cuttings	96.28 d	95.33 c	85.21 a
	in vitro	94.11 d		79.94 a
Krymsk 5	stem cuttings	82.41 c	72.88 a	
	in vitro	63.35 a		
Pi-ku 1	stem cuttings	76.26 b	81.50 b	
	in vitro	84.12 c		
		'Lapins'		
GiSelA 5	stem cuttings	99.52 e	97.07 b	73.88 a
	in vitro	95.36 d		77.43 a
Krymsk 5	stem cuttings	67.64 b	65.53 a	
	in vitro	63.21 a		
Pi-ku 1	stem cuttings	63.81 a	68.54 a	
	in vitro	73.74 c		
		'Vanda'		
GiSelA 5	stem cuttings	58.40 a	92.73 b	79.79 a
	in vitro	118.48 e		87.14 a
Krymsk 5	stem cuttings	105.24 d	85.45 ab	
	in vitro	65.66 b		
Pi-ku 1	stem cuttings	75.24 c	74.50 a	
	in vitro	74.09 c		

According to Duncan's test, data followed by the same letters separately for each variety do not differ significantly at p = 0.05

Table 9. Intracellular CO_2 (mol CO_2·mol^{-1}) of maiden sweet cherry trees in 2020

Rootstock (factor A)	Methods of propagation (factor B)	Interaction between AxB	Average for factor A	Average for factor B
'Bellise'				
GiSelA 5	stem cuttings	400.40 a	436.69 b	414.97 a
	in vitro	465.72 e		440.94 b
Krymsk 5	stem cuttings	432.92 c	418.59 a	
	in vitro	401.09 a		
Pi-ku 1	stem cuttings	404.85 b	431.58 ab	
	in vitro	451.03 d		
'Earlise'				
GiSelA 5	stem cuttings	445.04 d	450.67 c	427.47 a
	in vitro	457.90 e		432.96 a
Krymsk 5	stem cuttings	432.68 c	415.22 a	
	in vitro	397.76 a		
Pi-ku 1	stem cuttings	401.20 b	429.77 b	
	in vitro	444.05 d		
'Lapins'				
GiSelA 5	stem cuttings	445.17 e	450.67 c	416.75 a
	in vitro	455.97 f		417.97 a
Krymsk 5	stem cuttings	399.13 b	415.22 a	
	in vitro	391.41 a		
Pi-ku 1	stem cuttings	416.28 d	429.77 b	
	in vitro	406.54 c		
'Vanda'				
GiSelA 5	stem cuttings	404.36 b	435.39 b	403.38 a
	in vitro	458.67 d		455.25 b
Krymsk 5	stem cuttings	400.29 a	412.75 a	
	in vitro	425.21 c		
Pi-ku 1	stem cuttings	405.76 b	447.68 b	
	in vitro	471.63 e		

According to Duncan's test, data followed by the same letters separately for each variety do not differ significantly at $p = 0.05$

variety tested, the average E had the highest value for the 'GiSelA 5' rootstock and the lowest for 'Pi-ku 1'. The propagation method did not differentiate the average results E of the 'Bellise' and 'Vanda'.

The 'Bellise' and 'Earlise' in combination with the 'Pi-ku 1' and 'GiSelA 5' rootstocks had a better value of stomatal conductance (C; Tab. 8). For the 'Lapins' and 'Vanda', only the average for the 'GiSelA 5' rootstock had a higher C value. The averages for propagation methods did not differ for all varieties.

Higher intracellular CO_2 (I CO_2) for the first three varieties was found for the 'GiSelA 5' rootstock and lower for 'Krymsk 5' (Tab. 9). For the last variety, the averages for the 'GiSelA 5' and 'Pi-ku 1' rootstocks were better than those for 'Krymsk 5'. The average for the in vitro method had a higher I CO_2 value for 'Bellise' and 'Vanda'. No differences were found for the other two varieties.

DISCUSSION

An important factor in determining the suitability of rootstocks for nursery production is the high percentage of maiden sweet cherry trees obtained [Baryła et al. 2013]. Our experiment obtained the lowest number of maiden trees on the 'Krymsk 5' rootstock, depending on the variety, from 53.5 to 62.4%. The studies by Janes and Pae [2004] are consistent with this result, indicating a low yield of three varieties of maiden sweet cherry trees grown on 'GiSelA 5' and 'Krymsk 5' (VSL-2) rootstocks. The authors obtained a higher percentage on the 'GiSelA 5' rootstock (approx. 60%) than on 'Krymsk 5' (approx. 33%), except for one variety, for which the result was 68%. Similarly, in the experiment, maidens' efficiency was consistently higher on the 'GiSelA 5' rootstock than on the 'Krymsk 5' rootstock. The percentage of maiden trees obtained by the abovementioned authors was, on average several percent lower than the own percentage. However, the authors indicated that the low percentage of maiden trees may have been influenced by adverse weather conditions such as a prolonged dry period and high summer and low winter temperatures. Such unfavorable conditions were not recorded in the experiment under consideration, especially temperature drops in winter to –32°C, but only to –15°C. It could have resulted in a frosting of the leaf buds formed and, consequently, in lower maiden tree yields.

In the experiment, better results for the percentage of maiden trees were obtained on the 'GiSelA 5' (60–85%) and 'Pi-ku 1' (66–85%) rootstocks. Different results for the percentage of maiden trees were obtained by Baryła et al. [2013] during three series of experiments; in only one year, they obtained a high percentage of maiden trees of the 'Regina' variety on the 'GiSelA 5' rootstock, amounting to 90.8%. In the other two years, it did not exceed 60%. Meanwhile, Bujdosó and Hrotkó [2006] noted the variable efficiency of maiden sweet cherry trees on the 'GiSelA 5' rootstock. Depending on the variety, it ranged between 56% and 86%, similar to the result obtained in the experiment.

In the experiment, except for 'Vanda', the highest number of maiden sweet cherry trees was obtained on the 'Krymsk 5' rootstock. In contrast, lower maiden tree height was found on the 'GiSelA 5' and 'Pi-ku 1' rootstocks. Similar results for the height of maiden sweet cherry trees on the 'GiSelA 5' rootstock were obtained by Bujdosó and Hrotkó [2006], who, depending on the seven varieties tested, obtained a height ranging from 103 cm to 149 cm. A greater height of the 'Lapins' on the 'GiSelA 5' rootstock was obtained by Sitarek and Grzyb [2007], amounting to approx. 145 cm. However, the trees of this variety obtained by these authors were significantly taller than the other varieties tested, with similar heights.

In the experiment, trees grown on rootstocks obtained from shoot cuttings were mainly taller than those from in vitro. Only in the case of the 'Vanda' was an opposite relationship found. It suggests that the suitability of rootstocks from this method of propagation is not inferior to those from the in vitro method. It is not easy to refer to the results of other authors, as they did not use rootstocks other than those obtained from the *in vitro* method.

Maiden trees grown on 'GiSelA 5' and 'Pi-ku 1' rootstocks had similar trunk diameters. It is not fully in line with the opinion of Sitarek and Rozpara [2008], who found that 3-year-old 'Regina' cherry trees on the 'Pi-ku 1' rootstock grew significantly less than those on the 'GiSelA 5' rootstock. However, the differences could be due to the different ages of the trees tested. The reduction in the vigor of sweet cherry trees grown on the 'GiSelA 5' rootstock, as assessed by trunk diameter measurements, has been confirmed by several authors [Cantín et al. 2010, Sitarek and Grzyb 2010, Baryła et al. 2014, Świerczyński et al. 2019]. Baryła et al. [2014] obtained 'Regina' maiden trees on the 'GiSelA 5' rootstock with a diameter of 14.2 mm. In the experiment, the diameter of the trunks of the maiden trees grown on the 'GiSelA 5' rootstock was dependent on the variety, although it was larger than in the study conducted by the abovementioned authors. Similarly, smaller diameters of maiden trees grown on the 'GiSelA 5' rootstock were obtained by Bujdosó and Hrotkó [2006] (11–14 mm). It may have been influenced by the heights at which the diameter measurement was taken. In the experiment described here, the trunk diameter was measured at 20 cm above the shield budding site, while the abovementioned authors took measurements at 30 cm above the shield budding site, which reduced this parameter.

One of the most critical determinants of the quality of maiden trees is the number and length of lateral shoots. Both the rootstock and variety influence the vigor and branching pattern of the trees [Baryła et al. 2014]. In the experiment under consideration, the highest sum of lateral shoot lengths for most varieties was obtained on the 'Krymsk 5' rootstock, propagated by the in vitro method. Research conducted by Baryła et al. [2014] on the 'Regina' of maiden trees on the 'GiSelA 5' rootstock showed a higher total lateral shoot length of 160 cm, a result superior to our research. Testing three-year-old trees of 'Regina' on 'GiSelA 5' and 'Pi-ku 1' rootstocks, Sitarek and Rozpara [2008] obtained a greater length of lateral shoots of trees on the 'GiSelA 5' rootstock, indicating weaker growth of trees on the 'Pi-ku 1' rootstock. An opposite relationship was observed in one-year-old nursery trees in the experiment. However, the tendency to form lateral shoots can be reversed later in tree growth in an orchard. Multiple factors, such as soil quality and weather conditions, influence it.

Measurements of the physiological processes of the maiden trees showed significant differences between the rootstocks tested and, to a lesser extent, between the way they were propagated. A higher net photosynthetic intensity was obtained for maiden trees grown on 'GiSelA 5' and 'Krymsk 5' rootstocks. However, the growth power of maiden trees on these rootstocks differed significantly. Apart from net photosynthetic intensity, the remaining parameters (E, C, and I CO_2) reached the highest values for maiden trees grown on the 'GiSelA 5' rootstock. These results did not confirm the vigor of maiden trees on the individual rootstocks. Trees on the 'Krymsk' rootstock grew the strongest. A similar study was carried out by Świerczyński et al. [2019], who analyzed the effect of biopreparations on the parameters of photosynthetic activity of 'Vanda' maiden sweet cherry trees. They found slightly higher values for net photosynthetic intensity and stomatal conductance than those obtained in the experiment under consideration. However, they obtained lower parameters for stomatal conductance and intracellular CO_2. However, comparing results from different years is difficult due to the different climatic and soil conditions. Many authors point to a link between an increase in photosynthetic intensity and an increase in stomatal conductance [Romero et al. 2004, Proietti et al. 2006, Almadi et al. 2020], which was not fully confirmed in the experiment conducted. However, a strong correlation between stomatal conductance and intracellular CO_2 was observed, as confirmed by the study by Świerczyński et al. [2021]. According to some authors [Rosati et al. 2018, Almadi et al. 2020], higher photosynthetic intensity results in stronger tree growth, which was not fully confirmed in our study.

CONCLUSIONS

The 'Krymsk 5' rootstock had a lower maiden tree efficiency than the other two rootstocks tested. In contrast, the vigor of maiden trees on this rootstock was significantly higher. As a rule, rootstocks derived from shoot cuttings yielded a lower percentage of maiden trees. For most of the varieties tested, rootstocks obtained from the in vitro method improved the growth of the trees as assessed by their diameter and length of lateral shoots. The activity of the vital processes of the maiden trees varied with the rootstock used. Most often, the lowest levels of the parameters tested (E, C, and I CO2) were found for trees grown on the 'Krymsk 5' rootstock, which did not reflect the most vigorous growth of maiden trees grown on this rootstock.

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