Yuzuncu Yil University
Journal of Agricultural Sciences
(Yüzüncü Yıl Üniversitesi Tarım Bilimleri Dergisi)
https://dergipark.org.tr/en/pub/yyutbd
ISSN: 1308-7576
e-ISSN: 1308-7584

Research Article

Effects of Leaf Removal at Different Phenological Stages on Yield, Quality, and Growth of Karaerik Grapevines Trained in the Baran System

Tevhit GEÇİM*[1], Abdurrahim BOZKURT[2], Nalan Nazan KALKAN[3]

[1,2,3]Horticultural Research Institute Directorate, Erzincan, Türkiye

[1]https://orcid.org/0000-0003-2406-9929, [2]https://orcid.org/0000-0001-7315-202X, [3]https://orcid.org/0000-0002-9204-7281

*Corresponding author e-mail: tevhit.gecim@tarimorman.gov.tr

Article Info
Received: 12.01.2026
Accepted: 27.04.2026
Online published: 08.06.2026
DOI: 10.29133/yyutbd.1861975

Keywords
Erzincan,
Leaf removal,
Phenological stage,
Winter buds,
Yield components

Abstract: This study evaluated the effects of basal leaf removal at different phenological stages on yield, fruit quality, phytochemical composition, and winter bud physiology of the Karaerik grape cultivar under the Baran training system. Basal leaf removal was applied by removing five basal leaves at full flowering, pea-size berry, and veraison, and compared with an untreated control. The experiment was carried out over two consecutive growing seasons (2023 and 2024) using a randomized block design. The timing of leaf removal significantly influenced yield components and berry characteristics. Control vines produced the highest fresh grape yield (8.98 kg vine^{-1}), whereas vines defoliated at full flowering showed a moderate yield reduction (7.43 kg vine^{-1}). Despite this reduction, full flowering treatment substantially decreased cluster compactness (OIV-204: 4.58) compared with the control (7.58) and reduced the incidence of cracked and decayed berries by approximately 80%. Early defoliation also promoted berry growth, resulting in the highest single berry weight (5.91 g). Technological maturity parameters were positively affected by early leaf removal. The full flowering treatment resulted in the highest total soluble solids (19.07%), maturity index (27.42), and total phenolic content (504.57 mg L^{-1}). Moreover, leaf removal at full flowering and at pea-size berry significantly increased soluble carbohydrate concentrations in winter buds and reduced primary bud cold injury and necrosis. Overall, basal leaf removal at full flowering emerged as an effective vineyard management strategy to improve fruit quality, enhance phytochemical accumulation, and increase winter bud cold tolerance in Karaerik grapes cultivated under the Baran training system.

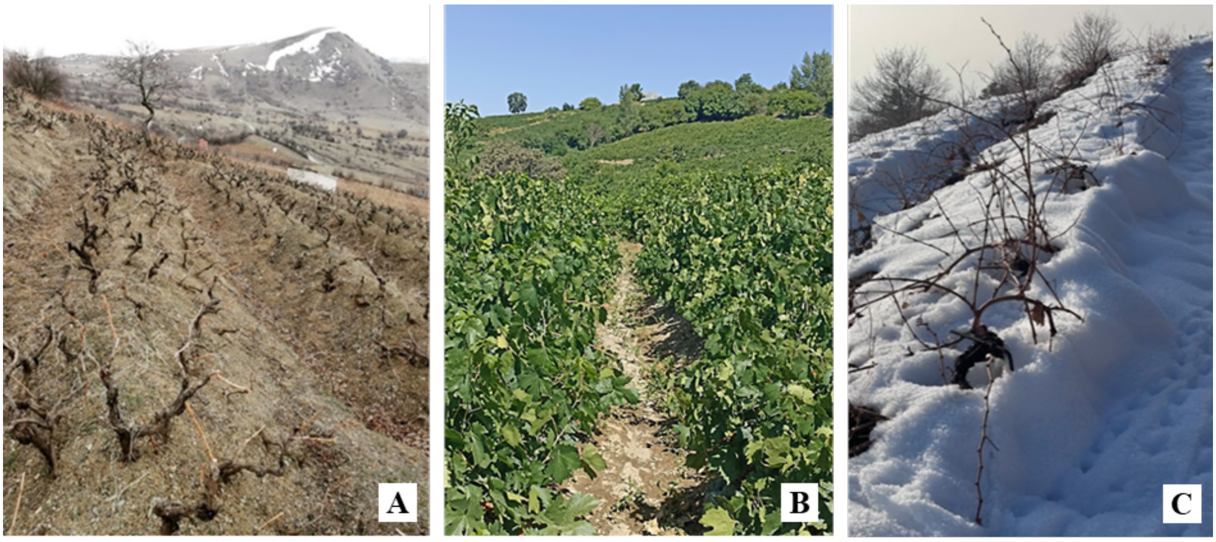
To Cite: Geçim, T, Bozkurt, A, Kalkan, N N, 2026. Effects of Leaf Removal at Different Phenological Stages on Yield, Quality, and Growth of Karaerik Grapevines Trained in the Baran System. *Yuzuncu Yil University Journal of Agricultural Sciences*, (1): 1861975.
DOI: https://doi.org/10.29133/yyutbd.1861975

1. Introduction

Türkiye possesses an exceptionally rich grapevine genetic resource owing to its pronounced topographical heterogeneity, the simultaneous presence of diverse climatic zones, and intensive cultural interactions sustained throughout history. Beyond the historical and cultural significance of viticulture, this genetic diversity holds strategic importance for agricultural sustainability, resilience to climate change, and the advancement of grapevine breeding programs. However, in recent decades, local grapevine varieties and their associated traditional cultivation systems have been subjected to increasing threats. Changes in agricultural production patterns, the widespread adoption of standardized cultivars, rural depopulation, the abandonment of traditional practices, natural disasters, dam construction projects, and the conversion of agricultural land to non-agricultural uses have collectively accelerated genetic erosion and contributed to the irreversible loss of valuable biological and cultural heritage (Sabır et al., 2009; Uyak, 2010; Doğan et al., 2017).

Within this context, the conservation of local grapevine genotypes and the traditional viticultural practices associated with them is recognized as a fundamental pillar of sustainable viticulture (Geçim et al., 2025; Cantürk, 2026). One notable example is the "Baran" training system, which has a history of approximately two centuries and is a widely used cultivation method in the Erzincan region. This system was developed in response to harsh continental climatic conditions and the specific ecological requirements of the Karaerik grape cultivar. In the Baran training system, vine trunks are positioned at ground level or within shallow trenches, allowing the insulating effect of snow cover to be utilized during winter while benefiting from the moderating influence of soil temperature on vegetative growth during the summer (Figure 1) (Kalkan et al., 2024).

Due to these structural characteristics, the Baran training system facilitates the production of high-quality grapes, minimizes wind-related mechanical damage, and enables natural terracing on sloped landscapes. Nevertheless, the system also presents several limitations, including high labor demands, incompatibility with modern mechanization, and increased susceptibility to fungal diseases resulting from the low canopy position. Although it competes unfavorably with contemporary trellis systems in terms of yield potential and labor efficiency, the Baran training system continues to represent a sustainable viticultural model. It plays a crucial role in preserving regional grapevine genetic resources, demonstrates strong adaptation to specific microclimatic conditions, and maintains cultural continuity within the viticultural heritage of the region (Karadoğan et al., 2022).



Figures 1. Baran training system at different season: A) Fall, B) Summer, C) Winter.

In the Karaerik grape cultivar cultivated under the Baran training system, several agronomic challenges may arise during the production process. The cultivar's high yield potential, vigorous vegetative growth, and compact cluster architecture can contribute to increased yield losses, particularly during the harvest period. In viticulture, yield and fruit quality are among the primary determinants of growers' economic returns and are largely governed by the genetic characteristics of the cultivar. However, it is well established that environmental conditions and vineyard management practices exert a decisive influence on yield components and fruit composition (Keller, 2020).

Physiological canopy management practices, including leaf removal, lateral shoot removal, shoot tipping, and topping, are commonly employed to regulate canopy density. These interventions enhance air circulation within the canopy and improve light penetration to the fruiting zone, thereby increasing photosynthetic efficiency and promoting more uniform and balanced fruit ripening (Çelik et al., 1998; Poni et al., 2006; Matthews, 2016; Korkutal et al., 2018; Türk and Kose, 2024).

Leaf removal is a practice based on the selective removal of basal leaves surrounding the cluster zone at specific phenological stages. This practice increases air movement around the clusters, improves the utilization of solar radiation, and allows the regulation of berry temperature (Poni et al., 2017). Increased exposure of clusters to solar radiation may alter the microenvironment surrounding the berries and affect their physiological and biochemical responses. Although excessive UV-B radiation can cause adverse effects in plants, such as DNA damage, protein degradation, and impairments in photosynthetic functions, moderate exposure may stimulate protective defense mechanisms associated with the synthesis and accumulation of secondary metabolites (Martínez-Lüscher et al., 2013; Gökçen et al., 2026). Therefore, leaf removal not only contributes to improving cluster aeration and disease management but may also enhance certain quality-related compounds in grape berries. This practice is widely used, particularly in cool and humid climatic conditions, to reduce the incidence of fungal diseases. In addition, leaf removal improves many marketing-related characteristics of table grapes, such as berry size, coloration, and overall visual appearance (English et al., 1989; Smart et al., 1990). Previous studies have reported that leaf removal positively affects berry skin development, sugar accumulation, and color uniformity, thereby increasing the commercial value of table grape cultivars (Hunter et al., 1991; Staff et al., 1997; Poni et al., 2006). Therefore, leaf removal is considered a fundamental cultural practice aimed at enhancing quality and ensuring product safety in table grape production systems (Sivilotti et al., 2016).

Numerous studies conducted on wine grape cultivars have demonstrated that cluster-zone leaf removal suppresses the development of fungal diseases by improving canopy aeration and promotes the accumulation of color compounds, aroma precursors, and phenolic substances in berries exposed to sunlight (Poni et al., 2009; Tardaguila et al., 2010; Lee and Skinkis, 2013). In contrast, scientific evidence regarding the effects of leaf removal on quality traits in table grape cultivars such as Karaerik—characterized by compact clusters, large berries, and thin skins—remains limited. Given the morphological and physiological differences between wine and table grape cultivars, findings derived from wine grapes may not always be directly applicable to table grape production.

In table grape cultivars, excessively compact cluster structures may lead to quality deterioration during both postharvest handling and fresh consumption. Consequently, leaf removal strategies aimed at achieving looser and more uniform cluster structures have gained increasing attention. Variations in the leaf-to-fruit ratio influence the balance of photosynthate allocation within the vine and may result in significant changes in yield, cluster architecture, berry growth, soluble solids accumulation, and carbohydrate reserves (Koblet et al., 1994; Bennett et al., 2005; Poni et al., 2006; Intrieri et al., 2008; Zenoni et al., 2017). However, excessive or improperly timed leaf removal may also induce adverse effects, including reduced fruit set, yield losses, smaller berry size, and delayed ripening (Kliewer and Bledsoe, 1986; Chorti et al., 2010). Therefore, the timing, intensity, and phenological suitability of leaf removal practices are critical factors determining their effectiveness.

The effects of leaf removal are not limited to yield and cluster morphology but may also induce significant changes in grape biochemical composition. Phenolic compounds, in particular, play a key role in the development of sensory attributes such as color, flavor, and aroma (Bal et al., 2011; Tahmaz et al., 2022). By increasing light exposure in the cluster zone, leaf removal stimulates the synthesis of phenolic compounds, thereby enhancing organoleptic quality. This improvement increases market appeal for fresh consumption and contributes to greater technological value in grape production.

The present study aimed to evaluate the effects of removing the first five basal leaves at full flowering, pea-size berry, and veraison stages on yield and quality parameters, as well as on bud physiology and cold hardiness, in the Karaerik grape cultivar grown under the Baran training system. The results are expected to contribute to the optimization of sustainable viticultural practices and to the conservation and effective utilization of local grapevine genetic resources.

2. Materials and Methods

2.1. Material

This study was conducted in a vineyard located at 39°39′52.02″N and 39°44′20.08″E, at an altitude of 1207 m above sea level. All vines were grown on their own roots and managed under uniform cultural and viticultural practices. The soil structure of the experimental vineyard was characterized as sandy-loam, slightly alkaline, and moderately calcareous, and the vineyard was irrigated using a surface (flood) irrigation method. The vines used in the experiment were at full production stage and trained according to the Baran system, a traditional low-head training system. This system is characterized by positioning the vines close to the ground on ridge-shaped soil structures formed along the row. Shoots are pruned to short spurs (3–4 buds), and are progressively oriented over the ridge structure to regulate vegetative growth and improve the microclimatic conditions within the canopy. Planting distances were arranged as 3.0 m between rows and 2.0 m within rows. During winter pruning, 24 buds were retained per vine. Fourteen days after bud break, the numbers of shoots and inflorescences were determined and standardized to 20 per vine.

Meteorological data for the 2023–2024 period used in this study were obtained from a meteorological station (Field Climate) located approximately 300 m from the experimental site. Within the scope of the study, monthly average, maximum, and minimum temperatures (°C), average relative humidity (%), and total monthly precipitation (mm) were evaluated.

2.2. Method

2.2.1. Cultural practices, leaf removal treatments and phenological observations

Throughout the growing season, shoot thinning, water sprout removal, and shoot tipping were applied uniformly to all treatments, including the control, in order to minimize potential variability arising from canopy management practices and to ensure treatment comparability.

Phenological observations and leaf removal treatments were carried out according to the phenological scale defined by the International Organisation of Vine and Wine (2009), and, in order to ensure consistency in phenological timing, the timing of leaf removal applications was cross-referenced with the developmental stage definitions reported by Lorenz et al. (1995). Accordingly, the first five basal leaves of each shoot were manually removed at the stages of full flowering (FF), pea size (PS), and véraison (V) (Figure 2).

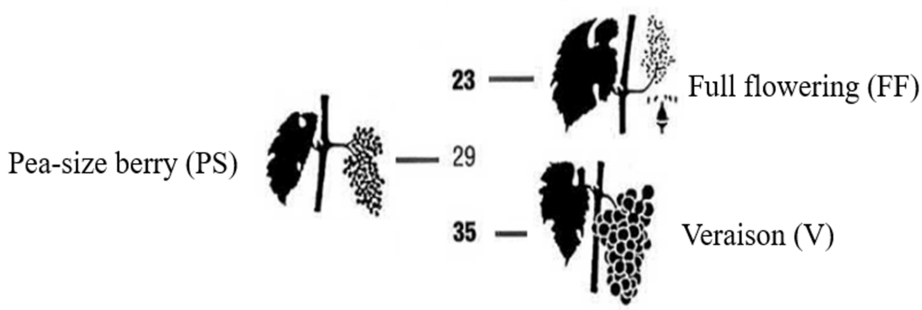


Figure 2. Leaf removal periods according to the phenological scale stages (Lorenz et al., 1995).

2.2.2. Yield and quality traits

Marketable grape yield was determined as kilograms per vine (kg vine^{-1}). Cluster characteristics, including cluster weight (g) and cluster dimensions (width and length, cm), were measured. Cluster compactness was assessed according to the criteria of the International Organisation of Vine and Wine (OIV, 2009) using the OIV 204 scale.

For berry traits, the number of berries per cluster (berries cluster^{-1}), single berry weight (g), and berry dimensions (width and length, mm) were recorded. In addition, the incidence of cracked and decayed berries was calculated as counts per 100 berries.

2.2.3. Technological maturity and phytochemical–biochemical analyses

At harvest, total soluble solids (TSS, %) were measured in grape berries using a refractometric method. Titratable acidity (TA, %) and pH were determined in must samples, and the maturity index (TSS TA^{-1}) was calculated from these parameters.

In addition to phytochemical and biochemical analyses were conducted to evaluate berry composition in greater detail. One day prior to harvest, 0.5 kg of grape berries was collected from each replication. Total phenolic content was determined using the method of Singleton and Rossi (1965) and expressed as gallic acid equivalents (GAE, mg L^{-1}). Total flavonoid content was analyzed according to the method of Zhishen et al. (1999) and expressed as catechin equivalents (CE, mg g^{-1}).

2.2.4. Assessment of winter buds

Soluble carbohydrate content (mg g^{-1}): The first four fruitful winter buds from one-year-old canes were collected from each vine in December to assess carbohydrate accumulation. Soluble carbohydrate content was determined using a modified anthrone method (Yemm and Wills, 1954).

Primary bud necrosis (PBN, %): After leaf fall, the first four fruitful winter buds from one-year-old canes were collected from each vine and examined microscopically. In each replication, a total of 40 primary buds (10 canes × 4 buds) were evaluated, and buds were longitudinally dissected under a stereomicroscope; primary buds showing browning or blackening of the central meristematic tissues were classified as necrotic. The incidence of necrosis in primary buds was calculated and expressed as a percentage (Zabadal et al., 2007; Keller, 2015).

Primary bud necrosis = (Number of necrotic primary buds / Total number of examined primary buds) × 100.

Primary bud cold injury (%): To evaluate the freezing tolerance of winter buds under different leaf removal treatments, ten canes bearing four buds each were collected per vine approximately 15–20 days prior to spring pruning. The samples were transported to the laboratory, and freezing injury was assessed microscopically. A total of 40 primary buds per replication were evaluated, and buds were dissected longitudinally; buds exhibiting browning or tissue collapse in the primary bud primordia after exposure to low temperatures were considered as cold-injured. Cold hardiness of the buds was calculated and expressed as a percentage (Mills et al., 2006; Zabadal et al., 2007; Keller, 2015).

Primary bud cold injury = (Number of cold-injured primary buds / Total number of examined primary buds) × 100.

2.3. Statistical analysis

Statistical analyses were performed using JMP Pro 17.0.0 (JMP Statistical Discovery LLC, United Kingdom). The experiment was designed according to a factorial arrangement within a randomized complete block design, with four replications, each replication consisting of three vines. The data were analyzed using a two-way ANOVA including year, leaf removal treatments, and their interaction (Year × Treatment). Blocks were included in the statistical model; however, block effects were not statistically significant and therefore are not presented in the tables. Mean comparisons for parametric data were performed using the LSD (least significant difference) test. Prior to ANOVA, assumptions of normality and homogeneity of variances were evaluated using the Shapiro–Wilk and Levene tests, respectively. For variables that did not meet the assumption of normal distribution (cluster compactness degree), non-parametric analyses were conducted using the Kruskal–Wallis test. When significant differences were detected, pairwise comparisons were performed using the Steel–Dwass multiple comparison test. Since the Kruskal–Wallis test does not support factorial interaction analysis, non-parametric evaluations were conducted separately within each year. Grouping of treatments was based on Steel–Dwass results, and treatments sharing the same letter were considered not significantly different. Statistical significance was evaluated at the $p<0.05$ and $p<0.01$ levels.

3. Results and Discussion

Within the scope of this study, leaf removal applications were carried out at different phenological stages in the Karaerik grape cultivar. The dates on which leaf removal applications were performed for each year are presented in Table 1. The effects of leaf removal practices conducted at different phenological stages on the phenological development of the vine are summarized below.

Table 1. Dates of leaf removal in 2023 and 2024 years

Year \ Treatment	Full flowering (FF)	Pea-size berry (PS)	Veraison (V)
2023	20 June	04 July	15 August
2024	12 June	26 June	15 August

3.1. Effects of leaf removal on phenological stages and its comparison with some meteorological data

The effects of different leaf removal practices on the phenological development of Karaerik grapevines trained under the Baran system were evaluated over two growing seasons. The results indicated that, in both 2023 and 2024, the examined phenological stages - bud break, full flowering, veraison, and harvest - exhibited only minor and biologically insignificant differences among treatments.

When the meteorological conditions of the two experimental years are considered (Table 2), phenological development appears to be primarily driven by interannual climatic variability rather than leaf removal practices. In particular, the slightly earlier bud break observed in 2024 can be associated with higher mean temperatures in April (12.45 °C in 2024 vs. 9.92 °C in 2023), which likely accelerated early-season vine activity.

Table 2. Monthly meteorological data for the experimental vineyard in 2023 and 2024 years

Months	Year 2023					Year 2024				
	Air Temperature (°C)			RH (%)	Precip. (mm)	Air Temperature (°C)			RH (%)	Precip. (mm)
	Mean	Max	Min	Mean	Total	Mean	Max	Min	Mean	Total
January	0.01	12.93	-10.74	59.17	20.73	-0.32	8.42	-12.45	74.33	6.80
February	-3.87	10.76	-19.01	68.04	16.65	2.63	13.24	-14.03	63.69	12.42
March	6.72	17.34	-4.96	68.40	30.28	5.17	23.18	-5.86	64.26	33.85
April	9.92	17.43	1.01	71.29	177.22	12.45	22.44	4.25	65.42	96.52
May	14.22	24.50	4.29	69.14	105.20	13.71	22.38	4.22	71.37	107.29
June	21.36	27.13	11.92	59.92	71.13	22.84	30.14	11.91	61.26	167.15
July	24.62	31.28	13.72	50.33	67.80	23.43	32.04	14.52	48.20	95.10
August	25.27	35.22	13.99	30.01	15.83	26.16	38.21	18.79	22.39	23.58
September	19.43	29.20	11.27	47.19	21.62	15.19	28.63	10.84	43.22	98.88
October	10.37	23.55	3.31	58.20	32.91	10.65	22.60	4.98	56.05	129.33
November	7.49	20.27	-7.08	71.16	54.43	3.31	16.99	-10.09	69.12	11.80
December	3.02	13.65	-12.51	81.34	42.20	-2.12	11.21	-31.28	82.61	17.63

In 2023, bud break occurred between 4 and 5 May across all treatments. However, since leaf removal treatments were applied later in the season at defined phenological stages, it was not physiologically plausible to attribute any variation at bud break to the leaf removal practices. Therefore, the slight differences observed in bud break timing among treatments were considered to reflect natural vineyard variability and seasonal environmental conditions rather than treatment effects. Similarly, full flowering dates differed by only 1–2 days among treatments. Although the earliest veraison was recorded in the FF treatment and the latest in the V treatment, these minor shifts did not substantially alter the overall phenological progression. The fact that harvest was conducted on the same date for all treatments further indicates that leaf removal timing did not lead to meaningful changes in the duration of the ripening period (Table 3).

Climatic conditions during the flowering and berry development periods further support this interpretation. For instance, higher precipitation in June 2024 (167.15 mm) compared to 2023 (71.13 mm), combined with comparable temperature regimes, did not translate into substantial shifts in flowering or veraison timing (Table 2, 3), suggesting that Karaerik grapevines exhibit a relatively stable phenological response under varying moisture conditions.

The observations from 2024 were consistent with the previous year. Although bud break dates varied slightly among treatments, these differences were considered within the range of normal annual variation driven by environmental conditions. Minor differences during full flowering and veraison did not significantly impact the overall phenological progression. Harvest was again carried out on the same date for all treatments, demonstrating that the phenological development of the vines followed a similar course regardless of the timing of leaf removal (Table 3).

Table 3. Dates of phenological stages under different treatments

Year	Treatment	Bud Burst Date	Full Flowering Date	Veraison Date	Harvest Date
2023	FF	04 May	20 June	15 August	14 September
	PS	04 May	20 June	16 August	
	V	05 May	21 June	17 August	
	C	04 May	22 June	16 August	
2024	FF	25 April	10 June	15 August	16 September
	PS	24 April	12 June	14 August	
	V	26 April	10 June	15 August	
	C	26 April	11 June	15 August	

FF: Full flowering, PS: Pea-size berry, V: Veraison, C: Control.

Moreover, the higher temperatures recorded during the ripening period in 2024, particularly in August (mean 26.16 °C vs. 25.27 °C in 2023), along with lower relative humidity, did not result in an earlier harvest (Table 2, 3), indicating that thermal accumulation differences between years were insufficient to markedly alter the duration of the ripening phase. This further reinforces the conclusion that phenology was more closely linked to general climatic thresholds than to canopy management interventions.

Nevertheless, although leaf removal did not exert a pronounced effect on phenological timing, it produced significant indirect effects on canopy structure and the cluster-zone microclimate. Under the Baran training system, reducing canopy density through leaf removal increased light interception by the clusters and enhanced air circulation within the canopy. These microclimatic improvements were observed to positively influence berry coloration, particularly by promoting anthocyanin accumulation in the berry skin. Consequently, leaf removal practices primarily affect the microclimatic factors that determine grape quality rather than accelerating phenological development.

The results indicate that the timing of leaf removal in the Baran training system does not play a determining role in grapevine phenology. However, by modulating the cluster-zone microclimate, leaf removal provides beneficial effects on quality parameters, especially berry coloration. This suggests that leaf removal in the Baran system should be considered not as a phenological intervention but as a cultural practice aimed at enhancing fruit quality.

3.2. Effects of leaf removal on yield, cluster and berry structure

Leaf removal applied at different phenological stages produced significant differences in yield, cluster characteristics, and berry morphology. When the influence of leaf removal timing on yield, cluster weight, cluster compactness, and berry morphological traits was evaluated, the main effect of period (PME) was found to be statistically significant for all examined parameters ($p<0.01$) (Table 4). These results suggest that variations in canopy density associated with leaf removal timing may have modified the cluster-zone microclimate and influenced the canopy–root balance of the vines.

The highest mean yield was obtained from the control treatment (8.98 kg vine^{-1}), which was significantly higher than the yields recorded for leaf removal applied at full flowering (FF), pea-size berry (PS), and veraison (V) stages. Similarly, cluster weight was highest in the control treatment (445.61 g), whereas early-season leaf removal at full flowering markedly reduced cluster weight (Table 4). This reduction indicates that early leaf removal limits assimilate supply during flowering and fertilization, thereby reducing fruit set and overall yield. The suppressive effects of early leaf removal on yield have been consistently reported in previous studies (Poni et al., 2006; Intrieri et al., 2008; Wegher et al., 2025).

In contrast, early leaf removal positively influenced cluster structure. According to the non-parametric Kruskal–Wallis test, cluster compactness (OIV-204) differed significantly among treatments ($p<0.001$), and the Steel–Dwass multiple comparison test revealed two distinct statistical groups (Table 4). The lowest cluster compactness was recorded in the FF treatment (4.58), which was statistically similar to the PS treatment, whereas the control exhibited the highest value (7.58), grouped together with the veraison treatment in the same higher compactness class. The grouping results indicated that FF and PS treatments formed the lower compactness group, while BD and control treatments constituted the higher compactness group, demonstrating that early leaf removal significantly reduced cluster compactness compared with late defoliation and control vines. Higher cluster compactness in the control was associated with increased berry cracking and rot incidence; cracked and rotten berries per 100 berries were 11.21 and 10.67, respectively, in the control, compared with 2.08 and 1.96 in the FF treatment (Table 5). These results suggest that early leaf removal improves air circulation within the cluster, reduces humidity, and thereby decreases physiological berry disorders. Similar findings have been reported in previous studies showing that leaf removal reduces cluster compactness and limits the development of fungal pathogens such as *Botrytis cinerea* (Würz et al., 2020; Hed and Centinari, 2024).

Table 4. Effects of leaf removal on yield and cluster characteristics

Traits	Years	Time of Leaf Removal Applications				
		FF	PS	V	C	YME
Fresh grape yield (kg vine^{-1})	2023	7.27±0.23 ^{ns}	7.80±0.32	8.14±0.22	8.57±0.22	7.94±0.53 ^{ns}
	2024	7.60±0.58	7.88±0.31	7.71±0.50	9.40±0.54	8.14±0.99
	PME	7.43±0.43 *C**	7.84±0.41 *BC*	7.93±0.46 *B*	8.98±0.48 *A*	
Cluster weight (g)	2023	369.37±10.79 *d***	392.75±10.02 *cd*	405.88±5.50 *bc*	425.70±4.60 *b*	398.42±22.04 ^{ns}
	2024	379.17±22.00 *cd*	388.38±14.79 *cd*	387.09±23.71 *cd*	465.52±23.60 *a*	405.04±31.07
	PME	374.27±18.01 *C**	390.57±16.92 *BC*	396.48±19.09 *B*	445.61±20.14 *A*	
Number of berries per cluster (number cluster^{-1})	2023	61.32±5.12 ^{ns}	71.51±8.24	72.82±5.28	86.14±9.44	72.95±8.43 ^{ns}
	2024	64.75±4.87	70.38±7.10	77.50±8.44	94.00±11.36	76.66±9,76
	PME	63.03±5.29 *C**	70.94±5.20 *BC*	75.16±4.58 *B*	90.07±5.64 *A*	
Cluster width (cm)	2023	10.45±0.91 ^{ns}	10.78±0.39	11.19±1.24	11.29±0.49	10.93±0.90 ^{ns}
	2024	11.06±1.22	11.28±0.80	11.88±0.38	11.56±0.72	11.45±0.89
	PME	10.76±1.12 ^{ns}	11.03±1.11	11.53±1.04	11.43±1.07	
Cluster length (cm)	2023	16.62±0.97 ^{ns}	16.74±0.96	15.73±1.29	14.64±0.73	15.93±1.31 ^{ns}
	2024	18.13±0.89	16.38±0.75	16.75±0.18	16.31±0.60	16.89±0.99
	PME	17.37±1.20 *A**	16.56±0.99 *AB*	16.24±0.83 *BC*	15.47±0.83 *C*	
Cluster compactness degree (OIV-204)	2023	4.67±0.33 *b**	5.00±0.82 *b*	6.67±0.33 *a*	7.67±0.67 *a*	6.00±1.18 ^{ns}
	2024	4.50±0.87 *b*	5.67±0.94 *b*	7.00±0.82 *a*	7.50±0.99 *a*	6.16±1.08
	PME	4.58±0.66 *B**	5.33±0.61 *B*	6.83±0.69 *A*	7.58±0.89 *A*	

Values are presented as mean ± standard deviation (M±SD).
FF: Full flowering, PS: Pea-size berry, V: Veraison, C: Control; PME: Period Main Effect, YME: Year Main Effect. OIV-204: 1 = very loose, 3 = loose, 5 = medium, 7 = compact, 9 = very compact (OIV, 2009).
Different lowercase letters within the same row and uppercase letters within the same column indicate statistically significant differences based on the LSD post hoc test *p<0.01 and ** p<0.05 ns: indicates non-significant differences (p>0.05).

Table 5. Effects of leaf removal on yield, cluster, and berry characteristics

Traits	Years	Time of Leaf Removal Applications				
		FF	PS	V	C	YME
Single berry weight (g)	2023	5.91±0.41 ^{ns}	5.51±0.43	5.71±0.15	5.17±0.38	5.57±0.45 ^{ns}
	2024	5.91±0.16	5.80±0.65	5.08±0.43	5.21±0.34	5.50±0.56
	PME	5.91±0.31 *A***	5.65±0.31 *AB*	5.40±0.27 *B*	5.19±0.28 *B*	
Berry width (mm)	2023	21.63±0.84 ^{ns}	21.94±1.23	21.13±1.36	20.91±0.91	21.40±1.18 *A**
	2024	21.28±0.21	19.88±1.23	19.19±0.33	19.20±0.27	19.89±1.08 *B*
	PME	21.45±0.64 *A***	20.91±0.61 *AB*	20.16±0.69 *B*	20.05±0.89 *B*	
Berry length (mm)	2023	25.62±0.46 ^{ns}	25.35±0.53	22.14±1.59	22.58±1.36	23.93±1.92 *A**
	2024	24.10±0.97	23.35±0.78	19.93±0.49	20.07±0.23	21.86±2.00 *B*
	PME	24.86±1.07 *A**	24.35±1.07 *A*	21.04±1.08 *B*	21.33±1.12 *B*	
Number of cracked berries (number 100^{-1})	2023	2.17±0.76 ^{ns}	3.33±1.80	6.08±0.64	10.33±1.65	5.92±3.20 ^{ns}
	2024	1.75±0.72	3.50±0.83	6.75±0.86	11.00±1.72	5.92±3.70
	PME	2.08±0.87 *C**	3.75±0.86 *C*	6.63±1.17 *B*	11.21±1.16 *A*	
Number of decayed berries (number 100^{-1})	2023	2.33±0.47 ^{ns}	3.75±0.72	6.17±1.34	11.42±1.96	5.48±2.15 ^{ns}
	2024	1.83±0.76	3.75±1.77	7.08±2.59	11.00±2.38	5.75±3.20
	PME	1.96±0.92 *A**	3.42±0.98 *C*	6.42±1.23 *B*	10.67±1.24 *A*	

Values are presented as mean ± standard deviation (M±SD).
FF: Full flowering, PS: Pea-size berry, V: Veraison, C: Control; PME: Period Main Effect, YME: Year Main Effect.
Different lowercase letters within the same row and uppercase letters within the same column indicate statistically significant differences based on the LSD post hoc test *p<0.01 and ** p<0.05 ns: indicates non-significant differences (p>0.05).

Leaf removal timing also significantly influenced berry morphology. The highest values for single berry weight (5.91 g), berry width (21.45 mm), and berry length (24.86 mm) were observed in vines subjected to FF leaf removal, with statistically lower values recorded in the veraison and control treatments (Table 5). These results indicate that early leaf removal reduces berry number per vine, directing a greater proportion of photosynthates to fewer berries and thereby increasing berry size. In addition, enhanced light penetration and elevated cluster-zone temperatures likely supported berry development by stimulating cell division and expansion. Similarly, Türk and Köse (2024) reported that microelement applications and their combination with green pruning (unproductive shoot removal, leaf removal, shoot tip removal, shoot topping) practices significantly increased cluster and berry size parameters, indicating that canopy and nutrient management strategies can strongly influence berry morphology and structural traits.

Although previous studies report varying effects of early leaf removal on berry size, many have similarly emphasized that defoliation performed during the flowering period increases berry weight and dimensions (Tardáguila et al., 2008; Palliotti et al., 2012). Conversely, some studies have indicated that late-season leaf removal has limited or statistically insignificant effects on berry size (Kılıç, 2019). These discrepancies are likely attributable to differences in cultivar characteristics, climatic conditions, and the intensity of the applied treatments.

In conclusion, the findings of this study demonstrate that the timing of leaf removal is a critical factor in balancing yield and quality components. Although early-season leaf removal reduces overall yield, it decreases cluster compactness, reduces berry cracking and rot incidence, and increases berry size. Therefore, in table grape production aimed at quality improvement, leaf removal practices should be carefully planned according to the phenological stage.

3.3. Effects on technological maturity and must composition

Leaf removal treatments were found to significantly affect total soluble solids (TSS) and maturity index, whereas titratable acidity (TA) and must pH were not significantly influenced (Table 6). The main effect of period (PME) was significant at $p<0.05$ for TSS and at $p<0.01$ for the maturity index, indicating that the timing of defoliation plays a critical role in sugar accumulation dynamics.

Among the treatments, the highest TSS value (19.07%) was recorded in vines subjected to leaf removal at full flowering (FF), which was significantly higher than the values obtained in the veraison (17.06%) and control (17.60%) treatments (p). Correspondingly, the maturity index reached its maximum in the FF treatment (27.42), while lower values were observed in the veraison (25.67) and control (25.47) treatments (Table 6). These results indicate that early leaf removal accelerates technological maturity, primarily through enhanced sugar accumulation in the berries.

The increase in soluble solids following early leaf removal can be explained by several interrelated physiological mechanisms. Removal of basal leaves in the cluster zone during flowering improves light interception and local temperature conditions around the clusters, thereby enhancing the photosynthetic efficiency of the remaining leaves and facilitating more effective translocation of photoassimilates to developing berries. Similar findings have been reported by Feng et al. (2015), Parker et al. (2015) and VanderWeide et al. (2021) demonstrating that early-stage leaf removal increases berry sugar concentration and advances ripening. In addition, Köse et al. (2018) reported that leaf removal, particularly at lower intensity, positively affects TSS, titratable acidity and several cluster and berry traits, supporting the role of defoliation in improving grape quality parameters. Similarly, Gatti et al. (2012) reported that preflowering defoliation increased sugar concentration and phenolic content despite a yield reduction of 32% compared to the control, indicating that early canopy management practices can enhance grape composition while partially limiting yield.

In contrast, titratable acidity and must pH were not significantly affected by the leaf removal treatments in this study (Table 6). This suggests that, although early leaf removal promotes sugar accumulation, it does not markedly alter organic acid metabolism under the prevailing environmental conditions. These results are consistent with previous reports indicating that, particularly under moderate leaf removal intensity, sugar accumulation is more strongly influenced than malic or tartaric acid degradation (Intrieri et al., 2008; Palliotti et al., 2012). In agreement with this, Gatti et al. (2012) demonstrated that technological maturity parameters may respond differently depending on the crop regulation technique, with similar sugar levels being associated with contrasting titratable acidity and pH values.

Overall, the findings indicate that early leaf removal applied at full flowering (FF) improves technological maturity by increasing sugar concentration and the maturity index without adversely affecting acidity. This balance represents a desirable quality criterion in both table and wine grape production, where achieving high sugar levels alongside adequate acidity is critical. Consequently, the results contribute meaningfully to the literature by supporting phenology-based leaf removal as an effective canopy management strategy for optimizing grape ripening and must composition.

Table 6. Effects of leaf removal on technological maturity and must composition parameters

Traits	Years	Time of Leaf Removal Applications				
		FF	PS	V	C	YME
Total soluble solids (TSS, %)	2023	18.78±0.63 *ns*	17.82±0.42	17.34±0.46	17.64±0.71	17.90±0.78 *ns*
	2024	19.35±1.19	18.54±1.03	16.77±0.60	17.56±0.37	18.06±1.30
	PME	19.07±0.99 *A**	18.18±1.03 *AB*	17.06±1.13 *C*	17.60±1.19 *BC*	
Titratable acidity (%)	2023	0.70±0.01 *ns*	0.70±0.01	0.66±0.02	0.67±0.03	0.68±0.03 *ns*
	2024	0.69±0.01	0.69±0.05	0.67±0.02	0.71±0.02	0.69±0.04
	PME	0.70±0.01 *ns*	0.70±0.01	0.67±0.01	0.69±0.01	
pH	2023	3.54±0.05 *ab***	3.58±0.02 *ab*	3.63±0.04 *a*	3.52±0.07 *a*	3.57±0.06 *ns*
	2024	3.58±0.03 *ab*	3.50±0.04 *b*	3.53±0.06 *b*	3.59±0.10 *b*	3.55±0.07
	PME	3.56±0.04 *ns*	3.54±0.04	3.58±0.03	3.55±0.03	
Maturity index (%)	2023	26.85±0.82 *ab***	25.36±0.61 *bc*	26.38±1.23 *abc*	26.27±1.45 *abc*	26.21±1.21 *ns*
	2024	27.99±1.44 *a*	27.02±0.71 *ab*	24.97±1.21 *c*	24.67±1.01 *c*	26.16±1.79
	PME	27.42±1.31 *A***	26.19±1.43 *AB*	25.67±1.60 *B*	25.47±1.72 *B*	

Values are presented as mean ± standard deviation (M±SD).
FF: Full flowering, PS: Pea-size berry, V: Veraison, C: Control; PME: Period Main Effect, YME: Year Main Effect.
Different lowercase letters within the same row and uppercase letters within the same column indicate statistically significant differences based on the LSD post hoc test *$p<0.01$ and ** $p<0.05$ ns: indicates non-significant differences ($p>0.05$).

3.4. Effects on phytochemical composition

Leaf removal applied at different phenological stages plays a decisive role in shaping the phytochemical composition of grape berries by altering light exposure and the microclimate within the cluster zone. In this study, total phenolic content was significantly affected by both the main effect of year (YME) and the main effect of treatment period (PME) ($p<0.01$) (Table 7), indicating that the timing of leaf removal exerts a strong regulatory influence on phenolic metabolism.

Across phenological stages, the highest total phenolic content was observed in vines subjected to FF leaf removal (504.57 mg L^{-1}), which was significantly higher than the values recorded in the veraison (V) and control treatments (Table 7). The lower phenolic levels in the control treatment may be attributed to reduced light interception in the cluster zone, leading to lower activation of the phenylpropanoid pathway. Several studies have similarly reported that early-season leaf removal enhances light penetration in the cluster zone and stimulates phenolic compound synthesis (Ristic et al., 2007; Pastore et al., 2013; Quartacci et al., 2022). Consistently, Gatti et al. (2012) reported that preflowering defoliation significantly increased total phenolics and anthocyanin concentrations, which was associated with reduced cluster compactness and enhanced skin-to-pulp ratio.

The enhancing effect of leaf removal at the full flowering (FF) stage on total phenolic content can be attributed to the increased light penetration within the cluster zone and the consequent stimulation of metabolic processes involved in the biosynthesis of phenolic compounds. In particular, leaf removal performed at the full flowering stage is considered to promote the accumulation of phenolic acids and other non-flavonoid phenolic fractions by supporting the activation of the phenylpropanoid pathway**.** This phenomenon is associated with an increase in the activity of light-sensitive enzymes (e.g., phenylalanine ammonia-lyase, PAL), which may contribute to the enhanced synthesis of secondary metabolites. Indeed, previous studies have demonstrated that leaf removal practices applied during early and mid-phenological stages increase the total phenolic content, with this increase being particularly pronounced in phenolic acid and flavanol fractions (Gambacorta et al., 2022; Quartacci et al., 2022).

Regarding interannual variation, total phenolic content in 2024 was significantly higher than in 2023 (485.36 vs. 444.62 mg L^{-1}) (Table 7), highlighting the sensitivity of phenolic accumulation to environmental conditions. Factors such as temperature, light intensity, and water status are known to directly influence phenolic metabolism. Poni et al. (2006) and Tardáguila et al. (2008) emphasized that interannual climatic variability can substantially affect phenolic synthesis and accumulation. The year-to-year differences observed in this study are therefore consistent with the literature and support the interpretation of phenolic compounds as part of an adaptive response to environmental stress.

In contrast, total flavonoid content was not significantly influenced by the treatment period (p>0.05), although the main effect of year was significant (p<0.05) (Table 7). This suggests that leaf removal does not directly increase total flavonoid concentration but may influence specific phenolic subgroups or alter the compositional profile of phenolics. Indeed, some studies have reported that leaf removal modifies flavonoid composition and distribution rather than total flavonoid content, with particular increases observed in anthocyanin and flavanol fractions (Gambacorta et al., 2022).

Although previous research indicates that early leaf removal can stimulate flavonoid biosynthesis and enhance antioxidant capacity, these effects may vary depending on cultivar, environmental conditions, and analytical methodology. In the present study, the observed interannual variability in flavonoid content underscores the dominant role of environmental factors in regulating flavonoid metabolism. Therefore, it can be concluded that flavonoid accumulation is more sensitive to climatic conditions than to leaf removal practices.

Table 7. Effects of leaf removal on phytochemical composition

Traits	Years	Time of Leaf Removal Applications				
		FF	**PS**	**V**	**C**	**YME**
Total phenolic content (mg L^{-1})	2023	485.56±37.46 ^{ns}	455.11±28.78	399.72±42.66	438.07±55.26	444.62±42.32 *B***
	2024	523.59±31.26	491.95±30.95	480.98±43.46	444.91±39.44	485.36±46.20 *A*
	PME	504.57±39.39 *A***	473.53±35.55 *AB*	440.35±43.30 *B*	441.49±37.24 *B*	
Total flavonoid content (mg g^{-1})	2023	92.67±15.23 ^{ns}	90.17±11.07	83.60±1.76	93.67±17.78	90.03±13.56 *B**
	2024	106.30±15.70	104.17±8.02	98.55±6.71	92.62±11.70	100.41±12.31 *A*
	PME	99.48±16.90 ^{ns}	97.17±17.16	91.08±16.28	93.15±16.84	

Values are presented as mean ± standard deviation (M±SD).
FF: Full flowering, PS: Pea-size berry, V: Veraison, C: Control; PME: Period Main Effect, YME: Year Main Effect.
Different lowercase letters within the same row and uppercase letters within the same column indicate statistically significant differences based on the LSD post hoc test *p<0.01 and ** p<0.05 ns: indicates non-significant differences (p>0.05).

Overall, the findings of this study demonstrate that early leaf removal, particularly when applied at full flowering (FF), significantly increases total phenolic content, whereas total flavonoid content is more strongly influenced by interannual environmental variability. These results are largely consistent with previous studies emphasizing the effects of leaf removal on phenolic metabolism and indicate that phenology-based leaf removal strategies represent an effective vineyard management tool for enhancing phytochemical quality in grapes.

3.5. Effects on winter bud physiology

The timing of leaf removal was a key factor influencing carbohydrate reserves and cold hardiness of winter buds, highlighting the long-term physiological effects of canopy management. Soluble carbohydrate content in primary buds was significantly affected by leaf removal timing (p<0.01). The highest values were recorded in the FF (11.01 mg g^{-1}) and pea-size berry (PS, 10.51 mg g^{-1}) treatments, whereas lower levels were observed in the veraison (V, 7.39 mg g^{-1}) and control (3.89 mg g^{-1}) treatments (Table 8). These results indicate that early leaf removal enhances the canopy–root balance and promotes carbohydrate accumulation prior to dormancy. The elevated carbohydrate reserves observed in the FF and PS treatments suggest that early removal of basal leaves reduces shading, increases photosynthetic efficiency, and facilitates storage of reserve carbohydrates in perennial organs. These findings are consistent with previous studies reporting that early leaf removal increases carbohydrate accumulation in buds and shoot wood (Smith and Centinari, 2019; Kaya, 2020; Rende et al., 2018).

In parallel with soluble carbohydrate accumulation, cold injury rates in primary buds were significantly influenced by leaf removal timing (p<0.01). The lowest cold injury was recorded in the FF (4.94%) and PS (5.10%) treatments, whereas the highest value was observed in the control (8.95%). Similarly, primary bud necrosis was lowest in the FF treatment (2.75%) and increased to 8.21% in the control (p<0.01) (Table 8). These results demonstrate that early leaf removal exerts a protective effect on bud viability and cold hardiness. The reduction in cold injury and necrosis rates is likely associated with increased light exposure following early defoliation, which accelerates lignification and strengthens cold acclimation. This mechanism is consistent with previous studies emphasizing the importance of canopy openness for enhancing winter hardiness (Howell and Shaulis, 1980; Fennell and Hoover, 1991; Zabadal et al., 2007).

Table 8. Effects of leaf removal on winter bud

Traits	Years	Time of Leaf Removal Applications				
		FF	PS	V	C	YME
Soluble carbohydrate content (mg g^{-1})	2023	12.53±0.20 *a***	10.76±0.94 *b*	6.99±0.59 *c*	4.29±0.46 *d*	8.64±3.27 *A***
	2024	9.48±1.72 *b*	10.26±1.09 *b*	7.80±0.66 *c*	3.49±0.29 *d*	7.76±2.83 *B*
	PME	11.01±1.95 *A**	10.51±1.89 *A*	7.39±1.80 *B*	3.89±1.71 *C*	
Primary bud cold injury (%)	2023	5.15±1.20 ^{ns}	4.87±1.00	7.42±1.20	8.99±2.25	6.61±2.26 ^{ns}
	2024	4.74±1.23	5.33±1.22	7.62±1.44	8.90±1.18	6.65±2.11
	PME	4.94±1.23 *B**	5.10±1.12 *B*	7.52±1.10 *A*	8.95±1.01 *A*	
Primary bud necrosism (%)	2023	2.42±0.49 ^{ns}	3.17±0.29	5.17±0.60	7.50±1.57	4.56±2.16 ^{ns}
	2024	3.08±0.60	3.75±0.36	5.17±1.07	8.92±1.09	5.23±2.41
	PME	2.75±0.64 *C**	3.46±0.64 *C*	5.17±0.65 *B*	8.21±0.66 *A*	

Values are presented as mean ± standard deviation (M±SD).
FF: Full flowering, PS: Pea-size berry, V: Veraison, C: Control; PME: Period Main Effect, YME: Year Main Effect.
Different lowercase letters within the same row and uppercase letters within the same column indicate statistically significant differences based on the LSD post hoc test *$p<0.01$ and ** $p<0.05$ ns: indicates non-significant differences ($p>0.05$).

In conclusion, early leaf removal, particularly when applied at full flowering (FF) and the pea-size berry (PS) stage, enhanced carbohydrate storage, reduced cold-induced bud damage, and produced lasting positive effects on winter bud physiology. These results highlight early defoliation as an effective vineyard management strategy for improving vine resilience and sustainability under continental climate conditions.

Conclusion

This study demonstrates that the timing of basal leaf removal significantly influences yield, fruit quality, phytochemical composition, and winter bud physiology of the Karaerik grape cultivar cultivated under the Baran training system. Although control vines produced the highest yield (8.98 kg vine^{-1}), they exhibited excessive cluster compactness (OIV-204: 7.58), elevated rates of berry cracking and decay (>10 per 100 berries), lower phenolic content, and increased winter bud damage.

Early leaf removal at full flowering markedly improved berry size (5.91 g), technological maturity (TSS: 19.07%; maturity index: 27.42), and phenolic accumulation (504.57 mg L^{-1}), while reducing primary bud cold injury and necrosis by more than 50% compared with the control ($p<0.01$). Despite a moderate reduction in yield, the overall improvements in fruit quality, marketability, and vine cold hardiness clearly outweigh the losses in production.

Therefore, basal leaf removal at the full flowering stage is recommended as a scientifically supported and sustainable canopy management practice for quality-oriented Karaerik grape production under the Baran training system, particularly in regions characterized by harsh continental climatic conditions.

Ethical Statement

Ethical approval is not required for this study.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Artificial Intelligence Declaration

The authors declares that no generative artificial intelligence tools were used at any stage of the preparation of this manuscript, including the writing, editing, or refinement of the text, or the creation of any images, figures, graphics, tables, or related titles.

Funding Statement

The authors declare that this study received no financial support.

Author Contributions

Conceptualization: GEÇİM, T.; Materials and Methods: GEÇİM, T.; Data Collection and Processing: GEÇİM, T. BOZKURT, A. KALKAN, N.N.; Statistical Analysis: GEÇİM, T.; Literature Review: GEÇİM, T.; Manuscript Writing, Review, and Editing: GEÇİM, T. All authors reviewed and approved the final version of the manuscript.

Acknowledgements

I would like to express my gratitude to the Erzincan Horticultural Research Institute Directorate and its staff for their support in conducting this study.

References

Bal, E., Kök, D., & Çelik, S. (2011). The effect of some post-harvest treatments on Kozak black grape variety. *Journal of Tekirdag Agricultural Faculty*, *8*(2), 65–76.

Bennett, J., Jarvis, P., Creasy, G. L., & Trought, M. C. (2005). Influence of defoliation on overwintering carbohydrate reserves, return bloom, and yield of mature Chardonnay grapevines. *American Journal of Enology and Viticulture, 56*(4), 386–393. https://doi.org/10.5344/ajev.2005.56.4.386

Cantürk, S. (2026). Determination of generative performance of some Turkish hybrid grape cultivars (*Vitis vinifera* L.) in Çukurova conditions. *ISPEC Journal of Agricultural Sciences*, *10*(1), 153-165. https://doi.org/10.5281/zenodo.18347684

Chorti, E., Guidoni, S., Ferrandino, A., & Novello, V. (2010). Effect of different cluster sunlight exposure levels on ripening and anthocyanin accumulation in Nebbiolo grapes. *American Journal of Enology and Viticulture, 61*(1), 23–30. https://doi.org/10.5344/ajev.2010.61.1.23

Çelik, H., Ağaoğlu, Y. S., Fidan, Y., Marasalı, B., & Söylemezoğlu, G. (1998). *Genel bağcılık*. Sunfidan A.Ş.

Doğan, A., Uyak, C., & Saday, M. (2017). Ampelographic characterization of local grape varieties grown in the Hizan (Bitlis) region. *Yuzuncu Yıl University Journal of Agricultural Sciences, 27*(3), 424–435.

English, J. T., Thomas, C. S., Marios, J. J., & Gubler, W. D. (1989). Microclimates of grapevine canopies associated with leaf removal and control of Botrytis bunch rot. *Phytopathology, 79*, 395–401. https://doi.org/10.1094/Phyto-79-395

Feng, H., Yuan, F., Skinkis, P. A., & Qian, M. C. (2015). Influence of cluster zone leaf removal on Pinot noir grape chemical and volatile composition. *Food Chemistry, 173*, 414–423. https://doi.org/10.1016/j.foodchem.2014.09.149

Fennell, A., & Hoover, E. (1991). Photoperiod influences growth, bud dormancy, and cold acclimation in *Vitis labruscana* and *V. riparia*. *Journal of the American Society for Horticultural Science, 116*(2), 270–273. https://doi.org/10.21273/JASHS.116.2.270

Gambacorta, G., Faccia, M., Natrella, G., Noviello, M., Masi, G., & Tarricone, L. (2022). Early basal leaf removal at different sides of the canopy improves the quality of Aglianico wine. *Foods, 11*(19), 3140. https://doi.org/10.3390/foods11193140

Gatti, M., Bernizzoni, F., Civardi, S., & Poni, S. (2012). Effects of cluster thinning and preflowering leaf removal on growth and grape composition in cv. Sangiovese. *American Journal of Enology and Viticulture*, *63*(3), 325-332. https://doi.org/10.5344/ajev.2012.11118

Geçim, T., Doğan, N. Y., Pinar, H., & Bozkurt, A. (2025). Assessment of the susceptibility of grapevine genotypes in the Eastern Anatolia Region genetic resource plot to powdery mildew (*Erysiphe necator*) under natural infection conditions. *Turkish Journal of Agricultural and Natural Sciences*, *12*(2), 368–378. https://doi.org/10.30910/turkjans.1603167

Gökçen, İ. S., Çelik, M., & Keskin, N. (2026). Time-dependent changes in photosynthetic and phenolic responses in 'Horoz Karası' grape variety exposed to UV-B stress. *ISPEC Journal of Agricultural Sciences*, *10*(1), 263-274. https://doi.org/10.5281/zenodo.18692291

Hed, B., & Centinari, M. (2024). Mechanical leaf removal for improved Botrytis bunch rot control in *Vitis vinifera* 'Pinot gris' and 'Pinot noir' grapevines in the Northeastern United States. *Plant Disease, 108*(10), 3156–3162. https://doi.org/10.1094/PDIS-02-24-0383-RE

Howell, G. S., & Shaulis, N. (1980). Factors influencing within-vine variation in the cold resistance of cane and primary bud tissues. *American Journal of Enology and Viticulture, 31*(2), 158–161. https://doi.org/10.5344/ajev.1980.31.2.158

Hunter, J. J., de Villiers, Q. T., & Watts, J. E. (1991). The effect of partial defoliation on quality characteristics of *Vitis vinifera* L. cv. Cabernet Sauvignon grapes: Sugars, acids and pH. *South African Journal of Enology and Viticulture, 12*(1), 42–50. https://doi.org/10.5344/ajev.1991.42.1.13

Intrieri, C., Filippetti, I., Allegro, G., Centinari, M., & Poni, S. (2008). Early defoliation (hand vs mechanical) for improved crop control and grape composition in Sangiovese (*Vitis vinifera* L.). *Australian Journal of Grape and Wine Research, 14*(1), 25–32. https://doi.org/10.1111/j.1755-0238.2008.00004.x

Kalkan, N. N., Kiracı, M. A., Kadıoğlu, Z., & Esmek, İ. (2024). Economic analysis of baran system and some cord training systems in Erzincan conditions. *Bahçe Journal, 53*(Special Issue 1), 81-86. https://doi.org/10.53471/bahce.1481897

Karadoğan, B., Kalkan, N. N., Kaya, O., Bozkurt, A., & Geçim, T. (2022). A training system specific to ecology and variety:" Baran. *Chapters On Viticulture*, 155-168.

Kaya, O. (2020). Defoliation alleviates cold-induced oxidative damage in dormant buds of grapevine by up-regulating soluble carbohydrates and decreasing ROS. *Acta Physiologiae Plantarum, 42*(7), 106. https://doi.org/10.1007/s11738-020-03093-1

Köse, B., Çelik, H., & Çelik, D. (2018). Determination of the effects of less and excessive leaf removal on cluster characteristics in" Trakya ilkeren" grape variety.

Keller, M. (2015). *The science of grapevines* (2rd ed.). Academic Press.

Keller, M. (2020). *The science of grapevines* (3rd ed.). Academic Press.

Kılıç, M. S. (2019). *Effects of some summer pruning practices on fruit yield and quality in Red Globe grape variety.* (Master's thesis), Isparta University of Applied Sciences, Isparta, Türkiye.

Kliewer, M., & Bledsoe, A. (1986). Influence of hedging and leaf removal on canopy microclimate, grape composition, and wine quality under California conditions. In *Proceedings of the Symposium on Grapevine Canopy and Vigor Management* (pp. 157–168). https://doi.org/10.17660/ActaHortic.1987.206.9

Koblet, W., Candolfi-Vasconcelos, M. C., Zweifel, W., & Howell, G. S. (1994). Influence of leaf removal, rootstock, and training system on yield and fruit composition of Pinot noir grapevines. *American Journal of Enology and Viticulture*, *45*(2), 181-187. https://doi.org/10.5344/ajev.1994.45.2.181

Korkutal, İ., Bahar, E., & Bayram, S. (2018). Effects of different soil tillages and leaf removal applications on shoot and leaf characteristics and water stress of cv. Syrah. *Journal of Tekirdag Agricultural Faculty*, *15*(1), 1-13.

Lee, J., & Skinkis, P. A. (2013). Oregon 'Pinot noir' grape anthocyanin enhancement by early leaf removal. *Food Chemistry, 139*(1–4), 893–901. https://doi.org/10.1016/j.foodchem.2013.02.022

Martínez-Lüscher, J., Morales, F., Delrot, S., Sánchez-Díaz, M., Gomès, E., Aguirreolea, J., & Pascual, I. (2013). Short-and long-term physiological responses of grapevine leaves to UV-B radiation. *Plant Science*, *213*, 114-122. https://doi.org/10.1016/j.plantsci.2013.08.010

Matthews, M. A. (2016). *Terroir and other myths of winegrowing*. Univ of California Press.

Lorenz, D. H., Eichhorn, K. W., Bleiholder, H., Klose, R., Meier, U., & Weber, E. (1995). Growth stages of the grapevine: Phenological growth stages of the grapevine (*Vitis vinifera* L. ssp. *vinifera*)—Codes and descriptions according to the extended BBCH scale. *Australian Journal of Grape and Wine Research, 1*(2), 100–103. https://doi.org/10.1111/j.1755-0238.1995.tb00085.x

Mills, L. J., Ferguson, J. C., & Keller, M. (2006). Cold-hardiness evaluation of grapevine buds and cane tissues. *American Journal of Enology and Viticulture*, *57*(2), 194-200. https://doi.org/10.5344/ajev.2006.57.2.194

OIV. (2009). *OIV descriptor list for grape varieties and Vitis species*. Organisation Internationale de la Vigne et du Vin.

Palliotti, A., Cini, R., Silvestroni, O., Leoni, F., & Poni, S. (2012). Effects of late mechanized leaf removal above the clusters zone to delay grape ripening in'Sangiovese'vines. In *I International Workshop on Vineyard Mechanization and Grape and Wine Quality 978* (pp. 301-307). https://doi.org/10.17660/ActaHortic.2013.978.35

Parker, A. K., Hofmann, R. W., Van Leeuwen, C., McLachlan, A. R., & Trought, M. C. (2015). Manipulating the leaf area to fruit mass ratio alters the synchrony of total soluble solids accumulation and titratable acidity of grape berries. *Australian Journal of Grape and Wine Research*, *21*(2), 266-276. https://doi.org/10.1111/ajgw.12132

Pastore, C., Zenoni, S., Fasoli, M., Pezzotti, M., Tornielli, G. B., & Filippetti, I. (2013). Selective defoliation affects plant growth, fruit transcriptional ripening program and flavonoid metabolism in grapevine. *BMC Plant Biology*, *13*(1), 1-16. https://doi.org/10.1186/1471-2229-13-30

Poni, S., Bernizzoni, F., Civardi, S., & Libelli, N. (2009). Effects of pre-bloom leaf removal on growth of berry tissues and must composition in two red *Vitis vinifera* L. cultivars. *Australian Journal of Grape and Wine Research*, *15*(2), 185-193. https://doi.org/10.1111/j.1755-0238.2008.00044.x

Poni, S., Casalini, L., Bernizzoni, F., Civardi, S., & Intrieri, C. (2006). Effects of early defoliation on shoot photosynthesis, yield components, and grape composition. *American Journal of Enology and Viticulture, 57*(4), 397–407. https://doi.org/10.5344/ajev.2006.57.4.397

Poni, S., Chiari, G., Caffi, T., Bove, F., Tombesi, S., Moncalvo, A., & Gatti, M. (2017). Canopy physiology, vine performance and host-pathogen interaction in a fungi resistant cv. Sangiovese x Bianca accession vs. a susceptible clone. *Scientific Reports*, *7*(1), 6092. https://doi.org/10.1038/s41598-017-05530-7

Quartacci, M. F., Sgherri, C., & Pinzino, C. (2022). Impact of leaf removal on phenolics and antioxidant activity of Trebbiano berries (*Vitis vinifera* L.). *Plants*, *11*(10), 1303. https://doi.org/10.3390/plants11101303

Rende, M., Köse, C., & Kaya, O. (2018). An assessment of the relation between cold-hardiness and biochemical contents of winter buds of grapevine cv. 'Karaerik' in acclimation–hardening–deacclimation phases. *Mitteilungen Klosterneuburg Rebe und Wein Obstbau und Früchteverwertung, 68*(2), 67–81.

Ristic, R., Downey, M. O., Iland, P. G., Bindon, K., Francis, I. L., Herderich, M., & Robinson, S. P. (2007). Exclusion of sunlight from Shiraz grapes alters wine colour, tannin and sensory properties. *Australian Journal of Grape and Wine Research*, *13*(2), 53-65. https://doi.org/10.1111/j.1755-0238.2007.tb00235.x

Sabır, A., Tangolar, S., Buyukalaca, S., & Kafkas, S. (2009). Ampelographic and molecular diversity among grapevine (*Vitis* spp.) cultivars. *Czech Journal of Genetics and Plant Breeding, 45*(4), 160-168.

Singleton, V. L., & Rossi, J. A. (1965). Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *American Journal of Enology and Viticulture, 16*(3), 144–158. https://doi.org/10.5344/ajev.1965.16.3.144

Sivilotti, P., Herrera, J. C., Lisjak, K., Baša Česnik, H., Sabbatini, P., Peterlunger, E., & Castellarin, S. D. (2016). Impact of leaf removal, applied before and after flowering, on anthocyanin, tannin, and methoxypyrazine concentrations in 'Merlot'(*Vitis vinifera* L.) grapes and wines. *Journal of Agricultural and Food Chemistry*, *64*(22), 4487-4496.

Smart, R. E., Dick, J. K., Gravett, I. M., & Fisher, B. M. (1990). Canopy management to improve grape yield and wine quality-principles and practices. *South African Journal of Enology and Viticulture*, *11*(1), 3-17.

Smith, M. S., & Centinari, M. (2019). Impacts of early leaf removal and cluster thinning on Grüner Veltliner production, fruit composition, and vine health. *American Journal of Enology and Viticulture, 70*(3), 308–317. https://doi.org/10.5344/ajev.2019.18100

Staff, S. L., Percival, D. C., Sullivan, J. A., & Fisher, K. H. (1997). Fruit zone leaf removal influences vegetative, yield, disease, fruit composition, and wine sensory attributes of *Vitis vinifera*

L.'Optima'and'Cabernet franc'. *Canadian Journal of Plant Science*, *77*(1), 149-153. https://doi.org/10.4141/P95-184

Tahmaz, H., Küskü, D. Y., Söylemezoğlu, G., & Çelik, H. (2022). Phenolic compound and antioxidant capacity contents of *Vitis labrusca* L. genotypes. *Journal of Tekirdag Agricultural Faculty*, *19*(2). https://doi.org/10.33462/jotaf.952108

Tardáguila, J., De Toda, F. M., Poni, S., & Diago, M. P. (2010). Impact of early leaf removal on yield and fruit and wine composition of *Vitis vinifera* L. Graciano and Carignan. *American Journal of Enology and Viticulture*, *61*(3), 372-381. https://doi.org/10.5344/ajev.2010.61.3.372

Tardáguila, J., Diago, M. P., Martínez de Toda, F., Poni, S., & Vilanova de la Torre, M. D. M. (2008). Effects of timing of leaf removal on yield, berry maturity, wine composition and sensory properties of cv. Grenache grown under non irrigated conditions. *J. Int. Sci. Vigne Vin, 42*(4), 221-229.

Türk, F., & Köse, B. (2024). Effects of green pruning and combine microelement applications on bud fruitfulness, vegetative development and cluster characteristics of ‘Trakya İlkeren’grape cultivar. *International Journal of Agriculture Environment and Food Sciences*, *8*(1), 94-110. https://doi.org/10.31015/jaefs.2024.1.11

Uyak, C. (2010). *A study on the determination of the ampelographic characteristics of grape cultivars grown in the Siirt Region.* (Ph.D. Dissertation), Van Yüzüncü Yıl University, Van, Türkiye.

VanderWeide, J., Gottschalk, C., Schultze, S. R., Nasrollahiazar, E., Poni, S., & Sabbatini, P. (2021). Impacts of pre-bloom leaf removal on wine grape production and quality parameters: A systematic review and meta-analysis. *Frontiers in Plant Science*, *11*, 621585. https://doi.org/10.3389/fpls.2020.621585

Wegher, M., Niedrist, G., Tagliavini, M., Abella, M. D. A., Giuliani, N., & Andreotti, C. (2025). Impact of leaf removal on recovery of young grapevines under heatwave conditions: A study in an ecotron environment. *Oeno One*, *59*(3), 1-14. https://doi.org/10.20870/oeno-one.2025.59.3.7462

Würz, D. A., Rufato, L., Bogo, A., Allebrandt, R., de Bem, B. P., Marcon Filho, J. L., & Bonin, B. F. (2020). Effects of leaf removal on grape cluster architecture and control of Botrytis bunch rot in Sauvignon Blanc grapevines in Southern Brazil. *Crop Protection*, *131*, 105079. https://doi.org/10.1016/j.cropro.2020.105079

Yemm, E. W., & Willis, A. (1954). The estimation of carbohydrates in plant extracts by anthrone. *Biochemical Journal*, *57*(3), 508.

Zabadal, T. J., Dami, I. E., Goffinet, M. C., Martinson, T. E., & Chien, M. L. (2007). *Winter injury to grapevines and methods of protection* (Extension Bulletin E-2930). Michigan State University Extension.

Zenoni, S., Dal Santo, S., Tornielli, G. B., D’Incà, E., Filippetti, I., Pastore, C., & Poni, S. (2017). Transcriptional responses to pre-flowering leaf defoliation in grapevine berry from different growing sites, years, and genotypes. *Frontiers in Plant Science*, *8*, 630. https://doi.org/10.3389/fpls.2017.00630

Zhishen, J., Mengcheng, T., & Jianming, W. (1999). The determination of flavonoid contents in mulberry and their scavenging effects on superoxide radicals. *Food Chemistry, 64*, 555–559. https://doi.org/10.1016/S0308-8146(98)00102-2