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The effect of rootstocks on the growth, yield and fruit quality of hybrid grape varieties in cold climate conditions

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Abstract: Viniculture in colder countries requires the use of rootstocks adapted to the climatic and soil conditions, which influence the essential characteristics of the vine yield in terms of the physiological and morphological features. The current study was carried out in 2015–2018 in southern Poland to examine the impact of the '5BB', '125AA', '101-14M', 'SO4' and 'Börner' rootstocks on the growth, yield and fruit quality of three grape varieties: 'Seyval Blanc', 'Johanniter' and 'Solaris'. The following biometric parameters were compared: the increment in the trunk cross-sectional area, number of inflorescences on the vine, total yield, mean weight of a cluster and chemical parameters, such as the total soluble solid (TSS) content and grape titratable acidity (TA). The cluster weight of the individual varieties was also assessed in eight categories by weight (0–700 g). The results showed that 'Solaris' and 'Johanniter' grafted onto 'Börner' and 'Seyval Blanc' onto '5BB' had significantly increased trunk diameters. For the 'Solaris' cultivar, the 'Börner' rootstock increased the TSS volume by 8.2%. In the 'Seyval Blanc' cultivar, '125AA' and 'Börner' reduced the TSS content and increased the content of TA in the berries. In the 'Johanniter' cultivar, the 'Börner' rootstock led to an increase in the TSS content with a concomitant increase in the TA.

Keywords: berry quality; grape ripeness; strength of growth; TA; TSS; grape size

The domestication of grapevines goes back to prehistoric times. Products made of *Vitis vinifera* were part of everyday life as well as cultural and religious celebrations (Censi et al. 2014). In Poland, the grapevine appeared with the advent of Christianity (10^{th} century) and was cultivated until the middle of the 16^{th} century with various results. The cooling of the climate effectively discouraged Polish gardeners from continuing the demanding cultivation of *V. vinifera*. In the second half of the nineteenth century, an accidentally imported aphid – Grape phylloxera (*Daktulosphaira vitifoliae)* – from North America, decimated European vineyards, and afterwards vineyards on other continents also, excluding only a few countries. The reconstruction and saving the remaining grapevines, after other unsuccessful attempts, was based on the grafting of noble varieties of *V. vinifera* onto resistant rootstocks of North American species or interspecies hybrids: *V. labrusca, V. riparia, V. rupestris* and *V. berlandieri* (Vršič et al. 2015; Ollat et al. 2016; Mijowska et al. 2017). Grafting is one of the oldest horticultural practices, already in use 9 000 years ago in China and now used in most commercial crops worldwide (Mudge et al. 2009; Gautier et al. 2019). The combination of independent progeny and rootstock traits adapts the grapevine to the existing biotic and abiotic conditions. The selection of appropriate rootstocks has become a protective tool against phylloxera, but the adaptability to climatic and soil conditions can also be taken into account (Gu 2001; Walker, Clingeleffer 2009; Somkuwar et al. 2011; Zhang et al. 2016; Ferlito et al. 2020). Rootstocks should be selected both in terms of the characteristics of a given variety and the

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clone (growth rate, yield, nutrient requirements), as well as the soil conditions (soil moisture, soil fertility, active calcium content, etc.). Rootstocks affect the nutrient uptake from the soil, and thus the plant growth, length of the growing season and yield (Reynolds, Wardle 2001; Mijowska et al. 2017).

Climate change, which has a destabilising effect on wine-growing, is setting new limits for viticulture around the world. Poland, as a zone A country, could become a good region for the production of quality wine, provided that the material is adapted to the environmental conditions (Duchêne 2016). The aim of this study that was conducted in 2015–2018 was to investigate the influence of '5BB', '125AA', '101-14M', 'SO4' and 'Börner' rootstocks on the growth, yield and fruit quality of three grape varieties: 'Seyval Blanc', 'Johanniter' and 'Solaris'. The results will provide information to growers that will help to better select rootstocks for the above varieties, grown under "cool climate" conditions.

MATERIAL AND METHODS

Description of the area. Field research was carried out in a vineyard at the Experimental Station of the University of Agriculture in southern Poland (50°08'29.4"N 19°55'50.7"E). The experiment was established in 2013 and data were collected during three growing seasons. Plants were planted from two-season potted cuttings, one year after inoculation on individual rootstocks. The plants had a well-developed root system.

Characteristics of the varieties. 'Seyval Blanc' is an interspecific hybrid: 43.75% *V. vinifera*, 28.15% *V. rupestris*, 12.5% *V. berlandieri*, 12.5% *V. riparia* and 3.1% *V. licencumi*.

'Solaris', a German variety that is a cross of Merzling × Geisenheim 6493 ('Zarya severa' × 'Muskat Ottonel'), registered as *Vitis vinifera* (73.4% *V. vinifera* + 7% *V. rupestris* + 3.1% *V. berlandieri* + 3.1% *V. riparia* + 0.8% *V. lincecumi*) (Julius Kühn-Institut).

'Johanniter', a cross of Riesling and Freiburg 589-54 [Seyve-Villard 12.481 × ('Ruländer' × 'Gutedel')] (Julius Kühn-Institut).

Rootstocks used. 'Kober 5BB' *V. berlandieri* × *V. riparia*: rootstock often used in Europe due to its very high tolerance to the soil conditions. 'Kober 5BB' transfers a short growing season to the grafted varieties. Frost resistance is highest in the group *V. berlandieri* × *V. riparia*, but with a tendency to negatively affect the effectiveness of the flowering (Mijowska et al. 2017).

'Kober 125AA' *V. berlandieri* × *V. riparia*: (intermediate rootstock between '5BB' and S04). Like '5BB', it tolerates a wide range of soils, except dry soils. It is characterised by medium growth and high resistance to freezing. It has a good effect on both the flowering and fruit setting (Shaffer 2004).

Arnold Bőrner *V. riparia 183 G* × *V. cinerea:* shows high drought tolerance to the contribution from *V. cinerea* in the species cross. It may also shorten the growing period (Zhang et al. 2009).

'Selection Oppenheim No. 4' ('SO4') *V. berlandieri* × *V. riparia*: rootstock developed in Germany. It requires light, fertile soils, and is not suitable for dry soils. It is characterised by a short growing season having high resistance to phylloxera and weak frost resistance. It has a beneficial effect on the flowering and fruit setting (Shaffer 2004).

'R101-14M' *V. riparia* × *V. rupestris*: a widely used rootstock, especially in the northeast US and Ukraine. It shows a high sensitivity to a water deficit in the substrate. It is characterised by the early ripening of fruits and the weakening of the growth of the grafted varieties. It has a very beneficial effect on the yield (Shaffer 2004).

Arrangement of the experiment. The cultivation system used in this study is the most common system used in vineyards in Poland, i.e., permanent turf in inter-row spaces and 80 cm wide herbicide strips. Irrigation was not installed, and point watering was used only in the period immediately after planting. Spraying against fungal diseases was performed according to the Fruit Plant Protection Programme, valid for a given year. During the experiment, no "green harvest" was carried out and the shortening of the shoots was carried out in the veraison phase.

Vines were grown 2.5 m × 1 m apart and were trained in a single Guyot system. The experiment included 'Seyval Blanc', 'Johanniter' and 'Solaris' varieties grafted onto five rootstocks: 'Kober 5BB', 'Kober 125AA', 'Bőrner', 'SO4' and '101-14'.

The measurements of each combination of rootstock and variety were conducted in three replicates, one replicate being comprised of five vines (Figure 1).

Weather data. Meteorological data was collected from the iMetos go IMT meteorological station located next to the vineyard in Garlica Murowana in 2015–2018. The average air temperatures during the growing season in two consecutive years, 2016 and 2017, did not differ from each other, while the

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Solaris	*****	○○○○○	◊◊◊◊◊	□□□□□	●●●●●
Solaris	○○○○○	◊◊◊◊◊	*****	□□□□□	●●●●●
Solaris	□□□□□	*****	○○○○○	◊◊◊◊◊	●●●●●
Johanniter	*****	○○○○○	◊◊◊◊◊	□□□□□	●●●●●
Johanniter	○○○○○	◊◊◊◊◊	*****	●●●●●	□□□□□
Johanniter	◊◊◊◊◊	*****	○○○○○	□□□□□	●●●●●
Seyval Blanc	*****	○○○○○	◊◊◊◊◊	□□□□□	●●●●●
Seyval Blanc	□□□□□	●●●●●	*****	○○○○○	◊◊◊◊◊
Seyval Blanc	○○○○○	◊◊◊◊◊	□□□□□	●●●●●	*****

* rootstock 12AA
○ rootstock 5BB
◊ rootstock SO4
□ rootstock 5BB
● rootstock Bőrner

Figure 1. Combination of the vine plantings in the experiment

temperature in 2018 was 12% higher than in 2016 and 2017 (Figure 2A). The temperatures dropped below 0 °C in April and May in 2016 and 2017 and caused the freezing of the young shoots and flower buds. The highest total precipitation was recorded in 2017 (Figure 2B), which was 50% higher than the average total precipitation for 1951–2010 in Poland and was optimal for viticulture. The lowest rainfall was recorded in 2016 and was 100% lower than the minimum cultivation requirements. The highest air humidity was recorded in 2016, while the lowest was recorded in 2018 (Figure 2C).

Methods. The assessed indices included the increment in the trunk cross-sectional area (ITCSA), number of inflorescences on a vine, total yield, average weight of one cluster, total soluble solid (TSS) content and grape titratable acidity (TA).

Vine measurements and biometric assessment of the ITCSA. The vine trunk diameter at a height of 30 cm from the base was measured in spring (bud break phase) and autumn (leaf fall phase) in 2015 and 2018, using electronic callipers. The cross-sectional area of the trunk (mm^2) was calculated according to the formula:

$$P = \frac{\pi \times d^2}{4} \quad (1)$$

where: d – the trunk diameter.

The following measurements and calculations were performed for the tested combinations: number of inflorescences/plants (pieces), total yield (kg), and average cluster weight (g).

In order to determine the qualitative parameters at harvest maturity, ten clusters were collected for each combination, from which ten completely healthy berries with intact skin (total of 100 berries) were randomly selected.

Cluster evaluation. The grape weight was assessed according to the scale of the individual varieties, and divided into five categories by the cluster weight. The percentage of each class was calculated for all the combinations: 0–59 g, 60–100 g, 101–200 g, 201–300 g, 301–700 g.

Chemical measurements. The total TA was determined by the acid-base titration method using 0.1 mol/L NaOH to pH 8.1. A Jenway 3020 pH meter (Jenway Ltd., Dunmow, UK) was used for this pur-

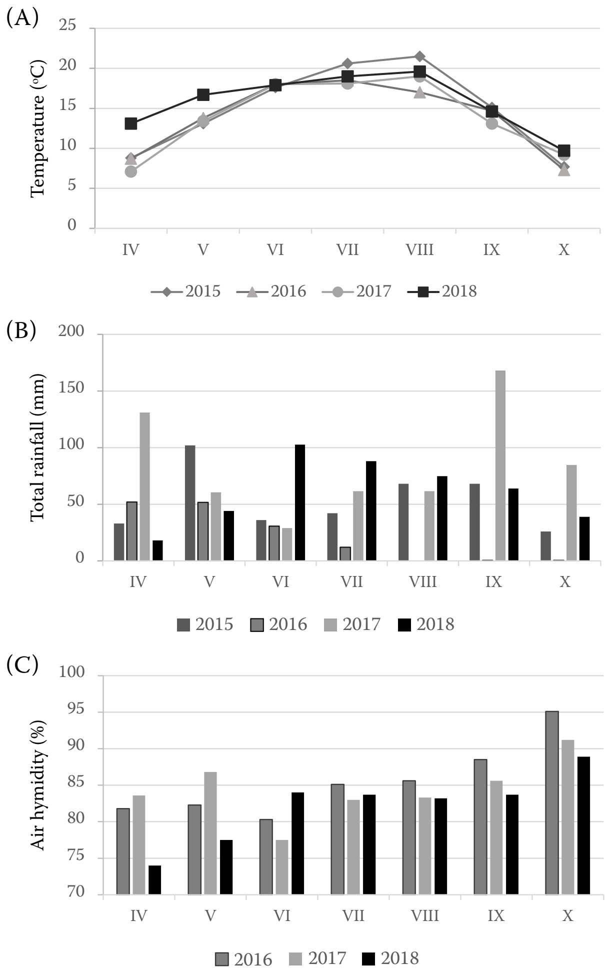

Figure 2. Weather in 2015–2018

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pose. Measurements were performed in three replicates. The results are expressed as tartaric acid (g/L).

The content of the TSS and soluble substances was tested at room temperature using an ATAGO PR-100 digital refractometer (ATAGO, PR-100, Tokyo, Japan) with a measuring range of 0.0–32.0%. Measurements were performed in three replicates and the results were expressed on a scale (°B).

The fruit harvest maturity index was calculated as the ratio of the TSS to the TA and expressed in °B/g/L.

Statistics. All the statistical calculations were performed for each year and for each variety separately. The results were analysed using one-way analysis of variance (ANOVA). Tukey's test was used to assess the significance of the differences between the means at a significance level of $P < 0.05$.

RESULTS AND DISCUSSION

This study provides information on the effects of five rootstocks on the quality and yield of three hybrid grape varieties. There are few reports in the literature regarding the influence of rootstocks on the fruit quality and grapevine morphology in zone A conditions. Fruits obtained from grapevines grown in a "cool climate" are characterised by lower sugar levels, and thus a lower alcohol content is obtained from them with a high acidity and polyphenol content (Izajasz-Parchańska et al. 2014).

Vine analysis – biometric assessment. The ITCSA variable (Figure 3) is a direct tool applied in the dendrological evaluation of the growth rate. The measurements were performed in 2015 and 2018. Figure 3 shows the results of the cross-sectional area increments for the three discussed varieties on the five rootstocks. After three growing seasons of the ITSCA experiment, the increment for the varieties 'Solaris' and 'Johanniter' was similar, regardless of the applied rootstocks, and averaged 109.6 mm^2 and 87.6 mm^2, respectively. The highest trunk increment for 'Seyval Blanc' was recorded on the 'SO4' and '5BB' rootstocks, although Whiting (2004) pointed to frequently arising compatibility problems of these two rootstocks with noble varieties. In this study, symptoms of incompatibility were not recorded for the observed varieties, and the rootstocks stimulated the growth of the stem base, similar to the study by Clingeleffer and Emmanuelli (2006) on the variety 'Sunmuscat'. In 2018, the highest increment of the stem base of the varieties 'Solaris' and 'Johanniter' was observed on the 'Börner' rootstock.

It was found, that the rootstocks influenced the shoot length of the grapevine varieties (Tables 1, 2, 3). In 2016, significant differences in the shoot lengths were recorded for the variety 'Solaris' depending on the rootstock (Table 1). The longest shoots were recorded for the grapevine grafted on the 'SO4' rootstock, while the shortest ones were recorded for the grapevine grafted on the '125AA' rootstock. No statistical differences in the length of the shoots were recorded in 2016 for the varieties 'Seyval Blanc' and 'Johanniter' (Tables 1 and 2), and in 2018 for

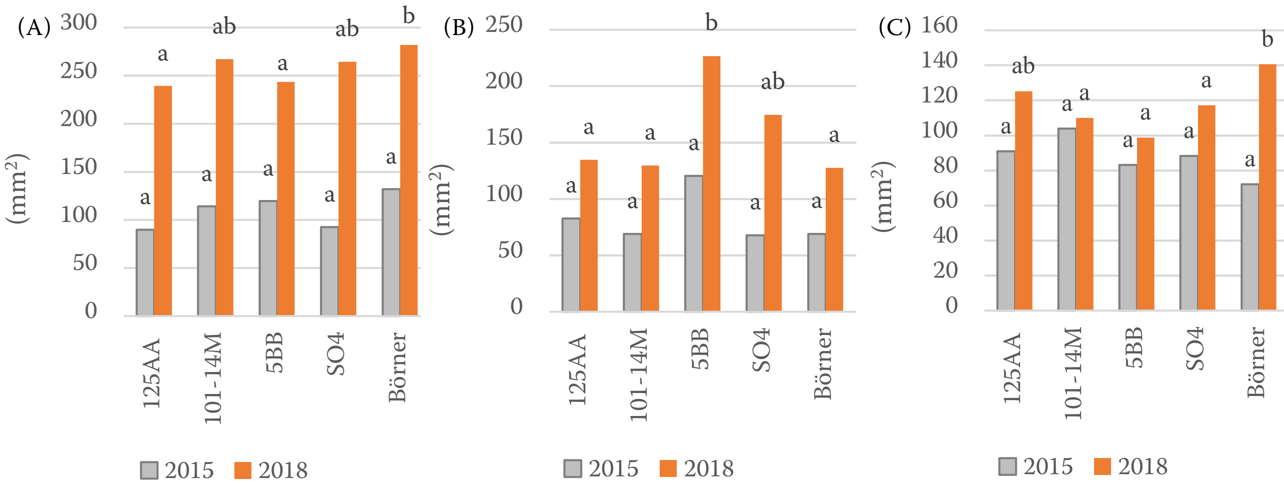

Figure 3. Increment in the trunk base cross-sectional area (mm^2) in the two seasons, 2015 and 2018 for the varieties: (A) 'Solaris', (B) 'Seyval Blanc', (C) 'Johanniter'

All the statistical calculations were performed for each year and for each variety separately

[a,b]Mean values followed by different letters are significantly different ($P < 0.05$)

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Table 1. Biometric characteristics of the vine and quality parameters of the 'Solaris' must depending on the rootstock

Rootstock	Biometric assessment								Quality parameters of the juice							
	Shoot length (cm)		Number of inflorescences (pcs /vine)		Yield (kg/vine)		Average cluster weight (g)		pH		TSS (°B)		TA (g/L)		TSS/TA	
	2016	2018	2016	2018	2016	2018	2016	2018	2016	2018	2016	2018	2016	2018	2016	2018
125AA	106.9^{b}	110.0^{a}	17.0^{a}	24.7^{a}	0.1^{a}	2.8^{a}	108.0^{c}	122.4^{ab}	3.41^{b}	3.16^{b}	22.2^{c}	21.8^{bc}	7.5^{ab}	7.6^{a}	2.96^{c}	2.86^{cd}
R101-14M	128.1^{ab}	126.0^{a}	15.7^{a}	25.5^{a}	0.3^{a}	2.7^{a}	305.0^{a}	122.2^{ab}	3.49^{a}	3.20^{ab}	24.0^{ab}	22.0^{bc}	7.5^{ab}	7.5^{a}	3.20^{b}	2.93^{c}
5BB	137.6^{ab}	138.0^{a}	16.7^{a}	22.9^{a}	0.4^{a}	2.2^{a}	196.0^{b}	114.6^{b}	3.43^{a}	3.21^{ab}	23.8^{bc}	22.8^{ab}	7.9^{a}	7.4^{a}	3.01^{c}	3.08^{b}
SO4	139.0^{a}	136.0^{a}	14.0^{a}	19.0^{a}	0.3^{a}	2.0^{a}	347.0^{a}	119.0^{ab}	3.49^{a}	3.22^{ab}	24.1^{ab}	21.4^{c}	6.6^{b}	7.7^{a}	3.65^{a}	2.78^{d}
Börner	127.6^{ab}	106.0^{a}	17.9^{a}	21.2^{a}	0.1^{a}	2.4^{a}	91.0^{c}	127.9^{a}	3.42^{b}	3.25^{a}	25.2^{a}	23.3^{a}	8.1^{a}	6.8^{a}	3.11^{b}	3.43^{a}

$^{a–d}$Mean values followed by different letters are significantly different ($P < 0.05$)

All the statistical calculations were performed for each year separately; TSS – total soluble solid; TA – titratable acidity

the variety 'Solaris'. In 2018, differences in the shoot length in relation to the rootstock were noted for the varieties 'Seyval Blanc' and 'Johanniter'. The 'Seyval Blanc' variety produced the longest shoots on the 'SO4' and 'Börner' rootstocks, while for 'Johanniter', the longest shoots were recorded for the '5BB' and 'SO4' rootstocks. Li et al. (2019) investigated eight rootstocks, including 'R101-14M', '5BB' and 'SO4', but they found no effect of the rootstocks on the grapevine Marselan shoot length.

The three grapevine varieties varied depending on the dates of flowering and the number of inflorescences (Tables 1, 2, 3). In terms of the flowering dates, 'Solaris' was the first to bloom, followed by 'Seyval Blanc' and 'Johanniter'. These findings were in agreement with other studies described in Polish climatic conditions (Myśliwiec et al. 2018). In the first year of full fruiting (2016 year), no differences in the number of inflorescences related to the rootstock for any of the varieties were recorded. In the next season (2017), the spring frost damaged 100% of the inflorescences. The first differences in the number of inflorescences were recorded in 2018. For the variety 'Seyval Blanc', a significantly greater number of inflorescences were recorded for the '5BB' and 'Börner' rootstock, while the grapevines on the 'SO4' and 'R101-14M' rootstocks showed a tendency to have a greater number of inflorescences (Table 2). For the variety 'Johanniter', the 'Börner' rootstock also showed a positive effect on the number of inflorescences, and a tendency towards having more inflorescences was noted for the '125AA' and '5BB' rootstocks (Table 3). Generally, it was found that the grapevines grafted on the '5BB' and 'Börner' rootstocks produced up to 28.3% more inflorescences per plant in comparison

Table 2. Biometric characteristics of the vine and quality parameters of the 'Seyval Blanc' must depending on the rootstock

Rootstock	Biometric assessment								Quality parameters of the juice							
	Shoot length (cm)		Number of inflorescences (pcs /vine)		Yield (kg/vine)		Average cluster weight (g)		pH		TSS (°B)		TA (g/L)		TSS/TA	
	2016	2018	2016	2018	2016	2018	2016	2018	2016	2018	2016	2018	2016	2018	2016	2018
125AA	120.9^{a}	81.0^{b}	13.5^{a}	23.1^{b}	2.9^{a}	4.9^{a}	110.0^{a}	161.4^{a}	3.26^{a}	3.18^{b}	20.1^{bc}	17.0^{b}	7.2^{a}	8.6^{a}	2.80^{a}	1.98^{c}
R101-14M	108.2^{a}	90.0^{b}	9.8^{a}	26.4^{ab}	3.1^{a}	4.8^{a}	162.0^{a}	168.2^{a}	3.29^{a}	3.20^{ab}	19.8^{c}	19.1^{a}	6.7^{a}	7.4^{b}	2.95^{ab}	2.58^{a}
5BB	109.0^{a}	91.0^{b}	10.1^{a}	31.7^{a}	2.8^{a}	5.4^{a}	74.0^{b}	164.6^{a}	3.29^{a}	3.23^{a}	20.8^{a}	19.5^{a}	6.6^{a}	7.5^{b}	3.15^{a}	2.60^{a}
SO4	113.6^{a}	110.0^{a}	10.2^{a}	24.1^{ab}	3.1^{a}	4.7^{a}	73.0^{b}	169.3^{a}	3.28^{a}	3.24^{a}	20.7^{ab}	19.2^{a}	7.0^{a}	7.6^{b}	2.95^{ab}	2.52^{a}
Börner	113.9^{a}	118.0^{a}	12.3^{a}	32.0^{a}	3.8^{a}	5.3^{a}	151.0^{a}	161.0^{a}	3.24^{a}	3.17^{b}	20.2^{ab}	17.7^{b}	8.0^{a}	7.9^{a}	2.52^{b}	2.24^{b}

$^{a–c}$Mean values followed by different letters are significantly different ($P < 0.05$)

All the statistical calculations were performed for each year separately; TSS – total soluble solid; TA – titratable acidity

Table 3. Biometric characteristics of the vine and quality parameters of the 'Johanniter' must depending on the rootstock

Rootstock	Biometric assessment								Quality parameters of the juice							
	Shoot length (cm)		Number of inflorescences (pcs /vine)		Yield (kg/vine)		Average cluster weight (g)		pH		TSS (°B)		TA (g/L)		TSS/TA	
	2016	2018	2016	2018	2016	2018	2016	2018	2016	2018	2016	2018	2016	2018	2016	2018
125AA	98.7^{a}	90.0^{ab}	15.7^{a}	29.6^{ab}	0.6^{a}	3.2^{a}	232.0^{a}	205.5^{ab}	3.26^{a}	3.32^{a}	18.8^{ab}	19.5^{ab}	7.1^{ab}	9.3^{a}	2.64^{a}	2.10^{c}
R101-14M	99.3^{a}	92.0^{ab}	15.0^{a}	24.8^{b}	0.6^{a}	3.9^{a}	231.0^{a}	214.6^{ab}	3.31^{a}	3.31^{a}	20.0^{a}	19.6^{ab}	7.7^{ab}	7.1^{b}	2.58^{a}	2.62^{a}
5BB	101.9^{a}	101.0^{a}	15.7^{a}	31.5^{ab}	0.4^{a}	3.7^{a}	242.0^{a}	201.9^{b}	3.31^{a}	3.30^{a}	19.8^{a}	18.9^{b}	7.6^{a}	7.2^{b}	2.61^{a}	2.64^{a}
SO4	110.3^{a}	101.0^{a}	17.0^{a}	25.4^{b}	0.4^{a}	3.6^{a}	254.0^{a}	222.6^{a}	3.33^{a}	3.30^{a}	17.8^{b}	19.5^{ab}	7.6^{ab}	7.6^{b}	2.34^{b}	2.56^{a}
Börner	107.7^{a}	80.0^{b}	12.8^{a}	34.6^{a}	1.1^{a}	3.9^{a}	331.0^{b}	199.9^{b}	3.28^{a}	3.33^{a}	17.8^{b}	20.1^{a}	6.7^{b}	9.0^{a}	2.65^{a}	2.24^{b}

^{a,b}Mean values followed by different letters are significantly different ($P < 0.05$)

All the statistical calculations were performed for each year separately; TSS – total soluble solid; TA – titratable acidity

to the other rootstocks. The tendency of having a different number of inflorescences on the shoots depending on the rootstock was also observed in other species, e.g., the kiwi (Wang et al. 1994), apple trees (Tworkoski, Miller 2007), pear trees (Almeida et al. 2020), peach trees (Bussi et al. 1995) and sweet cherry trees (Dziedzic et al. 2019; Long et al. 2019). Keller et al. (2001), studying the effect of the rootstock on the number of flowers in inflorescences, found that the 'SO4' rootstock stimulated a greater number of flowers in the inflorescence in the variety Müller-Thurgau. Overall, there are very few studies on the effect of the rootstock on the number of inflorescences in grapevines.

The yield of the grapevine fruit was obtained in 2016 and 2018 (Tables 1, 2, 3). In both years of the experiment, no significant differences in the yield related to the applied rootstock were observed. The low yield of the varieties 'Solaris' and 'Johanniter' in 2016 was associated with the spring frost damage to the flowers (Tables 1 and 3). No significant differences in the yield between the rootstocks were found in 2018. Stevens et al. (2008), Wooldridge et al. (2010) and Wang et al. (2019) reached similar findings and showed no rootstock effects on the grapevine yield. Pulko et al. (2012) also used three rootstocks ('5BB', 'Börner' and 'SO4') in their experiment with the variety 'Sauvignon Blanc'. The authors noted an increase yield on the 'Börner' rootstock (13% to 35%) in comparison to the other rootstocks analysed. Wooldridge et al. (2010) and Bou Nader et al. (2019) found that the yield was dependent on a clear interaction between the noble variety, rootstock and soil type. Lovisolo et al. (2016) and Romero et al. (2018) demonstrated that rootstocks had an effect on the water uptake from the soil, and thus on the vigour, productivity and berry quality. However, other studies reported no significant effect of the rootstocks on the grapevine yield, probably due to differences in the experimental and edaphoclimatic conditions (Kidman et al. 2014; Zhang et al. 2016). The results of the experiment have suggested that further studies on the effect of the rootstocks on the yield are necessary.

The weight of a single fruit cluster was assessed to determine the yield quality (Tables 1, 2, 3). In 2016, for the variety 'Solaris', the greatest impact on the cluster weight was obtained on the 'SO4' and 'R101-14M' rootstocks. The smallest clusters were observed on the 'Börner' rootstock (Table 1). For the variety 'Seyval Blanc', the largest clusters were recorded on the '125AA', 'R101-14M' and 'Börner' rootstocks (Table 2). No significant differences in the cluster weight were noted for the variety 'Johanniter' (Table 3). In 2018, rootstock did not significantly affect average cluster weight. The rootstocks showed a different effect on the average cluster weight depending on the year. The difference in the average cluster weight for all cultivars in 2016 was very large and ranged from 73 g ('Seyval Blanc') to 347 g ('Solaris'), while more uniform results were only observed in 2018. The 'Solaris' cultivar with the Börner rootstock had a higher average cluster weight compared to the other rootstocks, similarly for the 'Johanniter' cultivar with the 'SO4' rootstock. In the cultivar 'Seyval Blanc' there were no significant differences in the mean cluster weight. The study of Romero et al. (2018) demonstrated a very high variation in the average cluster weight depending on the applied rootstock.

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In the presented experiment, the cluster weights were divided into five weight classes for each combination. Figure 4 shows the percentage of each class in the yield. Many authors have reported that the average cluster weight of *V. vinifera* varieties varied between 100 and 200 g (Gatti et al. 2012; Bogicevic et al. 2015; Sabir et al. 2020). In the discussed experiment, no statistical differences in the average cluster weight were found between the rootstocks, but a regularity in the cluster weight distribution was visible for each cultivar. For the variety 'Solaris', the cluster weight most often ranged from 60 to 200 g (Figure 4A). For the variety 'Johanniter', the clusters weighing from 100 to 200 g represented the highest percentage (Figure 4B). For the variety 'Seyval Blanc', the cluster weight most often ranged from 200 g to 300 g (Figure 4C). This last variety was very heterogeneous with regard to the cluster weight, with a large proportion of small clusters below 60 g, as well as five other weight categories.

Chemical measurements. The total soluble solid (TSS), organic titratable acid (TA) contents and the pH value of the grape must are the most important indicators of the grapevine fruit maturity and harvest date. The values depend primarily on two variables: the climatic conditions between the flowering and harvest and also on the fruit to leaf ratio of the plants (Duchêne 2016; Lampíř, Žaloudek 2018).

To assess the effect of the variety and rootstock on the inner characteristics of the grape must, the grape must quality parameters were assessed (Tables 1, 2, 3). The quantitative measure of the acidity of grape must is the pH level, known as an important factor affecting the must and wine stability (Mpelasoka et al. 2003). Zhang et al. (2015). In the discussed work, the authors noted a comparable pH range of the must for the same variety. For the variety 'Solaris', the pH value ranged from 3.09 to 3.43 (Table 1). The lowest pH parameters were recorded for the '125AA' rootstock in both years and for the 'Börner' rootstock in the first year of the experiment. Pulko et al. (2012) observed the highest pH on the 'Börner' rootstock. In 2018, higher pH was recorded for 'Seyval Blanc' cultivar grafted on '5BB' and 'SO4' rootstocks compared to other rootstocks. Significant differences, depending on the rootstock, were not observed for the cultivar Johannite (Table 3).

In a region with relatively cool conditions for viticulture, such as Poland, the TSS during harvesting is the main parameter determining the later wine quality, conditioning the lack of additional treatments before fermentation (Zhang et al. 2015). The TSS depends on the variety and climatic conditions occurring in the period between the flowering and fruit harvest (Duchêne 2016). In the present experiment, a high difference in the TSS values was observed for three cultivars on five rootstocks (Tables 1, 2, 3). No recurring relationship was observed for the effect of the rootstock on the TSS; however, the TSS for the varieties 'Solaris' and 'Seyval Blanc' was the highest for the 'SO4' and 'Börner' rootstocks in 2016. For the variety 'Seyval Blanc', the '5BB' rootstock was also present in the same significance

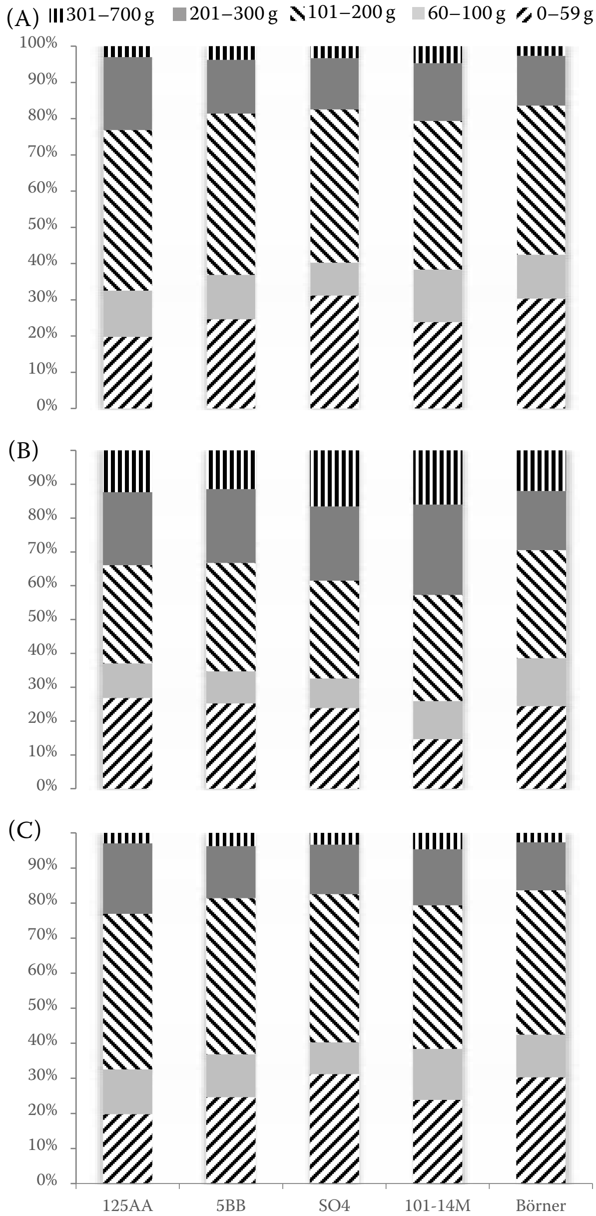

Figure 4. Yield share in the five cluster weight categories: (A) 'Solaris', (B) 'Seyval Blanc', (C) 'Johanniter'

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group. In 2018, these relationships were not recorded again, but the '5BB' and 'Börner' rootstocks contributed to the highest TSS for the variety 'Solaris'. Liu et al. (2015) determined a level of 21.1 °B for the variety 'Solaris' as being adequate for a "cool region", in our study we obtained significantly higher TSS for this variety in both study years, a mean 23.9 °B in 2016 and 22.3 °B in 2018. These results were similar to the values published in the work of Samoticha et al. (2017). Pulko et al. (2012) analysed the effect of the 'Börner' and '5BB' rootstocks on the variety Sauvignon Blanc, and similar our experiment, recorded an increase in the TSS levels on these rootstocks. When analysing the impact of the rootstocks, it can be concluded that the 'Börner' and '5BB' rootstocks increased the TSS on average by 11.7% in 2016 and by 8% in 2018 compared to the other rootstocks. In a study carried out in similar climatic conditions, Izajasz-Parchańska et al. (2014) observed a significantly higher TSS (22 °B) for the cultivar 'Seyval Blanc' than in our experiment, where we obtained similar results to Slegers et al. (2017) (19.7 °B). Jin et al. (2016) analysed the effect of the '101-14M', '5BB' and'SO4' rootstocks on the variety 'Summer Black' and found that the '101-14M' rootstock accumulated a higher TSS content compared to the other two, while we did not observe a similar relationship in our work.

The TA in grapes, similar to the pH, affects the microbiological stability of wine. It is assumed that hybrid cultivars have a higher TA content than *V. vinifera* varieties (Riesterer-Loper et al. 2019; Schrader et al. 2020). The must acidity is an important parameter and determines the later taste of wine (Cioch, Tuszyński 2014). In the discussed experiment, the highest TA content for the variety 'Solaris' was recorded in 2016 on the '5BB' and 'Börner' rootstock, while the lowest was recorded on the 'SO4' rootstock (Table 1). For the variety 'Seyval Blanc', no statistical differences were found in 2016, while in 2018, the '125AA' and 'Börner' rootstocks contributed to an increased TA content (Table 2). A similar relationship was observed for the cultivar 'Johanniter' in 2018 (Table 3). The same variety in 2016, on the '5BB' rootstock, had a statistically higher TA level than the other combinations. Li et al. (2019), for the 'Marselan' variety, recorded the highest acidity on the 'SO4' rootstock and the lowest on the '101-14M' rootstock. In study conducted by Izajasz-Parchańska et al. (2014), the TA for the 'Solaris' variety was 6.5 g/L, while Samoticha et al. (2017) reported a significantly higher TA – at 9.3 g/L. The study of Greyling (2019) on the variety 'Seyval Blanc' showed differences in the TA content in relation to the amount of sunlight in the vineyard. The values obtained by Greyling (2019) and Izajasz-Parchańska (2014) were similar to the values obtained by us in the present study. The study of Slegers at al. (2017) recorded a higher TA (9.7 g/L) for the same cultivar.

The TSS to TA ratio is defined as the grape maturity coefficient. A high or low index may indicate an incorrect harvest date or a disturbance in the veraison stage caused by inappropriate weather conditions (Ju et al. 2016; Shahab et al. 2020). A TSS/TA ratio in a range of 2.1–3.3 is regarded as optimal for white grapes (Yair 2004). During two seasons of the experiment, significant differences were recorded for the TSS/TA ratio between the rootstocks. 'Solaris', as the earliest maturing variety, was in the upper limit of this range, sometimes even exceeding it (Table 1). In 2016, the highest ratio was recorded for the 'SO4' rootstock, i.e., 3.65, which was associated with a low TA level in relation to a high TSS. The phenomenon of an increase in the sugar concentration and a decrease in the acidity associated with a higher pH during grape maturation has been described by many researchers (Ollat et al. 2002; Keller 2010; Téthal et al. 2015). In 2018, the relationship occurred again for the 'Börner' rootstock. In the variety 'Seyval Blanc' grown on the '125AA' rootstock, a low TSS and high TA resulted in a decrease in the coefficient to 1.98 in 2018 only, which was below the range defined as optimal (Table 2). For the remaining rootstocks, the coefficient was within the optimal range, as for the variety 'Johanniter' in both study years (Table 3).

CONCLUSION

A significant factor when selecting varieties for new plantings is the time required by a given variety to produce a crop with good physicochemical parameters. The conducted experiment showed that the rootstocks did not determine the yield size, but significantly improved its quality.

In Polish climatic conditions, we found that the rootstock can significantly change the physicochemical parameters, i.e., TSS content and acidity. This was particularly evident with the 'Börner' rootstock, and '5BB' to a lesser extent, for the 'Solaris' strain. The rootstocks 'R101-14M', '5BB' and 'SO4' positively affected the TSS and TA of the 'Seyval Blanc' and 'Johanniter'cultivars.

Further research on the effect of the rootstocks on the physicochemical characteristics of a variety will allow the creation of a physicochemical profile of cultivated hybrid varieties.

REFERENCES

Almeida G.K., Fioravanço J.C., Marodin G.A.B. (2020): Vegetative growth and productive performance of "Abate Fetel" and "Rocha" pear trees on quince rootstocks. Pesquisa Agropecuária Brasileira: 55.

Bogicevic M., Maras V., Mugoša M., Kodžulović V., Raičević J., Šućur S., Failla O. (2015): The effects of early leaf removal and cluster thinning treatments on berry growth and grape composition in cultivars Vranac and Cabernet Sauvignon. Chemical and Biological Technologies in Agriculture, 2: 1–8.

Bou Nader K., Stoll M., Rauhut D., Patz C.D., Jung R., Loehnertz O., Schultz H.R., Hilbert G., Renaud C., Roby J.P., (2019): Impact of grapevine age on water status and productivity of *Vitis vinifera* L. cv. 'Riesling'. European Journal of Agronomy, 104: 1–12.

Bussi C., Huguet J.G., Besset J., Girard T. (1995): Rootstock effects on the growth and fruit yield of peach. European Journal of Agronomy, 4: 387–393.

Censi P., Saiano F., Pisciotta A., Tuzzolino N. (2014): Geochemical behaviour of rare earths in *Vitis vinifera* grafted onto different rootstocks and growing on several soils. Science of the Total Environment, 473–474: 597–608.

Cioch M., Tuszyński T. (2014): Biologiczne metody odkwaszania win gronowych. Engineering Sciences and Technologies, 1: 10–23.

Clingeleffer P.R., Emmanuelli D.R. (2006): An assessment of rootstocks for Sunmuscat (*Vitis vinifera* L.): a new drying variety. Australian Journal of Grape and Wine Research, 12: 135–140.

Duchêne É. (2016): How can grapevine genetics contribute to the adaptation to climate change. OENO One, 50: 113–124.

Dziedzic E., Bieniasz M., Kowalczyk B. (2019): Morphological and physiological features of sweet cherry floral organ affecting the potential fruit crop in relation to the rootstock. Scientia Horticulturae, 251: 127–135.

Ferlito F., Distefano G., Gentile A., Allegra M., Lakso A.N., Nicolosi E. (2020): Scion–rootstock interactions influence the growth and behaviour of the grapevine root system in a heavy clay soil. Australian Journal of Grape and Wine Research, 26: 68–78.

Gatti M., Bernizzoni F., Civardi S., Poni S. (2012): Effects of cluster thinning and preflowering leaf removal on growth and grape composition in cv. Sangiovese. American Journal of Enology and Viticulture, 63: 325–332.

Gautier A.T., Chambaud C., Brocard L., Ollat N., Gambetta G.A., Delrot S., Cookson S.J. (2019): Merging genotypes: graft union formation and scion–rootstock interactions. Journal of Experimental Botany, 70: 747–755.

Greyling I. (2019): Extraction and bioconversion of aroma impact compounds from Sauvignon Blanc grapes to wine matrices during white wine production. [MSc. Thesis.] Stellenbosch, Stellenbosch University, 1–119.

Gu S. (2001): Effect of Rootstocks on Grapevines. *Vitis*. Kentucky State University: 1–19.

Izajasz-Parchańska M., Cioch M., Tuszyński T. (2014): Monitoring parametrów dojrzałości technologicznej winogron na terenie małopolskiej winnicy Srebrna Góra, w sezonie wegetacyjnym 2012. Acta Agrophysica, 21: 263–278.

Jin Z-X., Sun T-Y., Sun H., Yue Q-Y., Yao Y-X. (2016): Modifications of 'Summer Black' grape berry quality as affected by the different rootstocks. Scientia Horticulturae, 210: 130–137.

Ju Y-L., Liu M., Zhao H., Meng J-F., Fang Y-L. (2016): Effects of exogenous abscisic acid and methyl jasmonate on anthocyanin composition, fatty acids, and volatile coupounds of Cabernet Sauvignon (*Vitis vinifera* L.) grape berries. Molecules, 21: 1354.

Julius Kühn-Institut. *Vitis* International Variety Catalogue - 'Solaris', 'Johanniter'. Available at http://www.vivc.de

Keller M., Kummer M., Vasconcelos M.C. (2001): Reproductive growth of grapevines in response to nitrogensupply and rootstock. Australian Journal of Grape and Wine Research, 7: 12–18.

Keller M. (2010): Managing grapevines to optimise fruit development in a challenging environment: A climate change primer for viticulturists. Australian Journal of Grape and Wine Research,16: 56–69.

Kidman C.M., Mantilla S.O., Dry P.R., Mccarthy M.G., Collins C. (2014): Effect of water stress on the reproductive performance of Shiraz (*Vitis vinifera* L.) grafted to rootstocks. American Journal of Enology and Viticulture, 65: 96–108.

Lampíř L., Žaloudek J. (2018): Influence of summer management practices and date of harvesting on organic acids concentration and sugar concentration in grapes of *Vitis vinifera* L., cv. 'Riesling'. Horticultural Science (Prague), 45: 213–218.

Li M., Guo Z., Jia N., Yuan J., Han B., Yin Y., Sun Y., Liu C., Zhao S. (2019): Evaluation of eight rootstocks on the growth and berry quality of 'Marselan' grapevines. Scientia Horticulturae, 248: 58–61.

Liu J., Toldam-Andersen T.B., Petersen M.A., Zhang S., Arneborg N., Bredie W.L.P. (2015): Instrumental and sensory

https://doi.org/10.17221/58/2021-HORTSCI

characterisation of 'Solaris' white wines in Denmark. Food Chemistry, 166: 133–142.

Long L.E., Iezzoni A., Seavert C., Auvil T., Kaiser C., Brewer L.J. (2019): New cherry rootstock and cultivar interactions directly affect orchard profitability. Acta Horticulturae (ISHS), 1235: 197–206.

Lovisolo C., Lavoie-Lamoureux A., Tramontini S., Ferrandino A. (2016): Grapevine adaptations to water stress: new perspectives about soil/plant interactions. Theoretical and Experimental Plant Physiology, 28: 53–66.

Mijowska K., Ochmian I., Oszmiański J. (2017): Rootstock effects on polyphenol content in grapes of 'Regent' cultivated under cool climate condition. Journal of Applied Botany and Food Quality, 90: 159–164.

Mpelasoka B.S., Schachtman D.P., Treeby M.T., Thomas MR. (2003): A review of potassium nutrition in grapevines with special emphasis on berry accumulation. Australian Journal of Grape and Wine Research, 9: 154–168.

Mudge K., Jcinick J., Scofield S. (2009): A History of Grafting. Chapter 6. In: Janick J. (ed.): Horticultural Review, Vol. 35. John Wiley and Sons: 437–493.

Myśliwiec R., Mazurek J., Bosak W., Wawro E. (2018): Winorośl i wino, wiedza i praktyka. Part 1. In: Fund na Rzecz Rozw i Promocji Winiarstwa Galicja Vitis. Jasło: 127–140.

Ollat N., Diakou-Verdin P., Carde J.P., Barrieu F., Gaudillère J.P., Moing A. (2002): Grape berry development : A review. Journal International des Sciences de la Vigne et du Vin, 36: 109–131.

Pulko B., Vršič S., Valdhuber J. (2012): Influence of various rootstocks on the yield and grape composition of Sauvignon Blanc. Czech Journal of Food Sciences, 30: 467–473.

Reynolds A.G., Wardle D.A. (2001): Rootstocks impact vine performance and fruit composition of grapes in British Columbia. HortTechnology, 11: 419–427.

Riesterer-Loper J., Workmaster B.A., Atucha A. (2019): Impact of fruit zone sunlight exposure on ripening profiles of cold climate interspecific hybrid winegrapes. American Journal of Enology and Viticulture, 70: 286–296.

Romero P., Botía P., Navarro J.M. (2018): Selecting rootstocks to improve vine performance and vineyard sustainability in deficit irrigated Monastrell grapevines under semiarid conditions. Agricultural Water Management, 209: 73–93.

Sabir A., Kilinc S., Sabir F. (2020): Qualitative and quantitative responses of early ripening table grape cultivars (*Vitis vinifera* L.) to pollination treatments under controlled growing condition. Erwerbs-Obstbau, 62: 75–80

Samoticha J., Wojdyło A., Golis T. (2017): Phenolic composition, physicochemical properties and antioxidant activity of interspecific hybrids of grapes growing in Poland. Food Chemistry, 215: 263–273.

Schrader J.A., Cochran D.R., Domoto P.A., Nonnecke G.R. (2020): Yield and berry composition of cold-climate grape cultivars and advanced selections in Iowa climate. Horttechnology, 30: 193–203.

Shaffer R., Sampaio T.L., Pinkerton J., Vasconcelos M.C. (2004): Grapevine Rootstocks for Oregon Vineyards. Oregon State University Extension Publication, 12.

Shahab M., Roberto S.R., Ahmed S., Carlos Colombo R., Silvestre P., Koyama R., Teodoro De Souza R. (2020): Relationship between anthocyanins and skin color of table grapes treated with abscisic acid at different stages of berry ripening. Scientia Horticulturae, 259: 108859.

Slegers A., Angers P., Pedneault K. (2017): Volatile compounds from must and wines from five white grape varieties. Journal of Food Chemistry and Nanotechnology, 3: 8–18.

Somkuwar R.G., Bondage D.D., Surange M.S., Ramteke S.D., (2011): Rooting behaviour, polyphenol oxidase activity, and biochemical changes in grape rootstocks at diff erent growth stages. Turkish Journal of Agriculture and Forestry, 35: 281–287.

Stevens R.M., Pech J.M., Gibberd M.R., Walker R.R., Jones J.A., Taylor J., Nicholas P.R. (2008): Effect of reduced irrigation on growth, yield, ripening rates and water relations of Chardonnay vines grafted to five rootstocks. Australian Journal of Grape and Wine Research, 14: 177–190.

Téthal J., Baroň M., Sotolář R., Ailer S., Sochor J. (2015): Effect of grapevine rootstocks on qualitative parameters of the Cerason variety. Czech Journal of Food Sciences, 33: 570–579.

Tworkoski T., Miller S. (2007): Rootstock effect on growth of apple scions with different growth habits. Scientia Horticulturae, 111: 335–343.

Vršič S., Pulko B., Kocsis L. (2015): Factors influencing grafting success and compatibility of grape rootstocks. Scientia Horticulturae, 181: 168–173.

Walker R., Clingeleffer P. (2009): Rootstock attributes and selection for Australian conditions. American Society for Enology and Viticulture (ASEV). Napa Valley, California, (June): 23–26.

Wang Y., Chen W.K., Gao X.T., He L., Yang X.H., He F., Duan C.Q., Wang J. (2019): Rootstock-mediated effects on cabernet sauvignon performance: vine growth, berry ripening, flavonoids, and aromatic profiles. International Journal of Molecular Sciences, 20: 401.

Wang Z.Y., Patterson K.J., Gould K.S., Lowe R.G. (1994): Rootstock effects on budburst and flowering in kiwifruit. Scientia Horticulturae, 57: 187–199.

Whiting J. (2004): Grapevine rootstocks. Viticulture. Tom 1 Resources. Edited by P.R. Dry and B.G. Coo, 167–188.

Wooldridge J., Louw P.J.E., Conradie W.J. (2010): Effects of rootstock on grapevine performance, petiole and must composition, and overall wine score of *Vitis vinifera* cv. Chardonnay and Pinot Noir. South African Journal of Enology and Viticulture, 31: 45–48.

https://doi.org/10.17221/58/2021-HORTSCI

Yair M. (2014): Concepts in wine technology. Wine Appreciation Guild: 16–19.

Zhang J., Hausmann L., Eibach R., Welter L.J., Töpfer R., Zyprian E.M. (2009): A framework map from grapevine V3125 (*Vitis vinifera* "*Schiava gross*" × 'Riesling') × rootstock cultivar "Börner" (*Vitis riparia* × *Vitis cinerea*) to localize genetic determinants of phylloxera root resistance. Theoretical and Applied Genetics, 119: 1039–1051.

Zhang L., Marguerit E., Rossdeutsch L., Ollat N., Gambetta G.A. (2016): The influence of grapevine rootstocks on scion growth and drought resistance. Theoretical and Experimental Plant Physiology, 28: 143–157.

Zhang S., Petersen M., Liu J., Toldam-Andersen T. (2015): Influence of pre-fermentation treatments on wine volatile and sensory profile of the new disease tolerant cultivar 'Solaris'. Molecules, 20: 21609–21625.

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