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OPTIMIZING PRODUCTIVITY AND FRUIT QUALITY OF ‘MUSCAT HAMBURG’ CULTIVAR THROUGH PRUNING INTENSITY

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Abstract

Pruning is a key practice in viticulture, influencing grapevine productivity, fruit quality, and plant health. As the climate evolves, adapting pruning strategies to optimize grape yield and quality becomes increasingly vital. This study was conducted in the grapevine fields of the Research Station for Viticulture and Oenology Murfatlar, Romania, on ‘Muscat Hamburg’, a table grape cultivar. Three pruning variants were evaluated over a 3-year span (2022-2024): V1 (24 buds), V2 (32 buds), and a control (38 buds). The impact of these variants was assessed on parameters such as total shoots, fertile shoots, fertility percentage, cluster weight, weight of 100 berries, sugars, total acidity and pH. Climate data were analyzed and statistical analysis was performed to compare the variants. Results show that V1 outperformed V2 and the control in fertility percentage (72.9%), cluster weight (195 g), and weight of 100 berries (256 g). Additionally, the glucoacidimetric ratio was highest in V1 (70.1) compared to V2 and the control. And pH values (3.50) were similar across all variants. These findings indicate that pruning with 26 buds optimizes grapevine productivity and fruit quality.

Key words*: pruning, climate change, grapevine productivity, cluster weight, optimisation.*

INTRODUCTION

The manipulation of crop yield is a well-established practice. In commercial vineyards, techniques such as vine pruning, which reduces the number of cluster-bearing buds, and crop thinning, which lowers the number of grape clusters, are commonly employed to control yield. Since yield directly influences the quantity of wine produced during a harvest, and considering the ease with which it can be adjusted, along with the longstanding belief that higher yields negatively impact wine quality, it is surprising that there has been limited research on how crop yield affects the aromas and flavors of wine (Chapmant et al., 2004).

Building upon the established practice of yield manipulation, in Romania, the sustainable development of the viticulture sector, particularly for table grape varieties like ‘Muscat Hamburg’, depends on the precise management of agronomic practices (Cuharschi et al., 2019). These include vine pruning, green operations, irrigation, and pest control, all aimed at enhancing grape quality and cluster weight (Gatti et al., 2016). Although the overall grape yield may suffer, optimizing the bud load through pruning can lead to significant improvements in the weight of the clusters, which is crucial for producing high-quality table grapes (Davel, 2015).

Variations in the number of growing fruits not only directly affect yield but can also lead to negative impacts on the size and quality of the harvested organs (Kliewer & Dokoozlian, 2005). Bud fertility (the number of bunches per shoot) and the number of flowers per bunch are closely related, with the primary branching of inflorescences playing a significant role in determining the total number of flowers within each inflorescence (Dunn & Martin, 2007).

Some studies show that the primary factors influencing grapevine yield are the number of bunches per vine and the number of berries per bunch, which contribute approximately 60%

and 30% to seasonal yield variation, respectively. In contrast, berry weight accounts for only around 10% of the seasonal yield variation (Clingeleffer et al., 2003).

Various techniques have been employed for yield manipulation in viticulture, including shoot trimming, post-veraison distal leaf removal, late winter pruning, and double pruning, all aimed at mitigating the effects of climate change by delaying maturation and preserving acidity under fluctuating temperatures (De Toda et al., 2013). However, their effectiveness varies depending on environmental conditions and grape varieties, requiring further research to determine their long-term impact on grape quality and vineyard management (Zheng et al., 2017).

Given the variability in their effectiveness depending on environmental conditions and grape varieties, with appropriate training methods and pruning systems, the accumulation of aroma precursors can be promoted, enhancing the wine's sensory profile. Additionally, these systems can influence bunch weight, which directly impacts grape quality (Clingeleffer, 2010).

In response to climate evolution, various pruning systems can help reduce stress on the plant and improve grape quality. These systems are essential for optimizing vine health and fruit composition, supporting the plant in adapting to shifting environmental conditions (Martin & Dunn, 2000).

This study aimed to investigate the impact of varying bud load per cane on key physiological and biochemical parameters, including vine fertility, cluster weight, berry weight, and glucoacidimetric profiles. The study also examined how these pruning strategies, intended to mitigate the effects of climate change, influence grapevine metabolism, phytochemical composition, and overall grape quality.

MATERIALS AND METHODS

The study was conducted from 2022 to 2024 at the Murfatlar Research Station for Viticulture and Oenology, situated in the central part of the Dobrogean Plateau (44°10'36''N; 28°25'22''E) a semi-arid climate, typical of the Dobrogean Plain, due to low rainfall and high evapotranspiration (Chelcea et al., 2016). The research focused on the 'Muscat Hamburg' cultivar (Figure 1), an old variety that exhibits a high adaptability potential to temperate continental climates (Vujović et al., 2017).

Figure 1. 'Muscat Hamburg'

Winter pruning was performed at different lengths over three consecutive years, from 2022 to 2024. Three variants were tested: a control group with 38 buds, V1 with 24 buds, and V2 with 32 buds, each having different pruning lengths.

Inflorescences were identified using the multiplied horizontal sectioning method of the buds, which involved placing the sections on glass slides fused with distilled water for observation under the microscope. The microscope used for these observations was the Kern Optics OBN 135. The number of total (TS) and fertile shoots (FS) was counted, and the number of inflorescences (INF) per variant was assessed. The fertility percentage (F %) was calculated using the formula: F (%) = (100*TS/FS).

Fertility indices were used based on the percentage of fertile shoots, with the fertility coefficient being either absolute or relative. The absolute fertility coefficient (AFC) was calculated using the formula AFC = INF/FS, while the relative fertility coefficient (RFC) was calculated as RFC = INF/TS. Productivity is influenced by cluster weight (CW), which is specific to each variety which is specific to each variety and was determined using a RADWAG PS600 analytical balance with a precision error of ± 0.01 g. The absolute production index (API) was calculated using the formula API = AFC * CW, and the relative production index (RPI) was calculated as RPI = RFC * CW. In addition, the total berry weight per vine in kilograms (TVW) was calculated using the formula INF x IPR (Pop, 2010). Post-harvest, research was conducted to characterize the quality of the grapes by determining the weight of 100 berries, sugar content (g/L), total acidity (g/L H_2SO_4), pH, and by calculating the glucoacidimetric index (GAI) which is calculated by the sugars/ total acidity ratio (Stanescu, 1960). The evaluation of grape maturity also considered commercial quality standards, including minimum GAI thresholds defined by OIV Resolution VITI 1/2008. (Bucur & Dejeu, 2018). The climatic data from the vineyard for 2022, 2023, and 2024 were assessed using the iMetos 3.3 weather station by Pessl Instruments, located at the center of the plantation. Additionally, climatic indices were evaluated during the assessment (Irimia et al., 2017; Jolly et al., 2005). The real heliothermal index (IHr) was calculated using the formula $IHr = I \times \Sigma tu\,(°C) \times 10^{-6}$ (Branas, 1974). The hydrothermal coefficient (HC) was calculated using the formula $HC = Pg / (\Sigma ta\,(°C) \times 10)$, where *Pg* represents the total precipitation during the growing season (Zaldea et al., 2021). The vine bioclimatic index (Ibcv) was then calculated using the formula $Ibcv = [(I \times \Sigma ta\,(°C))/(Pg \times Ndg)]/10$, where *Ndg* is the number of days in the growing season with average temperatures above 10 °C (Constantinescu et al., 1964). Finally, the oenoclimate aptitude index (IAOe) was determined using the formula $IAOe = I + \Sigma ta\,(°C) - (Pg - 250)$ (Teodorescu et al., 1987). Statistical analysis was conducted using Microsoft Excel 2021 and IBM SPSS Statistics 26 to process the data collected in this study. Descriptive statistics, including mean and standard deviation, were calculated for both continuous and categorical variables. Additionally, ANOVA was performed to determine significant differences among the pruning variants (Stahle & Wold, 1989).

RESULTS AND DISCUSSIONS

Across the three experimental years, fertility percentages exhibited substantial variation, as shown in Table 1, highlighting the influence of climatic conditions and pruning intensity.

Table 1. Bud fertility and cluster weight in 'Muscat Hamburg' under different pruning variants (2022-2024)

Variant	TS	FS	F%	INF	CW (g)
MH_C_2022	20	10	50.00	13	180
MH_V1_2022	16	10	62.50	15	187
MH_V2_2022	17	8	47.06	14	180
MH_C_2023	21	13	61.90	14	174
MH_V1_2023	16	13	82.48	16	210
MH_V2_2023	18	10	55.56	16	176
MH_C_2024	19	11	57.89	18	170
MH_V1_2024	19	14	73.68	14	189
MH_V2_2024	18	9	50.00	14	176

In 2022, fertility ranged from 47.06% (MH_V2) to 62.50% (MH_V1), with the control (MH_C) showing an intermediate value of 50.00%. A similar trend was observed in cluster weight, where the highest values were recorded for MH_V1 (187 g), while MH_C and MH_V2 maintained equal weights (180 g).
In 2023, improved fertility was observed across all variants, particularly in MH_V1 (82.48%), followed by MH_C (61.90%) and MH_V2 (55.56%), suggesting that the more intensive pruning strategy (V1) promoted enhanced bud differentiation and fruit set. This was accompanied by a significant increase in cluster weight, reaching 210 g in MH_V1, while MH_C (174 g) and MH_V2 (176 g) remained relatively stable.

Table 2. Tests of between-subjects effects on fertility across different pruning variants (2022-2024)

Dependent Variable:		Measurement			
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	782.707[a]	2	391.35	7.547	0.023
Intercept	32528.527	1	32528.52	627.303	0.000
Treatment	782.707	2	391.35	7.547	0.02
Error	311.127	6	51.855		
Total	33622.362	9			
Corrected Total	1093.835	8			

a. R Squared = 0.716 (Adjusted R Squared = 0.621)

In 2024, bud fertility declined in all variants, likely due to excessive rainfall and altered thermal conditions. The highest fertility was again observed in MH_V1 (73.68%), followed by MH_C (57.89%) and MH_V2 (50.00%), mirroring trends from previous years. Cluster weights showed a similar pattern, with MH_V1 (189 g) maintaining superiority, while MH_C

(170 g) and MH_V2 (176 g) displayed minor fluctuations.

Statistical analysis of the fertility data revealed a significant effect of pruning treatment on reproductive potential ($F = 7.547$, $p = 0.023$), as shown in Table 2.

The results indicated that the MH_V1 variant consistently outperformed the other treatments, exhibiting the highest fertility percentages across all years. Specifically, MH_V1 demonstrated a fertility of 82.48% in 2023 and 73.68% in 2024, which was notably higher than both the control (MH_C) and the MH_V2 variants. This suggests that the more intensive pruning applied in MH_V1 is more conducive to optimal bud differentiation and fruit set. This trend is clearly depicted in Figure 2, which shows the fertility percentages for each variant over the three years.

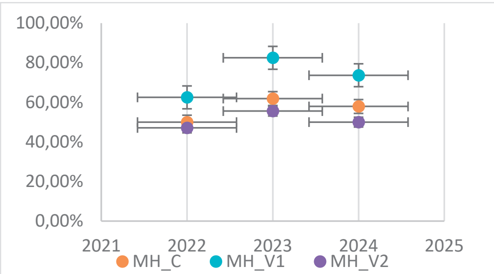

Figure 2. Fertility percentages (%) across different pruning variants (2022-2024)

The analysis further indicates that the treatment factor (pruning variant) explained a substantial portion of the variance in fertility, with the corrected model accounting for 71.6% of the total variability ($R^2 = 0.716$, Adjusted $R^2 = 0.621$). This suggested a strong influence of pruning intensity on bud fertility, with statistically significant differences observed between variants.

Cluster weight (CW) was also assessed to further evaluate the impact of pruning treatments. Table 3 presents the cluster weight data for each variant over the three years.

The ANOVA revealed a significant difference between the pruning variants ($F = 5.89$, $p = 0.038$), where the Between Groups variation explained 758.22 of the sum of squares, and the Within Groups variation accounted for 386. The F crit value was 5.14, confirming the statistical relevance of the observed differences.

Table 3. Cluster weight (g) for different pruning variants (2022-2024)

CW (g)	2022	2023	2024	Avg.	St. dev. ±
MH_C (g)	180	174	170	174.67	5.03
MH_V1 (g)	187	210	189	195.33	12.74
MH_V2 (g)	180	176	176	177.33	2.31

MH_V1 variant consistently resulted in the highest cluster weights, with an average of 195.33 g across the three years. In comparison, the MH_C variant had a lower average cluster weight of 174.67 g, and MH_V2 had an average of 177.33 g. The MH_V1 variant also exhibited a relatively higher standard deviation (± 12.74 g), indicating more variability in cluster weight compared to MH_C (± 5.03 g) and MH_V2 (± 2.31 g), which had more consistent results. These differences highlight the superior performance of MH_V1 in terms of cluster weight, but also the greater variability within that treatment.

The statistical significance of these differences was assessed using ANOVA, with the results presented in Table 4.

Table 4. ANOVA analysis of cluster weight variation across different pruning treatments (2022-2024)

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	758.22	2	379.11	5,89	0.04	5.14
Within Groups	386	6	64.33			
Total	1,144.22	8				

Further examination was conducted on several productivity-related indices, including the absolute fertility coefficient (AFC), relative fertility coefficient (RFC), absolute productivity index (API), and relative productivity index (RPI). As shown in Table 5, the MH_V1 variant exhibited the highest AFC in 2023, while MH_V2 demonstrated the highest RFC in 2022 and 2023.

However, regarding actual productivity, MH_V1 came close to MH_V2, which consistently demonstrated higher productivity. The average total cluster weight for MH_V2 was 4.25 kg, while MH_V1 averaged 3.66 kg. Despite MH_V2's higher overall weight, MH_V1 showed competitive performance, likely due to its more efficient conversion of fertile shoots into productive clusters in 2023.

Table 5. Productivity indices and total cluster weight for different pruning variants (2022-2024)

Variant	AFC	RFC	API	RPI	TVW
MH_C_2022	0.7	1.3	117.0	234.0	3.04
MH_V1_2022	0.9	1.5	175.3	280.5	4.21
MH_V2_2022	0.8	1.8	148.2	315.0	4.41
MH_C_2023	0.7	1.1	116.0	187.4	2.62
MH_V1_2023	1.0	1.2	210.0	258.5	4.14
MH_V2_2023	0.9	1.6	156.4	281.6	4.51
MH_C_2024	0.9	1.6	161.1	278.2	5.01
MH_V1_2024	0.7	1.0	139.3	189.0	2.65
MH_V2_2024	0.8	1.6	136.9	273.8	3.83

The climatic conditions over the three years studied (2022-2024) exhibited notable interannual variability. In 2022, the year was characterized by moderately dry conditions, with a total annual rainfall of 383.7 mm, out of which 206.7 mm occurred during the growing season. The hydrothermal coefficient (HC) was 0.6, and the oenoclimate aptitude index (IAOe) reached 5250.7, indicating a balanced but somewhat dry year. The average temperatures in July and August were 25.7 °C and 26.1 °C, respectively, while the average temperature during the first two-thirds of June was 22.2 °C. The number of days with temperatures exceeding 30 °C was 67, and the bioactive period lasted for 207 days, suggesting a typical thermal regime favorable for grape ripening.

In 2023, the climate turned drier and slightly warmer. Annual precipitation dropped to 318.1 mm, with only 170.9 mm during the growing season. Consequently, the HC decreased to 0.5, reflecting limited water availability, while the IAOe slightly decreased to 5197.2. Despite this, the annual average temperature increased to 14.8 °C, with July and August averaging 26.8 °C and 26.9 °C, respectively. September also showed a notable rise, averaging 22.2 °C. However, the number of hot days (>30 °C) dropped to 62, and the bioactive period slightly shortened to 205 days. Sunshine duration was also lower than in 2022, totaling 1311.8 hours, which may have contributed to a more compressed growing season. Despite these limitations, the useful thermal sum (Σtu) was relatively high at 2398.3 °C, and the vine bioclimatic index (Ibcv) reached 13.9, indicating favorable ripening potential.

By 2024, climatic conditions shifted toward higher humidity, with the annual rainfall increasing to 406.2 mm, and growing season precipitation reaching 345.6 mm, the highest of the three years. As a result, the HC rose to 1.1, and the year was classified as humid.

The Ibcv dropped to 7.3, suggesting lower bioclimatic suitability, likely due to excessive moisture.

However, thermal conditions remained very favorable, with a useful thermal sum of 3266 °C, the highest in the studied interval, and an IAOe of 5277.4, slightly surpassing the previous years. July temperatures peaked at 28.5 °C, and the average during the first two-thirds of June reached 25.8 °C, indicating an early onset of high thermal accumulation.

The number of days above 30 °C increased to 75, and the bioactive period extended to 211 days, reflecting an extended ripening phase. Nonetheless, sunshine duration remained the lowest, at 1301.1 hours, which might have moderated sugar accumulation despite the favorable thermal regime (Table 6).

Table 6. Climatic conditions and viticultural indices for 2022-2024

Year	2022	2023	2024
Global (Σt°g)	5020.6	5416.6	5136.9
Active, (Σt°a)	4549.4	4795.3	4792.9
Useful (Σt°u)	2208.8	2398.3	3266
Avg. T. July (°C)	25.7	26.8	28.5
Avg. T. August (°C)	26.1	26.9	26.1
Avg. T. September (°C)	19.6	22.2	19.8
Absolute min. air T. (°C/date)	-9.6	-9.8	-10.3
Absolute min. soil temperature (°C)	-12.1	-10.1	-12.2
Annual avg. T (°C)	13.7	14.8	14.5
Annual rainfalls (mm)	383.7	318.1	406.2
Growing season rainfalls (mm) (Pg)	206.7	170.9	345.6
Growing season sunshine (hours)	1400.8	1311.8	1301.1
Avg. max. T. August (°C)	32	31.9	31.6
Avg. T during 2/3 of June.	22.2	21.7	25.8
No days > 30°C (Ndg)	67	62	75
Bioactive period (days)	207	205	211
Ihr	4.5	4.4	9.7
HC	0.6	0.5	1.1
Ibcv	12.3	13.9	7.3
IAOe	5250.7	5197.2	5277.4
IH	2520.8	2434.3	3340.65

Variability in grape composition (sugar content and acidity) were closely linked to variations of the climatic conditions in each year (Table 6 and Table 7).

Table 7. Grape composition and quality assessment (2022-2024)

Variant	100 berries (g)	Sugars g/L	Total g/H_2SO_4	pH
MH_C_2022	176.00	181.30	2.80	3.56
MH_V1_2022	215.00	198.68	2.35	3.59
MH_V2_2022	194.00	182.50	2.77	3.60
MH_C_2023	290.00	181.67	3.65	3.55
MH_V1_2023	305.00	203.36	3.15	3.60
MH_V2_2023	300.00	179.76	3.54	3.55
MH_C_2024	211.00	179.94	3.86	3.35
MH_V1_2024	257.00	197.50	3.23	3.30
MH_V2_2024	224.00	184.43	3.66	3.40

MH_V1 variant consistently demonstrated the highest sugar content, with values of 198.68 g/L in 2022, 203.36 g/L in 2023, and 197.50 g/L in 2024. In comparison, the MH_C variant exhibited lower sugar levels, ranging from 181.30 g/L in 2022 to 179.94 g/L in 2024. The MH_V2 variant showed intermediate sugar content, with 182.50 g/L in 2022, 179.76 g/L in 2023, and 184.43 g/L in 2024.

Regarding total acidity, MH_V1 had the lowest acidity in 2022 (2.35 g/L) but experienced a rise in acidity in subsequent years, reaching 3.23 g/L in 2024. The MH_C variant, initially at 2.80 g/L in 2022, saw a gradual increase in acidity over the years, peaking at 3.86 g/L in 2024. The MH_V2 variant started with an acidity of 2.77 g/L in 2022, which increased to 3.54 g/L in 2023 and 3.66 g/L in 2024.

In terms of berry weight, the MH_V1 variant consistently had the heaviest berries, particularly in 2023 (305 g), while the MH_C variant had the lightest berries, especially in 2022 (176 g). The MH_V2 variant exhibited intermediate berry weights, with values of 194 g in 2022, 300 g in 2023, and 224 g in 2024.

The pH levels of the variants also varied across the years. The pH of MH_V1 remained relatively stable, at 3.59 in 2022, 3.60 in 2023, and 3.30 in 2024. Meanwhile, the MH_C variant showed a decline in pH from 3.56 in 2022 to 3.35 in 2024, and the pH of the MH_V2 variant shifted from 3.60 in 2022 to 3.40 in 2024, reflecting a slight increase in acidity over time.

Furthermore, the Glucoacidimetric Index (GAI) was calculated for each variant over the three years of study. As shown in Table 8, the GAI values indicated noticeable differences across variants and years.

Table 8. Descriptive statistics of the glucoacidimetric index (GAI) for different variants (2022-2024)

V.	Range	Min	Max	Mean	St. Dev	Var.
MH_C	18.2	46.6	64.8	53.7333	±9.71665	94.413
MH_V1	23.4	61.1	84.5	70.0667	±12.62154	159.303
MH_V2	15.5	50.4	65.9	55.7	±8.83572	78.07

Descriptive statistics for the GAI across all years showed that MH_V1 had the highest mean GAI of 70.07, followed by MH_V2 with a mean of 55.70, and MH_C with the lowest mean of 53.73. In terms of variability, MH_V1 exhibited the highest standard deviation (±12.62), suggesting greater variation in its GAI values over the years. In contrast, MH_V2 showed the least variability with a standard deviation of ±8.84, while MH_C had a moderate deviation (±9.72). Regarding variance, MH_V1 also had the highest variance (159.30), indicating that the GAI values for MH_V1 were more spread out over the years compared to the other variants. MH_V2 exhibited the lowest variance (78.07), suggesting a more consistent GAI across the three years. MH_C had a variance of 94.41, indicating moderate variability in its GAI over the study period.

In 2022, MH_V1 showed the highest GAI (84.5), followed by MH_V2 (65.9) and MH_C (64.8). Over the course of the study, the GAI values decreased for all variants. Specifically, in 2023, MH_V1 again led with a GAI of 64.6, while MH_V2 and MH_C showed 50.8 and 49.8, respectively. By 2024, MH_V1 maintained the highest GAI (61.1), while MH_V2 and MH_C continued to exhibit lower values (50.4 and 46.6, respectively).

The results suggest that MH_V1 consistently had the best sugar-to-acid ratio across the years, as observed in Figure 3, indicating its potential for producing grapes with a more favorable balance of sweetness and acidity. Furthermore, when comparing these values to commercial maturity standards for table grapes, as outlined by the OIV Resolution VITI 1/2008, it is evident that MH_V1 meets or exceeds the minimum sugar/acid ratio threshold of 20:1 in all years. Its mean GAI of 70.07 and minimum yearly value of 61.1 clearly surpass this requirement. MH_V2 and MH_C also show values above the 20:1 threshold, with minimum GAI values of 50.4 and 46.6

respectively; however, their lower mean GAI (55.70 and 53.73) and higher year-to-year variability suggest that in less favorable conditions, these variants may risk falling closer to the commercial acceptability margin. Therefore, MH_V1 not only demonstrates superior average quality but also greater reliability in maintaining commercial maturity standards across different years.

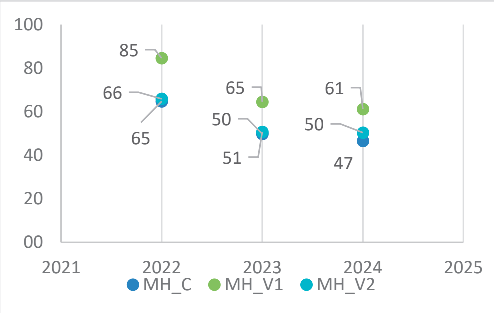

Figure 3. Glucoacidimetric index variation across variants (2022-2024)

However, the greater variance in MH_V1 highlights the influence of climatic variations, making its GAI values more sensitive to environmental changes. In contrast, MH_V2 exhibited a more stable GAI across years, suggesting a more consistent performance regardless of yearly climate fluctuations.

CONCLUSIONS

Across the three experimental years, fertility percentages varied significantly due to climatic conditions and pruning intensity. MH_V1 consistently outperformed MH_V2, with higher fertility rates, indicating that the more intensive pruning strategy promoted better bud differentiation and fruit set.

Although MH_V2 recorded the highest total cluster weight, MH_V1 demonstrated more efficient reproductive performance by converting a higher proportion of fertile shoots into productive clusters, highlighting its superior agronomic efficiency.

Statistical analysis confirmed the significant impact of pruning intensity on reproductive potential. MH_V1 showed consistently better results than MH_V2, reinforcing the conclusion that more intensive pruning had a favorable effect on fertility and productivity.

Climatic variability across the years influenced grape composition. Despite fluctuations in weather conditions, MH_V1 maintained higher sugar levels and a more favorable sugar-to-acid ratio compared to MH_V2, aligning with commercial quality standards.

While MH_V1 exhibited greater sensitivity to environmental changes, MH_V2 showed more stable but lower performance. Overall, MH_V1 proved to be the more productive and qualitatively superior variant, particularly under favorable climatic conditions.

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