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A study on the effects of rootstocks on the vine balance of the 'Cerason' cultivar

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Abstract: 'Cerason' is an interspecific cultivar of grapevine that has been bred and selected in the Czech Republic (2008). The cultivar is a result of crossing the cultivars 'Merlan' and 'Fratava' and shows very promising potential within the framework of a fungus-resistant (PIWI) cultivar, making it particularly suitable for organic wine-making. This paper presents the results of an experiment performed with seven selected rootstock cultivars (viz. 'Kober 125AA', 'Amos', 'Börner', 'Crâciunel 2', 'Kober 5BB', 'K1SO4' and 'Teleki 5C') and some data about the effects of these rootstocks on the quantitative variables of the cultivar 'Cerason'. The aim of this study was to choose and specify the rootstock cultivars that would be the most suitable for a given locality. The following traits were monitored and recorded: plant vitality, the yielding capacity of the individual plants, and the number and weight of clusters per vine. The weight of 100 berries was also an important variable. The rootstock cultivars 'Kober 125AA' and 'Kober 5BB' were evaluated as the best for optimal growth and fertility (especially a higher fertility index, pruning weight and weight of clusters). The experimental results indicated that the cultivar 'Crâciunel 2' could also be a suitable rootstock. The 'Kober 125AA' rootstock also showed the most optimal Ravaz index, with an average of 5.9 over the three-year observation period.

Keywords: agronomic variables; 'Cerason'; morphological variables; rootstock; yield

At present, tens of billions of United States dollars (USD) are being spent worldwide on the chemical protection of vineyards and grapevines. The damages caused by the most important diseases and pests are increasing every year, and, consequently, the costs of these protective measures are growing as well. In addition to direct financial losses, not only the human population, but also nature is endangered by risks resulting from the application of a wide spectrum of various pesticides (Cabras, Angioni 2000; Dorosh et al. 2021).

In the fight against these negative factors, the breeding and selection of new cultivars and rootstocks that show increased fungus resistance (PIWI, interspecific cultivars) play an important role. In recent years, the application of environmentally

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friendly technologies (integrated wine production and organic wine production) has enabled the minimisation of the frequency of application of some preparations. However, to exploit the properties of these new cultivars, we must also understand their relationship (i.e. compatibility and affinity) with different rootstocks (Vršič et al. 2015; Chitarra et al. 2017; Klimek et al. 2022a).

Nowadays, the pest phylloxera (*Dactulosphaera vitifoliae*) is spreading rapidly. The reasons for this are probably due to climate change, resistance to insecticides and gentle cultivation practices that significantly limit the use of active ingredients (Ailer et al. 2024). For that reason, rootstock cultivars represent an integral part of contemporary breeding programmes implemented in breeding stations in many countries. The rootstock plays a crucial role in the process of plant adaptation to specific environments (Kowalczyk et al. 2022; Tedesco et al. 2022; Kapłan et al. 2023). It influences not only the plant growth, size of fruit and earliness of the harvest, but also the resistance of vines to drought and/or frosts (i.e. to changing climatic factors), pests and diseases (some rootstocks, for example, repel nematodes and are phylloxera resistant) and adaptation of plants to different chemical properties of the soil (pH) (Brighenti et al. 2011; Brighenti et al. 2012; Klimek et al. 2022b). An inappropriate combination of rootstock and variety can contribute to growing stress and related damage, affecting wine quality. One of these is atypical ageing (Ailer et al. 2022).

Besides soil conditions, climatic factors also play an important role. It is well known that local weather conditions and the physical and chemical properties of the soil influence, above all, the growth and yields of plants, the ripening of grapes, the concentrations of aromatic compounds, and also the overall annual variability (Gladstones 2011; Keller 2020). The most appropriate way to achieve profitability is to produce grapes for wines in the category of higher protected designation of origin, and this requires the creation of optimal agrotechnical systems for grape production (Janás et al. 2023).

The aim of this study was to evaluate the effects of individual rootstocks on the quantitative variables of the cultivar 'Cerason' as manifested in the given locality. Hypothetically, more vigorous rootstocks should dominate.

MATERIAL AND METHODS

Characteristics of the vineyard and climatic dates. The grapes used for the individual analyses were harvested in the experimental vineyard of the Faculty of Horticulture, Mendel University in Lednice, vineyard "Na Valtické" (48.7897°N, 16.7975°E), for three consecutive growing seasons (2013 to 2015). The altitude of this locality is 176 m, and the region is characterised as dry, warm and with mild winters. The vineyard was planted in an open, mostly flat, slightly sloped area with sufficient solar radiation, facing northeast. The average annual temperature in this locality is 9 °C, and the average annual rainfall is 516.6 mm. The climatic conditions for growing seasons are recorded in Table 1. All three experimental years were below the normal annual precipitation. The soil is sandy-loam with 20–24% clay particles. The initial soil analysis (at a depth of 30 cm) showed the following parameters: pH 7.5; N_{min} 18.2 mg/kg; P 51.7 mg/kg; K 266.8 mg/kg; Ca6 687 mg/kg (April 2012). Grapevines of the 'Cerason' variety were planted in 2005 with a spacing of 2.20 m × 0.9 m using the Rhine-

Table 1. The main climatic data from the monitored years (monitoring period from April to October)

Climatic data	Year		
	2013	2014	2015
Sum of active temperatures above 10 °C (°C)	3 110.1	2 984.9	3 295.6
Huglin heat sum index (April to September)	1 675.9	1 694.3	1 804.9
Number of days with temperatures above 10 °C (days)	185.0	181.0	194.0
Sum of sunshine (hours)	1 387.3	1 299.7	1 483.5
Average temperature in the active period (°C)	15.6	15.8	15.9
Average of the maximum temperatures (°C)	30.3	28.8	30.1
Average of the minimum temperatures (°C)	5.3	4.0	3.9
Rainfall in the active period (mm)	253.9	509.9	235.7

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Hessian training system and horizontally balanced canes. Disease was controlled using integrated protection systems.

Experimental design. The cultivar under study (i.e. 'Cerason') was grafted onto seven different rootstocks 'Kober 125AA', 'Amos', 'Börner', 'Crâciunel 2', 'K1SO4', 'Kober 5BB', 'Teleki 5C' (further in the text, only abbreviations are used for some of the rootstocks, i.e. '125AA', 'CR2', '5BB' and 'T5C'). The rootstocks '125AA', '5BB' and 'CR2' are commonly used within the Czech Republic; 'T5C' is used for the current climate change (drought); 'Börner' is a newer German rootstock; 'Amos' and 'K1SO4' are newer Czech rootstocks. The vines were planted in 2005. The vine training was of medium height with one cane (8–10 nodes per cane). The spacing of the vines was 1 m × 2.2 m (vine × row).

Cultivar 'Cerason' (Synonym: Mi-5-100). 'Cerason' is a blue-skinned Czech PIWI cultivar that resulted from the crossing of the cultivars 'Merlan' (Merlot × Seibel 13 666) × 'Fratava' (Blaufrankisch × St. Laurent). It produces distinctive fruit wines of a very dark colour with the aroma of cherries (Pavloušek 2008; Pavloušek 2010a).

Rootstocks. Altogether, seven rootstock varieties were tested. All of them are routinely used in viticultural practice. Two are very vigorous ('5BB', 'Börner'), two show a medium vigour ('125AA', 'CR2'), and the growth of the remaining three ('Amos', 'K1SO4' and 'T5C') are rather weak (Pospíšilová et al. 2005; Kapłan et al. 2018).

Sampling. The evaluation of the harvest (i.e. the number and weight of the grapes and the number and weight of the lignified shoots) was performed at the dates in Table 2. In each combination of rootstocks and grafts of 'Cerason', the variables were evaluated from samples taken on 20 plants, which were planted in a checkerboard pattern on a total of five ranks.

Evaluation of agronomic variables. Individual vines were monitored from the agrotechnical and ampelographical points of view. The following basic variables were evaluated: the number of cane prunings per vine, their weight per plant, mean shoot weight, number and weight of grapes per vine, average cluster weight and weight of 100 berries [this was a modified classificator CPVO-TP/50/1 by Pavloušek (2010b)]. The results were processed statistically.

Table 2. Dates of the harvest and pruning of the 'Cerason' variety

Date of	Year		
	2013	2014	2015
Harvest	17. 10.	11. 10.	14. 10.
Pruning	12. 12.	11. 12.	10. 12.

Field measurements. The study of the effects of seven rootstocks on the blue juice cultivar 'Cerason' was conducted in 2013–2015. The yields and some other quantitative variables were recorded.

When evaluating the individual vines, growth vigour was evaluated as one of the most important variables influencing both the quality and weight of the grapes. Our monitoring was also focused on the yield characteristics, i.e. the numbers and weights of the grapes, because just these characteristics were influenced by the rootstocks.

Broadly speaking, the number of cane prunings per vine should be constant (because this variable is also dependent on the methods of pruning and desuckering). If the shoot numbers per vine are higher, the internodes are usually shorter, while the cluster number and yield are increased (these grapes, however, are smaller and their weight is lower). On the other hand, if the shoot numbers per vine are lower, the internodes are longer, the cane prunings are more robust, the leaves are larger, and the cluster number is reduced. However, stronger cane prunings require more nutrients.

Ravaz index (RI). If we compare the final vegetation biomass of the vines in each given season with the measurement of the crop yield taken in the same vineyards in the previous harvest, the data can be used to calculate the ratio of the fruit yield to the vegetation weight. This ratio is the basis for the RI (yield/pruning weight), an early metric of vine balance first pioneered by the French viticulturist Louis Ravaz in the early 20th century. Research on grapevines has suggested that optimal crop load values fall between 5 and 10 (Ravaz 1903; Harner, Centinari 2017).

Evaluation of the fertility. Fertility is an important indicator of the yield and quality of the grapes and affects the potential quality of the wine. Among the observed variables were the cluster number per vine, the yield per vine and also the weight of 100 berries at harvest.

Statistical evaluation methods. Basic statistical methods, such as analysis of variance (ANOVA) and Tukey's test, as well as the newer principal component analysis (PCA) method, were used to visualise the obtained multivariate data.

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RESULTS AND DISCUSSION

Number of shoots per vine. The shoot thinning (canopy management) should be roughly constant (it is also dependent on the cut).

Figure 1 shows the number of shoots; it is clear that the highest number of shoots was on the stocks '5BB' in 2013, 'T5C' in 2014 and 'Börner' in 2015. Stable results were achieved by the stock of '125AA', 'Börner' and 'T5C' in all the monitored years. Their number was, on average, from 9 to 15 per vine.

The pruning weight. The pruning weight is one of the indicators of the vigour and growth of the vine. Its values contribute to the appropriate choice of shrub load, optimum leaf area size and long-term vitality of the vineyard. This is the weight of the shoots, which are cut in the winter (one shoot was left on the vine-cane).

The weight of pruning on the 'Cerason' PIWI variety (Figure 2) ranged from 0.2 to 0.7 kg in 2013, 0.25 to 0.80 kg in 2014 and 0.15 to 0.65 kg in 2015. In all three years, the rootstocks '125AA', '5BB' and 'T5C' had a higher weight, ranging from 0.4 to 0.8 kg. The remaining rootstocks are, in some cases, twice as low. The lowest weight of the prunings was observed on the 'Amos' and 'K1SO4' rootstocks.

The cluster number per vine. The highest cluster number per vine was recorded in the combination with the rootstock '5BB' in 2013, followed by 'T5C' and 'CR2' (Figure 3). The cluster number produced per plant ranged between 3 and 50 pieces. Most clusters were collected on the rootstock '5BB', 37 pieces on average. In 2014, the cluster numbers were highest on the rootstock '125AA', 'K1SO4' and 'Börner'. Similar results were achieved in 2015, when '125AA', 'Börner' and 'T5C' ranked among the top three. The variety 'Amos' had the lowest results in both 2014 and 2015, and the results indicate weaker vegetative growth, limiting its fertility (few and smaller clusters).

Shoot fruitfulness – the number of clusters per vine/number of shoots per vine (so-called fertility index). Stable higher values of the so-called fertility index were reached in 2014–2015 by the vines

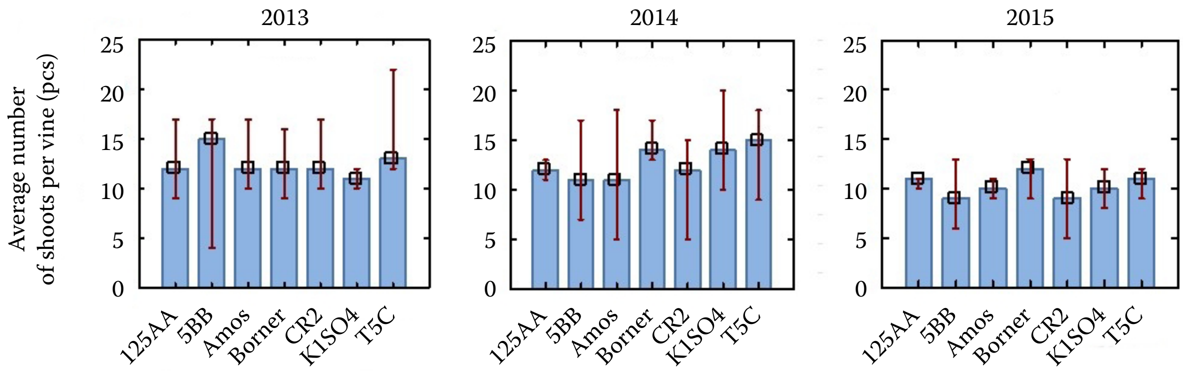

Figure 1. Effects of the individual rootstocks on the number of shoots of the 'Cerason' cultivar grafted to seven rootstocks (monitored years 2013, 2014, 2015)

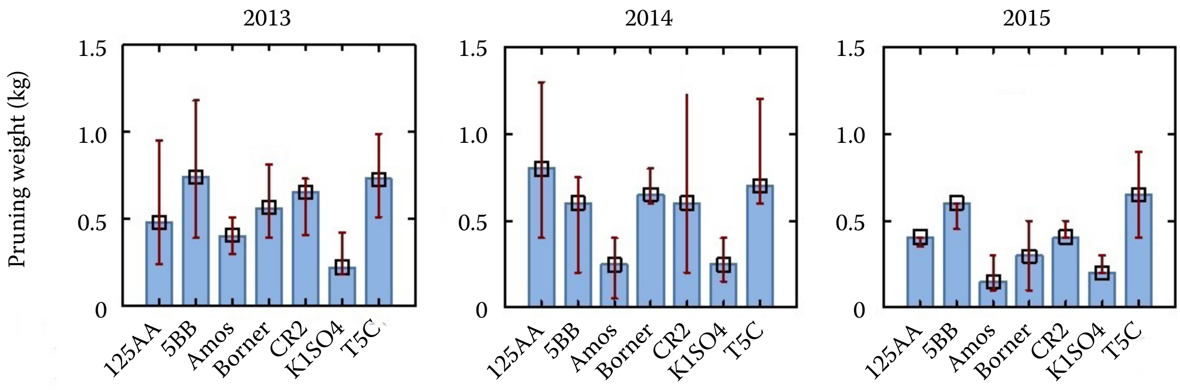

Figure 2. Effects of individual rootstocks on the total pruning weight per vine, for the 'Cerason' cultivar grafted to seven rootstocks (monitored years 2013, 2014, 2015)

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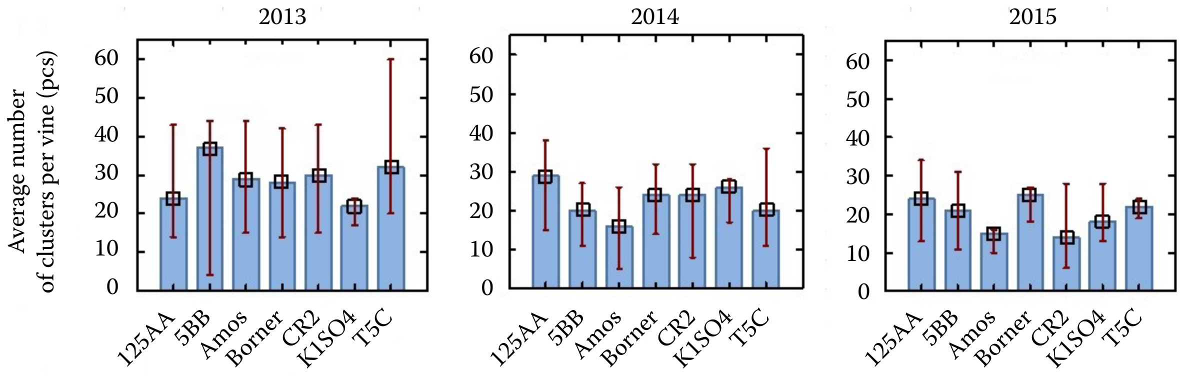

Figure 3. Effect of the individual rootstocks on the cluster number per vine for the 'Cerason' cultivar grafted to seven rootstocks (monitored years 2013, 2014, 2015)

on the rootstock 'Kober 125AA'; in 2013, then 'Teleki 5C' (Figure 4). However, the fertility coefficient is not completely related to the yield, because the more grapes there are on the vine, the smaller (less substantial) they are, and, overall, there may be more grapes on the bush, but the yield can only be medium to lower (Kraus 1980).

Weight of clusters per vine. The weights of the clusters produced per plant ranged from 1.8 to 4.3 kg in 2013 (Figure 5). The highest weight of grapes on the vine was achieved on the '5BB' rootstock in 2013, but individual vines showed great downward variability. The '125AA', 'Börner' and 'T5C' base also achieved very good results in the same year.

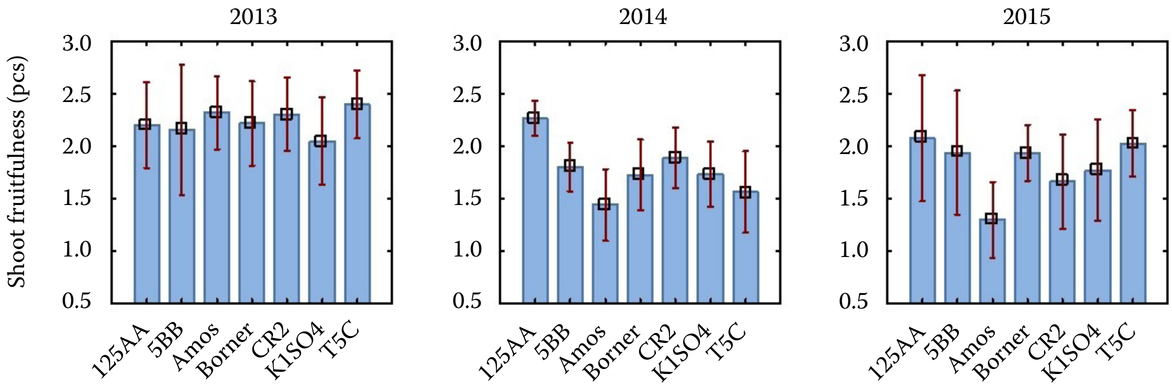

Figure 4. Shoot fruitfulness influenced by the individual rootstocks of the 'Cerason' cultivar grafted to seven rootstocks [monitored years 2013 (non-significant), 2014 ($P < 0.01$), 2015 (non-significant)]

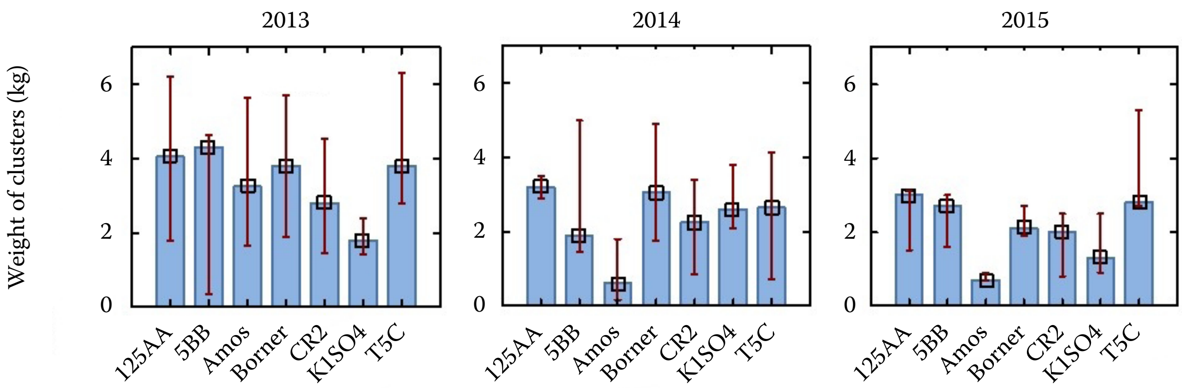

Figure 5. Effect of the individual rootstocks on the weight of all the clusters produced per vine of the 'Cerason' cultivar grafted to the seven rootstocks (monitored years 2013, 2014, 2015)

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This was repeated in the following years, in 2014 and 2015. The worst results were recorded on the rootstock 'Amos' with an average yield of 0.6 kg per vine. The rootstock '125AA' consistently achieved stably higher values in all the monitored years.

Ravaz index (RI). RI represents the ratio of the vegetative to reproductive growth. It is based on the optimal ratio between the yield, bush growth and grape quality. Specifically, it expresses the weight ratio of the clusters to the cut vines from one vine.

In Figure 6, the influence of the rootstocks within the individual years on RI can be seen. In 2013, the highest RI was 'Amos', at 9.3. In 2014, compared with the other rootstocks, it was 5. A similar result (5.3) was achieved in 2015 as well. Another rootstock with the highest RI in 2014 was 'K1SO4' with a value of 10.5. The second-highest RI was also seen in 2013 (7.7) and 2015 (6.5). The 'Börner', '125AA' and 'T5C' rootstocks showed optimum results. The lowest RI in all the years were 'CR2' and '5BB'. The values were below 5.

The optimal values of the RI are 5–7, and these values therefore represent the optimal growth and fertility of the vine (the fruit yield/dormant pruning weight following harvest). However, the optimal values of the index are also influenced by the thickness of the vines or the size of the clusters themselves. Values of 3–10 can therefore be considered acceptable. This index also, de facto, determines the corresponding level of pruning (if it is in equilibrium with growth). The values of the RI at the lower limit indicate vines with a low number of grapes or vines growing very lushly, having a large leaf area compared to the yield. In this case, it is advisable to increase the fertility load or perform interventions that weaken the plant growth. Values at the upper limit of the index indicate a high grape stock or weak shrub growth. In this case, it is appropriate to reduce the load or perform interventions to support plant growth, such as increasing the leaf area (Keller 2010; Matthews 2015; Franco et al. 2024).

The mean cluster weight. The average mass of one cluster on the vine is directly related to its numbers on the vine, the strength of growth of the vine and is reflected in the fertility.

The mean weight of one grape was from 36 g (for 'Amos') to 142 g (for the 'T5C' rootstock). The 'Börner', '125AA' and '5BB' rootstocks also achieved high weights of one grape. On the other hand, 'Amos' and 'K1SO4' showed the smallest weights (Figure 7).

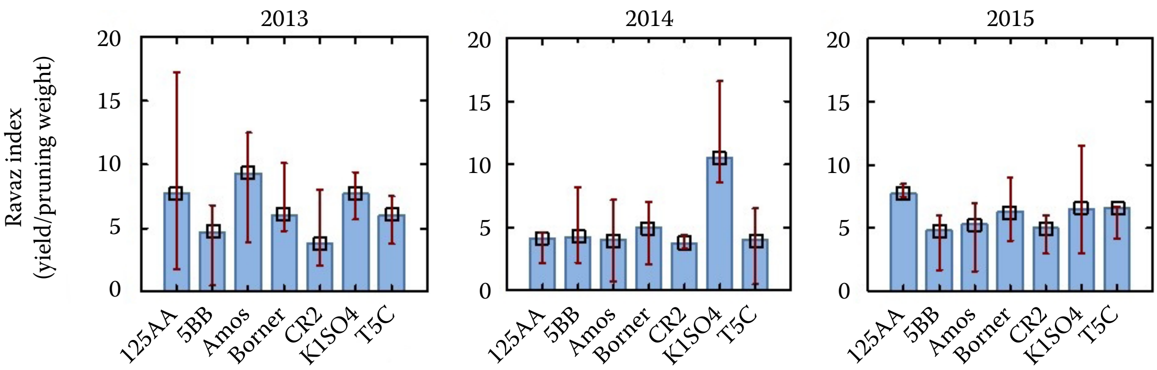

Figure 6. Ravaz index of the 'Cerason' cultivar grafted to the seven rootstocks (monitored years 2013, 2014, 2015)

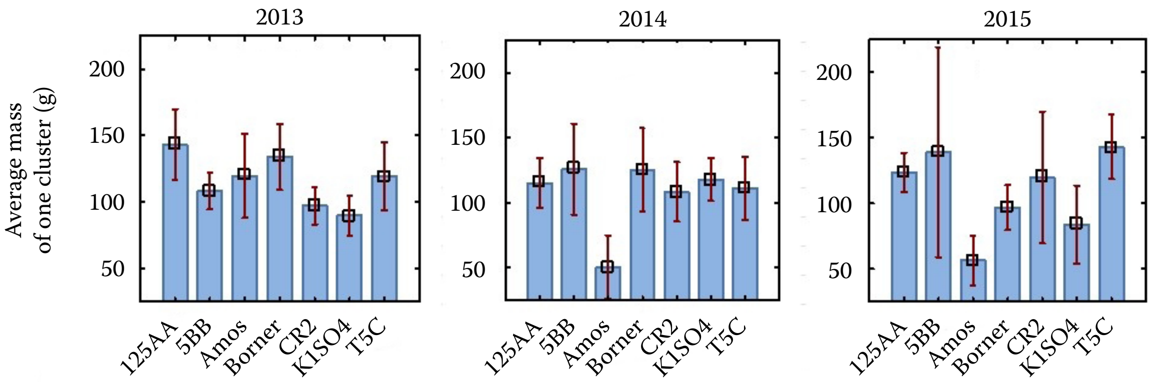

Figure 7. Effects of the individual rootstocks on the average mass of one cluster on the vine of the 'Cerason' cultivar grafted to the seven rootstocks [monitored years 2013 ($P < 0.01$), 2014 ($P < 0.01$), 2015 ($P < 0.01$)]

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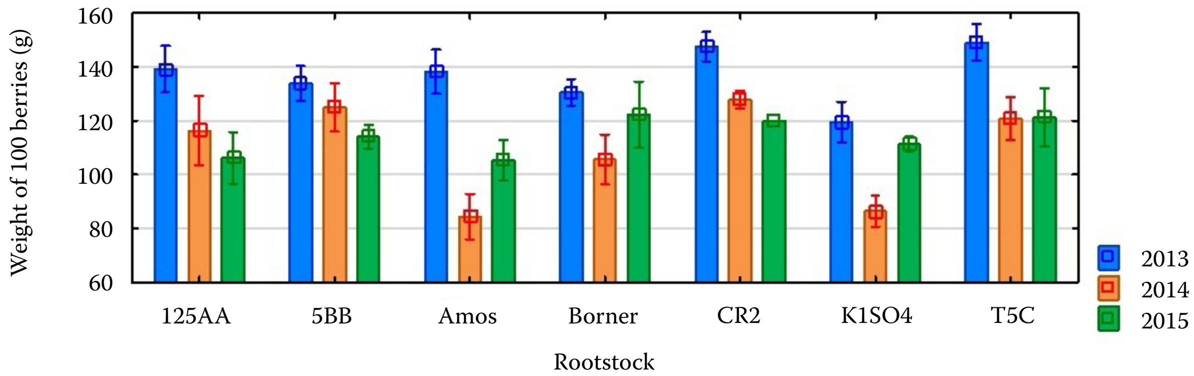

Figure 8. Weight of 100 berries in the years 2013 ($P < 0.01$), 2014 ($P < 0.01$), 2015 ($P < 0.01$) on the 'Cerason' rootstock

Figure 8 shows the weight of 100 berries at harvest in 2013, 2014 and 2015 for 'Cerason'. In 2013, the weight of 100 berries was the highest on the rootstocks 'T5C' (149 g), 'CR2' (147.6 g) and '125AA' (139.2 g). The lowest weight of 100 berries was on the rootstock 'K1SO4' (119.6 g). In 2014, the highest weight of 100 berries was on the rootstocks 'CR2' (127.8 g), '5BB' (124.8 g) and 'T5C' (121 g), the lowest weight of 100 berries was on the 'Amos' (84.4 g) and 'K1SO4' (86.4 g) rootstocks. In 2015, the highest weight of 100 berries was measured for the 'Börner' (122.2 g) and 'T5C' (121 g) rootstock, while the lowest gain was for the 'Amos' and 'K1SO4' rootstocks (84.4 g and 86.4 g, respectively).

As reported by Reynolds et al. (1994) and Naor et al. (2002), the numbers and weights of the canopy unit (shoots) are regulated by suitable prunings.

Additionally, reducing the inter-row distance (spacing) to 1 m decreased the number of cane prunings per vine, while yields per unit area (i.e. per ha) increased, with no change in the qualitative variables (Kliewer et al. 2000).

In combination with the rootstock cultivar 'Amos', the internodes were shorter, so that it was possible to expect the formation of more prunings and shoot thinnings (this expectation was corroborated later on). At the same time, however, attenuated growth was observed as well as a high number of small cane prunings. In comparison with other rootstocks under study, the average weight of one annual shoot in this variant was also lower. The rootstock '5C' belonged to the group of cultivars with attenuated growth, and the produced internodes were also shorter. The number of cane prunings was lower than in the combination with the rootstock 'Amos', but their higher weight compensated for this reduced number. The highest mean weight of one shoot was recorded in the variant with the rootstock '5C'. The rootstock '125AA' showed a medium effect on the vigour. Although there was an average number of cane prunings per plant, their weight was higher, and the average weight of one cane was also one of the highest. The more vigorous rootstock '5BB' produced a high number of cane prunings, and their average weight was medium. Another of the more robust rootstocks, 'Börner', produced only a high number of cane prunings with an average total weight per vine. The rootstock 'K1SO4' produced a high number of weak cane prunings, but the values of their average total weight and also of the weight of one cane were low.

Reynolds and Wardle (2001) examined nine varieties on four rootstocks, including a rooted variant. No major differences in the number and weight of the grapes and the weight of the berries were observed. The rootstock 'SO4' produced the smallest berries, while the rootstock '5BB' had the lowest weight of the shoots. The differences in the pH and titratable acids were minimal. The newer tested 'K1SO4' (derived from 'SO4') rootstock actually had the lowest berry weight. The average number of shoots per vine, however, was the highest in our study.

As mentioned by Naor et al. (2002), the weight of berries did not affect the number of cane prunings per vine; this variable, however, increased after thinning the grapes.

The rootstock '125AA' shows medium vigour, and all its ampelographic variables were average and (above all) uniform. The grapes were of a medium size, and it was possible to expect an ideal course of their maturation; this means that there is a good relationship between their quantity and quality, and the variance is very low (i.e. at the minimum level). 'Börner' is a rootstock cultivar that shows medium to vigorous

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growth. It produced an average cluster number, and their weight was low (this indicated that the grapes were small). Under the given conditions, such yields are not ideal. This means that the potential of this rootstock consists in growth, not in fecundity.

The medium vigorous rootstock 'CR2' occupied second place as far as the cluster number per vine was concerned. It was evaluated as the best one not only in terms of yield per vine, but also produced grapes with the highest mean berry weight. However, the samples showed the highest variability of all the rootstocks under study. This phenomenon may cause problems during harvest because small grapes are already overripe, exhibiting increased sugar and pigment content, but lower levels of acid. On the other hand, big grapes are usually not ripe and should not be harvested because they are still waiting to enter the stage of harvest maturity. Although the rootstock 'Amos' initially showed medium vigorous growth, its growth later became poor. Similar to the rootstock '125AA', it showed positive harvest variables (i.e. high fecundity as well as good weight and medium size of grapes). The variance of these variables was small. 'T5C' is a weakly growing rootstock and is recommended for localities with loamy soils and a high groundwater level. Under these conditions, this combination also produced a good number of grapes with a good weight. The size of the grapes was increased, but the variance was also higher. '5BB' was a rootstock that showed the most vigorous growth; the highest number of produced grapes also corroborated this. Although the total weight of grapes per vine was good, their size was small. 'K1SO4' is a rootstock showing medium vigour of growth. It also produced the lowest cluster number with a small weight. However, the size of the grapes produced in this combination was comparable with those recorded in variants with the rootstocks '5BB' and 'Börner' (Table 3).

Principal component analysis (PCA). For a broader comparison of all the monitored data, a modern multivariate statistical method – PCA was used. A PCA was performed on the dataset of seven rootstocks and eight traits to provide an overview visualisation in a reduced dimension. Table 4 summarises the PCA results. The total variability was explained by six principal components (PCs). However, three of them could be considered the most important, because they presented eigenvalues > 1.0. Of these PCs, the first two (PC1 and PC2) accounted for 79.53% of the total variation.

PC1, which explained 60.73% of the total variation, was effective in separating 'K1SO4' and 'Amos' from the other rootstocks, mainly from 'T5C' and '125AA'

Table 3. The mean values for all the years (2013–2015) and for all the rootstocks

Rootstock	Average number of clusters per vine (pcs)	Average weight of clusters per vine (kg)	Average of pruning weight per vine (kg)	Average number of shoots per vine (pcs)	Ravaz index (yield/pruning weight)	Shoots fruitfulness (pcs)	Average mass of one cluster (g)	Average weight of 100 berries (g)
125AA	26.05	3.36^{a}	0.63^{ab}	11.79	6.73^{ab}	2.19^{a}	127.79^{a}	122.60^{c}
5BB	23.37	2.75^{ab}	0.64^{ab}	11.26	4.46^{b}	1.97^{ab}	122.84^{ab}	107.90^{d}
Amos	20.32	1.84^{b}	0.29^{c}	11.21	5.93^{b}	1.73^{b}	77.68^{c}	122.04^{c}
Borner	25.32	3.07^{a}	0.53^{b}	12.95	6.86^{ab}	1.96^{ab}	121.00^{ab}	126.81^{b}
CR 2	23.11	2.38^{ab}	0.60^{ab}	11.26	4.59^{b}	1.98^{ab}	107.26^{ab}	129.66^{a}
K1SO4	22.79	2.32^{ab}	0.25^{c}	12.32	9.56^{a}	1.86^{ab}	98.58^{bc}	105.92^{d}
T5C	27.84	3.38^{a}	0.73^{a}	13.84	4.89^{b}	1.99^{ab}	122.58^{ab}	131.39^{a}
	ns	**	**	ns	*	*	**	**
2013	29.39^{a}	3.41^{a}	0.57^{a}	12.71^{a}	6.79	2.23^{a}	115.92	136.87^{a}
2014	21.88^{b}	2.44^{b}	0.57^{a}	12.39^{ab}	5.31	1.77^{b}	107.84	109.50^{c}
2015	19.86^{b}	2.17^{b}	0.40^{b}	10.80^{b}	6.41	1.82^{b}	108.94	114.39^{b}
	**	**	**	*	ns	**	ns	**
Average	24.11	2.73	0.52	12.09	6.15	1.95	111.11	120.25

*,**significant differences between the rootstocks and years at $P < 0.05$, $P < 0.01$, respectively; ns – non-significant

[a–d]different letters within a column indicate a significant difference according to Tukey's test ($P < 0.05$)

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Table 4. Factor loadings, eigenvalues and proportion of variation associated with six principal components (PC) of the principal component analysis of eight yield components and other quantitative traits in seven rootstocks

Traits	PC1	PC2	PC3	PC4	PC5	PC6
Average number of clusters per vine	0.955423	–0.241930	–0.142430	–0.028660	–0.086600	0.005426
Average weight of clusters per vine	0.964341	–0.218370	0.055008	–0.006670	0.020078	–0.137430
Average of pruning weight per vine	0.900545	0.398361	0.105002	–0.123490	–0.031570	0.055278
Average number of shoots per vine	0.576496	–0.505980	–0.592880	–0.241860	–0.012800	0.038326
Ravaz index	–0.353370	–0.901070	0.033542	0.246169	0.023693	0.030447
Shoots fruitfulness	0.836140	–0.040840	0.421451	0.340651	–0.068290	0.029546
Average mass of one cluster	0.920822	–0.096670	0.333329	–0.082840	0.151320	0.043285
Average weight of 100 berries	0.447209	0.401235	–0.709320	0.364231	0.056625	0.003736
Eigenvalue	4.858025	1.504844	1.178827	0.390782	0.040392	0.027130
% Total	60.725320	18.810550	14.735340	4.884769	0.504904	0.339122
Cumulative	60.725320	79.535870	94.271200	99.155970	99.660880	100

(Figure 9A). 'CR2' and '5BB' were centred on the PC1 axis. The examination of the PC1 loadings (Figure 9B) suggested that the separation was due to the cluster number, cluster weight, shoot weight, shoot number, fertility, one cluster weight, and the weight of 100 berries, which have positive loadings and to RI with a negative loading. The PC1 scores and loadings suggested that 'T5C' and '125AA' presented the highest fertility, as well as the number and weight of clusters, and they also showed heavier shoots. The opposite occurred in 'Amos', which showed low fertility, the lowest cluster number and weight, and low shoot number and weight. 'K1SO4' had the lowest shoot weight, low fertility, and low cluster weight, but also the highest RI (disproportionate to the growth and fertility). However, the other studied rootstocks presented intermediate and similar values, mainly 'CR2', '5BB' and 'Börner', which were centred on the PC1 axis. PC2 accounted for 18.81% of the total variation. It was effective in separating 'CR2', 'Amos' and '5BB', mainly 'Börner' and 'K1SO4'. 'T5C' and '125AA' were centred on the PC2 axis. The examination of the PC2 loadings plot (Figure 9B) indicates that the most important variables contributing to the PC2 cluster

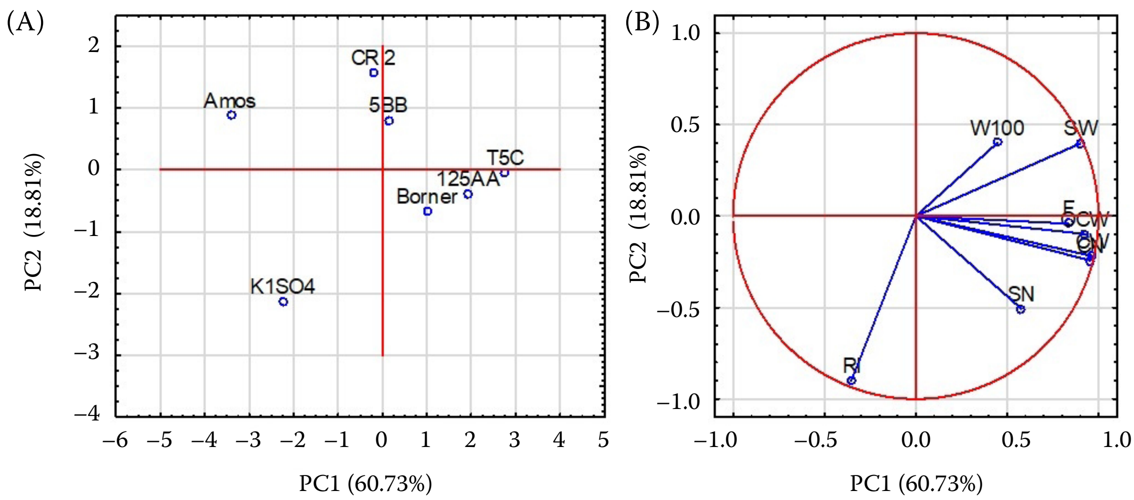

Figure 9. Comparison of the (A) individual rootstocks and (B) observed factors of the principal component analysis of 17 yield components and physicochemical traits in 14 scion-rootstock grapevine combinations

CN – cluster number (average number of clusters per vine); CW – cluster weight (average weight of clusters per vine); SW – shoot weight (average of pruning weight per vine); SN – shoot number (average number of shoots per vine), RI – Ravaz index; F – fertility (shoots fruitfulness); OCW – one cluster weight (average mass of one cluster); W100 – weight of 100 berries; PC1,2 – principal components

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weight and weight of 100 berries, which presented positive loadings and RI and shoot number with high negative loadings. The PC2 scores and loadings indicated that 'K1SO4' was the rootstock with the lowest weight of 100 berries and small cluster weight. The opposite occurred in 'CR2', which had a low RI and a high weight of 100 berries; the data in Table 3 further corroborate this. Therefore, the principal components analysis was efficient in confirming the results presented in this paper.

CONCLUSION

This study was focused on the evaluation of the suitability of the combination of 'Cerason' cultivar grafts with individual grapevine rootstocks. For the given growing conditions, the best combinations were chosen on the basis of the evaluation of the recorded quantitative variables. Of these, the results of the evaluation of the yields played a key role. Therootstocks '125AA' and '5BB' were evaluated as being good ones. However, '125AA' is more ideal for the given location due to its higher resistance to calcium in the soil (higher pH). From the viewpoint of the yields and size of grapes, 'CR2' could also be a suitable rootstock because, in this case, the low cluster number produced per plant was compensated for by their size. The quantity and weight of grapes, i.e. the parameters most influencing the yield, were similar for these rootstocks in all the monitored years, without any major fluctuations.

Although the rootstock 'T5C' also gave interesting results. In some cases, the differences between the rootstocks under study were very small; however, the results obtained in these three years were influenced not only by existing weather conditions, but also by the pedological conditions of the experimental vineyard (a very dry location with a higher content of active Ca in the soil). As expected, the generally more luxuriantly growing rootstocks with a better root system showed better results.

The rainier year 2014 shows an increase in the weight of the cane prunings and thus a worse RI (outside the optimal 5–7) compared to the other years.

It is also necessary to monitor qualitative variables because they are important from the perspective of producing a good raw material for wine making. The evaluation of the growth and monitoring of the variables mentioned above will also continue in the following years.

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