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OPEN ACCESS

Received: 12.2.2023
Revised: 16.3.2023
Accepted: 22.3.2023
Published: 23.3.2023

Slovak Journal of Food Sciences

Potravinarstvo Slovak Journal of Food Sciences
vol. 17, 2023, p. 231-241
https://doi.org/10.5219/1877
ISSN: 1337-0960 online
www.potravinarstvo.com

Utilization of different yield regulation methods of the vine for production of wines of higher designation protected of origin

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ABSTRACT

Grape yield regulation is a method used to improve grape quality parameters. Experiments were carried out in 2021 on the grapevine (*Vitis vinifera* L.) wine varieties 'Feteasca regala' and 'Sauvignon blanc', focusing on the effect of two different methods of grape yield regulation on its selected parameters and must sugar content. The first method used was cluster thinning, leaving one bunch on the shoot. The next method used was cluster tipping when we removed the terminal part of each bunch. Yield reduction was carried out in the period between pea-sized berry phenophase (BBCH 75) and bunch closure phenophase (BBCH 77). The operations were carried out manually. Cluster thinning did not lead to a statistically significant difference in bunch weight compared to the control in any of the studied varieties. We observed a statistically significant (p <0.05) decrease in the average bunch weight in the variant cluster tipping. The 'Feteasca regala' hectare yield was 32.25% lower in the cluster thinning than the control. The hectare yield in the cluster thinning variant was reduced by 46.61% compared with the control. Cluster thinning variant of the Sauvignon blanc variety had a 19.13% lower yield than the control variant. The cluster tipping variant had a 29.03% lower yield than the control variant. In the case of the cluster thinning method, we observed a greater decrease in grape yield compared to the cluster tipping method. The obtained results indicate that cluster tipping method is preferable to the cluster thinning in terms of the profitability of grape production. The must sugar content was statistically significantly (p <0.05) increased in all the yield reduction variants. The variety 'Feteasca regala' had the highest sugar content of the must in the cluster thinning method, 19.42 kg/hL. The highest sugar content of 'Sauvignon blanc' was 21.33 kg/hL in the variant with cluster tipping. This shows that regulating the grape yield can improve the quality parameters of the grapes. On the other hand, it may lead to a decrease in yield per hectare below the break-even point. The justness and intensity of the method used must be carefully considered.

Keywords: Grapevine, Feteasca regala, Sauvignon blanc, Yield regulation, Sugar content

INTRODUCTION

Several factors influence the quality of grapes. It is mostly shaped by the variety's genotype, the site's environmental conditions and the used agro technique **[1]**. Low night temperatures can positively influence grape quality during ripening, which commonly occurs in cooler viticultural areas during grape ripening **[2]**. By yield reduction, we can positively influence the ripening of grapes and create the conditions for improving their qualitative parameters. Although we will lose a significant part of the harvest, giving up part of the yield in years with high grape yields is sometimes a necessity. For the production of quality wines, there are national limits on the maximum yield per hectare for the production of quality wines, which can be resolved by reducing the yield. In order to make viticulture economically efficient, we must keep the vineyard fully engaged and apply modern cultivation technologies. The selection of a suitable site, the choice of the right rootstock-variety combination and the implementation of adequate agrotechnical measures are also important **[3]**.

Grape yield control is a technique mainly used in wine-growing countries with cooler climates. Cooler climates provide fewer days for the crop to ripen sufficiently, so it is advisable to promote optimal ripening of the grapes **[4]**. Mawdsley et al. **[5]** argue that the effect of grape yield regulation is always weaker than that of climatic conditions during vegetation. Yield regulation can positively prevent some fungal diseases and reduce the severity of disease, especially *Botrytis cinerea*. The given fact relates to a looser arrangement of berries in the bunch, especially when using a cluster tipping method **[6]**, **[7]**. A smaller grape crop improves grape ripening **[8-10]**. It can improve grape quality and wine quality parameters **[11]**.

Sugar content belongs to the main quality parameters of grape. It is a changeable parameter with a less stable spatio-temporal progression **[12]**. Sugars are the basic elements of alcoholic fermentation. The two dominant sugars in grape berries are glucose and fructose. Simultaneously, there is a low concentration of sucrose, maltose, xylose and other sugars **[13]**. As grape berries ripen, sucrose from the leaves accumulates as glucose and fructose in the berry vacuoles **[14]**. Most studies have confirmed in yield-controlled variants higher sugar content and lower titratable acidity in must, increased content of polyphenolic compounds and increased intensity of berry colour **[9]**, **[15]**, **[17]**. One of the benefits may also be an increase in the total phenolic content of the grapes or berry skin **[18]**, **[19]**. Grapes from bush-regulated variants have higher antioxidant activity **[20]**, generally associated with higher polyphenol content **[21]**. Condurso et al. **[22]** observed a positive effect of grape yield regulation on the quantity and species composition of aromatic compounds in wine.

Important aspects of grape yield reduction are the intensity of the intervention and the timing of the intervention. The intensity of the intervention is directly related to the economics of vine cultivation. Strong yield control can lead to more significant benefits in the quality composition of the grapes. On the other hand, increasing the intensity of grape regulation reduces the quantity of grapes produced, which can lead to lower profitability. An intervention implemented at different stages of berry development may affect some quality parameters of grapes **[23-25]**. When choosing the right date for regulating grape reduction, we have to base our decision on the dynamics of berry growth. The most significant berry growth is observed 30-40 days after fertilization of the inflorescences. If we intervene in this period, all the assimilates are directed to the clusters left on the vine. The intervention results are the increase in berry size and cluster density, which, although it increases the overall yield per cluster, reduces the overall quality and health of the clusters. The most suitable period for yield control is the stage between the phenophase of pea-sized berries and berry softening **[26]**. Too radical yield regulation can negatively affect the wine's character. Yield reduction in a vineyard whose growth is very strong leads to high content of IBMP (3-isobutyl-2-methoxypyrazine), which is a manifestation of an imbalanced state of the bush **[27]**.

We aimed to prove the validity of performing grape yield regulation by experiments.

Scientific Hypothesis

In our study, we investigate hypothesis:

a. Grape yield regulation (cluster thinning, cluster tipping) reduces the yield.
b. A smaller quantity of yield can lead to the improvement of wine grape qualitative parameter as sugar content.

MATERIAL AND METHODOLOGY

Samples

The experiments were held in the wine-growing village Vráble, belonging to the Nitra wine-growing region. The planting was established in 2006. The main soil unit in the vineyard site is pseudo glacial brown earth. The vineyard is cultivated with full black fallow and is managed on the Rhine-Hesse line with 1 stalk. The row spacing is 1.2 m, the rows are spaced 1.5 m apart. The pruning of the fruiting wood follows the Guyot pruning principle, leaving one 10-bud and a 2-bud reserve trunnion. The varieties 'Feteasca regala' and 'Sauvignon blanc' grafted on rootstock SO4 were used in the experiment.

- Location: Nitra wine-growing region, Vráble wine-growing district, Vráble wine-growing village.
- Varieties: Variety I: Feteasca regala (FR) – Romanian white wine grape variety with middle-sized clusters and thin berry skin; Variety II: Sauvignon blanc (SB) – French white wine grape variety with small to medium-sized compact clusters and hard berry skin **[38]**.

Chemicals

No chemicals were used for the experiment.

Instruments

Laboratory scales EMB 6000-1 (Kern, Germany).

Laboratory Methods

Cluster weight (g): The weight of the clusters was measured using laboratory scales.

Grape yield (g/bush): Grape yield was calculated by multiplying the cluster weight by the number of bunches on the vine.

Hectare yield (t/ha): We calculated the hectare yield by the conjunction of the grape yield and the number of grapevines present on an area of 1 ha (1):

$$10000/(1.2 \times 1.5) = \text{number of bushes per 1 ha} \times \text{grape yield per vine} = \text{yield per ha} \qquad (1)$$

Sugar content of must (kg/hL): To determine the sugar content of the must we used a Czechoslovak standardized must meter according to STN 25 7621.

Estimated yield (EUR): We calculate the yield per hectare using an economic formula (2):

$$\text{Yield} = \text{yield (kg/ha)} \times \text{realisation price (EUR/kg)} \qquad (2)$$

Description of the Experiment

Number of samples analyzed: 6

Number of repeated analyses: 18

Number of experiment replication: 1

Design of the experiment: In 2021, the growing season was 40 days shorter than the long-term normal **[28]**. The cold beginning of the growing season caused a delayed onset of budding and flowering of the vines. Due to the high temperatures above the long-term average in the summer months, grape ripening was not delayed. The year 2021 was below average annual precipitation. The cumulative sum of sunshine duration reached normal values during the grape ripening period **[29]**, **[30]**. On 15th July, a severe hailstorm occurred in the study area, damaging developing grapes and causing an increased incidence of berry rot. During the experiment, we observed the effect of two different methods of grape yield reduction (cluster thinning, cluster tipping) on selected parameters. In each variant, we treated 15 grapevines. The interventions were carried out on 8th August 2021, between the phenophases of pea-sized berries (BBCH 75) and bunch closure (BBCH 77). The cluster thinning method consisted of leaving one bunch on the shoot. In the case of the cluster tipping, we did not remove any bunches, but we shortened all bunches by about half their length. We harvested a grape on 28th September 2021.

A B

Figure 1 Example of yield regulation of grapevines variety SB, before (A) and after (B) yield regulation - removal of whole bunches

Statistical Analysis

The statistical program XLSTAT v.2021.4.1 (Addinsoft, France) was used for analyses of the obtained data. The Shapiro-Wilk test was used to distribute the data at the statistical significance level of $p = 0.05$. ANOVA – Tukey test was used to test whether there was a statistically significant difference between the samples ($p = 0.05$).

RESULTS AND DISCUSSION

Cluster weight (g)

The average cluster weight in the control variant of 'Feteasca regala' was 119.7 g. In the variant with cluster thinning, we measured an average cluster weight of 120.9 g. In this intervention, we did not remove parts of the bunches. Therefore, the average cluster weight is almost identical to the control. In the case of cluster tipping, we observed a decrease in the average cluster weight to 85.1 g. The difference between the variant with cluster tipping and the control variant is statistically significant (p <0.05).

In the control variant of the 'Sauvignon blanc' variety, we measured an average bunch weight of 175.5 g. This cluster weight is well above average compared to the ampelographic characterisation of the variety **[35],** and the difference represents an increase of up to 62.25 %. In the whole bunch removal variant, we measured an average cluster weight of 180.2 g. This average cluster weight confirms the high above-average nature of this parameter in the experiment. Cluster tipping reduced the average cluster weight to 116.5 g. A decrease in cluster weight in a cluster tipping variant was statistically significant (p <0.05) compared to the control.

Table 1 Average cluster weight (g).

Sample	Mean ±SD	Min	Max	CV (%)
FR K	119.7 ±18.3a	93	145	15.3
FR A	120.9 ±17.6a	96	141	14.5
FR B	85.1 ±19.9b	59	117	23.4
SB K	175.5 ±33.8a	126	234	19.3
SB A	180.2 ±28.6a	130	219	15.9
SB B	116.5 ±21.6b	71	139	18.5

Note: FR – Feteasca regala, SB – Sauvignon blanc, K – control, A – whole bunch removal, B – bunching, SD – standard deviation, Min – minimum, Max – maximum, CV – coefficient of variation; a, b means rows with different letter are statistically different (Tukey test, p <0.05).

Grape yield (g/bush) and hectare yield (t/ha)

Feteasca regala

The highest yield for the variety 'Feteasca regala' was found, as expected, in the control variant, at 2234.0 g/bush with a hectare yield of 10.14 t/ha. In the cluster thinning variant, we recorded an average yield of 1798.0 g/bush of grapes with a hectare yield of 8.2 t/ha, which is 19.13% lower average hectare yield than in the control variant. In bunching, one-third to one-half of the length of the bunch is removed. As we remove the lower part, which is less voluminous, while giving room for the development of the berries left behind, the reduction in yield may not be more than one-third of that of the untreated variant. The lowest yield was recorded for the variant with one bunch per shoot, i.e. 1431.5 g/bush. This value represents a reduction of 32.25% compared to the control variant. The differences between the variant with the cluster thinning variant and the control variant were statistically significant (p <0.05). The yield decrease for the cluster tipping variant was not statistically significant (p >0.05) compared to the control variant.

Sauvignon blanc

In the case of 'Sauvignon blanc', we found the highest yield in the control variant, namely 2687.5 g/bush, giving a yield per hectare of 11.85 t/ha. The second highest grape yield and yield per hectare were recorded in the bunching variant, with 1561.0 g/bush of grapes with 8.41 t/ha as a yield per hectare. This means a yield reduction of 29.03% compared to the control variant. Removing whole bunches decreased the average yield of grapes to 1025.0 g/bush with 6.35 t/ha as a yield per hectare. This is almost half the decrease compared to the control variant; therefore, the profitability of such an intervention may already be negatively affected. The differences between the experimental and control variants were statistically significant (p <0.05).

Table 2 Average grape yield (g/bush).

Sample	Mean ±SD	Min	Max	CV (%)
FR K	2234.0 ±172.5a	2112	2356	6.3
FR A	1431.5 ±58.7b	1390	1473	22.2
FR B	1798.0 ±250.3ab	1621	1975	2.6
SB K	2687.5 ±170.4a	2567	2808	7.7
SB A	1025.0 ±227.7b	864	1186	4.1
SB B	1561.0 ±41.0b	1532	1590	13.9

Note: FR – Feteasca regala, SB – Sauvignon blanc, K – control, A – removal of whole bunches, B – bunching, SD – standard deviation, Min – minimum, Max – maximum, CV – coefficient of variation; a, b means that rows with a different letter are statistically different (Tukey test, p <0.05).

Table 3 Average grape yield per hectare (t/ha).

Sample	Yield per hectare	Yield decrease (%)	
FR K	10.14	-	-
FR A	6.87	3.27	32.25
FR B	8.20	1.94	19.13
SB K	11.85	-	-
SB A	6.35	5.50	46.61
SB B	8.41	3.44	29.03

Note: FR – Feteasca regala, SB – Sauvignon blanc, K – control, A – removal of whole bunches, B – bunching, SD – standard deviation, Min – minimum, Max – maximum, CV – coefficient of variation; a, b means that rows with a different letter are statistically different (Tukey test, p <0.05).

Sugar content of must (kg/hL)

In all variants studied, we found statistically significant differences (p <0.05) in must sugar content between the yield reduction variants and control variants. The lowest sugar content was measured in the control variant in all measurements. The control variant of 'Feteasca regala' had an average sugar content of 18.17 kg/hL, in the control variant of 'Sauvignon blanc' we measured an average must sugar content of 19.67 kg/hL. In the whole cluster removal variant of 'Feteasca regala' we measured a sugar content of 19.42 kg/hL. The 'Sauvignon blanc' variety had a must sugar content of 20.33 kg/hL in the whole cluster removal variant. A cluster tipping of 'Feteasca regala' led to an increase in the average sugar content to 19.00 kg/hL. The 'Sauvignon blanc' variety had a must sugar content of 21.33 kg/hL in the tipping variant.

Table 4 Sugar content in must (kg/hL)

Sample	Mean ± SD	Min	Max	CV (%)
FR K	18.17 ± 0,29a	18.00	18.50	1.59
FR A	19.42 ± 0,14b	19.25	19.50	0.74
FR B	19.00 ± 0,50ab	18.50	19.50	2.63
SB K	19.67 ± 0,29a	19.50	20.00	1.47
SB A	20.33 ± 0,29b	20.00	20.50	1.42
SB B	21.33 ± 0,29b	21.00	21.50	1.35

Note: FR – Feteasca regala, SB – Sauvignon blanc, K – control, A – removal of whole bunches, B – bunching, SD – standard deviation, Min – minimum, Max – maximum, CV – coefficient of variation; a, b means that rows with a different letter are statistically different (Tukey test, p <0.05).

Estimated yield (EUR)

Yield reduction decreases the revenue by the labour costs necessary for its implementation, which amount to 0.05 €/bush. At the same time, the quantity of grapes is reduced. On the other hand, it is a good way of increasing the quality of the grapes, which can increase their price. In order to achieve a yield analogous to that of the control variant, we are forced to increase the realisation price of the grapes in the case of the variants with yield reduction.

At a grape price of 0.50 €/kg, the revenue per hectare in the control variant FR K would be 5 070 € . In order to achieve the same yield per hectare, we would have to thinning clusters at a price of 0.78 €/kg in the FR A variant. In FR B, we would have to increase the realisation price of the grapes to 0.65 €/kg. In the control variant SB K, at a grape price of 0.50 €/kg, we would obtain a revenue per hectare of 5 925 €. We would have to increase the grape price to 0.98 €/kg to achieve the same yield in SB A. In variant SB B, we would need to increase the realisation price of grapes to 0.74 €/kg.

Our aim was to prove the validity of performing grape yield regulation by experiments. The cluster weight in our experiment did not change demonstrably in variant of cluster thinning. Other authors have also come to similar findings on the different varieties **[31]**. In an experiment, Zhuang et al. **[32]** found that removal of whole bunches in different years may lead to a different decrease in bunch weight. We observed lower cluster weight in the case of cluster tipping compared to the control. Our finding is contradicted by studies in which the effect of subsequent berry enlargement increased bunch weight to a level analogous to the control or in some cases surpassed this weight **[33]**. Authors have reported an increase in the berry weight of tipping bunches **[34]**, **[35]**, **[36]**, **[37]**.

Pospíšilová et al. **[38]** quantify the average hectare yield of 'Feteasca regala' at 10 tons or more, with which the observed yield of 10.14 t/ha fully corresponds. For the variety 'Sauvignon blanc', the author quotes an average yield of 8.50 t/ha, whereas the yield of 11.85 t/ha calculated by us is significantly higher than this value. The above-average yield in the control variant may be related to the high number of grape vines per ha (up to 5 5554), the above-average rainfall during intense berry growth, and the high water-holding capacity of the soil in the locality.

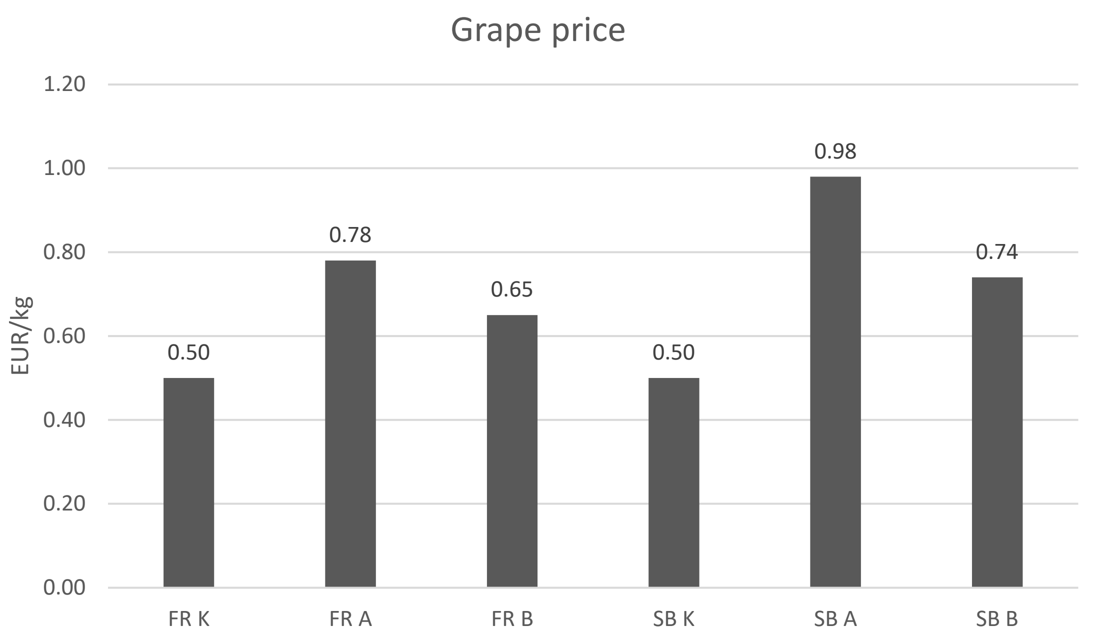

Figure 2 Graphical representation of the realisation prices of the grapes needed to achieve the same yield as the control. Note: FR – Feteasca regala, SB – Sauvignon blanc, K – control, A – removal of whole bunches, B – bunching.

The regulation of the grape yield usually leads to a decline in yield. Kok **[31]** investigated the effect of cluster thinning on selected parameters of the cultivar 'Sauvignon blanc'. A cluster weight was not demonstrably affected, but in the case of yield, there was a decrease of 37.50 %, which is analogous to the value we measured. Mančík (2017) **[39]** in his experiment evaluate the effect of cluster tipping on the quantitative and qualitative parameters of the cultivar 'Erilon'. Compared to the control, cluster tipping reduced yield by 39.80%. This decrease is significantly higher than in our case, with a 19.13 % decline in yield per hectare for 'Feteasca regala' and a 29.03 % decline in yield per hectare for 'Sauvigon blanc'. Our results indicate that the response of the varieties to the yield reduction is different, which may partly explain the differences in our results. The difference in sugar content of grapes measured by refractometer between the control and the cluster tipping variant is reported by the Mančík **[39]** to be only 0.35 kg/hL, which is less than the difference we measured in our experiment.

A yield decrease was also observed by Ruffo Roberto et al. **[7]** in an experiment with the cultivar 'BRS Vitoria' under the cluster thinning method. Fazekas et al. **[40]** in the cultivar 'Kékfrankos' recorded a yield decrease, but a greater yield decline was caused by cluster tipping when compared to cluster thinning. In our results, cluster tipping caused a smaller yield decrease than cluster thinning, which is explained by the different intensities of regulation.

On the other hand, many authors have obtained an inconclusive difference in yield of the studied variants compared to the control **[35]**, **[37]**, **[41]**. Some authors reported a slight increase in yield after grape yield reduction **[34]**, **[36]**. The increase in yield may be due to the low intensity of grape regulation in conjunction with the bunching method. Another reason for the increase may be the implementation of the intervention at an earlier date and the subsequent response of vine by compensating for the lost part of the bunches in the form of an increase in berry volume and weight.

Sedlo **[42]** argues that there is no correlation between average sugar content and profitability. The vine grower is paid primarily for the grapes' quantity, not their sugar content. The situation is different if he decides to produce high-quality wines. In that case, a certain level of the sugar content of the grapes must be achieved, and the maximum hectare yield must not be exceeded. The author further reports that harvests below 5.5 t are not sufficiently profitable. We conclude that the interventions we have carried out can make production profitable despite the reduction in the hectare yield.

We found a statistically significant (p <0.05) increase in the total sugar content in all the studied variants. The conclusions of other authors are different. On the one hand, some authors of studies have reported an increase in sugar content **[4]**, **[8]**, **[11]**, **[34]**, **[43]**, **[45]**, **[46]**. On the other hand, many studies did not observe significant differences in the content of total sugars or an increase in °BX **[7]**, **[18]**, **[46]**. The ambiguous results may be due to the method used, the intensity of yield reduction, and the date of intervention, but also to varietal variability and vineyard vintage.

Říhová **[47]** describes an experiment in the Krasnodar region of Russia, where the effect of defoliation and yield regulation on must and wine quality was studied. The used varieties were 'Merlot', 'Cabernet Sauvignon' and 'Syrah'. The measures positively affected the sugar and alcohol content of the wine. We can agree with this study since we observed a positive effect of yield reduction on sugar content in our experiment.

De Barros et al. **[9]** investigated the effect of bunch yield reduction on the quality of 'Malbec' grapes. The experiment was carried out in Brazil. In the experimental plots, grape ripening improved after the intervention. The polyphenol content of the berries increased. First, the experiment took place in different climatic conditions to those of central Europe. Nevertheless, we can confirm some of the claims. In the grape yield reduction variants we have studied, grapes ripened better.

Pavloušek **[26]** argues that the cluster tipping method suits blue wine varieties. We applied to bunch to white wine varieties, and the results of this intervention suggest that cluster tipping may be a suitable method for yield reduction in this group of varieties as well.

CONCLUSION

In this work, we evaluated the effect of grape yield regulation of wine grape varieties on its selected parameters. We did not find statistically significant (p >0.05) changes in cluster weight in the sample of cluster thinning compared to the control. As expected, we observed a statistically significant (p <0.05) decrease in the case of cluster tipping, but the number of clusters on the bush compensated it. Our measurements showed statistically significant (p <0.05) differences in grape yield between the control and the regulated variants. The obtained results clearly show a decrease in yield in the case of the regulated variants. The statistically significant (*the calculated hectare yields of grape also confirmed p <0.05) decrease in yield.* A regulation of grape yield led to an increase in must sugar content compared with the control variant. The differences were statistically significant (p <0.05) in all the studied variants. The decrease in the quantity of grapes after the yield regulation and the increase in labour costs necessary for its implementation should be compensated for in the form of an increase in the realisation price of grapes. Based on the results obtained, it can be concluded that the regulation of the yield is important in improving its quality parameters. In order to confirm our results, it is necessary to conduct experiments over several vintages. The removal of whole bunches and bunching positively affected the sugar content of the must. After evaluating one growing year, we cannot determine which method of yield reduction is more suitable for the varieties we studied. Each variety responds differently to yield regulation, and the viticulturist must consider not only the improvement in grape quality parameters achieved but, above all, the profitability of the intervention. The most appropriate way to achieve profitability after the yield regulation has been regulated is to produce wines in the category of wines of higher protected designation of origin.

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Funds:

This work was funded by Vedecká Grantová Agentúra MŠVVaŠ SR a SAV (1/0239/21) "Modern analytical approaches to the identification of health safety risks and dual quality of selected foods".

Acknowledgments:

We would like to thank to the Operational Program Integrated Infrastructure: Demand-driven research for the sustainable and innovative food, Drive4SIFood 313011V336, cofunded by the European Regional Development Fund for administrative and technical support.

Conflict of Interest:

The authors declare no conflict of interest.

Ethical Statement:

This article does not contain any studies that would require an ethical statement.

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