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INSTITUTE OF VITICULTURE AND WINEMAKING – PLEVEN

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Impact of green pruning operations, cluster thinning and leaves, on the quantity and quality of grapes and wine of the varieties Cabernet Franc and Syrah in the Stara Zagora region

ABSTRACT

of a dissertation for awarding the educational and
scientific degree "Doctor"
in a professional direction 6.1. Plant breeding
scientific specialty "Viticulture"

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The dissertation contains 152 pages and includes 27 tables and 21 figures. The bibliography comprises 230 references (45 in Cyrillic and 185 in Latin script).

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Abbreviations Used in the Dissertation

AA - Antioxidant Activity: Reflects the ability of a substance to neutralize free radicals, a key indicator of the antioxidant properties of grapes and wine.
NSE - Non-Sugar Extract: Denotes the total content of non-sugar dissolved solids in wine, which contribute to its body and flavor profile.
GI - Glucoacidimetric Index: A parameter showing the balance between sugars and acids in grapes or wine, affecting their flavor.
GIS - Geographic Information System: A technology used for spatial analysis and mapping in viticulture, aiding vineyard monitoring and management.
NFPC - Non-Flavonoid Phenolic Compounds: Phenolic compounds in wine that are not flavonoids, often contributing to its antioxidant potential.
TPC - Total Phenolic Compounds: The overall phenolic content in grapes or wine, influencing color, flavor, and antioxidant capacity.
TA - Titrable Acidity: Indicates the total acids in wine, which are critical for its freshness and stability.
FPC - Flavonoid Phenolic Compounds: Phenols derived from flavonoids, responsible for wine's color, bitterness, and antioxidant properties.
LCI - Leaf Chlorophyll Index
MCARI - Modified Chlorophyll Absorption in Reflectance Index
NDVI - Normalized Difference Vegetation Index
NDWI - Normalized Difference Water Index

1. INTRODUCTION

The factors affecting the quality of grapes and the resulting wines include the cultivation area with its terroir characteristics (geographical location, soil, climate), the specifics and potential of the grape variety, the applied agronomic practices, vine training systems, pruning techniques (dormant and green pruning), grape processing and vinification methods, storage conditions, and others. Climate change poses a challenge for vineyard managers and winemakers, requiring the implementation of specific agronomic measures to preserve and improve the quality of grapes and wine. Green pruning plays a crucial role in controlling the yield, composition, and characteristics of the grape harvest. When properly implemented, it can significantly enhance the quality of the final product while reducing the negative impact of extreme climatic events. The most commonly practiced green pruning techniques include: shoot thinning, topping, cluster thinning, and leaf removal.

2. AIM OF THE DISSERTATION

Research and determination of the impact of green pruning operations, specifically cluster thinning and leaf thinning around the clusters, on the quantity and quality of grapes and wine from the Cabernet Franc and Syrah varieties grown in the micro-region of Stara Zagora.

OBJECTIVES OF THE DISSERTATION

To achieve the set goal, the following main tasks were completed:

1. Studying the impact of climatic factors on vine development.
2. Remote monitoring of the vineyard.
3. Investigating the effect of cluster and leaf thinning around the cluster zone on fertility indicators.
4. Examining the influence of cluster and leaf thinning in the cluster zone on the quantity and quality of grape yields.
5. Evaluating the effect of the applied green pruning operations on the phenolic content and chemical composition of the grapes from the studied varieties.
6. Investigating the impact of the applied green pruning operations on the antioxidant activity of grapes and wine from the studied varieties.
7. Studying the influence of the applied green pruning operations on the chemical composition and organoleptic characteristics of the experimental wines produced from the studied varieties.

3. MATERIALS AND METHODS OF THE RESEARCH

The research work for the dissertation was conducted during the period 2021–2023 in a vineyard located in the area of the village of Rakitnitsa, Stara Zagora region, at Trakia University – Stara Zagora, and the Institute of Viticulture and Enology – Pleven. The study focused on the red wine grape varieties Cabernet Franc and Syrah.

Experimental Design

1. Study of the Influence of Soil and Climatic Conditions:

1.1 Soil Characterization of the Area: Soil characteristics of the area: A composite soil sample taken from the vineyard was analyzed to determine the content of primary macronutrients phosphorus (P) and potassium (K), as well as micronutrients zinc, sodium, sulfur, iron, molybdenum, copper, boron, manganese, magnesium, and calcium (Zn, Na, S, Fe, Mo, Cu, B, Mn, Mg, Ca). Additionally, the soil's pH and carbonate content were examined.

1.2. Climatic Characteristics of the Area: A Meteobot weather station was installed in the vineyard, recording hourly data on air temperature (°C), air humidity (%), precipitation (mm), and soil temperature (°C) at a depth of 30 cm. The recorded data for the vegetation period were averaged using the Excel 2007 software.

2. Aerial Remote Monitoring of the Vineyard:

Remote monitoring utilized NDVI indices generated from GIS for June, July, and August 2021. In 2022, aerial remote monitoring was conducted using an unmanned aerial vehicle (UAV) – DJI Phantom 4 Multispectral – flying at a height of 20 meters above the vineyard. The generated indices covered a total area of 1.68 ha and included the experimental variants for the two studied grape varieties. Average values were recorded for the following indices: GNDVI, LCI, MCARI, NDVI, and NDWI.

3. Agronomy and Experimental Variants

The vines from the experimental variants of the studied varieties Cabernet Franc and Syrah were grown using the medium-stemmed two-arm Guyot training system. During the winter pruning, each vine was left with 4 canes, each with 2 buds, and 2 fruiting canes with a length of 10 buds. The total load per vine was 28 buds. For each variety, 90 vines were marked and distributed into three variants, with 30 vines per variant:

- V1 – No green pruning (control)
- V2 – Cluster thinning at the "pea size" stage

- V3 – Cluster thinning at the "pea size" stage and leaf thinning around the cluster zone, at the height of the clusters, without removing leaves above them, performed during the berry softening stage (veraison). For both varieties, in the V2 and V3 variants, 15 clusters were left on each vine.

4. Agrobiological Indicators

-Phenological Observations: These were conducted throughout the grapevine's growing season, from March to November, and included key growth stages such as sap flow, bud break, flowering, berry softening (color change), and technological maturity. For each phenophase, the start date, the date of peak occurrence, and the end date were recorded, following the methodology of Katérov et al. (1990).

-Actual Fertility: The indicators of actual fertility were assessed annually for each variant, starting after the flowering phase. This involved counting all the shoots that developed from the fruiting zones of the vine's training system, including those from the main and replacement buds, dormant buds, and axillary buds across all vines included in the study, as described by Katérov et al. (1990).

-Technological Indicators: The quantitative and qualitative parameters of the harvest were determined once the grapes reached technological maturity. These included the average mass of one grape cluster (g), the average mass of 100 berries (g), the average yield per vine (kg), and the structure of the grape and berry (g).

5. Determination of the Phenolic Content in Grapes from the Studied Varieties

The phenolic content of the grapes from the studied varieties was analyzed, focusing on the total phenolic compounds (TPC), flavonoid phenolic compounds (FPC), non-flavonoid phenolic compounds (NFPC), and monomeric anthocyanins in the structural elements of the grape (cluster, seeds, skins, whole berries) at technological maturity, after harvest (Stoianov et al., 2004; Stoianov, 2007).

6. Grape Processing and Winemaking for the Studied Varieties

The grapes from the studied varieties were transported and processed at the Experimental Winery of the Institute of Viticulture and Enology – Pleven, following the experimental variants, with each variant using 20 kg of grapes. The classical scheme for the production of red dry wines under microvinification conditions was employed:

- Red grapes → Crushing → Destemming → Sulfiting (50 mg/kg SO2) → Inoculation with pure culture of Saccharomyces cerevisiae Fermactive Cabernet dry wine yeast (10 g/hl) → Fermentation temperature 26°C → Separation from

solid parts → Further sulfiting (up to 25 mg/l free SO2) → Storage in full containers (Yankov, 1992; Abrasheva et al., 2008).

7. Determination of the Chemical Composition of Grapes from the Studied Varieties

The chemical composition of the grapes from the studied varieties was analyzed after crushing, in the obtained grape must. The commonly accepted methods in winemaking practice were used to determine reducing sugars, titratable acids, pH, and the glucoacidimetric index (Ivanov et al., 1979).

8. Determination of the Chemical Composition of the Obtained Experimental Red Wines

The commonly accepted methods in winemaking practice were used to determine alcohol, residual sugars, total and non-sugar extract, titratable acids, volatile acids, pH, O.F.S. (Total Soluble Extract), F.F.S. (Free Fermentable Sugars), N.F.S. (Non-Fermentable Sugars), anthocyanins, intensity, and hue of the color (Ivanov et al., 1979; Chobanova, 2007).

9. Determination of the Antioxidant Activity of Grapes and Wine from the Studied Varieties

The antioxidant activity (A.A.) in grape juice and wine from the experimental variants of the studied varieties was determined using the DPPH method as outlined by Tzanova et al. (2020).

10. Determination of the Organoleptic Characteristics and Sensory Evaluation of the Experimental Wines

The differences in the organoleptic profile of the experimental red wines were assessed by a tasting committee of enologists from the Department of Wine and Beer Technology at the University of Food Technologies – Plovdiv. The samples were evaluated on a 100-point scale, and the organoleptic indicators were presented using graphical representations in the form of spider diagrams (Tsvetanov, 2001; Prodanova, 2008).

11. Statistical Processing of the Results

The data from the chemical analyses were subjected to descriptive statistical processing, presented as the mean value and standard deviation (±SD) using Excel 2007 (Microsoft Office).

- To examine the influence of the grape variety and pruning type on yield per vine, cluster weight, and 100-berry weight, a one-way analysis of variance was applied at a statistical significance level of 0.05 for each year of the study. Duncan's test was used to determine the significance of differences between the varieties for the respective parameters.

4. RESULTS AND DISCUSSION

4.1. Climatic Characteristics

A Meteobot weather station was installed in the vineyard, recording hourly data on air temperature, relative humidity, precipitation, and soil temperature at a depth of 30 cm. The data were summarized as daily averages for each of the recorded climatic indicators in Figures 1, 2, and 3, organized by ten-day intervals for the months from March to November, for the period 2021–2023.

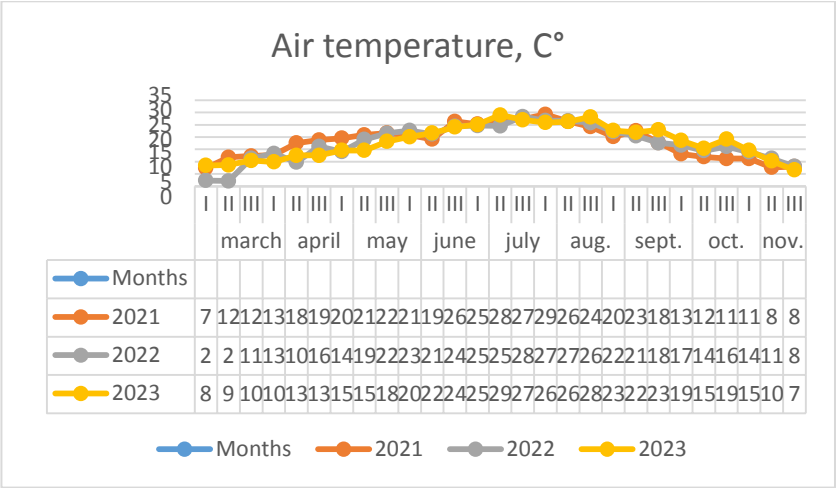


Figure 1. Air temperature, C°(2021-2023)

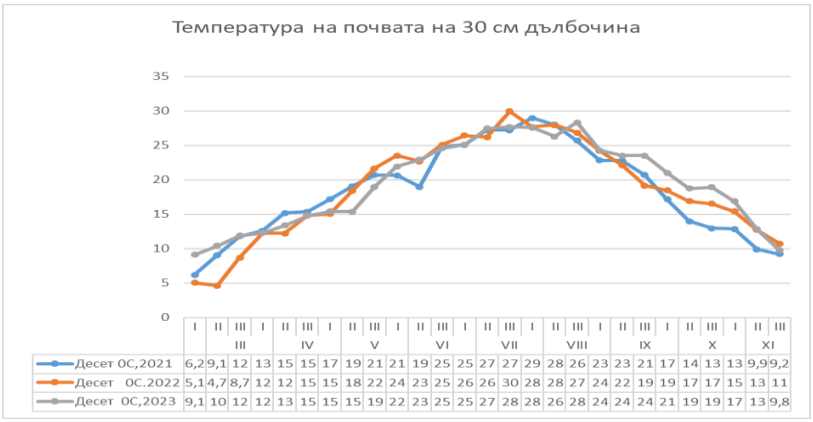


Figure 2. Soil temperature, C°(2021-2023)

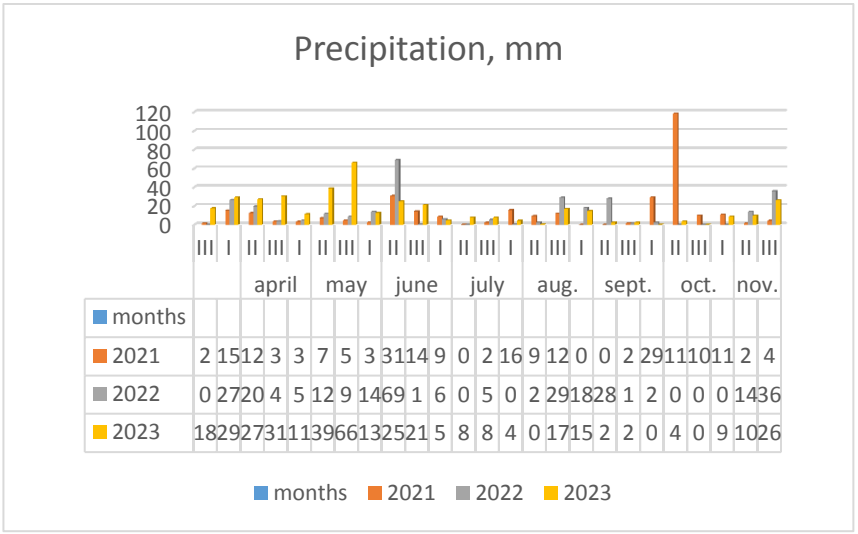


Figure 3. Precipitation, mm (2021-2023)

4.2. Aerial Remote Monitoring of the Vineyard

The images generated by GIS show the development of the vegetation index for June, July, and August 2021 (Figure 4). The series of GIS images illustrate an increase in the index from 0.38 in June to 0.40 at the beginning of July. This rise corresponds with the period of intensive vine growth. By August, a decrease in the index is registered, attributed to the reduction in photosynthetic activity of the green parts of the vine. This aligns with the climatic conditions of the respective months during the 2021 growing season.

In the second year, remote aerial monitoring was performed using an unmanned aerial vehicle (UAV) equipped with a specialized camera that allowed for the generation of vegetation indices. The NDVI index (Figure 5-c) was recorded with a value of 0.49, which is close to the average for the index and higher than in 2021. The measured LCI index (Figure 5-a) reflects the chlorophyll content in the leaves and is used to monitor the physiological state of the plants. The recorded average value of the index was 0.18. The MCARI index (Figure 5-b), an improved index for assessing chlorophyll content by reducing the influence of leaf and soil structure, showed an average value of 0.28, which is relatively low and could indicate a deficiency of nutrients.

The NDWI measures the water content in plants almost in real-time. Information about water stress is crucial for managing water resources. The vineyard showed that moisture was not evenly distributed, with some areas

having a low index (-0.58) during the monitoring period, indicating a lack of adequate moisture supply (Figure 6).

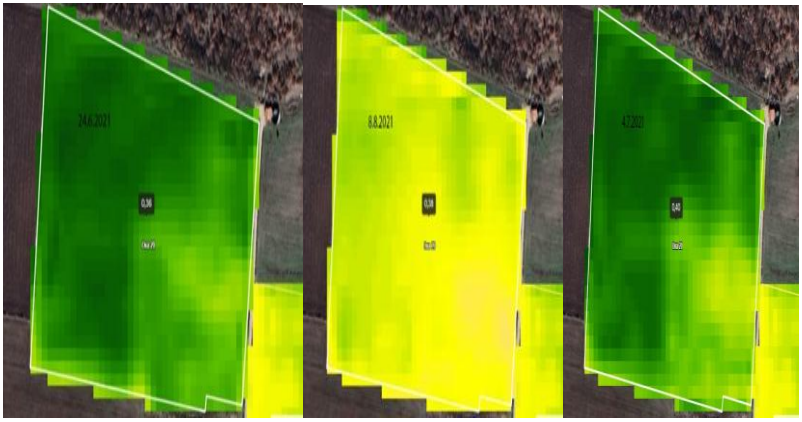


Figure 4. Vegetation Index NDVI for 2021

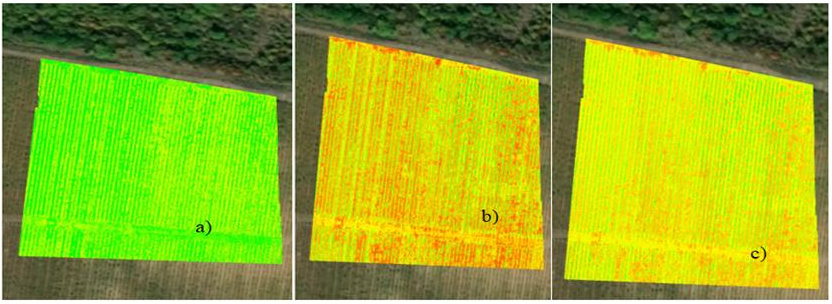


Figure 5. Vegetation Indices LCI, MCARI, NDVI for 2022



Figure 6. Normalized Difference Water Index (NDWI)

4.3. Phenological Observations

The study years are characterized by high average daily temperatures, especially during the summer, and varying amounts of precipitation during the growing season, as well as periods of drought. The specifics of the onset, progression, and duration of the phenophases for the two varieties, Cabernet Franc and Syrah, are presented in Table 1, Table 2, and Table 3.

Table 1. Phenological Observations in 2021

Phenophase	Cabernet Franc	Syrah
Sap flow	04.04. (start) - 08.04. (peak) - 12.04. (end)	04.04. (start) - 08.04. (peak) - 12.04. (end)
Bud break	14.04. (start) - 16.04. (peak) - 18.04. (end)	14.04. (start) - 16.04. (peak) - 18.04. (end)
Appearance of 1st leaf	20.04. (start) - 22.04. (peak) - 25.04. (end)	20.04. (start) - 22.04. (peak) - 25.04. (end)
Appearance of 1st cluster	27.04. (start) - 29.04. (peak) - 02.05. (end)	27.04. (start) - 29.04. (peak) - 02.05. (end)
Flowering	04.06. (start) - 08.06. (peak) - 14.06. (end)	04.06. (start) - 08.06. (peak) - 14.06. (end)
Berry pea size	30.07. (start) - 04.08. (peak) - 07.08. (end)	30.07. (start) - 04.08. (peak) - 07.08. (end)
Veraison	12.08. (start) - 25.08. (peak) - 30.08. (end)	12.08. (start) - 25.08. (peak) - 30.08. (end)
Technological maturity	25.09.	12.10.

Table 2. Phenological Observations in 2022

Phenophase	Cabernet Franc	Syrah
Sap flow	09.04. (start) - 12.04. (peak) - 15.04. (end)	09.04. (start) - 12.04. (peak) - 15.04. (end)
Bud break	19.04. (start) - 21.04. (peak) - 23.04. (end)	19.04. (start) - 21.04. (peak) - 23.04. (end)
Appearance of 1st leaf	23.04. (start) - 26.04. (peak) - 28.04. (end)	23.04. (start) - 26.04. (peak) - 28.04. (end)
Appearance of 1st cluster	30.04. (start) - 03.05. (peak) - 07.05. (end)	30.04. (start) - 03.05. (peak) - 07.05. (end)
Flowering	01.06. (start) - 03.06. (peak) - 09.06. (end)	01.06. (start) - 03.06. (peak) - 09.06. (end)

Phenophase	Cabernet Franc	Syrah
Berry pea size	08.07. (start) - 14.07. (peak) - 18.07. (end)	08.07. (start) - 14.07. (peak) - 18.07. (end)
Veraison	23.07. (start) - 03.08. (peak) - 10.08. (end)	23.07. (start) - 03.08. (peak) - 10.08. (end)
Technological maturity	11.09. (peak)	11.09. (peak)

Table 3. Phenological Observations in 2023

Phenophase	Cabernet Franc	Syrah
Sap flow	31.03. (start) - 04.04. (peak) - 07.04. (end)	31.03. (start) - 04.04. (peak) - 07.04. (end)
Bud break	11.04. (start) - 13.04. (peak) - 18.04. (end)	11.04. (start) - 13.04. (peak) - 18.04. (end)
Appearance of 1st leaf	18.04. (start) - 21.04. (peak) - 24.04. (end)	18.04. (start) - 21.04. (peak) - 24.04. (end)
Appearance of 1st cluster	26.04. (start) - 29.04. (peak) - 03.05. (end)	26.04. (start) - 29.04. (peak) - 03.05. (end)
Flowering	07.06. (start) - 12.06. (peak) - 20.06. (end)	07.06. (start) - 12.06. (peak) - 20.06. (end)
Berry pea size	14.07. (start) - 21.07. (peak) - 25.07. (end)	14.07. (start) - 21.07. (peak) - 25.07. (end)
Veraison	14.08. (start) - 21.08. (peak) - 25.08. (end)	14.08. (start) - 21.08. (peak) - 28.08. (end)
Technological maturity	25.09. (peak)	03.10. (peak)

The progression of phenophases is a variety-specific characteristic that is significantly influenced by specific climatic conditions. In the established experiment, the application of green pruning techniques, such as cluster normalization and leaf thinning in the cluster zone, did not affect the duration of the phenophases for the studied varieties, Cabernet Franc and Syrah. More significant influence was exerted by the timing and amount of precipitation, drought periods in the second half of the growing season, and the average daily temperatures of both air and soil at a depth of 30 cm.

4.4. Actual Fertility

4.4.1. Actual Fertility of Cabernet Franc

In 2021 and 2022, the percentage of developed lateral buds in the Cabernet Franc variety varied slightly, both for the canes and for the fruiting shoots. In 2023, the percentage of developed lateral buds from the canes was almost twice as high (13.51%) due to better thermal conditions and sufficient rainfall at the beginning of the growing season, while the percentage from the fruiting shoots remained the same as in previous years (10.00%). For the winter buds of the canes, the development percentage in 2022 was slightly higher compared to 2021. In 2023, the percentage of developed winter buds from the canes was similar to that of 2021.

One of the most important indicators characterizing the fertility of the vines is the actual fertility coefficient. Significant differences in this indicator were also observed over the three years. The climatic anomalies during the 2021 growing season negatively impacted the fertility coefficient values in 2022, as they coincided with the period of inflorescence formation in the winter buds. In 2021, the fertility coefficient was higher, reaching 1.63 – 1.66 along the length of the fruiting shoot, while in 2022 it reached 1.56 – 1.58. In 2023, the fertility coefficient had higher values compared to the previous two years, ranging from 1.84 – 1.87. The applied green pruning variants did not affect the fertility coefficient values of the shoots from lateral and winter buds. For the Cabernet Franc variety, the indicators such as the percentage of developed shoots, percentage of fruiting shoots, and fertility coefficient were si gnificantly influenced by climatic conditions, both from the previous year and the current growing season, which is why they showed varying values. The applied green pruning variants did not significantly affect the values of the percentage of developed buds, percentage of fruiting shoots, and fertility coefficient (Table No. 5).

Table 4. Percentage of Developed Buds for the Cabernet Franc Variety

Percentage of Developed Buds Along the Length of Fruiting Units														
2021														
variant	Cane			Fruit Shoot										
	Lat.bud	1	2	Lat.bud	1	2	3	4	5	6	7	8	9	10
V1	8,33	87,95	92,12	10,06	43,15	69,76	74,65	67,53a	63,76b	72,22	75,31	73,64	76,82a	84,89
V2	8,42	87,72	92,38	9,88	43,34	70,61	75,25	66,84b	64,84a	71,86	76,24	74,38	75,92b	85,23
V3	8,38	87,65	92,25	10,14	42,53	69,58	74,97	67,24ab	64,92a	72,34	75,73	73,82	76,91a	85,14
Sign.	0,802	0,567	0,761	0,386	0,134	0,072	0,151	0,043	0,007	0,205	0,351	0,153	0,042	0,428
2022														
variant	Cane			Fruit Shoot										
	Lat.bud	1	2	Lat.bud	1	2	3	4	5	6	7	8	9	10
V1	6,1c	93,90	95,12	7,06b	38,81	71,76	77,65	63,53	60,76	78,21	72,31	83,64	81,82	88,89
V2	7,08a	94,50	95,78	7,86a	40,33	72,58	77,65	62,89	61,14	78,56	71,81	84,29	82,12	86,11
V3	6,59b	93,72	96,23	8,04a	39,56	71,93	77,65	63,22	61,33	77,93	72,39	84,31	81,73	89,49
Sign.	0,007	0,305	0,132	0,008	0,077	0,158	1,000	0,433	0,257	0,511	0,409	0,190	0,647	0,387
2023														
variant	Cane			Fruit Shoot										
	Lat.bud	1	2	Lat.bud	1	2	3	4	5	6	7	8	9	10
V1	13,49	84,68ab	96,40	10,0b	44,10	81,00	73,00	70ab	76,00	76,60	78,95	76,47	88,89	95,00b
V2	14,33	85,22a	95,73	9,89b	44,36	80,78	73,08	69,24b	76,25	75,80	79,33	75,97	89,58	96,13a
V3	13,42	84,41b	96,36	10,62a	43,57	81,13	72,82	70,13a	75,92	76,22	79,12	76,67	88,62	95,43b
Sign.	0,207	0,010	0,372	0,020	0,196	0,656	0,731	0,050	0,563	0,150	0,468	0,204	0,116	0,020

Table 5. Fertility Coefficient for the Cabernet Franc Variety

Fertility Coefficient														
2021														
Variant	Cane			Fruit Shoot										
	Lat.bud	1	2	Lat.bud	1	2	3	4	5	6	7	8	9	10
V1	0,36	0,91	1,34	0,80	1,05	1,22	1,28	1,42	1,36	1,39	1,49	1,46	1,63	1,63
V2	0,33	0,93	1,36	0,78	1,09	1,25	1,31	1,44	1,38	1,41	1,48	1,48	1,65	1,65
V3	0,38	0,92	1,37	0,83	1,08	1,24	1,30	1,43	1,35	1,40	1,52	1,47	1,66	1,66
Sign.	0,202	0,801	0,562	0,304	0,369	0,562	0,523	0,864	0,355	0,729	0,182	0,770	0,376	0,317
2022														
Variant	Cane			Fruit Shoot										
	Lat.bud	1	2	Lat.bud	1	2	3	4	5	6	7	8	9	10
V1	0,38	0,94	1,10	0,72	1,06	1,25	1,24	1,40	1,38	1,37	1,41	1,48	1,56	1,52
V2	0,39	0,96	1,12	0,74	1,08	1,26	1,26	1,38	1,40	1,36	1,43	1,50	1,58	1,51
V3	0,38	0,95	1,13	0,73	1,09	1,27	1,26	1,41	1,39	1,37	1,42	1,51	1,56	1,50
Sign.	0,842	0,801	0,355	0,670	0,648	0,801	0,447	0,456	0,536	0,897	0,729	0,451	0,618	0,770
2023														
Variant	Cane			Fruit Shoot										
	Lat.bud	1	2	Lat.bud	1	2	3	4	5	6	7	8	9	10
V1	0,50	1,29	1,37	0,60	0,89	1,35	1,51	1,50	1,63	1,68	1,67	1,74	1,81	1,84
V2	0,51	0,98	1,39	0,62	0,91	1,36	1,52	1,52	1,66	1,69	1,69	1,76	1,82	1,87
V3	0,49	0,97	1,38	0,61	0,90	1,37	1,53	1,53	1,65	1,70	1,68	1,75	1,83	1,86
Sign.	0,536	0,435	0,614	0,692	0,729	0,770	0,729	0,355	0,204	0,781	0,536	0,614	0,630	0,422

4.4.2. Actual Fertility of Syrah

The percentage of developed lateral buds in the Syrah variety during the study period is higher compared to that of Cabernet Franc. It varied within relatively small ranges during the first two years – 2021 and 2022 – both for the canes and the fruiting shoots, respectively from 16.30 to 16.51% and from 17.48 to 17.53%, and from 18.97 to 19.24% and from 12.16 to 12.34% (Table No. 6). In 2023, the developed shoots from the lateral buds were significantly higher – from the canes from 30.87 to 31.21%, and from the fruiting shoots from 29.03 to 31.24%. For the winter buds on the canes, the development percentage was lower in 2022 compared to 2021 and 2023.

For the winter buds on the fruiting shoots, an increase in development was observed from the base to the tip, with the highest values in 2021 recorded in the last two winter buds (9th and 10th), in 2022 in the last three winter buds (8th, 9th, and 10th), and in 2023 in the 9th and 10th buds, where it reached 100% (Table No. 6). For some of the lateral and winter buds, significant differences were found between the three variants of green pruning, but for the others, the differences were not significant.

The climatic anomalies during the 2021 growing season also negatively impacted the fertility coefficient values for Syrah in 2022, as they coincided with the period of inflorescence formation in the winter buds. In 2021, the fertility coefficient was higher, reaching 1.91 – 1.94 along the length of the fruiting shoot, in the 10th winter bud (Table No. 7).

In 2022, the fertility coefficient had significantly lower values in the short fruiting units – from 0.31 to 0.34 for lateral buds, and from 1.05 to 1.08 for the 2nd winter bud. In 2023, the fertility coefficient for the canes was – lateral buds from 0.38 to 0.41, and for the 2nd winter bud from 1.05 to 1.08. For the fruiting shoots – lateral buds from 0.70 to 0.73, and for the winter buds – in the 5th bud, it reached over 1.50 and remained at this level up to the 10th winter bud. It was established that green pruning did not affect the fertility coefficient values. No significant differences were found either for the lateral or the winter buds. For the Syrah variety, the values of the actual fertility indicators were significantly influenced by climatic conditions both from the previous year and the current growing season, which is why they showed variation over the years of the study. The applied green pruning variants did not significantly affect the values of the percentage of developed buds, the percentage of fruiting shoots, or the fertility coefficient.

Table 6. Percentage of Developed Buds for the Syrah Variety

Percentage of Developed Buds Along the Length of Fruiting Units														
2021														
Variant	Cane			Fruit shoot										
	Lat.bud	1	2	Lat.bud	1	2	3	4	5	6	7	8	9	10
V1	16,30b	86,96c	92,17b	18,97c	46,55b	65,52c	77,98	82,76c	77,59c	70,69c	77,59b	77,59c	87,50c	89,46b
V2	16,44a	87,43a	92,40a	19,24a	46,86a	65,89b	79,78	83,24a	78,11a	71,34a	77,65b	77,68b	87,76b	90,35a
V3	16,51a	87,26b	92,33a	19,12b	46,78a	66,13a	79,65	83,13b	77,86b	71,16b	77,78a	77,89a	87,89a	90,18a
Sign.	0,001	0,000	0,022	0,000	0,002	0,000	0,272	0,000	0,000	0,000	0,002	0,000	0,000	0,047
2022														
Variant	Cane			Fruit shoot										
	Lat.bud	1	2	Lat.bud	1	2	3	4	5	6	7	8	9	10
V1	17,51	75,10	72,32	12,16b	55,10b	78,57b	80,61	81,25b	79,79	81,32b	80,95	83,82	86,54a	82,93
V2	17,48	75,13	73,41	12,34a	55,34a	78,68a	80,68	81,37a	79,82	81,41a	81,04	83,88	86,46b	82,92
V3	17,53	75,08	72,40	12,20b	55,05b	78,64ab	80,71	81,31ab	79,85	81,36ab	80,99	83,84	86,52a	82,98
Sign.	0,202	0,539	0,380	0,002	0,000	0,051	0,160	0,028	0,244	0,041	0,088	0,246	0,024	0,224
2023														
Variant	Cane			Fruit shoot										
	Lat.bud	1	2	Lat.bud	1	2	3	4	5	6	7	8	9	10
V1	31,10b	88,52b	95,69a	29,03	54,84b	75,27b	78,94ab	86,02b	85,56b	93,74b	91,52b	96,97b	100,00	100,00
V2	30,87c	88,58ab	95,74a	29,32	54,91ab	75,37a	78,98a	86,13a	85,63ab	93,87a	91 ,58ab	96,92ab	100,00	100,00
V3	31,21a	88,63a	95,58b	31,24	54,96a	75,32ab	78,87b	85,94c	85,68a	93,81ab	91,62a	96,86a	100,00	100,00
Sign.	0,000	0,044	0,009	0,020	0,018	0,066	0,036	0,003	0,018	0,019	0,065	0,080	x	x

Table 7. Fertility Coefficient for the Syrah Variety

Coefficient of fertility														
2021														
Variant	Cane			Fruit shoot										
	Lat.bud	1	2	Lat.bud	1	2	3	4	5	6	7	8	9	10
V1	0,77	1,23	1,57	0,81	1,48	1,55	1,67	1,67	1,69	1,76	1,82	1,76	1,84	1,91
V2	0,79	1,25	1,61	0,83	1,51	1,56	1,71	1,69	1,73	1,79	1,82	1,79	1,85	1,94
V3	0,80	1,25	1,58	0,84	1,49	1,57	1,70	1,70	1,71	1,77	1,82	1,78	1,87	1,93
Sign.	0,451	0,471	0,308	0,422	0,552	0,614	0,182	0,422	0,258	0,355	1,000	0,422	0,355	0,422
2022														
Variant	Cane			Fruit shoot										
	Lat.bud	1	2	Lat.bud	1	2	3	4	5	6	7	8	9	10
V1	0,32	0,71	1,02	0,38	0,74	1,02	1,06	1,19	1,17	1,09	1,10	1,03	1,11	1,09
V2	0,34	0,74	1,03	0,41	0,77	1,06	1,09	1,23	1,20	1,11	1,13	1,06	1,13	1,12
V3	0,31	0,73	1,05	0,40	0,75	1,03	1,08	1,20	1,18	1,12	1,11	1,05	1,14	1,11
Sign.	0,543	0,552	0,562	0,552	0,489	0,379	0,422	0,422	0,355	0,501	0,623	0,602	0,562	0,579
2023														
Variant	Cane			Fruit shoot										
	Lat.bud	1	2	Lat.bud	1	2	3	4	5	6	7	8	9	10
V1	0,38	0,66	1,05	0,70	1,04	1,17	1,36	1,39	1,55	1,56	1,43	1,59	1,52	1,56
V2	0,41	0,69	1,08	0,73	1,06	1,19	1,39	1,42	1,55	1,57	1,45	1,62	1,53	1,58
V3	0,40	0,67	1,06	0,72	1,07	1,20	1,38	1,40	1,55	1,58	1,44	1,60	1,55	1,59
Sign.	0,422	0,489	0,501	0,489	0,489	0,654	0,670	0,602	1,000	0,781	0,751	0,562	0,562	0,778

4.5. Grape Yield and Quality from the Studied Varieties

4.5.1. Grape Yield and Quality of Cabernet Franc

The comparative evaluation of the pruning variants on the yields per vine, cluster weight, and 100-berry weight in 2021 and 2022 revealed statistically significant differences between them (Tables No. 8 and 9). This trend continued in 2023, with the exception of the 100-berry weight, where no pruning influence was found at the 0.05 significance level (Table No. 10)

Presented through a one-way analysis of variance

From the results in Tables No. 8, 9, and 10, it can be concluded that during the study period, the type of pruning had a statistically significant impact on the yield per vine and cluster weight, but no significant differences were observed in the 100-berry weight

Table 8. Comparative Evaluation of the Yields for the Cabernet Franc Variety in 2021

Harvest Date	Variant	Yield per vine (g)	Cluster weight (g)	100-berry weight (g)
25.09.2021	V1	1633a	63b	97b
25.09.2021	V2	1035b	69ab	103a
25.09.2021	V3	1050b	70a	111a
	Sign.	0,000	0,082	0,034

Table 9. Comparative Evaluation of the Yields for the Cabernet Franc Variety in 2022

Harvest Date	Variant	Yield per vine (g)	Cluster weight (g)	100-berry weight (g)
11.09.2022	V1	1680a	84b	102b
11.09.2022	V2	1275b	85ab	109a
11.09.2022	V3	1335b	89a	112a
	Sign.	0,002	0,051	0,003

Table 10. Comparative Evaluation of the Yields for the Cabernet Franc Variety in 2023

Harvest Date	Variant	Yield per vine (g)	Cluster weight (g)	100-berry weight (g)
25.09.2023	V1	1963a	75b	90
25.09.2023	V2	1514b	100a	100
25.09.2023	V3	1538b	103a	98
	Sign.	0,000	0,006	0,077

4.5.2. Grape Yield and Quality of Syrah

Based on the results presented in Tables 11, 12, and 13, it can be concluded that in 2021 and 2023, the type of pruning had a statistically significant influence on both vine yield and average cluster weight. However, in 2022, pruning only significantly affected vine yield.

Table 11. Comparative Evaluation of the Yields for the Syrah Variety in 2021

Harvest Date	Variant	Yield per vine (g)	Cluster weight (g)	100-berry weight (g)
12.10.2021	V1	3074a	106b	112
12.10.2021	V2	2055c	137a	117
12.10.2021	V3	2145b	143a	124
	Sign.	0,000	0,002	0,094

Table 12. Comparative Evaluation of the Yields for the Syrah Variety in 2022

Harvest Date	Variant	Yield per vine (g)	Cluster weight (g)	100-berry weight (g)
11.09.2022	V1	2185a	104	131
11.09.2022	V2	1650c	110	128
11.09.2022	V3	1785b	119	127
	Sign.	0,000	0,140	0,766

Table 13. Comparative Evaluation of the Yields for the Syrah Variety in 2023

Harvest Date	Variant	Yield per vine (g)	Cluster weight (g)	100-berry weight (g)
03.10.2023	V1	3384a	114b	141
03.10.2023	V2	2250b	150a	144
03.10.2023	V3	2237b	149a	138
	Sign.	0,000	0,006	0,437

4.6. Phenolic Content in Grapes from the Studied Varieties

4.6.1. Phenolic Content in Cabernet Franc Grapes

The results presented in Table No. 14 show that the experimental variants of the Cabernet Franc variety have the highest anthocyanin content in the skins in 2021, and in the berries in 2023. Lower values of anthocyanins were recorded for the 2022 harvest.

Table 14. Phenolic Content in Cabernet Franc Grapes (2021–2023)

Variant	Anthocyanins (mg/100 g product)		TPC (g/100 g gallic acid/product)				NFPC (mg/100 g caffeic equivalent/product)				FFC (mg/100 g catechin equivalent/product)			
	skins	Berries	stems	seeds	skins	berries	stems	seeds	skins	berries	stems	Seeds	skins	Berries
2021														
V1	598,21 ±26,04	132,31 ±7,36	3,03 ±0,01	6,12 ±0,00	1,00 ±0,00	0,43 ±0,00	1066,25 ±25,50	1274,50 ±39,25	962,84 ±21,26	215,85 ±0,95	6968,71 ±70,70	7807,79 ±58,78	3289,35 ±54,77	851,68 ±21,60
V2	707,22 ±23,75	186,33 ±9,02	3,54 ±0,00	7,28 ±0,01	1,38 ±0,00	0,56 ±0,04	2039,98 ±10,96	2215,85 ±31,74	1676,01 ±36,33	406,65 ±1,06	9165,05 ±62,80	10142,21 ±46,71	5109,94 ±55,02	1008,71 ±60,48
V3	652,58 ±17,47	156,29 ±9,96	3,27 ±0,00	6,30 ±0,00	1,14 ±0,00	0,67 ±0,00	1166,26 ±25,50	1274,50 ±39,25	1050,97 ±44,97	280,66 ±2,30	7759,30 ±65,89	8604,59 ±48,00	4175,08 ±23,70	1047,98 ±29,66
2022														
V1	562,35 ±20,81	119,48 ±0,80	3,46 ±0,00	7,14 ±0,00	1,26 ±0,00	0,81 ±0,00	1582,21 ±3,92	1872,57 ±19,51	1357,53 ±1,92	361,86 ±0,96	6264,89 ±16,54	11640,71 ±43,64	5262,49 ±75,46	1658,60 ±11,71
V2	573,92 ±20,07	145,00 ±3,87	3,62 ±0,03	6,57 ±0,00	1,50 ±0,00	1,10 ±0,00	1814,78 ±3,34	1997,00 ±7,07	1672,06 ±15,56	413,03 ±17,52	7017,52 ±67,03	12923,35 ±76,17	5519,16 ±10,91	1726,23 ±9,48
V3	624,83 ±9,14	167,05 ±7,90	3,53 ±0,02	6,02 ±0,00	1,62 ±0,00	1,38 ±0,00	1924,74 ±3,57	2061,55 ±32,51	1444,44 ±12,19	442,88 ±0,85	6964,67 ±48,62	12146,91 ±40,61	5650,33 ±58,70	1829,80 ±16,10
2023														
V1	535,65 ±9,31	168,34 ±0,73	3,08 ±0,00	6,02 ±0,00	1,96 ±0,00	1,25 ±0,00	1278,10 ±6,72	2550,64 ±11,93	1080,48 ±8,54	482,90 ±1,30	7969,44 ±7,26	9948,53 ±13,08	3774,26 ±14,57	1163,06 ±7,62
V2	601,19 ±9,42	193,12 ±2,67	3,33 ±0,00	6,43 ±0,00	1,89 ±0,00	1,13 ±0,00	1154,97 ±9,82	2097,75 ±3,90	972,46 ±10,60	400,50 ±0,47	6603,68 ±4,66	9888,29 ±11,70	4804,86 ±11,25	1691,26 ±8,03
V3	657,58 ±5,86	211,83 ±5,23	3,57 ±0,00	6,35 ±0,00	2,21 ±0,01	1,32 ±0,00	2690,77 ±1,96	3138,00 ±11,76	1468,01 ±5,92	562,40 ±10,26	9979,48 ±9,02	12063,34 1,41	±5396,83 ±13,72	2091,88 ±6,84

For the 2021 and 2022 harvests, the clusters in the normalization variant (V2) contain the most TFC, while for the 2023 harvest, this was the case for the normalization and leaf thinning variant (V3).

Regarding NFC in the structural components of the grape, there is a trend for the content to be highest in the clusters, seeds, and berries in the normalization variant. For FFC, during the three years of the study, the highest content was found in the clusters and seeds in the normalization variant (V2) in 2021 and 2022, and in the normalization and leaf thinning variant (V3) in 2023.

4.6.2. Phenolic Content in Grapes of the Syrah Variety

The results of the phenolic content in Syrah grapes for the study period are presented in Table No. 15.

During the study period, Syrah showed better anthocyanin content in the grapes in 2021 and 2022. For the 2021 and 2023 harvests, the variant with cluster normalization and leaf thinning had the highest anthocyanin content in the skins and berries, while in 2022, the highest content was found in the variant with cluster normalization.

No similar trend was found in the accumulation of TFC in the structural components of the grapes from the studied variants of the Syrah variety. The clusters and seeds of the grapes from V3 in the 2021 harvest contained the highest amount of TFC. In the following two harvests, the clusters of grapes from V2 and the seeds from V1 were the richest in TFC. In 2021 and 2022, the skins of V3 contained the most TFC, while in 2023, this was observed in V2.

From the data on the content of NFC in the structural components of the grapes, a similar trend was found for the 2021 and 2023 harvests. The highest levels were found in the analyzed components of V3, and the lowest in the control. Regarding the established content of FFC, the results show that, similar to NFC, for the 2021 and 2023 harvests, the highest concentrations were in the structural components of V3 (except for seeds in 2023), while the lowest were in V1.

The applied green pruning operations, cluster normalization and cluster normalization with leaf thinning in the cluster zone, positively influenced the phenolic content of the grapes from the studied varieties Cabernet Franc and Syrah. Among the variants, the lowest phenolic content was recorded in the control (no green pruning).

Table 15. Phenolic Content in Syrah Grapes (2021–2023)

Variant	Anthocyanins (mg/100 g product)		TPC (g/100 g gallic acid/product)				NFPC (mg/100 g caffeic equivalent/product)				FFC (mg/100 g catechin equivalent/product)			
	Skins	Berries	stems	seeds	skins	berries	stems	seeds	skins	berries	stems	Seeds	skins	Berries
2021														
V1	654,94 ±5,86	118,15 ±1,15	3,22 ±0,02	6,23 ±0,00	1,21 ±0,00	0,67 ±0,00	1454,77 ±20,64	1704,78 ±10,92	1375,46 ±10,36	405,22 ±4,67	6213,70 ±98,12	8564,46 ±69,73	5040,81 ±73,66	1142,51 ±30,64
V2	775,43 ±26,84	158,92 ±4,02	3,37 ±0,00	6,85 ±0,00	1,44 ±0,00	0,72 ±0,00	1565,63 ±8,55	1786,36 ±8,48	1485,18 ±3,33	421,08 ±3,21	7079,19 ±96,58	11617,61 ±26,09	5533,44 ±76,75	1453,26 ±30,23
V3	950,44 ±51,40	172,60 ±6,95	4,08 ±0,00	7,00 ±0,00	1,64 ±0,02	0,82 ±0,00	2004,74 ±37,67	2204,13 ±12,81	1548,65 ±7,07	451,94 ±0,97	10273,77 ±74,38	12256,43 ±84,92	6631,80 ±45,21	2218,03 ±5,74
2022														
V1	874,48 ±19,27	174,41 ±10,56	2,88 ±0,00	7,38 ±0,00	1,35 ±0,00	0,90 ±0,00	1406,13 ±26,16	1602,63 ±10,19	1179,55 ±6,80	398,43 ±3,45	5130,33 ±97,25	12413,10 ±26,00	4012,47 ±25,87	1061,83 ±27,75
V2	927,32 ±10,76	185,78 ±1,21	3,30 ±0,00	6,33 ±0,00	1,38 ±0,00	0,78 ±0,00	1594,56 ±0,14	1775,19 ±0,00	1105,96 ±10,37	297,67 ±1,70	5564,40 ±25,98	13201,73 ±84,70	4933,43 ±96,06	1754,68 ±21,94
V3	627,00 ±16,84	170,52 ±4,31	3,10 ±0,01	5,74 ±0,00	1,50 ±0,00	0,95 ±0,01	1320,46 ±19,63	1564,07 ±3,40	997,27 ±5,25	264,55 ±1,70	5095,10 ±65,57	10423,78 ±12,37	4430,81 ±80,22	1563,60 ±4,72
2023														
V1	450,85 ±5,86	135,76 ±0,09	2,85 ±0,00	6,07 ±0,00	1,39 ±0,00	0,95 ±0,00	999,53 ±8,98	1682,56 ±5,12	898,70 ±9,91	255,85 ±1,46	3468,38 ±3,97	8176,06 ±7,50	3906,25 ±6,18	1509,66 ±2,90
V2	569,02 ±3,56	158,19 ±1,01	3,32 ±0,00	5,78 ±0,00	1,79 ±0,00	0,96 ±0,00	1343,72 ±3,92	2093,24 ±6,80	1118,81 ±11,76	359,98 ±3,54	6751,05 ±4,88	10955,05 ±7,82	4603,90 ±5,57	1796,82 ±8,30
V3	671,33 ±0,94	186,31 ±1,34	2,67 ±0,00	5,44 ±0,00	1,56 ±0,00	0,95 ±0,00	1843,06 ±6,11	2560,57 ±5,88	1443,08 ±10,68	424,40 ±1,96	7106,63 ±5,73	10300,68 ±4,57	6220,84 ±12,14	2213,52 ±2,06

The grapes from the Syrah variety have better anthocyanin content in the skins and berries compared to Cabernet Franc. For both studied varieties, the phenolic content of the structural components of the grapes (TFC, NFC, FFC) decreases in the following order: seeds > clusters > skins > berries. No overall trend was found in the phenolic content of the variants of the two varieties during the study period. For Cabernet Franc, the best phenolic content in 2021 was observed in the grapes from the cluster normalization variant, while in 2022 and 2023, the variant with cluster normalization and leaf thinning had higher values for the indicators. For Syrah, the best phenolic content in 2021 and 2023 was in the grapes from the cluster normalization and leaf thinning variant, while in 2022, the variant with cluster normalization had higher values for the indicators.

4.7. Chemical Composition and Antioxidant Activity of Grapes from the Studied Varieties

4.7.1. Chemical Composition of Cabernet Franc Grapes

The results of the chemical composition of Cabernet Franc grapes from the studied harvests are presented in Table 16. Key indicators were analyzed using standard methods commonly accepted in winemaking practice.

Table 16. Chemical Composition of Cabernet Franc Grapes (2021–2023)

Indicators / Variant	Harvest Date	Reducing Sugars, g/l	Titratable Acids, g/l	pH	GAP
2021					
V1	12/10/	225,00±0,00	6,38 ±0,00	3,10±0,01	3,52 ±0,08
V2	12/10/	225,33±2,88	6,00±0,00	3,11±0,01	3,75 ±0,06
V3	12/10/	226,33±1,15	6,13±0,23	3,12±0,01	3,69 ±0,14
2022					
V1	12/09/	238,68 ±1,53	6,60±0,04	3,45 ±0,01	3,61 ±0,03
V2	12/09/	243,33±2,31	6,42 ±0,03	3,40 ±0,03	3,76 ±0,02
V3	12/09/	241,00±1,73	6,43 ±0,03	3,42 ±0,03	3,75 ±0,02
2023					
V1	25/09/	233,67 ±1,15	6,00 ±0,08	3,32 ±0,01	3,90 ±0,03
V2	25/09/	242,33 ±2,31	5,75 ±0,05	3,38 ±0,01	4,21 ±0,02
V3	25/09/	238,00 ±3,00	6,09 ±0,06	3,36 ±0,01	3,91 ±0,02

The results indicate that, over the study period, the highest sugar accumulation in Cabernet Franc grapes was observed in the experimental variants from the 2022 harvest, while the lowest was recorded in the 2021 harvest. In all three years of the study, the control group (V1) showed the lowest reducing sugars content. For the 2022 and 2023 harvests, the highest sugar content was

observed in the V2 variant (cluster thinning), while in 2021, it was found in the V3 variant (cluster thinning and leaf thinning). The titratable acidity showed an inverse relationship with sugar accumulation in the grapes from the experimental variants, meaning that as sugar content increased, acidity decreased. However, no significant differences in titratable acidity were found between the variants across the years.

The Cabernet Franc grapes from the 2021–2023 harvests consistently showed high values for the Glucoacidimetric Index (GAP), which is indicative of a balanced chemical composition suitable for quality wine production. The 2023 harvest had the highest GAP, suggesting optimal conditions for the balance of sugar and acidity, while the 2021 harvest had the lowest GAP, indicating a less favorable balance.

4.7.2. Chemical Composition of Syrah Grapes

The chemical composition of Syrah grapes for the period 2021–2023 is presented in Table No. 17.

For Syrah, during the study period, the highest sugar content was observed in the 2022 harvest. In 2021 and 2023, the sugars in the experimental variants increased in the following order: Control (V1) < Normalization (V2) < Normalization and Leaf Thinning (V3). The amount of titratable acids changes in an inversely proportional relationship with the sugars. In all three years of the study, the highest acidity was found in the grapes from the control (V1). In terms of GAP (Grape Acid Profile), for the 2021 and 2023 harvests, the highest values were observed in the grapes after normalization and leaf thinning (V3), while in 2022, the highest values were found after cluster normalization (V2).

Table 17. Chemical Composition of Syrah grapes (2021-2023)

Indicators / Variant	Harvest Date	Reducing Sugars, g/l	itratable Acids , g/l	pH	GAP
2021					
V1	12/10/	189,33±1,53	6,45±0,21	3,08±0,01	2,93 ±0,08
V2	12/10/	202,66±1,15	5,94± 0,13	3,12±0,01	3,41 ±0,06
V3	12/10/	209,00±0,04	5,65±0,17	3,17±0,01	3,70 ±0,14
2022					
V1	11/09/	228,33±2,52	7,00±0,08	3,38 ±0,02	3,26 ±0,03
V2	11/09/	226,33±1,15	6,72±0,07	3,41 ±0,03	3,37 ±0,02
V3	11/09/	219,33±1,15	6,88±0,06	3,39 ±0,03	3,19 ±0,02
2023					
V1	03/10/	199,00±0,00	6,48±0,05	3,32 ±0,01	3,07 ±0,04
V2	03/10/	200,33±1,53	6,58±0,05	3,37 ±0,01	3,04 ±0,05
V3	03/10/	206,00±1,73	6,03±0,05	3,33 ±0,02	3,42 ±0,05

4.8. Antioxidant Activity of Grapes from the Studied Varieties

The antioxidant activity (AA) of the grape must from the experimental variants of the studied varieties is shown in Figures 7 and 8. The data reveals significantly higher AA in the must of Syrah compared to Cabernet Franc across all experimental variants during the study period.

For Cabernet Franc, the highest AA for the study period was recorded in the 2023 harvest, where the experimental variants also showed the best anthocyanin and total phenolic compounds (TPC) in the skins and berries, as well as non-flavonoid phenolic compounds (NFPC) and flavonoid phenolic compounds (FPC) in the whole berries (Figure 7, Table 14). The 2021 and 2023 harvests showed a trend where AA increased in the following order: cluster thinning and leaf thinning (V3) < cluster thinning (V2) < control (V1).

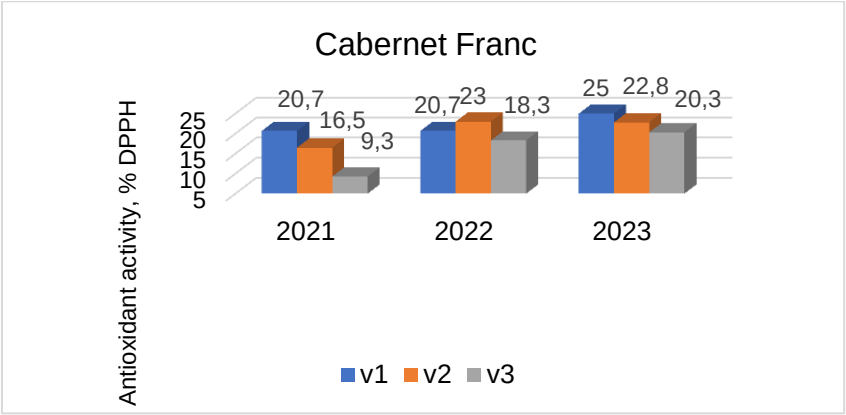


Figure 7. Antioxidant Activity of Grape Must from Cabernet Franc (2021–2023)

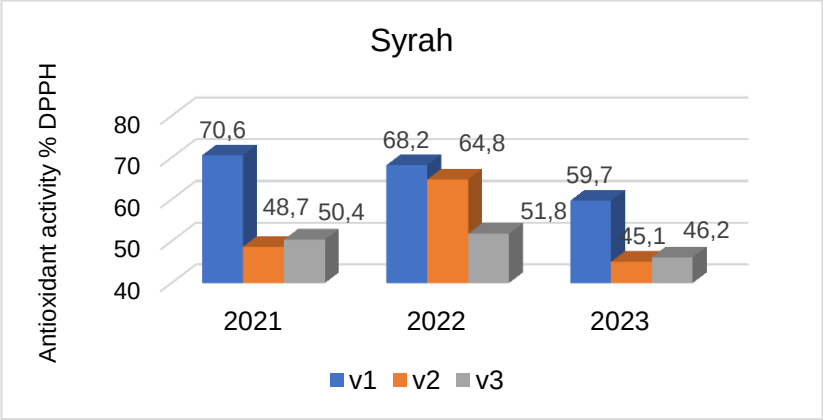


Figure 8. Antioxidant Activity of Grape Must from Syrah (2021–2023)

For Syrah, the highest AA was recorded in the control group (V1), despite the lowest levels of anthocyanin and phenolic content in the skins and berries of the grapes (Figure 8, Table 15). In 2021 and 2023, AA decreased in the following order: control > cluster thinning and leaf thinning (V3) > cluster thinning (V2). The difference in values between the pruning variants was minimal, with the most significant difference found between the control and other variants. The 2021 control (V1) had the highest AA value at 70.6%.

Syrah grapes exhibited significantly higher antioxidant activity compared to Cabernet Franc, primarily due to better phenolic content. The highest AA values were found in the controls for both varieties, with the exception of the cluster thinning variant (V2) for Cabernet Franc in 2022. For Cabernet Franc, the V3 variant (cluster thinning and leaf thinning) showed the lowest AA, while for Syrah, it was the V2 variant (cluster thinning), with the exception of 2022.

4.9. Chemical Composition and Antioxidant Activity of the Experimental Wines from the Studied Varieties

4.9.1. Chemical Composition of the Experimental Wines from Cabernet Franc

The Cabernet Franc wines from the study period (Table 18) show high alcohol content, which correlates with the sugar levels in the grapes from the respective harvests. The 2022 harvest wines had the highest alcohol concentration, followed by the 2023 wines.

The wines from the 2023 harvest had the highest total extract and non-sugar extract values, followed by the 2022 wines. The 2021 harvest wines had the lowest extract values. In the 2021 and 2023 harvests, the control (V1) wines were the least extractive, while the wines from the cluster thinning (V2) variant were the most extractive. In 2022, the cluster thinning (V2) variant had the lowest extract values, while the cluster thinning and leaf thinning (V3) variant showed the highest extract values. The wines from the 2022 harvest had the highest titratable acidity, due to the higher acidity of the grapes. For 2021 and 2022, the control (V1) wines showed the highest acidity, while in 2023, the highest acidity was found in the cluster thinning and leaf thinning (V3) variant.

The 2021 harvest wines had the highest levels of total phenolic compounds (TPC), flavonoid phenolic compounds (FPC), and non-flavonoid phenolic compounds (NFPC). In the 2022 and 2023 harvests, the quantities of these phenolic compounds were similar, with the V3 variant (cluster thinning and leaf thinning) showing the highest levels of TPC, FPC, and NFPC in 2023, and NFPC being highest in 2022.

The 2022 wines had significantly more anthocyanins compared to the other two harvests, resulting in a stronger, more intense color. In the cluster thinning and leaf thinning (V3) variant, the highest levels of anthocyanins were found in 2022 and 2023, while in 2021, the highest anthocyanin content was in the cluster thinning (V2) variant. The findings highlight a proportional relationship between the amount of anthocyanins and the intensity of color in the young wines. As anthocyanin content increased, the color intensity also increased, following similar patterns across the years and variants.

4.9.2. Chemical Composition of the Experimental Wines from Syrah

During the study period, among the samples of Syrah wine (Table №19), the highest alcohol content was recorded in wines from the 2022 harvest, followed by those from 2023. Wines from the variant with cluster thinning and leaf removal (V3) exhibited the highest alcohol concentration in 2021 and 2023, whereas for the 2022 harvest, the control variant—without green pruning—had the highest alcohol level. Wines from 2022 also had the highest total and sugar-free extract content, followed by 2023 and 2021. The control samples displayed the lowest extract levels, while the highest were observed in V3 (2021) and in the thinning variant (V2) in 2022 and 2023.

The highest titratable acidity was measured in 2022, due to the higher acidity of the grapes. In 2021, the control (V1) had the highest acidity, while in 2022 and 2023, it was the thinning variant (V2). The lowest titratable acidity was observed in wines from V3 in 2021 and 2023.

The control samples (V1) demonstrated the lowest concentrations of total, flavonoid, non-flavonoid phenolic compounds, and anthocyanins. The highest levels of these components were found in wines from V3 during 2021 and 2023, with the exception of non-flavonoid phenols. Samples from the 2022 harvest contained more total phenolic compounds, non-flavonoid phenolics, and anthocyanins compared to other harvests. That year, the thinning variant (V2) had the highest phenolic concentration, while the control displayed the most anthocyanins. The intensity of wine color was proportional to the anthocyanin content. Among all studied samples, wines from the control variant of the 2022 harvest had the highest color intensity and anthocyanin concentration.

Table 18. Chemical Composition of Experimental Wines from Cabernet franc

Indicators / Variety	Alcohol (vol.%)o	Total Extract g/l	Sugar, g/l	Non-sugar Extract, g/l	Titratable Acids, g/l	Volatile Acids,g/l	TPC, g/l gallic acid	FPC, mg/l, catechin equivalent	NPC mg/l caffeic acid equivalent	Anthocyanins mg/l	Nue T	Intensity (I) [abs. unit	pH
2021													
V1	12,50 ±0,07	28,73 ±0,25	1,55 ±0,07	27,19 ±0,29	5,62 ±0,32	0,27 ±0,00	2,05 ±0,01	3446,26 ±9,29	243,80 1,23	330,14 ±3,88	0,76 ±0,00	11,02 0,04	3,40 ±0,01
V2	12,81 ±0,05	29,20 ±0,20	1,07 ±0,12	28,13 ±0,29	5,22 ±0,08	0,25 ±0,04	2,69 ±0,01	4348,18 ±5,73	349,47 ±0,17	438,83 ±2,23	0,67 ±0,00	11,49 ±0,11	3,40 ±0,01
V3	12,97 ±0,07	29,13 ±0,06	1,19 ±0,15	27,94 ±0,13	5,39 ±0,08	0,27 ±0,00	2,49 ±0,01	4201,04 ±4,65	298,22 ±0,36	351,99 ±3,13	0,70 ±0,00	11,19 ±0,01	3,42 ±0,01
2022													
V1	13,35 ±0,04	27,23 ±0,11	1,85 ±0,10	25,38 ±0,20	6,35 ±0,05	0,42 ±0,00	1,64 ±0,06	2270,42 ±12,31	194,58 ±0,35	553,16 ±1,76	0,45 ±0,00	14,04 ±0,03	3,47 ±0,03
V2	13,74 ±0,05	26,23 ±0,11	1,73 ±0,06	24,50 ±0,08	6,21 ±0,02	0,56 ±0,03	1,77 ±0,00	2596,38 ±9,44	205,54 ±9,14	536,63 ±0,56	0,51 ±0,00	13,81 ±0,09	3,45 ±0,01
V3	13,63 ±0,02	27,47 ±0,06	1,62 ±0,09	25,85 ±0,14	6,31 ±0,02	0,48 ±0,00	1,75 ±0,01	2529,46 ±12,59	215,10 ±0,29	559,86 ±3,19	0,47 ±0,00	14,16 ±0,07	3,43 ±0,03
2023													
V1	13,31 ±0,03	30,29 ±0,01	3,06 ±0,14	27,24 ±0,14	5,57 ±0,15	0,34 ±0,03	1,57 ±0,01	2119,44 ±1,47	211,60 ±1,10	377,58 ±1,24	0,42 ±0,02	12,03 ±0,06	3,37 ±0,01
V2	13,75 ±0,05	31,40 ±0,00	2,63 ±0,13	28,77 ±0,14	5,40 ±0,3	0,32 ±0,03	1,61 ±0,00	2493,98 ±6,02	212,33 ±0,23	389,16 ±0,21	0,58 ±0,01	12,86 ±0,01	3,40 ±0,01
V3	13,51 ±0,01	31,03 ±0,06	2,98 ±0,11	28,06 ±0,05	5,86 ±0,12	0,36 ±0,00	1,75 ±0,01	2564,08 ±2,84	215,52 ±1,18	391,23 ±0,24	0,51 ±0,02	13,91 ±0,02	3,39 ±0,00

Table 19. Chemical Composition of Experimental Wines from Syrah

Indicators / Variety	Alcohol (vol.%)o	Total Extract (g/l) g/l	Sugar, g/l	Non -sugar Extract, g/l	Titratable Acids, g/l	Volatile Acids,g/l	TPC, g/l gallic acid	FPC, mg/l, catechin equivalent катехинов	NPC mg/l caffeic acid equivalent	Anthocyanins mg/l	Nue T	Intensity (I) [abs. unit	pH
2021													
V1	10,76 ±0,14	23,20 ±0,26	1,13 ±0,14	22,07 ±0,31	6,08 ±0,13	0,56 ±0,02	1,60 ±0,01	2376,71 ±9,48	229,58 ±2,18	452,80 ±1,08	0,42 ±0,00	11,93 ±0,03	3,36 ±0,02
V2	11,72 ±0,03	23,40 ±0,17	0,60 ±0,05	22,80 ±0,22	5,71 ±0,05	0,51 ±0,00	1,62 ±0,01	2509,10 ±15,75	237,06 ±1,10	474,03 ±1,50	0,44 ±0,01	12,10 ±0,05	3,42 ±0,01
V3	12,05 ±0,07	24,13 ±0,15	0,83 ±0,02	23,30 ±0,15	5,38 ±0,15	0,48 ±0,00	1,78 ±0,02	2571,00 ±1,48	265,11 ±0,17	506,33 ±46,49	0,46 ±0,00	12,96 ±0,02	3,46 ±0,01
2022													
V1	12,76 ±0,03	28,27 ±0,32	0,41 ±0,03	27,86 ±0,32	6,39 ±0,01	0,35 ±0,02	1,81 ±0,00	2504,04 ±4,19	250,81 ±0,09	567,54 ±1,19	0,42 ±0,01	14,76 ±0,02	3,47 ±0,03
V2	12,75 ±0,13	30,87 ±0,61	0,59 ±0,06	30,28 ±0,60	6,48 ±0,05	0,32 ±0,03	2,05 ±0,01	2596,45 ±1,93	291,70 ±1,75	531,10 ±4,48	0,42 ±0,00	14,20 ±0,02	3,46 ±0,03
V3	12,42 ±0,03	27,37 ±0,11	0,37 ±0,04	27,00 ±0,09	6,43 ±0,04	0,31 ±0,01	1,74 ±0,00	2385,97 ±6,18	242,02 ±0,94	491,22 ±1,84	0,44 ±0,00	13,70 ±0,01	3,57 ±0,02
2023													
V1	11,72 ±0,03	27,20 ±0,17	2,36 ±0,12	24,84 ±0,28	6,24 ±0,14	0,38 ±0,03	1,46 ±0,00	2413,16 ±3,22	261,77 ±0,56	255,47 ±0,31	0,69 ±0,00	10,13 ±0,03	3,35 ±0,03
V2	12,11 ±0,01	28,47 ±0,32	2,33 ±0,22	26,32 ±0,19	6,41 ±0,14	0,42 ±0,00	1,48 ±0,01	2356,72 ±9,70	262,00 ±3,60	275,56 ±0,06	0,80 ±0,00	10,61 ±0,27	3,32 ±0,01
V3	12,34 ±0,01	28,27 ±0,23	2,28 ±0,20	26,00 ±0,19	5,84 ±0,05	0,40 ±0,03	1,85 ±0,04	2626,72 ±0,82	260,94 ±0,17	292,56 ±0,67	0,58 ±0,01	11,24 ±0,00	3,36 ±0,01

4.10. Antioxidant Activity of the Experimental Wines from the Studied Varieties

The results show that despite differences in the antioxidant activity (AA) of the grape must from the studied varieties, the differences in the resulting wines are significantly smaller. This is due to their similar content of phenolic compounds and anthocyanins (Table No. 18, Table No. 19).

For the Cabernet Franc samples, higher AA was recorded in 2021 (85.2–86.2%) and 2023 (84.8–89.3%) (Figure 9). In 2022, the samples showed the lowest AA (80.8–81.6%), despite having the highest anthocyanin concentration across the three years. Among the experimental variants, the wines with the highest antioxidant activity in 2021 and 2023 were those produced following cluster normalization and leaf thinning, with AA of 86.2% and 89.3%, respectively.

For Syrah, the highest AA was observed in the samples from the 2021 harvest (88.7–90.1%), followed by 2023 (86.1–87.1%) (Figure 10). Despite the higher content of phenolic compounds (TFC, FFC, NFC) and anthocyanins (Table No. 19) compared to other years, the wines from the 2022 harvest displayed the lowest antioxidant activity (83.4–84.7%). In 2022, the sample with the highest AA (84.7%) was from the variant with cluster normalization and leaf thinning, even though it contained the lowest levels of phenolic substances and anthocyanins.

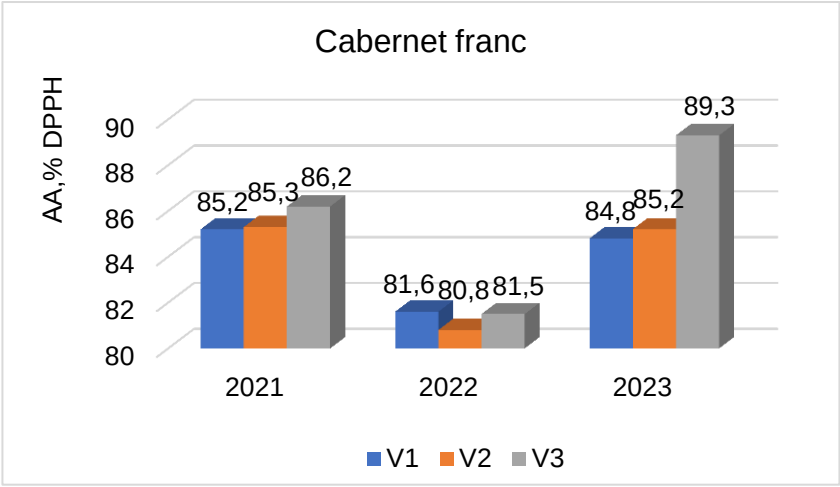


Figure 9. Antioxidant Activity of Experimental Wines from Cabernet Franc (2021–2023)

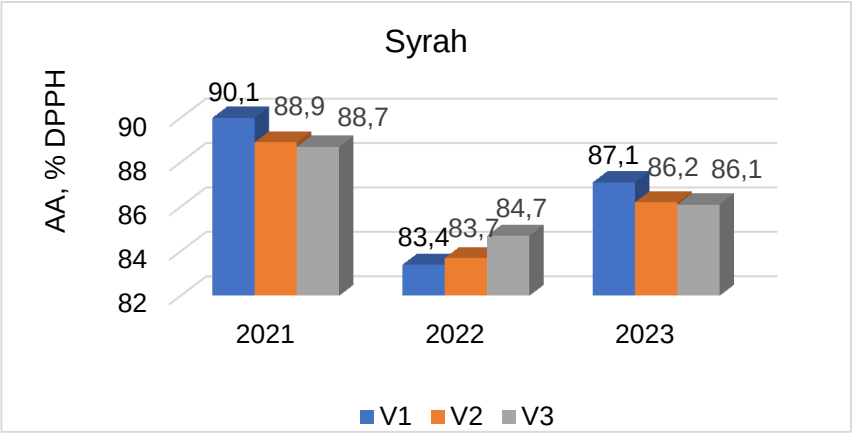


Figure 10. Antioxidant Activity of Experimental Wines from Syrah (2021–2023)

The operations of cluster normalization and cluster normalization with leaf thinning lead to an increase in the content of phenolics and anthocyanins in the resulting wines. The lowest concentrations were recorded in the controls for both varieties. Among the Cabernet Franc wines, the highest phenolic and anthocyanin content was found in the sample with cluster normalization (2021) and in the sample with cluster normalization and leaf thinning (2023). For the Syrah samples, higher levels of TPC (total phenolic content), FFC (flavonoid phenolic compounds), NFPC (non-flavonoid phenolic compounds), and anthocyanins were recorded in the variant with cluster normalization and leaf thinning (2021 and 2023) and in the variant with cluster normalization (2022).

The applied pruning operations did not significantly affect the antioxidant activity (AA) of the resulting experimental wines. For both varieties, the lowest activity was observed in the samples from the 2022 harvest. Wines from the 2021 and 2023 harvests exhibited higher AA, with the highest activity in Cabernet Franc being in the cluster normalization and leaf thinning variant, while for Syrah, it was in the control variant.

4.11. Organoleptic Characteristics of Experimental Red Wines from the Studied Varieties

The tasting evaluations with ranks from the organoleptic analysis of the young experimental Cabernet Franc wines are presented in Table No. 20, while the sensory characteristics are illustrated in Figure 16, Figure 17, and Figure 18.

Organoleptically, the three wine samples were very similar, with minor differences between them. The sample from the cluster thinning and leaf thinning

(V3) variant was rated the highest (80 points). This wine had a clean, intense aroma with predominant fruit notes and subtle vegetal nuances. On the palate, the wine was relatively balanced, with dominant acidity, and a soft aftertaste (Figure 11).

The tasting evaluations of Cabernet Franc wines from the 2022 vintage ranged between 80.0 and 84.0 points. These samples exhibited intense aromas and a rounded taste. The highest-rated sample was the variant with cluster thinning, followed by the control (Table № 20).

For the 2023 vintage, the control sample stood out aromatically, while the wine from the variant with cluster thinning and leaf thinning had distinct taste differences. The nighest-rated sample (83 points) was the variant with cluster and leaf thinning. This wine was characterized by a bright, deep ruby color, a clean and intense aroma with notes of dried fruits and spices (Figure 13).

Table 20. Tasting Scores and Ranks of Experimental Red Wines from Cabernet Franc and Syrah (2021–2023)

Variant	V1		V2		V3	
Variety	Score	Rank	Score	Rank	Score	Rank
	2021					
Cabernet franc	78	III	79	II	80	I
Syrah	79	III	81	II	83	I
	2022					
Cabernet franc	82	II	84	I	80	III
Syrah	80	II	83	I	79	III
	2023					
Cabernet franc	80	III	80	III	83	I
Syrah	78	III	80	II	81	I

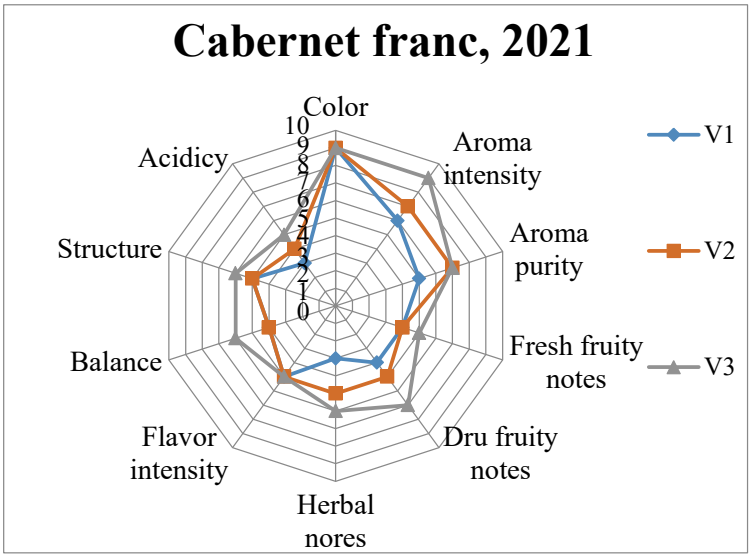


Figure 11. Sensory Profile of Experimental Wines from Cabernet Franc, Vintage 2021

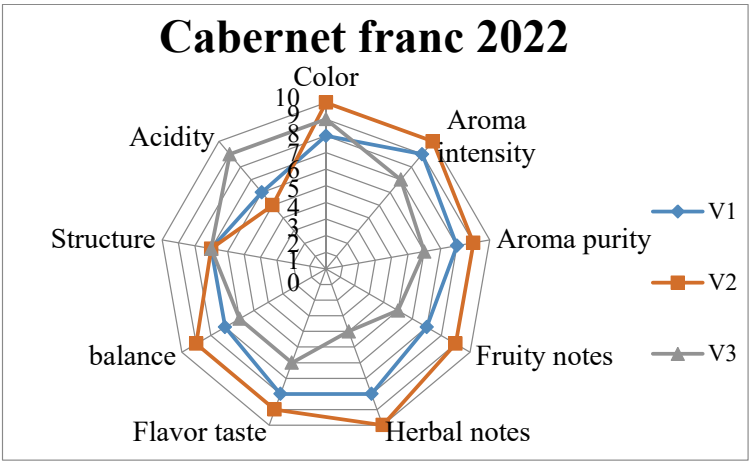


Figure 12. Sensory Profile of Experimental Wines from Cabernet Franc, Vintage 2022

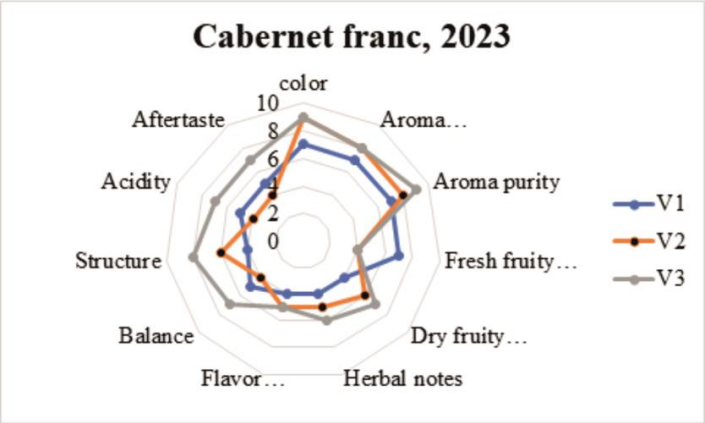


Figure 13. Sensory Profile of Experimental Wines from Cabernet Franc, Vintage 2023

The results of the tasting evaluations with ranks of the young experimental Syrah wines are presented in Table No. 20, while the sensory characteristics are illustrated in Figure 14, Figure 15, and Figure 16.

The average scores for the 2021 vintage wines range from 79.0 to 83.0 points. The highest-rated wine was the one made after cluster normalization and leaf thinning (83.0 points). This wine had a deep, sparkling ruby color, with a clean and intense aroma featuring dried fruit and vegetal notes. On the palate, the wine was well-balanced, with a full and rounded taste, accompanied by a soft aftertaste (Figure 14).

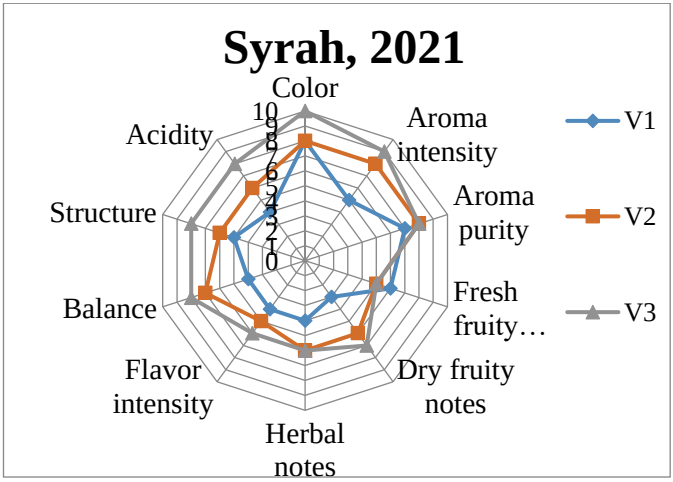


Figure 14. Sensory Profile of Experimental Wines from Syrah, Vintage 2021

The Syrah wines from the 2022 vintage have a similar sensory profile, but there are noticeable differences in both aroma and taste. The varietal character is present in the aroma of all three samples, but it is strongest and most typical in the variant with cluster normalization, which received the highest rating (83 points). This wine is dominated by ripe forest fruit nuances. In the wine from the cluster normalization and leaf thinning variant, the fruity character is more subtle, while in the control, it is cleaner and more fruit-forward, with vegetal notes (Figure 15).

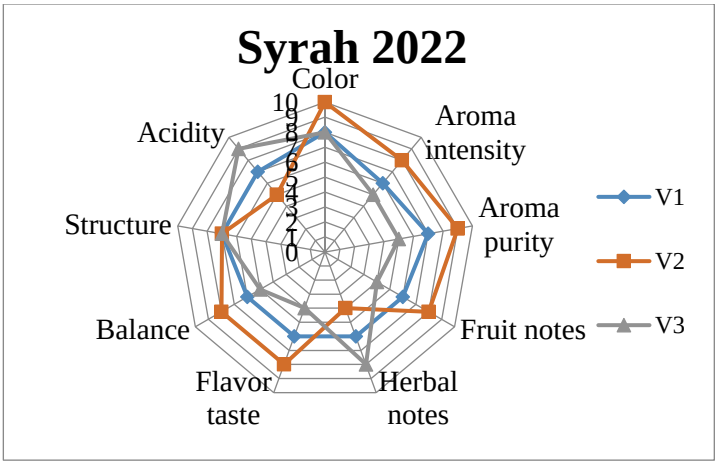


Figure 15. Sensory Profile of Experimental Wines from Syrah, Vintage 2022

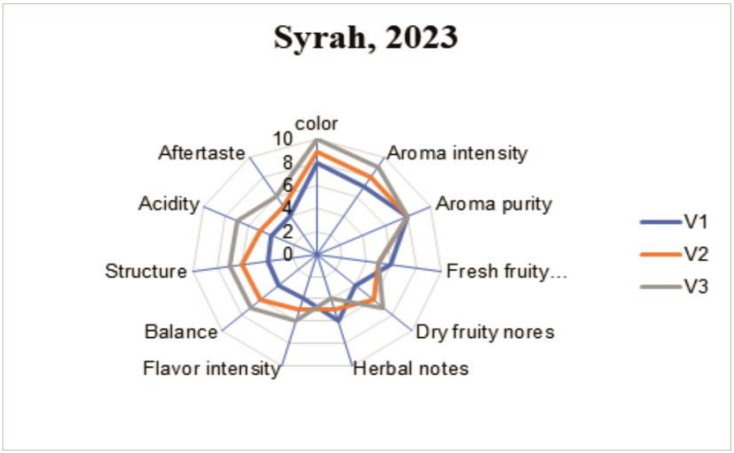


Figure 16. Sensory Profile of Experimental Wines from Syrah, Vintage 2023

The average tasting scores for the samples from the 2023 vintage range from 78.0 to 81.0 points. The highest-rated sample (81.0 points) is from the cluster normalization and leaf thinning variant. The wine has a deep and sparkling ruby color, with a clean and intense aroma featuring fresh fruit notes. On the palate, the wine is well-balanced, relatively well-structured, with dominant acidity in the finish (Figure 16).

5. SUMMARY CONCLUSIONS

Based on the research conducted from 2021 to 2023 on the impact of green pruning operations, including cluster and leaf thinning, on the quantity and quality of grapes and wine from the Cabernet Franc and Syrah varieties in the Stara Zagora region, the following conclusions were drawn:

1.The average values of climatic factors during the vegetative period varied across the years, affecting physiological processes, the onset of specific phenophases in vine development, and the duration between them. These variations influenced fertility, yield, and grape quality in the studied varieties, Cabernet Franc and Syrah.

1.1. The percentage of developed angular buds in Syrah was nearly twice as high as that in Cabernet Franc. For winter buds, the differences were much smaller, with values increasing from the base toward the apex of the fruiting canes.

1.2. The percentage of sprouted shoots, the proportion of fruit-bearing shoots, and the fertility coefficient were more significantly influenced by climatic conditions during both the previous and current vegetation periods than by the green pruning treatments studied.

1.3. The highest yields during the study were observed in the control (no green pruning). In the other two treatment variants, the yields decreased significantly.

1.4. The average weight of one cluster and 100 berries was the smallest in the control and increased in variants involving cluster and leaf thinning. No significant differences were observed in cluster and berry structural parameters among the variants.

2. The Applied Green Pruning Practices Enhance Phenolic Content and Sugar Accumulation in Grapes of the Studied Varieties:

2.1. The phenolic content in the structural elements of the grape—total phenolic compounds (TPC), non-flavonoid phenolic compounds (NFPC), flavonoid phenolic compounds (FPC), and anthocyanins—increased in both varieties in the following order: whole berries < skins < stems < seeds. The control (no green pruning) showed the lowest phenolic content. There was no consistent trend in phenolic content among the different pruning variants for both varieties.

2.2. The highest sugar accumulation for both varieties was recorded in 2022, attributed to favorable weather conditions during the grape ripening period. The control variants for both varieties had the lowest sugar concentration and the highest titratable acidity. Sugar accumulation increased across variants in the

following order: no green pruning < cluster thinning < cluster thinning and leaf thinning.

3. The Applied Green Pruning Practices Positively Influence Mainly the Chemical Composition and Organoleptic Characteristics of the Experimental Wines from Cabernet Franc and Syrah, and to a Lesser Extent Their Antioxidant Activity.

3.1. Variants with applied pruning showed higher levels of alcohol, non-sugar extract, phenolic compounds, and anthocyanins compared to the control variants without green pruning.

3.2. The applied green pruning practices positively influenced the sensory profile of the experimental wines. Organoleptic analysis rated the wines from the variants with cluster thinning and cluster thinning combined with leaf thinning higher than the control samples.

3.3. The implementation of green pruning operations, such as cluster thinning and leaf thinning, can positively impact the quality of grapes and wine from Cabernet Franc and Syrah varieties in years with climatic conditions close to typical and optimal for the temperate continental climate of the Stara Zagora microregion. However, in years with minimal rainfall and high air and soil temperatures, these practices did not lead to improvements in the technological properties of the grapes or the oenological characteristics of the wine.

6. CONTRIBUTIONS

6.1. Scientific Contributions:

6.1.1. For the first time, an assessment was conducted in Bulgaria on the impact of green pruning operations (cluster thinning and leaf thinning in the cluster zone) on the fertility coefficient, yield, and quality of grapes and wine from the Cabernet Franc and Syrah varieties in the Stara Zagora region.

6.1.2. Agro-biological traits (phenology, actual fertility, and yield) of Cabernet Franc and Syrah, under green pruning treatments (cluster thinning and cluster thinning + leaf thinning), complement the ampelographic profile of these varieties.

6.1.3. The positive influence of green pruning operations on phenolic content, chemical composition of grapes and wine, and organoleptic properties of red wines from Cabernet Franc and Syrah varieties in the Stara Zagora region was established and substantiated.

6.1.4.The efficacy of yield regulation and leaf thinning pruning methods for Cabernet Franc and Syrah was scientifically substantiated under climatic conditions typical for the Stara Zagora region.

6.2. Scientific-Applied Contributions:

6.2.1. Environmental and climatic conditions suitable for the effective application of green pruning practices in Cabernet Franc and Syrah cultivation in the Stara Zagora region were identified.

6.2.2. Green pruning during the "pea-sized berry" and "veraison" phases had a limited impact on bud sprouting percentage, fruiting shoot percentage, and fertility coefficient in the studied varieties.

6.2.3. Green pruning operations had the most significant positive effect on extractive and phenolic content in the red wines of Cabernet Franc and Syrah, with a lesser influence on antioxidant activity.

6.3. Practical Contributions:

6.3.1. The study scientifically justifies the effective and targeted application of cluster and leaf thinning in Cabernet Franc and Syrah varieties in the Stara Zagora microregion.

6.3.2. A framework was established for achieving different winter bud loads during dormant pruning, to optimize yield and enhance grape and wine quality.

6.3.3. The implemented green pruning practices enhance sugar accumulation in grapes and the technological properties of resulting red wines.

List of Publications Related to the Dissertation of PhD Student Ferihan Ademova Emurlova

1. Emurlova F., A. Ivanov. 2023. "Effect of green pruning on the fruitfulness of winter buds, quantity and quality of yield in Cabernet Franc cultivar." Agricultural Science and Technology, 15(3), 61-67.

2. Emurlova F., T. Yoncheva. 2023. "Impact of summer green pruning on the phenolic content of grapes from Cabernet Franc cultivar." Bulgarian Journal of Agricultural Science, 29(4), 703–708.