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THE IMPACT OF ROOTSTOCKS ON YIELD AND FRUIT QUALITY OF SELECTED GRAPE VARIETIES GROWN IN NORTHWESTERN POLAND

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Abstract. The research examined the influence of various rootstocks on grape yield and fruit quality across different grapevine cultivars, conducted between 2020 and 2022 in northwestern Poland. The study covered light-colored grape varieties including Solaris, Muscaris, Johanniter, Hibernal, Helios, Riesling, and Chardonnay, focusing on the organic vineyard management system. The experimental setup compared the yield, size of clusters and fruits, sugar content, and acidity of grapevines grafted onto three different rootstocks (SO4, 5BB, 125AA). The findings highlighted significant differences in the yield and fruit quality among the varieties, with Solaris achieving the highest yields on the SO4 rootstock. In contrast, Riesling and Chardonnay required significant yield reduction to meet optimal technological parameters. The study also revealed that while rootstocks had a minimal impact on sugar content and acidity, these parameters were primarily driven by the cultivar. The research underscores the importance of selecting suitable rootstock-cultivar combinations to optimize both the quantity and quality of grape production in response to specific environmental conditions, particularly in the context of climate change. These findings contribute valuable insights into the management of grapevine cultivation in cooler regions, offering recommendations for vineyard management to improve wine production quality.

Key words: climate impact, grape quality, rootstock, viticulture.

INTRODUCTION

The grapevine (*Vitis vinifera* L.) is one of the most important cultivated plants globally, mainly used for wine production. In Poland, over the past 30 years, numerous vineyards ranging from a few acres to several dozen hectares have been established. In the scale of Europe, Poland is still of minor significance in viticulture. Currently, these vineyards cover about 1000 hectares, with an average size of 1.4 hectares per vineyard. Their total area has doubled in the last decade. These vineyards are primarily located in the southern and western regions of Poland (https://winogrodnicy.pl/). Due to the lack of traditional viticulture

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and well-developed wine production infrastructure, conventional vineyards dominate. Considering the relatively recent establishment of vineyards in Poland, the impact of specific climatic and soil conditions on the quality of both the fruits and the resulting wine has not yet been thoroughly characterized (Błaszak et al. 2023). The climate in Poland differs from that of Southern and Western European countries, characterized by lower temperatures and sunlight exposure, different patterns of precipitation and frosts, etc., and different soil properties, mainly lower soil pH, usually below 7.0 (Mijowska et al. 2016; Figiel-Kroczyńska et al. 2021). The climate, soil properties, and agronomic practices shape the quality of the fruits and their quality. The climate, soil properties, and agronomic practices shape the quality of the fruits and the wine produced from them (Kostic et al. 2010). Often, the chemical composition of wine can reveal the region (soil, climate) where it was produced (Censi et al. 2014).

The tradition of viticulture in Szczecin dates back to the 13th century. Wine from vineyards located around the castle was a valued beverage of the Pomeranian dukes in Szczecin, as well as the dukes of Mecklenburg in Schwerin, Gustrow, and Stargard (Chełpiński et al. 2009). However, cultivation faces many challenges, including pest attacks, diseases, and environmental stress, which affect the quality and quantity of the fruits produced. In response to these challenges, vintners use various rootstocks on which they graft cultivated varieties (Migicovsky et al. 2021). Rootstocks, being grapevine varieties or other species from the genus Vitis, can significantly influence the development, health, and ultimately the quality of grapevine fruits (Pachnowska and Ochmian 2018).

Rootstocks can differ in their ability to absorb water and nutrients from the soil. Some rootstocks are characterized by a better ability to absorb water and nutrients, which directly translates to the health of the grapevine and the quality of the fruits produced (Ferlito et al. 2020; East et al. 2021).

The choice of rootstock also has a significant impact on the agronomic characteristics of the grapevine, including growth, yield size, and fruit ripening timing. Importantly, studies show that the rootstock can affect the chemical composition of the fruits, including the content of sugars, acids, phenolic compounds, and the aromatic and taste profile of wines (Darriaut et al. 2022). In the conducted studies, the impact of the rootstock on the quality of fruits of several grapevine varieties grown in the northwestern region of Poland was compared.

MATERIALS AND METHODS

Characteristics of the research area and plant material

The research was conducted between 2020 and 2022 at the Department of Horticulture of the West Pomeranian University of Technology in Szczecin. The subjects of the study were wine grape varieties with light-colored fruits: Solaris, Muscaris, Johanniter, Hibernal, Helios, Riesling, and Chardonnay. Fruit was taken from an organic plantation located near Szczecin in northwestern Poland (53°21’09.8”N 14°26’23.3”E).

Weather conditions during the experiment

Analyzing data on temperature and rainfall in Szczecin during the vegetation period from April to October in the years 2020–2022 compared to the long-term period (1951–2012), several significant trends and changes can be observed (Table 1), temperatures in 2020–2022 were mostly higher than the long-term average, indicating a warming trend. For example, in July and August of 2021 and 2022, temperatures were significantly higher than the long-term average temperatures. The average temperature in 2020–2022 (approx. 14.4–14.6°C) was higher than the long-term average (13.7°C).

Rainfall in 2020–2022 was generally lower than the long-term average for this period (390.6 mm). For instance, total rainfall in 2020 was 258.1 mm, which is significantly below the norm. Significant fluctuations in rainfall were noticeable, especially in July 2021, where rainfall reached 123 mm compared to the long-term average of 69.6 mm. Meanwhile, no rainfall was recorded in June.

The data indicate higher temperatures and lower rainfall compared to long-term averages, which aligns with general trends of climate change. These changes may pose challenges for agriculture in the Szczecin region and require adjustments in agricultural practices to effectively manage water resources and maintain healthy conditions for crops.

Table 1. Temperature and rainfall in the period from April to October (vegetation season) in 2020–2022 compared to the multiannual period (1951–2012) in Szczecin

Year	Month							
	IV	V	VI	VII	VIII	IX	X	mean
	average temperature [C°]							
2020	8.9	11.1	17.7	17.4	20.3	14.6	10.5	14.4
2021	5.9	11.6	19.3	20.3	16.7	15.1	10.1	14.1
2022	7.2	13.3	18.1	18.4	20.6	12.9	11.6	14.6
1951–2012	8.0	13.0	16.4	18.2	17.6	13.8	9.2	13.7
	rainfall [mm]							total
2020	20.1	34.0	26.6	21.3	40.0	72.3	43.8	258.1
2021	4.6	25.1	0.0	123	37.4	17.1	24.7	231.9
2022	19.9	25.2	27.6	67.5	23.4	39.0	22.2	224.8
1951–2012	39.7	62.9	48.2	69.6	74.2	58.7	37.3	**390.6**

Cultivation scheme

Plants were planted in 2016 at a spacing of 1.01 × 2.28 m (Fig. 1). Pruning is carried out in January–February. The plants were pruned with a Guyot (one arm) training system and vertically positioned with eight shoots with two clusters per each. On the plantation, weeds within the rows are controlled using a mechanical weeder, while in the inter-rows, cover crop mixtures (such as lucerne, red clover, and oil radish) are planted to enhance soil structure and enrich it with organic matter. During the growing season, shoots and excess leaves from the cluster zone are removed mechanically.

During the growing season (May–October), the following was applied for crop protection (in pure component per hectare):

- sulphur – 12.5 kg/ha, (withdrawal period – 56 days),
- copper (copper oxychloride and copper hydroxide) – 1.75 kg/ha (withdrawal period – 7 days),
- potassium carbonate – 17.5 kg/ha (withdrawal period – 0 day),
- potassium grey soap – 4 kg/ha (withdrawal period – 0 day).

Fig. 1. Vineyard plantation (phot. I. Ochmian)

Sample collection was conducted on a vineyard in late September/early October, using sterile containers (three containers of 5 kg fruit each). Each bulk sample, consisting of fruit from 10 vine bushes, was taken from different locations within the vineyard to ensure representativeness. After transport to the laboratory, juice was pressed from the fruit, and analyses were performed.

In the experiment, the yield, size of clusters and fruits, extract content, and organic acids were compared. The chemical composition of the fruits was analyzed in the juice taken from the mash directly after crushing the fruits with a pulp mill in three replicates. The total acidity was determined by titration method expressed as citric acid (according to PN-90/A-75101/04). The acidity was measured by titrating an aqueous extract solution of the fruits with 1N NaOH to the endpoint at pH = 8.1 (Pehametr Elmetron Poland). The content of the total extract was determined using an electronic refractometer PAL1 (Atago Japan).

Statistical analysis

All statistical analyses were performed with Statistica 12.5 (StatSoft Polska, Cracow, Poland). The data were subjected to one-factor variance analysis (ANOVA). Mean comparisons were performed using Tukey's least significant difference (LSD) test; significance was set at $p < 0.05$.

RESULTS AND DISCUSSION

An analysis of the research results concerning the impact of different rootstocks on the yield and quality of grapevine fruits showed significant differences in yield between individual grapevine varieties and types of rootstocks. Significant differences in yield were noted between grapevine varieties, with the varieties Solaris, Johanniter, Hibernal, and Helios achieving higher yields than the others – over 2 kg per plant. Hibernal yielded at a similar level in the studies of Gąstoł (2015). The influence of the rootstock on yield was noticeable but dependent on the cultivar. Other authors have also shown that the influence of the rootstock on grapevine yield is minimal or nonexistent (Stevens et al. 2008; Wang et al. 2019; Kowalczyk et al. 2022).

The highest yields were obtained from the Solaris cultivar on the SO4 rootstock – 2.58 kg per plant – equivalent to about 11 tons/ha (Table 2). From the same cultivar grafted onto 5BB, 2.05 kg per plant was harvested. The difference in yield per hectare is significant and amounts to almost 2 tons. The higher yield of these varieties results from the fact that they are hybrid varieties, specially created for cooler cultivation regions, where climatic conditions are not suitable for varieties grown, for example, in Southern Europe. However, in the studies of Klimek et al. (2023), the average yield of this cultivar was over 21 tons (Ziegler et al. 2020).

To obtain fruits with appropriate technological parameters, the yield of the Riesling and Chardonnay varieties had to be significantly reduced, averaging 1.25 kg and 1.02 kg per plant (about 5 tons/ha). In southern Germany, where the Riesling cultivar dominates, yields reached over 20 tons/ha. The Riesling cultivar is known for its good adaptation to cooler climates, making it an attractive choice for cultivation in these regions. Riesling has good tolerance to low temperatures and late frosts, which is important in the context of changing weather conditions in cooler regions. In cooler regions, where days are shorter and temperatures lower, the yield of Riesling may be lower compared to cultivation in warmer regions, which is confirmed by the obtained results. Chardonnay is a more demanding cultivar in terms of climatic conditions compared to Riesling. In cooler regions, where there is a risk of frosts and lower temperatures, the cultivation of Chardonnay may be more problematic, especially if appropriate cold protection techniques are not used. However, there are Chardonnay varieties, such as Chardonnay Musque, which show greater tolerance to cold and may perform better in such conditions (Versini et al. 1990).

Table 2. Yield and quality of fruits of the studied grapevine varieties depending on the applied rootstock – average over the years 2020–2022

Rootstock (A)	Cultivars (B)							
	Solaris	Muscaris	Johanniter	Hibernal	Riesling	Chardonnay	Helios	mean
	yield per plant [kg]							
SO4	2.58	1.75	2.09	1.96	1.30	1.03	2.34	**1.86**
5BB	2.05	1.58	1.94	2.17	1.25	0.92	2.48	**1.77**
125AA	2.30	1.89	2.22	2.23	1.19	1.11	2.25	**1.88**
Mean	**2.31**	**1.74**	**2.08**	**2.12**	**1.25**	**1.02**	**2.36**	–
$LSD_{0.05}$	A = 0.27		B = 0.25		A × B = 0.19 (n.s.)		–	
	weight of the cluster [g]							
SO4	144	127	175	117	98	110	117	**127**
5BB	163	143	169	113	103	114	139	**135**
125AA	138	122	165	125	92	117	113	**125**
Mean	**148**	**131**	**170**	**118**	**98**	**114**	**123**	–
$LSD_{0.05}$	A = 22		B = 19		A × B = 16		–	
	weight of 100 fruits [g]							
SO4	148	171	88	104	136	128	140	**131**
5BB	132	164	92	111	144	125	131	**128**
125AA	141	175	94	98	151	123	146	**133**
Mean	**140**	**170**	**91**	**104**	**144**	**125**	**139**	–
$LSD_{0.05}$	A = 15		B = 14		A × B = 11		–	

An analysis of the results in Table 2 indicates differences in the mass of clusters and the size of individual grapevine fruits depending on the cultivar and the rootstock used. The varied response of individual varieties to the applied rootstocks provides valuable information about their growth potential and productivity. This information is crucial for vineyard management and production optimization. Differences in the response of varieties to rootstocks may also suggest the need to adjust agronomic practices, such as fertilization or irrigation control, to maximize the production and quality potential of grapevines.

The 5BB rootstock appears to be the most effective for most of the studied varieties (Solaris, Muscaris, Riesling, Helios) in supporting greater cluster mass, which may suggest a better ability to absorb nutrients or greater resistance to local conditions. Clusters of the Solaris cultivar in the studies of Kowalczyk et al. (2022) had a significant discrepancy in mass – depending on the year of studies and rootstock, from 91 g to 347 g on the SO4 rootstock. Johanniter is characterized by the largest cluster mass on all rootstocks, which may indicate its particular adaptation to the conditions prevailing in the studied area. Particularly large clusters were found when using SO4 and 125AA rootstocks, where they reached masses of 175 g and 165 g, respectively. The 125AA rootstock generally influences a slight increase in fruit mass, which may indicate its usefulness in optimizing fruit size in commercial vineyards. This cultivar, however, is characterized by small fruit mass (100 fruits = 91 g). Riesling, known for smaller clusters, confirms its characteristics in these studies. Clusters were characterized by the lowest results in the group of studied varieties – the average cluster mass ranges from 92 to 103 g, which is significantly below the average for other varieties. However, it shows a high mass of 100 fruits (144 g).

This is consistent with other studies that show a significant influence of rootstocks on grapevine performance, including yield and fruit quality (Domingues Neto et al. 2023). However, the influence of the rootstock on yields is largely modified by the cultivar (Provost et al. 2021). The 125AA rootstock generally provided higher yields and better berry quality in Regent grapevines compared to other rootstocks (Klimek et al. 2022).

Table 3. The extract content and acidity of the fruits of the studied grapevine varieties depending on the applied rootstock – average over the years 2020–2022

Rootstock (A)	Cultivars (B)							
	Solaris	Muscaris	Johanniter	Hibernal	Riesling	Chardonnay	Helios	mean
				soluble solids – SS [%]				
SO4	25.3	22.9	23.2	20.4	19.8	20.1	23.4	**22.2**
5BB	25.9	22.7	23.6	20.1	20.0	20.5	23.3	**22.3**
125AA	25.5	23.0	23.7	19.6	20.5	20.2	23.6	**22.3**
Mean	**25.6**	**22.9**	**23.5**	**20.0**	**20.1**	**20.3**	**23.4**	–
$LSD_{0.05}$	A = 0.7		B = 0.6		A × B = 0.3		–	
				titratable acidity – TA [g/L]				
SO4	7.1	8.2	8.4	8.9	10.2	9.8	8.1	**8.7**
5BB	7.5	8.3	8.1	8.9	9.8	9.5	8.3	**8.6**
125AA	7.2	8.5	8.5	8.2	9.9	9.7	7.9	**8.6**
Mean	**7.3**	**8.3**	**8.3**	**8.7**	**10.0**	**9.7**	**8.1**	–
$LSD_{0.05}$	A = 0.6		B = 0.5		A × B = 0.3		–	

The results demonstrate how interactions between grape varieties and rootstocks influence key grape characteristics that are crucial for wine quality. Sugar content and acidity are critical for fermentation processes and the final flavor profile of the wine. The choice of an appropriate rootstock and cultivar combination can significantly impact the plants' adaptation to local conditions, thus optimizing the quality and quantity of the wine produced. Analyzing the interaction between varieties and their impact on fruit quality parameters can lead to better selection of genotypes adapted to specific environmental conditions and market preferences (Table 3).

The results indicate significant differences in sugar content and organic acids, mainly depending on the chosen cultivar, and to a lesser extent on the rootstock. The highest soluble solids (SS) were found in the Solaris cultivar, accompanied by a low acid level. A similar acid level was reported by Liu et al. (2015). This indicates the good adaptation of this cultivar to cooler climatic conditions (Becker and Toldam-Andersen 2012). However, in the case of some varieties like Riesling, which has a lower sugar content (20.1%), a significantly higher acidity (10.0 g/L) is recorded. However, such a large reduction in yield resulted in the technological parameters of the Riesling fruit being comparable to those grown in typical regions for this cultivar, such as southern Germany (Ziegler et al. 2020). Similar trends are observed in the Chardonnay cultivar. This suggests a possible inverse correlation between sugar content and acidity, particularly visible in these varieties. This confirms that these varieties are less adapted to cultivation in cooler areas with a shorter growing season (Becker and Toldam-Andersen 2012). In the northern regions of the USA, soluble solids were at a similar level to the present study, and depending on the year of harvest and pruning methods (yield limitation), it ranged from 18.2° to 22.3° Brix (Preszler et al. 2013).

The rootstocks did not show significant average differences in sugar content and acidity, which may suggest that the cultivar has a stronger influence on these parameters than the type of rootstock. A minor effect of rootstocks on the acid content in fruits was also shown by Kowalczyk et al. (2022), who observed more significant differences in total soluble solids. The fruits of the Solaris cultivar had TSS ranging from from 21.4° to 25.2° Brix, depending on the rootstock and the year of the study.

CONCLUSIONS

1. The study revealed significant differences in yield and fruit quality of grapevines depending on the rootstock used. The Solaris cultivar on SO4 rootstock achieved the highest yield (2.54 kg per plant), while the yield on 5BB rootstock was 2.05 kg per plant. These differences may result from the SO4 rootstock's superior ability to absorb nutrients and water.
2. Analysis of weather conditions from 2020–2022 indicates higher temperatures and lower rainfall compared to long-term averages. These climate changes may necessitate adaptations in agricultural practices to maintain healthy conditions for grapevine cultivation and ensure optimal fruit quality.
3. The study results show that different grapevine varieties respond variably to the rootstocks used. The 5BB rootstock was most effective for the Solaris, Muscaris, Riesling, and Helios varieties, supporting greater cluster weight. In contrast, Johanniter exhibited the largest cluster weight on all rootstocks, indicating its particular adaptation to the conditions of the studied area.
4. Interactions between varieties and rootstocks significantly influence the sugar content and acidity of the fruits, which are crucial for wine quality. The Solaris cultivar had the

highest sugar content and low acidity, while the Riesling and Chardonnay varieties had lower sugar content but higher acidity. Rootstocks did not show significant differences in average sugar content and acidity, suggesting that the cultivar has a stronger influence on these parameters than the rootstock type.

5. Based on the conducted research, it is recommended to select appropriate combinations of rootstock and cultivar to optimize the quality and quantity of produced grapes. Choosing the SO4 rootstock for the Solaris cultivar and proper yield management for the Riesling and Chardonnay cultivar are crucial for obtaining fruits with suitable technological parameters, especially in the context of changing climate conditions in the northwestern Poland region.

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WPŁYW PODKŁADEK NA PLONOWANIE I JAKOŚĆ OWOCÓW WYBRANYCH ODMIAN WINOROŚLI UPRAWIANYCH W PÓŁNOCNO--ZACHODNIEJ POLSCE

Streszczenie: Badania przeprowadzone w latach 2020–2022 w północno-zachodniej Polsce dotyczyły wpływu różnych podkładek na plonowanie i jakość owoców winorośli dla wybranych odmian, takich jak Solaris, Muscaris, Johanniter, Hibernal, Helios, Riesling oraz Chardonnay. Badania skupiały się na systemie uprawy ekologicznej. W ramach eksperymentu porównano plon, wielkość gron i owoców, a także zawartość cukru i kwasowość winogron szczepionych na trzech różnych podkładkach (SO4, 5BB, 125AA). Wyniki wykazały istotne różnice w plonowaniu i jakości owoców między poszczególnymi odmianami. Odmiana Solaris osiągnęła najwyższe plony na podkładce SO4. Z kolei Riesling i Chardonnay wymagały znacznego ograniczenia plonu, aby uzyskać optymalne parametry technologiczne. Badanie pokazało, że podkładki miały minimalny wpływ na zawartość cukru i kwasowość, które były w głównej mierze zależne od odmiany. Wyniki podkreślają znaczenie odpowiedniego doboru kombinacji podkładki i odmiany, aby zoptymalizować zarówno ilość, jak i jakość produkcji winogron w odpowiedzi na specyficzne warunki środowiskowe, szczególnie w kontekście zmian klimatycznych. Uzyskane wyniki dostarczają cennych informacji na temat zarządzania uprawą winorośli w chłodniejszych regionach i rekomendacji dla poprawy jakości produkcji wina.

Slowa kluczowe: wpływ klimatu, jakość winogron, podkładka, uprawa winorośli.