International Journal of Horticultural Science and Technology
Journal homepage: https://ijhst.ut.ac.ir

Effects of Shading Nets on Physiological and Microclimatic Parameters of Four Iranian Grapevine Cultivars

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ARTICLE INFO

Article history:

Received: 23 April 2024,
Received in revised form: 13 August 2024,
Accepted: 14 August 2024

Article type:

Research paper

Keywords:

Chlorophyll stress,
Heat stress,
Humidity,
Vine,
Yield

ABSTRACT

Recent challenges such as climate change, heat stress, and dwindling water resources have become critical concerns in agriculture. This study aimed to assess the impact of using shade nets on physiological and microclimatic parameters, as well as the quantitative and qualitative yields of four grapevine cultivars. The cultivars Sahebi, Red Sultana, Red Asgari, and Mish Pestan were evaluated for traits such as chlorophyll fluorescence, yield, and microclimate conditions both under and outside a green shading net with 50% porosity. The shading net effectively lowered the temperature by 3.2 ºC while increasing humidity by 5.31%. Regarding chlorophyll stress, the net significantly increased maximum fluorescence and variable fluorescence by 48% and 46.2%, respectively, although it did not significantly affect primary fluorescence or the potential quantum yield. The net also resulted in significant reductions of external canopy temperature (15.9%), leaf temperature (17.6%), internal canopy temperature (15.2%), and CO_2 levels (6.5%). In contrast, canopy humidity rose by 64.3%. Under the shade net, internodal length increased by 66.2%, and vine yields saw an increase of up to 65%. The interaction effect between cultivar and the shading net was significant for internal canopy humidity, temperature, and total soluble solids. The findings demonstrated that using a shading net helped reduce heat stress, improved fruit quality, and delayed ripening. However, for table grape production, it is recommended to remove the shading net at the veraison stage to avoid delayed ripening.

Introduction

Grapes (*Vitis vinifera* L.) are one of the strategic fruit crops in Iran, ranking second in non-oil agricultural exports after pistachios (Rasoli and Dolati Baneh, 2018). In 2021, Iran ranked eighth globally in grape production, with about 2.5 million tons harvested from over 207,000 hectares (FAO, 2022). Of Iran's 26.3 million tons of horticultural production in 2022, around 3.14 million tons (11.9%) came from grapes, representing 97.6% of all small fruit production (FAO, 2022).

Climate scientists predict that future climate changes will increase variability and the intensity of extreme weather events (Thornton et al.,

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2014). The Intergovernmental Panel on Climate Change (IPCC), in its fourth analytical report, emphasizes that both weather and climate changes will drive forced human transformation. It also forecasts that the intensity, frequency, and type of abiotic stresses will become more predictable, even on smaller scales, due to climate changes (Mitchell et al., 2006; Meehl et al., 2007; Dong et al., 2015; Pokhrel et al., 2021).

These climatic shifts are already affecting crop yields and quality on a yearly basis, and grape production is no exception. Changes in climate impact grape and raisin production, affecting attributes like fruit flavor, ripening time, pigment formation, and overall yield (Irimia et al., 2019; Ammoniaci et al., 2021). Sunlight intensity and temperature have a direct influence on critical phenological stages of vines, including flower and berry abscission, berry weight, and the production of primary and secondary compounds like organic acids, sugars, vitamins, polyphenols, and aromatic compounds (Bindi et al., 2015; Reshef et al., 2019; Del-Castillo-Alonso et al., 2021).

Temperatures above 32°C can lead to higher concentrations of soluble solids in grape berries. However, when Brix levels exceed 26-27 degrees, this is often due to water evaporation rather than increased photosynthesis or sugar transport from leaves (De Orduna, 2010; Ju et al., 2018). Elevated total soluble solids (TSS) concentrations significantly impact fruit quality and the processing industry, particularly in terms of sensory changes and microbiological activity. Moreover, heat stress and increased TSS levels can activate glycolytic and pentose phosphate pathways, resulting in harmful byproducts like glycerol and acetic acid in the fruit (Erasmus et al., 2003; Coulter et al., 2008; Palliotti et al., 2014).

Temperature and solar radiation are key factors in vine metabolism (Borgogno-Mondino et al., 2020). However, excessive levels of photosynthetically active radiation can lead to increased transpiration and fruit dehydration, which are associated with a reduction in berry size (Bergqvist et al., 2021; Van Leeuwen and Destrac-Irvine, 2017; Carlomagno et al., 2018). Moreover, excessive sunlight or temperature can cause damage to plant tissues (Lobos et al., 2015). When temperatures exceed 30°C, the inhibition of photosystem activity, especially the most heat-sensitive components of the electron transport chain, leads to a decline in the capacity and quantum efficiency of CO_2 absorption (Georgieva et al., 2000).

Given the challenges posed by climate change, particularly the need to mitigate its impact on agriculture, strategies for controlling microclimatic conditions have gained importance. One effective approach is the use of shading nets in vineyards (Chorti et al., 2010). As biotic and abiotic stresses continue to affect crop production, the use of protected cultivation methods is expanding. This is particularly true in regions facing climate-related challenges such as drought. Shaded cultivation, specifically under shading nets, is increasingly viewed as a solution to combat these crises in many countries, including Iran (Rasoli et al., 2022).

Shading nets are especially important in viticulture as an adaptive technology to alleviate the effects of high temperatures, reduce evaporation, and limit transpiration (Lu et al., 2021; Naulleau et al., 2021). Positioned above the vine canopy, shading nets reduce the flow of photosynthetic photons and slow leaf photosynthesis, consequently delaying fruit ripening (Novello and De Palma, 2013; Villalobos et al., 2021). Studies show that shading nets can lower water stress and reduce canopy and cluster temperatures by as much as 7°C (Zha et al., 2022; Lobos et al., 2015). This study aimed to assess the impact of shading nets on select physiological and microclimatic parameters of four Iranian grape cultivars in the Takestan region.

Materials and Methods

Plant materials and project implementation design

This research was conducted in 2023 at the Takestan research station on four 15-year-old Iranian grapevine cultivars: Sahebi, Red Sultana, Red Asgari, and Mish Pestan. Nine vines from each cultivar were covered with a green shading net with 50% porosity, while another nine vines from each cultivar were left uncovered as the control. It is important to note that shading nets with a porosity of less than 50% (such as 40% or 30%) reportedly have no significant effect on quantitative and qualitative traits, whereas porosities higher than 50% can significantly reduce photosynthesis and yield (Wu et al., 2018).

The experiment was designed as a randomized complete block design (RCBD) with three replications, with each experimental unit consisting of three vines (Fig. 1). The planting distance for the vines was 2 × 3 m, and they were trained using a two-sided cordon system (Fig. 2). All vines underwent short-long winter pruning with four buds per cane, totaling 64 buds per vine, which was carried out in the last week of March. Summer pruning was also conducted during the growing season. Nutrient fertilizers were applied based on the results of a soil test. Irrigation took place from April 15th to October 30th, with a 10-day interval between irrigation sessions, using two drippers with a flow rate of 8 L h-1 for six hours each time.

Climatic conditions of the region

The research was conducted at the Takestan grape research station, located 3 km from Takestan city at 36°3'2″N and 49°40'51″E, with an elevation of 1250 m above sea level. The region had an average annual rainfall of 220 mm, concentrated mainly in autumn and winter. It experienced hot summers and cold winters, with minimum and maximum temperatures recorded at -30°C and 42°C, respectively, based on 30-year statistics. The average relative humidity was 52% annually, while the average annual evaporation was 1800 mm. The region experienced an average of 65 freezing days per year.

	Sahebi	Red Sultana	Red Asgari	Mish Pestan
Green shading net	1□ 2□ 3□	1□ 2□ 3□	1□ 2□ 3□	1□ 2□ 3□
Without shading net	1□ 2□ 3□	1□ 2□ 3□	1□ 2□ 3□	1□ 2□ 3□

Fig. 1. Project implementation plan (Green shading net □, Without shading net□) in three replications.

Fig. 2. Implementation of the shading net with a porosity at 50% in vineyard with bilateral cordon training system.

Assessed traits

The traits assessed in this study included canopy temperature, which was measured using an infrared thermometer (83-TI brand, Testo, Germany). The temperature of each vine was measured from 20 different points, and the average was recorded. Internodal length was determined by measuring the distance between the third and fourth nodes on 10 branches per vine, and their average was taken as the internodal length for each branch. Total soluble solids (TSS) were measured using a portable optical refractometer (SBR-32T, China). Primary fluorescence (Fo), maximum fluorescence (Fm), variable fluorescence (Fv), and quantum performance potential (Fv/Fm) were assessed using a Chlorophyll Fluorometer (Opti-Science OS-30 P, U.S.A.). Additionally, temperature, humidity, and canopy CO2 levels were measured using a portable CO_2 meter (AZ77535, China), while a digital temperature and humidity data logger (TESTO-174H, Germany) recorded inside and outside temperature and humidity under the shading net from April 1, 2021, to September 29, 2021. TSS was measured again using the same portable refractometer, and the total fruit yield of each vine was weighed using a scale with 0.1 g sensitivity.

Data analysis

For data analysis, SPSS Ver.26 was employed to test data normality, perform analysis of variance, and compare means using Tukey's test. To examine the internal relationships between the measured traits, factor analysis was conducted based on principal component analysis and varimax rotation using XLSTAT Ver.2019 via Microsoft Excel. The minimum significance level for all statistical tests was set at 0.05.

Results

During the first six months of 2023, an evaluation of temperature data recorded by the data logger revealed that the temperature beneath the shading net was significantly lower than that outside ($P<0.05$, Table 1, Fig. 3). Additionally, humidity levels under the shading net were significantly higher compared to those outside ($P<0.05$, Fig. 4, Table 1).

Table 1. Mean comparisons of temperature and humidity under and outside the shading nets.

Comparison	Mean difference	Standard deviation	T	Significance level
Temperature	3.2	0.97	16.3	0.001
Humidity	5.31	1.9	2.24	0.026

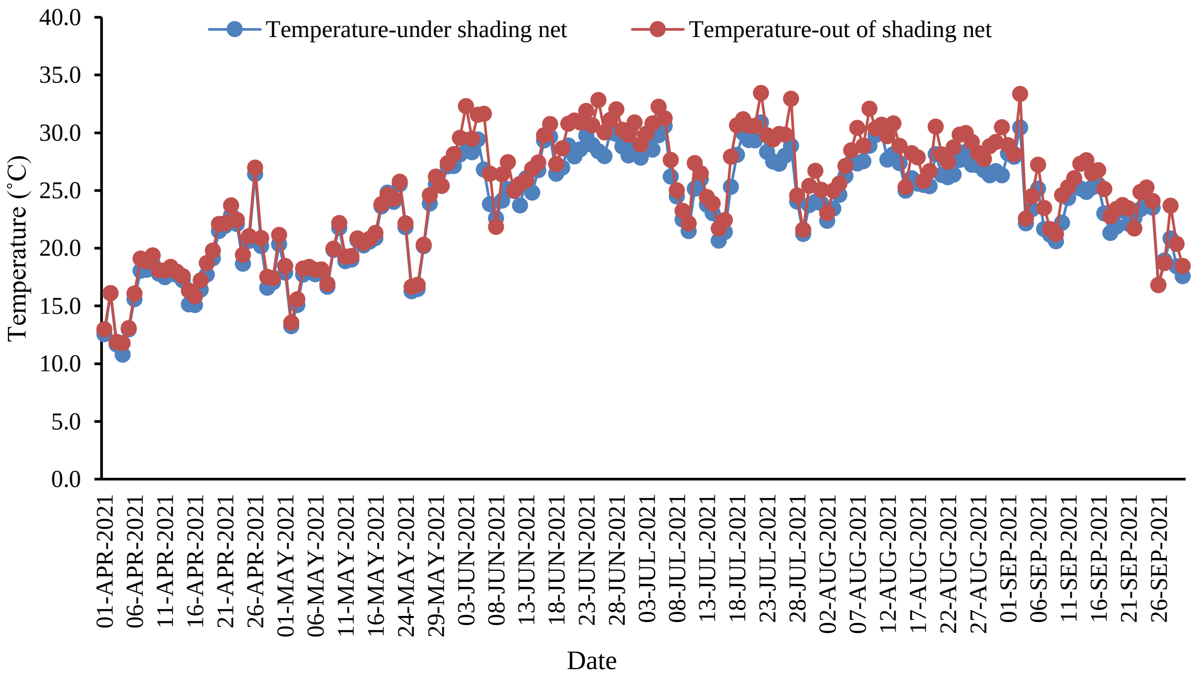

Fig. 3. Descriptive diagram temperature under and outside the shading nets based on the data logger system.

The analysis of variance revealed that the shading net had a significant effect on all measured traits, except for primary fluorescence (Fo) and quantum yield potential (Fv/Fm). The cultivars significantly influenced all traits, with the exceptions of Fv/Fm and canopy CO_2 levels. Additionally, the interaction effect between cultivar and shading net was significant only for canopy moisture, internal canopy temperature, and total soluble solids (TSS) (Table 2).
Comparative means for the shading net's effects on the studied traits are presented in Table 3. The

shading net significantly increased maximum fluorescence (Fm) and variable fluorescence (Fv) by 48% and 46.2%, respectively, indicating a reduction in chlorophyll stress. Furthermore, the shading net had a significant impact on microclimatic conditions surrounding the vines, resulting in a decrease in canopy temperature, leaf temperature, and internal canopy CO_2 by 15.9%, 17.6%, 15.2%, and 6.5%, respectively, while increasing internal canopy humidity by 64.3%.

The application of the shading net also led to a substantial increase in internodal length by 66.2% and enhanced vine yield by 65%. However, it resulted in a significant reduction in fruit TSS by 17.7% (Table 3). The highest values for initial fluorescence (232.7 ms), maximum fluorescence (939.2 ms), and variable fluorescence (666.1 ms) were recorded in the Red Sultana cultivar, although no significant differences were observed in quantum yield potential among the cultivars.

In terms of canopy and leaf temperatures, the highest readings (28 °C and 28.5 °C, respectively) were noted in the Red Asgari cultivar, while the lowest temperatures were recorded in the Red Sultana and Sahebi cultivars. The Red Sultana cultivar also exhibited the highest canopy moisture percentage (37.78%), while the Sahebi cultivar showed the lowest (20.86%). Furthermore, the Red Asgari cultivar had the highest canopy CO_2 concentration (427 ppm), with the Sahebi cultivar displaying the lowest (419.3 ppm).

Regarding internal canopy temperature, the highest value (34.95 °C) was observed in the Mish Pestan cultivar, whereas the lowest value (29.67 °C) was noted in the Red Sultana cultivar. No significant differences were found among the cultivars in terms of internodal length. Additionally, the Red Sultana cultivar exhibited the highest TSS (22.6 °Brix) and vine yield (6,547 g/v) (Table 3).

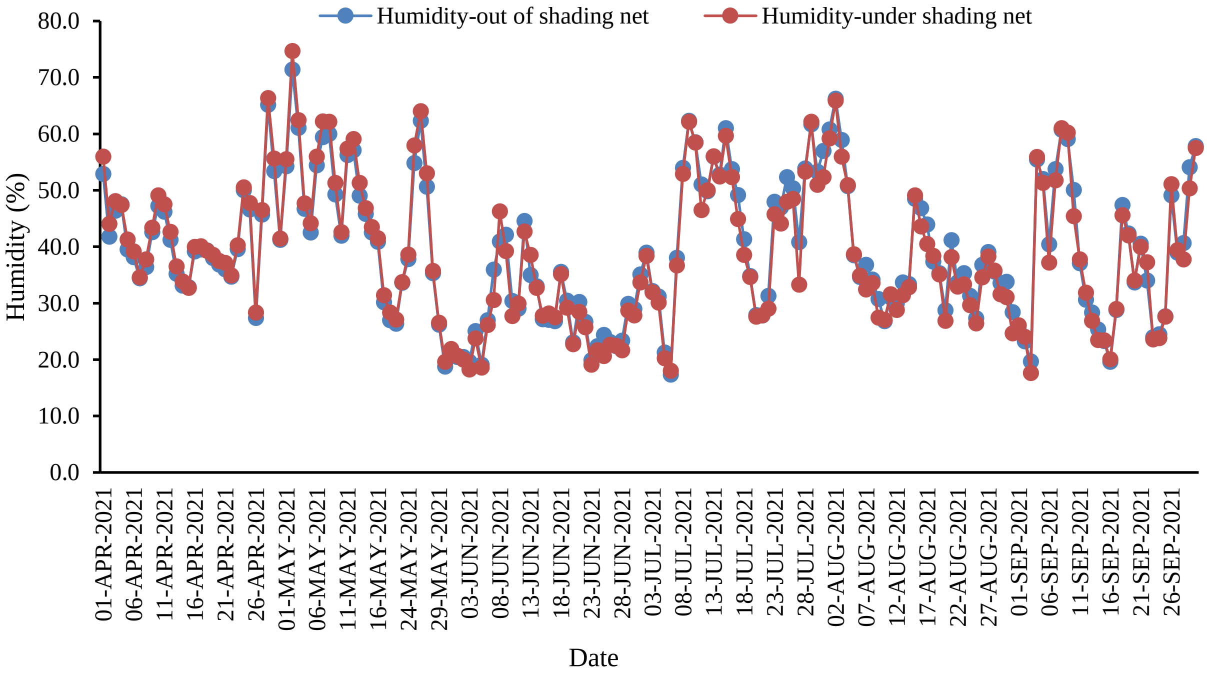

Fig. 4. Descriptive diagram humidity under and outside the shading net based on the data logger system.

The highest humidity inside the canopy (44.7%) was recorded in the Red Sultana cultivar under the shading net, while the lowest humidity (15%) was observed in the Mish Pestan cultivar outside the shading net (Fig. 5). Additionally, the temperature inside the canopy was consistently lower under the shading net across all studied cultivars. For instance, the Mish Pestan cultivar registered a temperature of 38.8 °C outside the shading net, whereas the Red Sultana cultivar exhibited a cooler temperature of 27.4 °C under the shading net (Fig. 6).

The TSS content was lower under the shading net compared to the outside condition in all grape cultivars. The highest TSS was recorded in the Red Sultana cultivar outside the shading net, while the lowest TSS was observed in the Sahebi cultivar under the shading net (Fig. 7).

Table 2. Mean square values of trait variance analysis in factorial experiments in the randomized complete block design (RCBD).

Source of variations	Degree of freedom	Primary fluorescence (F_o)	Maximum fluorescence (F_m)	Quantum performance potential (F_v/F_m)	Variable fluorescence (F_v)	Canopy temperature	Leaf temperature	Canopy CO_2	Canopy humidity	Canopy inside temperature	Vine yield	Total soluble solids	Internode length
Replication	2	394.8	840.1	0.004	1166.25	0.292	5.45	76.3	3.6	0.82	4013205.9	3.3	7.7
Shading Net	1	5.1	324570^{**}	0.001	143819.1^{**}	119.3^{**}	155.5^{**}	4320.2^{**}	961.4^{**}	178.3^{**}	19849837^{**}	96.4^{**}	45.9^{**}
Cultivar	3	24764.6^{**}	329646.5^{**}	0.003	176152^{**}	11.9^{**}	12.35^{*}	65.1	379.3^{**}	35.4^{**}	21573627^{**}	9.9^{*}	1.6^{ns}
Shading net × Cultivar	3	317.3	537.5	.003	764.8	0.8	7.7	36.2	3.73*	3.94^{*}	220784.8	6.4^{*}	2.1^{ns}
Error	14	235	6530.1	.002	6751.3	0.7	2.7	21.5	0.9	0.96	212527.9	1.9	1.6
Coefficient of variation %		13.6	6.4	19.9	3.1	6.3	1.1	3.7	2.9	13.6	19.5	6.6	22.4

**, * and ^{ns}: significant at 1 and 5 percent probability of error and non-significance, respectively

Table 3. Mean comparisons of the main effects of shading net and cultivar effect on chlorophyll fluorescence, microclimate, yield, and growth indicators by Tukey's method (α ≤ 0.05).

Treatments		Primary fluorescence (F_o)	Maximum fluorescence (F_m)	Quantum performance potential (F_v/F_m)	Primary fluorescence (F_o)	Canopy temperature (°C)	Leaf temperature (°C)	Canopy CO_2 (ppm)	Canopy humidity (%)	Canopy inside temperature (°C)	Vine yield (g/vine)	Total soluble solids (ºBrix)	Internode Length (cm)
Shading net	**In**	$136.1 \pm 62.6^{a*}$	474.9 ± 222.8^{b}	0.69 ± 0.06^{a}	335 ± 166^{b}	28.1 ± 1.3^{a}	28.9 ± 2.7^{a}	410.5 ± 7.3^{b}	19.7 ± 6.9^{b}	35.9 ± 2.8^{a}	4.2 ± 1^{a}	22.7 ± 2.4^{a}	2794 ± 216^{b}
	Out	137.2 ± 57.3^{a}	707.5 ± 22^{a}	0.69 ± 0.03^{a}	489 ± 171^{a}	23.7 ± 1.6^{b}	23.8 ± 1.8^{b}	437.3 ± 3.9^{a}	32.3 ± 7.6^{a}	30.5 ± 1.9^{b}	6.9 ± 1.6^{b}	18.6 ± 1.2^{b}	4613 ± 208^{a}
Cultivar	**Sahebi**	103.5 ± 7.5^{b}	434.3 ± 141.4^{b}	0.66 ± 0.03^{a}	290 ± 104^{b}	25.2 ± 2.6^{b}	25.4 ± 3.3^{b}	419.3 ± 18.1^{a}	20.8 ± 5.8^{c}	34.6 ± 3.1^{ab}	2762 ± 1608^{b}	19.9 ± 3.8^{b}	2762.3 ± 0.9^{a}
	Red Sultana	232.7 ± 27.5^{a}	939.2 ± 169.2^{a}	0.71 ± 0.04^{a}	666 ± 145^{a}	25 ± 2.7^{b}	25.6 ± 1.7^{b}	424 ± 16.8^{a}	37.8 ± 7.6^{a}	29.6 ± 2.6^{c}	6547 ± 2184^{a}	22.6 ± 3.1^{a}	6547 ± 2.8^{a}
	Red Asgari	112.5 ± 7.6^{b}	516.7 ± 128^{b}	0.69 ± 0.06^{a}	357 ± 95^{b}	28 ± 2.1^{a}	28.5 ± 3.6^{a}	427 ± 13.6^{a}	23.8 ± 7.4^{b}	33.4 ± 2.3^{b}	2682 ± 1457^{b}	20.4 ± 1.5^{b}	2682 ± 1.4^{a}
	Mish Pestan	98.2 ± 11.6^{b}	474.7 ± 137^{b}	0.72 ± 0.04^{a}	335 ± 85^{b}	25.3 ± 2.8^{b}	26 ± 4.3^{b}	425.3 ± 13.6^{a}	21.5 ± 7.3^{c}	34.9 ± 4.4^{a}	2824 ± 1170^{b}	19.8 ± 1.6^{b}	2824 ± 2^{a}

* :The presence of at least one common letter indicates no significant difference.

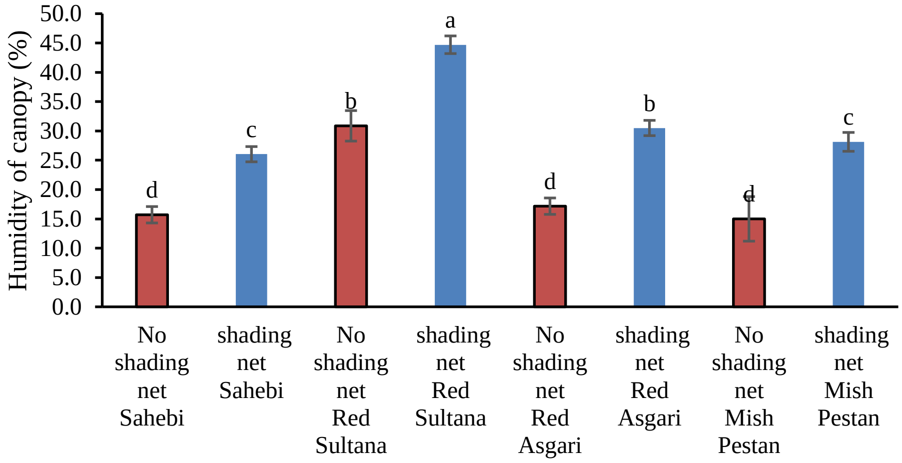

Fig. 5. Mean comparisons of the interaction effects of the cultivar × shading net on the humidity inside the canopy by Tukey's method (α ≤ 0.05).

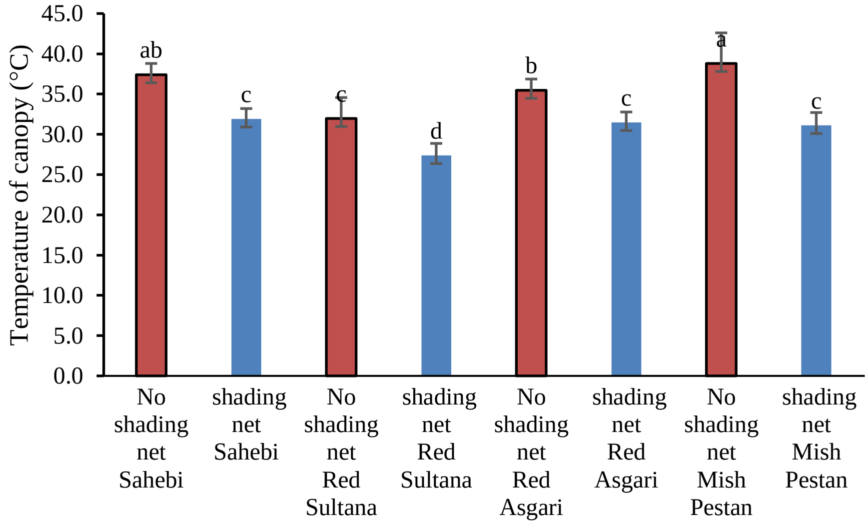

Fig. 6. Mean comparisons of the interaction effects of the cultivar × shading net on the internal canopy temperature by Tukey's method (α ≤ 0.05).

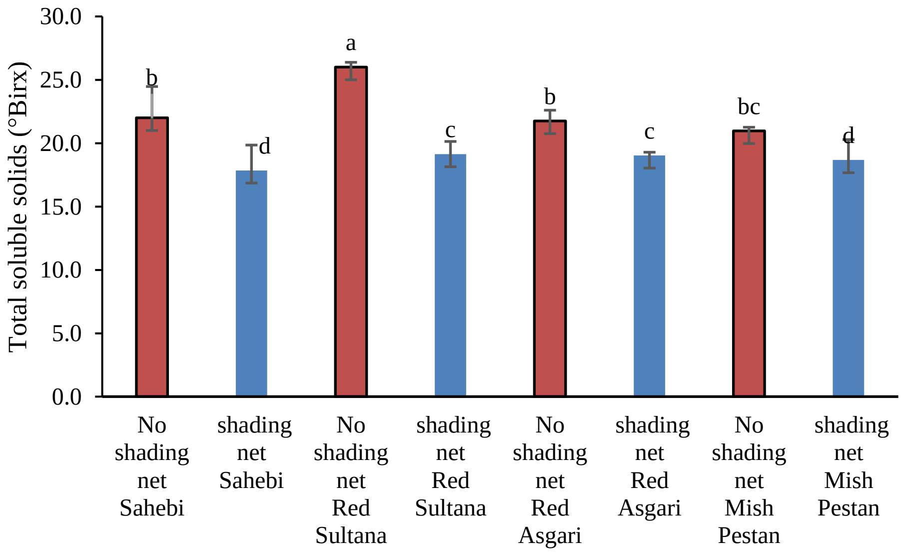

Fig. 7. Mean comparisons of the interaction effects of the cultivar × shading net on the TSS by Tukey's method (α ≤ 0.05).

The factor analysis of the traits revealed that the first factor (F1) and the second factor (F2) had the highest eigenvalues, explaining 58.45% and 23.19% of the variance, respectively. Collectively, these two factors accounted for 81.64% of the total variation observed in the traits (Table 4 and Fig. 8).

Table 4. Eigenvalues, changes, and cumulative changes of factors in factor analysis based on principal components analysis.

Factors	F1	F2	F3	F4	F5	F6	F7
Eigenvalue	7.015	2.783	1.026	0.623	0.486	0.054	0.014
Variability (%)	58.455	23.194	8.551	5.193	4.046	0.447	0.114
Cumulative (%)	58.455	81.648	90.199	95.393	99.439	99.886	100.000

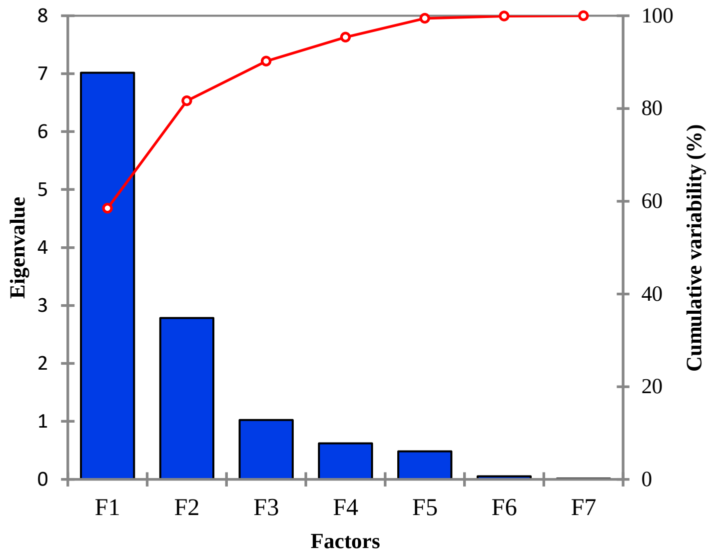

Fig. 8. Scree plot of eigenvalues and changes of factors based on principal components analysis.

The factor loadings of the traits following varimax rotation are presented in Table 5. The traits of initial fluorescence, maximum fluorescence, variable fluorescence, and humidity and temperature inside the canopy exhibited the highest correlation coefficients with the first factor. In contrast, quantum yield potential, canopy temperature, leaf temperature, canopy CO_2 levels, internode length, TSS, and vine yield demonstrated the highest correlation coefficients with the second factor. Figure 9 illustrates the relationships between the studied traits and the first and second factors. Specifically, the first factor highlights a strong internal relationship among traits associated with chlorophyll stress and moisture levels, while the second factor emphasizes the internal connections among traits related to growth, including photosynthesis (carbon dioxide), growth metrics, and yield.

Table 5. Factor loadings of traits in F1 and F2 factors after varimax rotation analysis based on principal components analysis.

Variables	F1	F2
Primary fluorescence (F_o)	**0.947**	0.230
Maximum fluorescence (F_m)	**0.970**	-0.239
Quantum performance potential (F_v/F_m)	0.286	**0.391**
Variable fluorescence (F_v)	**0.979**	-0.193
Canopy temperature	-0.384	**0.834**
Leaf temperature	-0.348	**0.797**
Canopy CO_2	0.294	**-0.877**
Canopy humidity	**0.885**	-0.453
Canopy inside temperature	**-0.774**	0.588
Internodal length	0.305	**-0.862**
Total soluble solids	0.223	**0.914**
Vine yield	0.473	**-0.536**

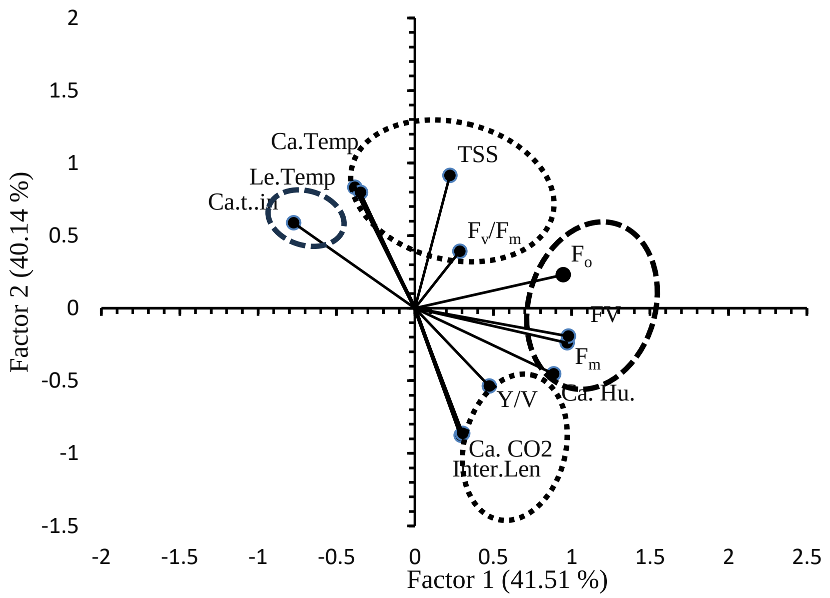

Fig. 9. Biplot of the traits correlation with the first and second factor after varimax rotation, Ca.T.In: Canopy temprature inside, Le. Temp: Leaf temperature, Ca.Temp: Canopy temprature, TSS: Total soluble solids, F_v/F_m: Quantum performance potential, F_o: Primary fluorescence, F_v: Variable fluorescence, Fm: Maximum fluorescence, Ca. Hu.: Canopy humidity, Y/V: Yield per vine, Ca. CO_2: Canopy CO_2, Inter. Len: Internode length.

Discussion

A general review of the results obtained from both the data logger and manual recordings revealed a significant decrease in canopy, leaf, and microclimate temperatures under the shading net compared to conditions outside the shade for the studied cultivars. In other words, the shading net contributed to cooling the environment, thereby reducing thermal stress. This finding aligns with the results of Oliveira et al. (2014), who demonstrated that shading nets significantly reduced light radiation in the canopy and alleviated water stress in grapevines. Similarly, research conducted by Cataldo et al. (2021), which investigated the effects of kaolin and shading nets on the ecophysiology, quantitative, and qualitative yield of the Sauvignon Blanc grape cultivar, indicated that a 70% shading net, combined with kaolin, mitigated negative water potential and lowered bud temperatures. Thus, it can be concluded that the use of shading nets effectively reduces temperatures both outside and inside the canopy, thereby diminishing the adverse effects of high temperatures during hot days in the growing season.

In this study, the shading net resulted in a significant increase in maximum and variable fluorescence compared to conditions without the shading net. However, there were no significant effects on primary fluorescence or quantum yield potential. Wu et al. (2018) reported that shading nets with a shading coefficient of less than 45% did not significantly affect photochemical efficiency or potential activity (Fv/Fo), which is consistent with the present findings. However, as the shading coefficient increased, both photochemical efficiency and potential activity declined. Furthermore, Greer and Weedon (2013) noted that the photosynthesis coefficient decreased by 35% in Semillon grapes grown outside compared to those grown under shading nets.

Given that the balance between nutrient consumption and the production of energy-generating substances is influenced by heat and drought stress, any imbalance can be identified through measurements of chlorophyll fluorescence (NadeAli et al., 2009). The significant increase in maximum and variable fluorescence, coupled with no significant changes in initial fluorescence and quantum yield potential, indicates a reduction in heat and drought stress, as well as less degradation of leaf chlorophyll, under shading net conditions (Paknejad et al., 2007).

In the present study, the shading net significantly increased yield in most cultivars. Specifically, the evaluation of the shading net's impact on the quantitative and qualitative yield of Red Sultana grapes demonstrated that white and green shading nets with a shading factor of 30% increased cluster weight by 107.2% and 141.8%, respectively, in the Takestan region (Rasoli et al., 2022). Similarly, Oliveira et al. (2014) reported a significant increase in yield for the Touriga Nacional grape cultivar when a shading net was used. Additionally, Serat and Kulkarni (2015) found that green shading with a 30% shading factor increased cluster weight, yield per hectare, and various yield components in the Thompson Seedless grape cultivar. Leghari et al. (2019) also noted that a shading net with a porosity of 50% improved yield and its components in the raisins grape cultivar. These findings indicate that the color of the shading net, the shading coefficient, and the grape cultivar significantly influence yield and its components.

Conversely, the present research observed a reduction in TSS in most cultivars under shading. This suggests that the shading net delayed fruit ripening. For instance, Pagay et al. (2012) noted that semi-permanent netting for birds significantly decreased TSS, pH, and color in the French Cabernet grape cultivar, corroborating the findings of the present study. In contrast, Serat and Kulkarni (2015) reported that the highest TSS, total sugar, reducing sugars, and the TSS to acidity ratio occurred in the Thompson Seedless grape cultivar when grown without shade, as compared to those under green shading with porosities of 30% and 50%. Increased ambient heat and the absence of shade promote higher carbohydrate compounds (such as fructose, sucrose, and glucose) (Pillet et al., 2012). Consequently, the accumulation of sugar content and the enhancement of fruit quality are delayed when utilizing a shading net. To expedite sugar content increase and early ripening, especially in table grape cultivars, removing the shade is essential for effective marketing.

The factor analysis revealed a positive internal relationship between yield and TSS, placing them within the same factor. The delay in TSS accumulation and fruit ripening significantly contributed to the increase in yield, underscoring the effectiveness of the shading net. These findings are consistent with those reported by Oliveira et al. (2014) and Serat and Kulkarni (2015).

Furthermore, the present research indicated that vine growth improved due to an increase in internode length across all cultivars under the shading net compared to conditions outside it. Jafary et al. (2022) found that a green shading net with a porosity of 50% positively affected the growth of the Rish Baba grape cultivar. However, Wu et al. (2018) demonstrated that a shading net with 45% shading did not significantly affect the growth of Yinhong grapes in a pot experiment, and gradual increases in shading beyond 45% led to reduced vine growth. One of the key indicators of enhanced growth and reduced drought stress is the increase in internode length, although this response varied among grape cultivars. The experimental environment (farm or greenhouse) also plays a crucial role in these outcomes (Heuvel et al., 2004).

The reduction in photosynthetic activity associated with high shading coefficients likely influences the vegetative growth of the vine and the accumulation of reserves. In particular, lower carbohydrate production that can be transported to the trunk and other organs may negatively affect growth in subsequent seasons, as this growth heavily depends on stored reserves (Yang et al., 1980; Keller et al., 1995). McArtney and Ferree (1999) observed that a high level of shading (70% and above) from flowering to harvest decreased root dry weight in treated vines. Furthermore, shaded plants exhibited lower concentrations of soluble sugars and amino nitrogen in the xylem in subsequent years, leading to a greater reliance on root sugars for growth. This reliance, combined with a decrease in the number and size of leaves, ultimately reduced the total leaf area in the following year (Greer et al., 2010).

Conclusions

The results of the present study indicated that the use of a green shading net with a 50% shading rate significantly decreased canopy, leaf, and microclimate temperatures while simultaneously increasing humidity beneath the shading net. This cooling effect on the environment led to a reduction in thermal stress, which was evidenced by a notable increase in maximum fluorescence and variable fluorescence under the shading net compared to conditions outside of it. These changes are indicative of reduced heat stress.

Additionally, the shading net promoted vegetative growth, resulting in a significant increase in vine yield for most cultivars. However, the use of the shading net also reduced the TSS content of the grapes, suggesting that the fruit took longer to reach the necessary TSS levels for harvesting.

In this context, two distinct approaches can be considered: (a) If the goal is to market the product quickly for fresh consumption, it is advisable to remove the shading net during the veraison stage to prevent delays in TSS accumulation. (b) Conversely, if the objective is to produce fruit for late-season harvesting and subsequent cold storage for off-season consumption, maintaining the shade until harvest can be beneficial, as it may enhance the storage life of the product. (c) In regions with high altitudes where sunburn is a concern, as well as in areas characterized by high average temperatures, it is recommended to retain the shading net until the crop ripens.

Acknowledgments
The authors express their gratitude to the head of the Agricultural and Natural Resources Research Center of Qazvin Province, the head of the Temperate Fruit Research Center, and all the experts and technicians of the biological laboratory for their invaluable cooperation during the experimentation process. This research did not receive any specific grant from funding agencies in the public, commercial, or non-profit sectors.

Conflict of Interest
The authors indicate no conflict of interest in this work.

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