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Effects of Photo-selective Shade Net Color and Shading Percentage on Reducing Sunburn and Increasing the Quantity and Quality of Pomegranate Fruit

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ABSTRACT

A prevalent problem in pomegranate fruit (*Punica granatum* L.) is sun damage that decreases the quantity and quality of fruit. The objective of the current research was to evaluate the effects of different photo-selective shade net colors and shading percentages on growth traits and pomegranate fruit quality for two years (2019 and 2020). Plots of pomegranate trees (cv. Malase Saveh) were covered to full canopy with two colors of photo-selective shade nets (white and green) and with two shading percentages (30 and 50%), compared to uncovered plots (control). The experiment was carried out in the Saveh region in the same orchard at the time of fruit set (10 June) and the shading treatments were maintained on the trees for four months. The findings showed that shade nets increased relative leaf water content while decreasing temperature and light intensity in the canopy, compared to the control. Pomegranates under nets had a much higher fruit weight and yield than those on uncovered trees. The percentage of sunburn on fruits was dramatically reduced when a shade net was used. In uncovered trees, the percentage of sunburn was 27.85%, whereas in shade treatments, the percentage of sunburn was 0 - 4.5%. The white shade net allowed 50% PAR (Photosynthetically Active Radiation) and caused the highest fruit weight, juice percentage, aril weight and yield, maximum color of fruits and arils, as well as the lowest level of proline content among the shading treatments. The highest values of total anthocyanin (55.13 mg/100 mL), total phenolics (34 mg GAE/100 mL) and vitamin C (21.32 mg/100 mL) were observed after using the white shade net of 50% PAR. As a result, this type of net is recommended for pomegranate orchards because of its efficiency in improving yield and marketable fruits.

Introduction

The current increase in global warming has posed severe challenges to food production, particularly in arid and semi-arid regions such as Iran. The increase in air temperature, solar radiation intensity (Meena et al. 2016), a significant

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reduction in annual nighttime temperatures, the increase in the number of annual hot summer nights (Alexander et al. 2006; Howden et al. 2007), and a decrease in water resources are only a few of the concerns in the 21st century (Zhou et al. 2018). Warm climatic conditions cause a significant rise in transpiration rate due to decreased photosynthetic activity and negative impacts on plant development (Zhou et al. 2018). Pomegranate (*Punica granatum* L.) is a species of the Punicaceae family. It is one of the most popular table fruits in the world, due to its delicious juice and nutritional and medicinal advantages. This fruit crop is highly adaptable, since it grows well in hot, Mediterranean, and even temperate climates. Pomegranates have a high economic value in Iran because they have one of the largest cultivation areas in the world. However, pomegranate sunburn is a major challenge in the warm climate of the pomegranate orchard (Kale et al. 2018). Sunburn is a physiological problem caused by high temperatures and strong direct sunlight, and it harms all quality parameters of pomegranate fruit (Lal et al. 2017; Meena et al. 2016). Sunburn happens mostly on the surface of pomegranate fruits when the temperature rises above 35 °C. In some locations, the rate of sunburn damage is estimated to be as high as 40% to 50% (Yazici and Kaynak, 2009). Protecting crops from excessive sun radiation and enhancing the thermal climate requires covering the fruits with specific fabric, paper bags, or shade nets. To decrease sunburn, many strategies have been explored, such as boosting humidity surrounding the plant, using cloth or paper bags to cover fruits, and using reflective materials. The latter and chemicals are favored because of the convenience they offer in application. Nonetheless, their use in food products remains yet to be ideal (Kalcsits et al. 2017). Humans are now attempting to modify and improve the morphology and physiology of plants by controlling the environment in which they grow. To achieve the same goals, shade nets have been employed to increase the quantity and quality of fruits on trees (Stamps 2009). Photo-selective shade nets are a novel agro-technological idea that combine physical protection with sun radiation differential filtering (Jokar et al. 2021). Their efficiency has been examined in different crops, climate zones, and production systems (Shahak 2006). Color shade nets provide maximum protection and indirectly enhance tolerance to climate change and global warming, while offering the possibility of differential screening of solar radiation (Abul-Soud et al. 2014). These nets provide a protective shield layer and adjust the microclimate without reducing light quality (Briassoulis et al. 2007; Stamps 2009). The efficiency of shade nets is determined by commercial shading statistics, which measure a net's ability to either reflect or absorb solar rays (Castellano et al. 2008). Photo-selective shade nets affect the growth and development of crops, at stages such as fruit set, harvest time, fruit production, while affecting fruit size, color, internal and exterior features, thereby reducing the risk of physiological illnesses (Racsko et al. 2012). Many studies have discovered that using colored shade nets can improve tree health, photosynthesis, fruit quality, fruit diameter, and harvest time (Arthurs et al. 2013). The application of red and blue photo-selective nets on peach trees (Shahak 2006) resulted in a 30% increase in production while also improving fruit size and juice. In Iran, an experiment with yellow shade nets on fig trees enhanced leaf relative water content, chlorophyll and carotenoid contents, fruit antioxidant activity, anthocyanin content, and titratable acidity, but reduced dry fruit diameter (Jokar et al. 2021). According to Kale et al. (2018), using a black shade net (50%) from May to August (until harvest time) caused a rich red color on the pomegranate peel and arils. Also, it decreased the sunburn to 2.9%, compared to 17% on trees without any cover. Since the available literature has not reported on the use of shade nets and its influence on quantitative and qualitative characteristics of pomegranate fruits in dry, hot regions in Iran, the current research aimed to assess sunburn damage on pomegranates and analyze the effects of netting color and shading percentage on the quantitative and qualitative features of 'Malase Saveh' pomegranate fruit.

Materials and Methods

Experimental design and netting characteristics

This experiment was performed in two growing seasons (2018–2019 and 2019–2020) on six-year-old pomegranate trees (cv. "Malase Saveh") under hot and dry climatic conditions. Trees were spaced at 4 × 5 m in sandy soils located in an orchard in Saveh, Iran (35°02' N, 50°35' E). Standard horticultural practices were applied to pomegranate trees. Irrigation and fertilizer were applied using a drip irrigation system. The experiment was set up as a three-replication randomized complete block design. Each block consisted of three adjacent rows. Each plot had two trees (18 trees in total). During fruit development, two types of color shade nets (green and white) were used at two shading percentages (30% and 50% PAR). The control group consisted of trees exposed to full sunlight (i.e. open field without any treatment) (Table 1). On June 10, the nets were erected horizontally at 3 m height on each tree, where they remained for four months while the fruits matured. The canopy temperature, fruit temperature, light intensity, relative leaf water content, and leaf proline concentration were all assessed after the shade nets were installed. At the time of fruit harvest, the quantitative and qualitative properties of the fruits and fruit juice were assessed.

Table 1. The different photo-selective color shade nets used in this experiment.

Code	Net type, color, shading %
C	Control (without net)
G30%	Photo-selective net, Green, 30%
G50%	Photo-selective net, Green, 50%
W30%	Photo-selective net, White, 30%
W50%	Photo-selective net, White, 50%

Measurement of tree characteristics

Canopy and fruit temperature

Infrared thermometers (Testo 830- T2, Germany) were used for recording canopy temperature (°C) on four sun-exposed leaves and fruits collected from different sides of each tree for each replication. The measurements were carried out between 1:00 and 2:00 PM (Bijanzadeh et al. 2013).

Light intensity

From 1:00 to 2:00 PM, a solar power meter (TES, 1333) was used for measuring light intensity at a distance of 20 cm below the color sheets and across the tree canopy. The intensity of light was measured in lux per meter (Lux/m).

Relative water content (RWC)

After installing the nets, five well-matured young leaves were selected for RWC determination. A total of 15 uniform disks (10 mm diameter) were separated from the leaves. After measuring the fresh weight of discs by a digital scale (A&D EJ-303, Korea), they were immersed in double-deionized water for 24 hours under low light intensity to measure the turgid weight (TW). The leaf was then dried in a 70°C oven for 48 hours to obtain its dry weight (DW). The following equation was used to determine RWC (%):

$$RWC\% = \frac{(FW - DW)}{(TW - DW)} \times 100$$

Quantification of proline content

Proline content of leaves was determined as described by Bates et al. (1973). Leaf samples were powdered in liquid nitrogen, and 0.5 g of pulverized tissue was homogenized in 10 mL of aqueous sulfosalicylic acid (3% w/v). Then, the homogenate was filtered using a Whatman No. 1 filter paper. Accordingly, two milliliters of filtered extract were combined with two milliliters of ninhydrin and two milliliters of glacial acetic acid. For 1 hour, the reaction mixture was incubated in a boiling water bath, and then transferred to an ice bath. The organic phase was extracted using four milliliters of toluene added to the mixture. An ultraviolet-visible spectrophotometer (Bel Engineering, Italy) was used to measure the extract's absorbance at 520 nm, while toluene was used as a control. A calibration curve was used to calculate proline concentration, represented as micromole proline/gram fresh weight.

Measurement of fruit physical properties

The fresh weight of the fruits was measured using a digital scale (Mettler AJ50, Hong Kong) with a precision of 0.001 g. The rinds were gently sliced with a sharp knife in the equatorial zone after measuring fruit fresh weight to remove the arils. In measuring the rind weight, aril weight, and juice percentage of the fruit, the peel and arils were manually separated. Sunburned and cracking parts of the fruits were calculated (%) (ratio of sunburned and cracked fruits to total fruits on trees), and 10 fruits from each tree were randomly selected from four sides. Following a procedure used by Fawole and Opara (2013), aril color was determined. After measuring the pomegranate juice content, a 5 ml juice was centrifuged at 5000 rpm for 10 min at 4 °C to determine juice color based on the absorbance at 530 nm using a spectrophotometer. Five replicates were used for each analysis, with each replicate being made up of four fruits.

Measurement of biochemical traits of juice

TSS, TA and pH

Biochemical parameters such as pH, TSS, TA, phenols, antioxidants, and vitamin C were measured in fresh pomegranate arils. By extracting and mixing one drop of juice from each fruit into a digital refractometer (Atago NI, Japan) at 20°C, and expressing the data in percentages, the amounts of total soluble solids (°Brix) in the juice were determined. Titratable acidity was measured by titrating juice samples (5 mL) with 0.1 N NaOH to a titration endpoint of pH 8.2, which was monitored using a pH meter (Labtron)

(AOAC, 1970). The pH values of the aril juice samples were measured at room temperature using a pH meter (WTW 526, Germany) which had been calibrated to a pH range of 4 to 7.

Ascorbic acid
Ascorbic acid was determined by employing a method described by Ruck (1963). Thirty-gram portions of the homogenized sample were blended with 100 ml of 0.4% oxalic acid for 2 min in a Waring blender. The blended mixture was made up of 500 ml with 0.4% oxalic acid and filtered. The filtrate (20 ml) was titrated with standard 2,6-dichlorophenol indophenol. The results were expressed as mg per 100 ml juice.

Total phenolic content
The total phenolic content was quantified using the Folin Ciocalteu reagent (Singleton, Orthofer, & Lamuela-Raventos, 1999). Briefly, for each sample, 5 mL of pomegranate juice was mixed with 5 mL of MeOH/water (80:20 v/v) containing 2 mM NaF, and was then centrifuged at 15,000 g for 15 min. Subsequently, 50 mL of the sample was mixed with 2.5 mL of Folin Ciocalteu reagent (1:10 v/v), 450 mL of phosphate buffer (pH 7.8) and 2 mL of sodium carbonate (75 g/ L). The samples were left in a water bath at 50 °C for 5 min. Absorption values were measured at 760 nm using a spectrophotometer. The results (mean ± standard error) were expressed as milligrams of gallic acid equivalent per 100 mL of juice (mg GAE/100 mL).

Total anthocyanin content
Total anthocyanin content was measured using a spectrophotometric method, according to Rapisarda et al. (2001). Specifically, 2 mL of juice sample was diluted to a volume of 25 mL at a pH value of 1 (with 125 mL of 0.2 M KCl and 375 mL of 0.2 M HCl). A second portion (2 mL) was diluted with a buffered solution (pH 4.5) to make 25 mL. This included 400 mL sodium acetate 1 M, 240 mL HCl 1 M, and 360 mL H2O. The absorbance values of the solutions were measured at 510 nm. Anthocyanin concentrations were calculated using Equation (1):

$$C\text{mg/L} = (\text{AbspH1} - \text{AbspH4.5}) \times 484.82 \times 1000 / 24\,825 \times \text{DF}$$

Where 484.82 is the molecular mass of cyanidin-3-glucoside, 24 825 is the molar absorptive of cyanidin-3-glucoside at 510 nm in a solution (pH 1), and DF is the dilution factor.

Statistical analysis
All data were presented as an average of two years. An analysis of variance was done for the combined analysis of variance across the tests in the two years. Mean data were obtained from the two years. Data were analyzed using SAS software (SAS Version 9.4; SAS Institute Inc., Cary, NC, USA.) and significant differences among the mean values were compared by Least Significant Difference (LSD) at $p<0.05$.

Results
Canopy temperature
The findings revealed that different colored shade nets had significant effects on environmental conditions as well as qualitative and quantitative aspects of pomegranate fruits. The color of the shade net and the shading level had significant effects on temperature and light intensity, according to the current research. As shade levels increased, the temperature and light intensity decreased (Fig. 1, 2 and 3). According to these findings, the average canopy temperature under both color shade nets reduced (Fig. 1) when compared to the control, notably during the warm months of the year (July, August, and September) (Fig. 1). In terms of mean canopy temperature, there were considerable variations between the shading treatments. Shading had a significant effect on canopy temperature. The control treatment had the maximum mean temperature (42.8 °C) in July, whereas shade net treatments caused the lowest temperature (25 °C). Furthermore, from June to September, green shade nets had lower canopy temperatures than white shade nets, and canopy temperatures became lower as a result of the 50% PAR shade nets, compared to those by the 30% PAR shade nets (Fig. 1).

Fruit temperature
During the two years, a significant difference in the mean temperature of the fruit surface was detected (Fig. 2). Green shade nets had a much better effect on reducing fruit temperature than white shade nets, especially when using the 50% PAR. In July, fruits of the control treatment had the highest mean temperature (47.2 °C) compared to the other treatment groups, whereas fruit temperatures ranged from 36.22 to 38.3 °C under the green and white shade nets with 50% PAR.

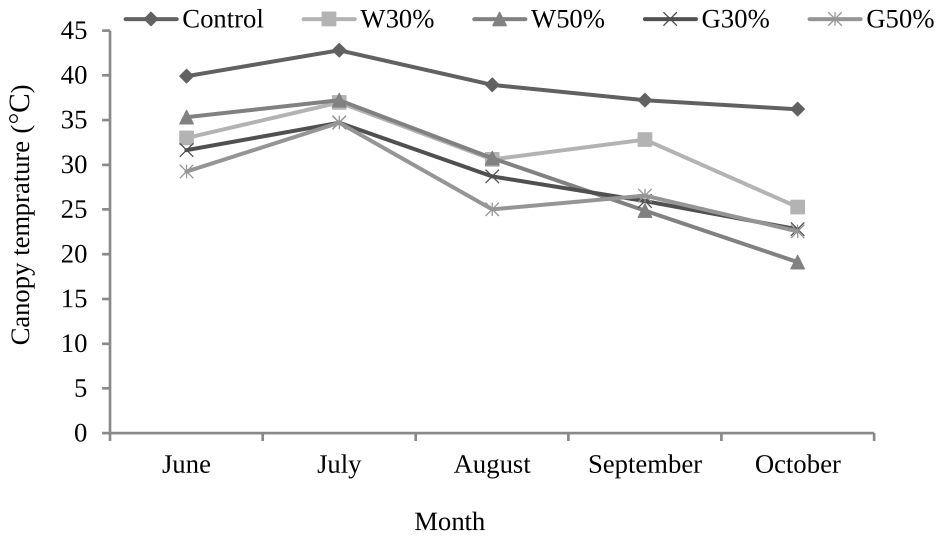

Fig. 1. Canopy temperature of pomegranate trees under different photo-selective color shade nets (mean values of the two-year period). C: control (without net), G30%: 30% green photo-selective net, G50%: 50% green photo-selective net, W30%: 30% white photo-selective net, W50%: 50% white photo-selective net

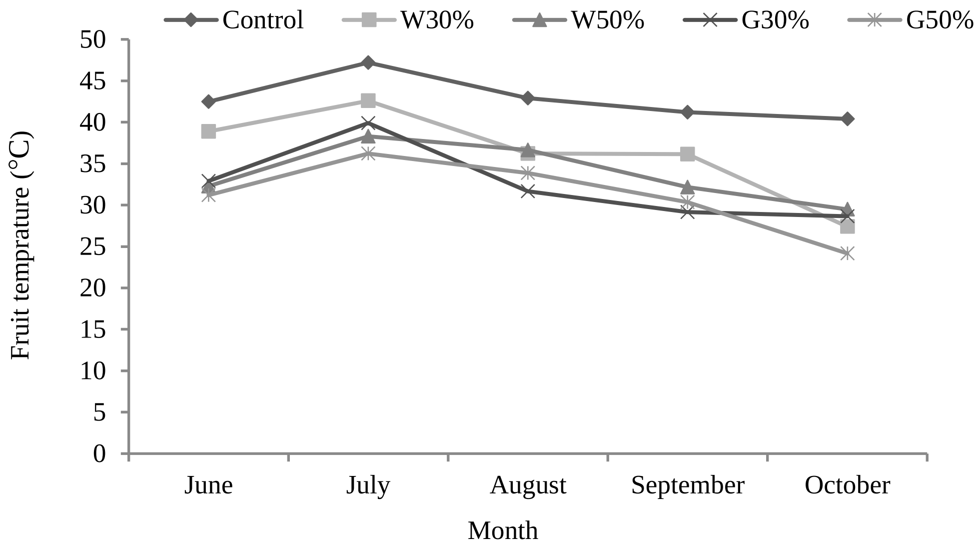

Fig. 2. Fruit temperature of pomegranate trees under different photo-selective color shade nets (mean values of the two-year period). C: control (without net), G30%: 30% green photo-selective net, G50%: 50% green photo-selective net, W30%: 30% white photo-selective net, W50%: 50% white photo-selective net

Light intensity

In trees covered with the shade nets, the mean light intensity dropped considerably (400 to 800 Lux/m), compared to the control (Fig. 3), and the minimum light intensity received by trees covered with the green shade net decreased by 50%. During the hot summer months, the monitoring of light intensity revealed that trees of the control group received maximum light intensity (about 1020 lux/m), whereas this parameter was 264.83 and 521.5 lux/m in trees covered with the white shade net (50% PAR) and the green shade net (50% PAR), respectively.

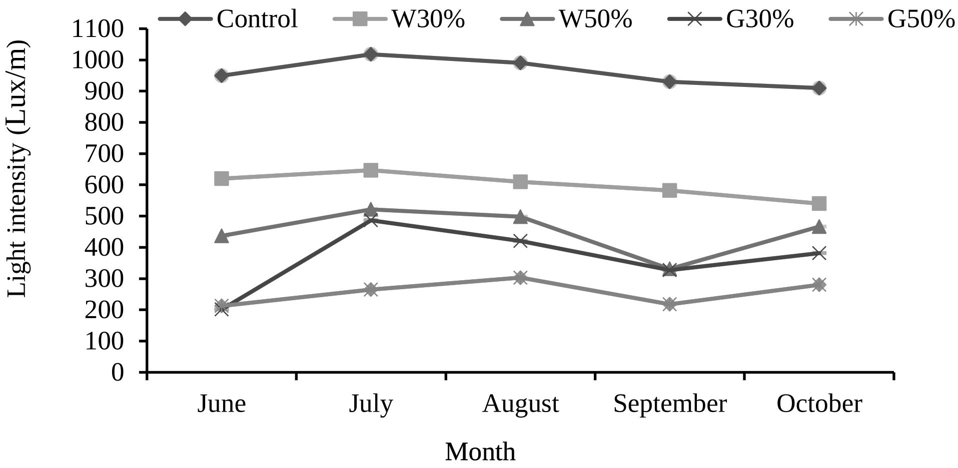

Fig. 3. Sunlight intensity on tree canopy under different photo-selective color shade nets (mean values of the two-year period). C: control (without net), G30%: 30% green photo-selective net, G50%: 50% green photo-selective net, W30%: 30% white photo-selective net, W50%: 50% white photo-selective net

Relative water content (RWC)

In both months of June and July, covering the trees with the shade nets enhanced the RWC (Fig. 4). There was a considerable increase in RWC underneath the white and green shade nets, compared to the control. The RWC had higher values by the effect of green shade nets, compared to white shade nets. As a result of using both nets, the RWC had higher values by the effect of 50% PAR, compared to the 30% PAR. Green netting resulted in the highest RWC (91.7 and 92.6%) in response to 50% PAR in both years, whereas pomegranate trees that received full solar light had the lowest RWC percentage (69.47 and 76.19%, respectively) (Fig. 4).

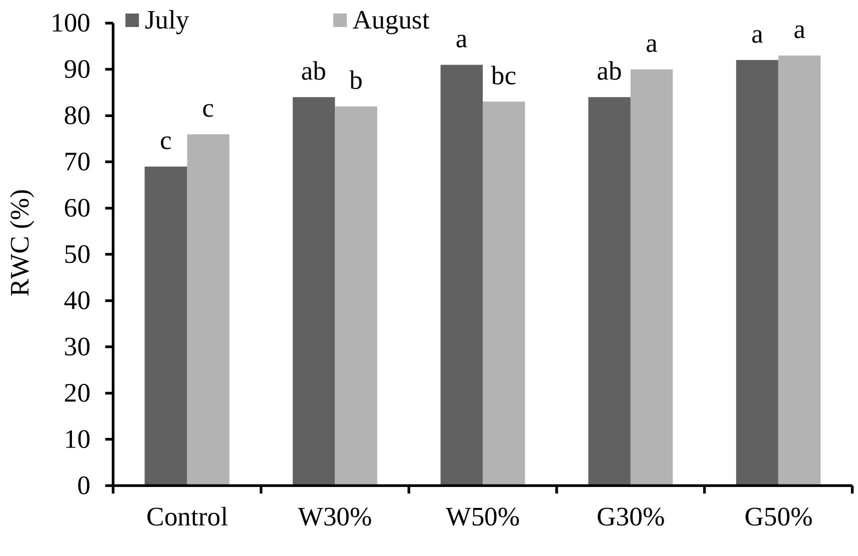

Fig. 4. Relative water content of pomegranate leaves under different photo-selective color shade nets (mean values of the two-year period). Different letter(s) on the bars indicate statistically significant differences (P<0.05). C: control (without net), G30%: 30% green photo-selective net, G50%: 50% green photo-selective net, W30%: 30% white photo-selective net, W50%: 50% white photo-selective net

Proline levels

Significant differences were observed in the concentrations of free proline in the pomegranate leaves under colored shade nets, compared to the control group (Fig. 5). According to the findings, the amount of proline in the covered trees declined significantly compared to the uncovered trees. The lowest proline concentrations were found in response to the 50% white shade nets (0.283 μmol/g FW) and 50% green shade nets (0.253 μmol/g FW), respectively. The highest levels of proline were found in trees of the control group and in trees covered with 30% PAR of both color shades.

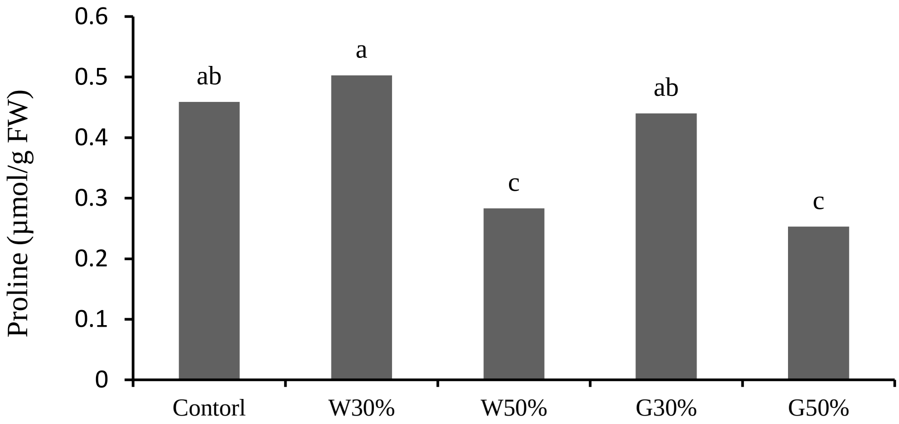

Fig. 5. Proline concentration of pomegranate leaves under different photo-selective color shade nets (mean values of the two-year period). Different letter(s) on the bars indicate statistically significant differences ($P<0.05$). C: control (without net), G30%: 30% green photo-selective net, G50%: 50% green photo-selective net, W30%: 30% white photo-selective net, W50%: 50% white photo-selective net

Sunburn and crack of pomegranate fruits

The percentage of sunburned pomegranate fruits was significantly reduced as a result of using the color shade nets. The most effective net for minimizing fruit sunburn was the green shade net (Table 2). Control fruits exhibited the highest percentage of sunburn (27.85%), and small percentages of sunburn (3 - 4.5%) were observed in fruits of trees under the 30% PAR shade nets of both colors. However, no sunburned fruit was observed under the 50% PAR shade nets. It was observed that the color and the percentage of shade had a significant effect on the percentage of fruit cracks (Table 2). The use of green color nets (50% PAR) resulted in a greater percentage of cracked fruits (15%), whereas trees under the white net had lower percentages of cracked fruits (8%), which were almost similar to that of the control (7%).

Table 2. Percentage of sunburn and cracking of pomegranate fruits under different photo-selective color shade nets (mean values of the two-year period).

Color net	Sun burn (%)	Cracking fruit (%)
C	27.85^{a*}	7.2^{c}
W30%	4.5^{b}	8^{c}
W50%	0^{c}	8.5^{c}
G30%	3^{b}	11.5^{b}
G50%	0^{c}	16^{a}

* Different letters in the same column indicate statistically significant differences. C: control (without net), G30%: 30% green photo-selective net, G50%: 50% green photo-selective net, W30%: 30% white photo-selective net, W50%: 50% white photo-selective net

Fruit physical properties

Compared to the control, colored shade nets improved fruit weight, yield, 100-aril weight, and fruit juice of trees under the covering (Table 3). Fruits grown under 50% PAR white net had the highest fruit weight, 100-aril weight, and juice percentage (395.4, 44.7, and 49.4%, respectively), whereas fruits growing without the nets had the lowest of these values (Table 3). Colored shade nets on the pomegranate trees increased their yield, compared to the case of uncovered trees, with a maximum yield of 29.7 kg/tree under the effect of 50% PAR white net and a minimum yield of 19.5 kg/tree in the control group (Table 3). Additionally, all cover treatments led to pomegranate fruits with darker aril colors than the control (Table 3).

Table 3. Physical properties of pomegranate fruits under different photo-selective color shade nets (mean values of the two-year period).

Color net	Fruit weight (g)	100 Aril weight(g)	Juice percentage (%)	Yield (kg/tree)	Aril Color (Abs. 520 nm)
C	301.3[bc*]	35.6[bc]	43.20 [c]	19. 5[c]	2.6[b]
W30%	359.3[ab]	40.9[ab]	46.08 [ab]	25.6[b]	3.7[a]
W50%	395.4[a]	44.7[a]	49.41 [a]	29.7[a]	4.1[a]
G30%	348.4[abc]	36.5[bc]	48.26 [ab]	22.3[bc]	3.7[a]
G50%	308.4[bc]	36.23[bc]	47.03 [ab]	21.8[bc]	3.7[a]

* Different letters in the same column indicate statistically significant differences. C: control (without net), G30%: 30% green photo-selective net, G50%: 50% green photo-selective net, W30%: 30% white photo-selective net, W50%: 50% white photo-selective net

Quality traits of pomegranate juice and proline content

Compared to the uncovered trees, using colored shade nets decreased the Total Soluble Solids (TSS) and Titrable Acidity (TA) of pomegranate fruits, although these reductions were not significant among shading treatments and the control (Table 4). The maximum TSS (16.03), TA (0.61), and lowest pH (3.08) were found in fruit juice of the uncovered fruits, whereas the lowest TSS (15.35-15.41) and TA (0.53-0.453) concentrations were found under the green shade nets (30 and 50%). Table 4 shows that the taste index of fruits (TSS/TA) under the effect of the white shade nets (30 and 50%) was similar to that of the uncovered fruits, although the 50% green shade net caused a higher taste index of fruits. The pH increased under the color shade nets as compared to the uncovered fruits; however, this decrease was not significant. Fruits in full sunlight and trees with white shade nets had the lowest pH values, whereas fruits under the green shade nets had the highest pH values (3.23-3.30). Furthermore, covering the trees with 30 and 50% PAR shade nets significantly increased the total anthocyanin content in the fruit juice (Fig. 6). Although white shade nets had a better effect on total anthocyanin content than green shade nets, the percentage of shading was not effective in this regard. The highest amount of total anthocyanins was observed in the fruits of trees covered with white shade nets (55.13 mg/100ml), while the lowest content of total anthocyanin was found in fruits of pomegranate trees without the covering (35.9 mg/100ml).

Table 4. Juice quality of pomegranate fruit under different photo-selective color shade nets (mean values of the two-year period).

Color net	Total Soluble Solid (°Brix)	TA(%)	Taste (TAA/TA)	pH
C	16.03[a]	0.61[a]	26.28[c]	3.08[bc]
W30%	15.36[ab]	0.563[ab]	27.28[bc]	3.18[ab]
W50%	15.53[ab]	0.596[a]	26.06[c]	3.09[bc]
G30%	15.35[ab]	0.53[abc]	28.96[bc]	3.23[ab]
G50%	15.41[ab]	0.453[bc]	34[a]	3.3[a]

* Different letters in the same column indicate statistically significant differences. C: control (without net), G30%: 30% green photo-selective net, G50%: 50% green photo-selective net, W30%: 30% white photo-selective net, W50%: 50% white photo-selective net

The amounts of total phenolics in the fruits treated with color shade nets increased compared to the control, but statistically, there were no significant differences among the treatments (Fig. 6). White shade nets caused better amounts of total phenolics than green shade nets. The white shade net of 50% PAR showed the highest concentration of total phenolics (34 mg GAE/100 ml), whereas the direct sunlight in the control group caused the lowest amount of total phenolics (23.1 mg GAE/100 ml). The results indicated that covering pomegranate trees with both color shades increased the amounts of vitamin C in the pomegranate fruit, but the color and percentage of shading had no effect on this increase (Fig. 6). Uncovered pomegranate trees had the lowest vitamin C content (17.01 mg/100ml), whereas fruit trees covered with white shade nets of 50% PAR had the highest vitamin C content (21.32 mg/100ml). Consequently, the uncovered fruits (control) and the white 50% PAR net resulted in the lowest and highest total anthocyanin content, total phenolics, and vitamin C levels, respectively.

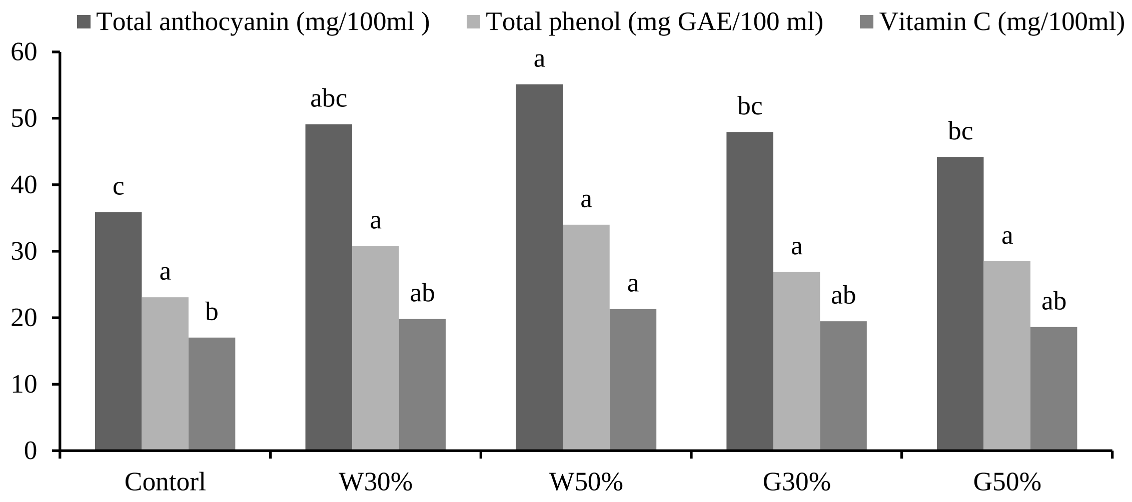

Fig. 6. Biochemical characteristics of pomegranate juice under different photo-selective color shade nets (mean values of the two-year period). Different letter(s) on the bars indicate statistically significant differences (P<0.05). C: control (without net), G30%: 30% green photo-selective net, G50%: 50% green photo-selective net, W30%: 30% white photo-selective net, W50%: 50% white photo-selective net

Discussion

In this study, the average temperatures of the fruits and the canopy of trees under color shade nets were considerably lower than those of control trees. Also, green shade nets with a PAR of 50% showed the highest effects on canopy temperature, compared to white shade nets with a PAR of 30%. According to Mahmood et al. (2018), shade netting decreases the entry of solar radiation, and thus has a high potential for moderating canopy temperature. Net shading caused a decrease in canopy temperature in this study. This drop in temperature was due to the decrease in radiation since the solar rays were intercepted by the nets (Iglesias et al. 2006). According to our findings, utilizing shade nets resulted in a temperature drop of 5-10°C, as confirmed by Iglesias et al. (2006). Stamps (2009) reported similar findings, indicating that photo-selective nettings can decrease the quantity of radiation, thereby reaching the crops underneath. Similarly, Ilić et al. (2017) found that color shade nets could reduce light intensity during the summer season when compared to the natural habitat.

In this study, shade treatments considerably enhanced the leaf relative water content (RWC) of trees growing under shade nets, compared to the control. Our findings matched those of Tinyane et al. (2018) who reported that the relative water content of apple leaves growing under shade nets was 3.24–12.9% higher than the control treatment. Sunburn is a critical challenge in producing pomegranate fruit. This includes brown sunburn with black patches and black sunburn, two cases that reportedly occurred when the fruit surface temperature reached 35, 40, and 45 ° C, respectively (Yazici et al. 2006). The findings of this study clearly showed that the use of white and green shade nets significantly reduced the frequency of sunburn. Trees of the control group had the highest percentage of sunburn (27.85%) compared to shade treatments. According to the findings, the 50% shade treatment was more efficient than the 30% shading in preventing sunburn. The 50% shading resulted in lower temperatures of the fruits and the canopy, according to previous studies, and might be an alternative for reducing heat stress in a prolonged summer season scenario from June to September. Meena et al. (2016) reported similar results in pomegranates. Also, Helyes et al. (2007) observed similar results in tomatoes. Sunburn of pomegranate fruits was 3.8, 4.6, 3.2, and 4.4% under red shade nets (50%), green shade nets (50%), dark shade nets (50%), and green shade nets (35%), respectively, whereas 8.4% sunburn was detected in the control samples (Meena et al. 2016). Since dark nets decrease light transmission, they appear to be more effective than white nets in avoiding sunburn injury (do Amarante et al. 2011). Our results showed that the dramatic decrease in temperature and light intensity, as well as an increase in relative water content, caused an increase in fruit cracking percentage under the 50% green shade net. The use of color shade nets had a good influence on the quantitative and qualitative characteristics of pomegranate fruit, according to our findings. Also, fruit weight increased under shade treatments compared to the control fruits. According to previous reports, using a shade net increased the size of the fruit, compared to the control (Mditshwa et al. 2019). Juice percentage was estimated to be higher in fruits under color shade nets and lowest in uncovered trees in this study. Thus, the lower aril weight and fruit juice percentage in the control plants might be due to a higher degree of moisture loss from the fruits.

Fruits with greater aril weight and more fruit juice were obtained under the shade net, owing to a significant decline in temperature and light intensity, as well as a reduction in water evaporation from the surface of the fruits and the prevention of sunburn. In India, under black shade nets (50%), there was a significant rise in aril weight and juice percentage compared to the control (Kale et al. 2018). The juice content of the fruit evaporates and is reduced at high temperatures on the fruit surface, which might impact the water content of the rind and arils (Ehteshami et al. 2011). Furthermore, the maximum yield of 29.7 kg in the white shade net (50%) was related to the highest individual fruit weight of 395.4 g and larger fruit size. The overall improvement in fruit production of the covered trees was most likely due to a reduction in the severity of heat stress throughout the summer season, whereas fruits grown in open fields were exposed to direct sunlight and absorbed high temperatures during harsh summers, leading to lower yields (Shahak 2006). Fruit yield decreased in trees with green shade nets compared to plants with white shade nets in this study. The percentage of cracked fruits increased and productivity declined under the green shade nets, owing to a considerable decrease in temperature and light intensity, thereby creating a humid environment, especially during fruit harvest. The white shade net significantly outperformed the green shade net and the control treatment, thereby improving fruit and aril color. The influence of shade net color on aril color reportedly had similar outcomes. Fruits that were exposed to direct sunlight in the sun had a poor color due to the high temperature, which resulted in a low overall anthocyanin concentration. Pomegranate fruits grown under various color shade nets, mainly black, had a deep red hue, but fruits grown in the control treatment had a brilliant red color (Kale et al. 2018). The color of pomegranate fruit under the red shade was reportedly more than the other shades and the control treatment when using different colored shade nets (i.e. green, red, and black) on pomegranate fruit (Meena et al. 2016). Poor color development in fruits grown in the open field, compared to trees grown under shade nets, has been previously observed (Meena et al. 2016) and is closely associated with poor anthocyanin concentration, owing to extremely high temperatures.

Our data revealed that applying the shade treatment slightly reduced TSS and TA, but increased the pH, compared to the control group. These findings are consistent with that of Seeley et al. (1980) who found that shading decreased the amount of soluble solids in apple fruits. Moreover, under rain-fed systems, covering fig trees with blue and yellow shade nets effectively decreased the total soluble solids (Jokar et al. 2021). Furthermore, as compared with the control, photosynthetically active sunlight and canopy temperature were significantly lower by the effect of a 75% shade net (Chang et al. 2016). The decrease in TSS level under some shading mesh approaches may be due to decreased light intensity, which limits the synthesis of primary and secondary metabolites, predominantly carbohydrates (Mditshwa et al. 2019). Jokar et al. (2021) reported that utilizing yellow netting on two fig cultivars reduced titratable acidity in the fruits.

In this study, the taste index exhibited high values under the green shade, but showed low levels under the white shades and in the uncovered fruits. According to a similar study, Mditshwa et al. (2019) reported that TSS/TA ratios in fruits grown under 7% transparent nets were significantly smaller than those grown under 25% white nets. Compared to the uncovered fruits, the use of white and green shade nets on pomegranate trees improved the amounts of total anthocyanin, total phenolics, and vitamin C. Although the effect of lowering soil temperature and tree canopy in such conditions might be deleterious to fruit coloration, the effect of limiting photosynthetic active radiation under shade nets can be the most significant cause of decreasing heat stress. As a result, it increases anthocyanin accumulation and improves fruit and seed color, thereby possibly increasing anthocyanin production (Arena et al. 2016). Shade nets provide a physical barrier and have a good impact on the production of fruit pigments such as anthocyanins (García-Sánchez et al. 2015). According to a previous study, yellow nets significantly increased antioxidant activity and anthocyanin concentration in fig fruits of the "Siah" cultivar (Jokar et al. 2021). Compared to sunlight-exposed control fruits, the total phenolics content in shaded fruits was slightly but not significantly higher. The biosynthesis of phenolic compounds is reportedly influenced to a significant extent by the quality and quantity of light (Johkan et al. 2013). Because the level of phenolic compounds in immature fruits is usually higher, and gradually declines over the growing season, the increase in total phenolic content under the shade net might be attributable to delayed maturity and fruit ripening (Kulkarni et al. 2005). The capacity of this specific shade netting design to allow penetration of far-red and red light into the canopy, an essential role in the accumulation of phenolic acids in plants, might be connected to the high phenolic content under the effect of the red net (50%) (Tegelberg et al. 2004). As a result, shades can decrease or enhance vitamin C in fruits under the shade, depending on their color and shading percentage when compared to the control. Photo-selective shade nets had a significant influence on proline content in the current research. The trees under shade nets with a 50% shading percentage had the lowest amount of proline. In fact, due to a significant reduction in temperature and light intensity received by the trees, the least amount of stress was imposed under the effect of the 50% shade in both colors, compared to the 30% shading and the control, which is consistent with earlier findings. Proline accumulation in many plants is non-toxic and functions as a stress mitigator (Yamada et al. 2005). In hot and dry years, proline accumulation in pomegranate trees has been found to increase (Halilova et al. 2009). Nasrabadi et al. (2019) also reported that in high stress situations, the quantity of proline increased considerably in pomegranate, compared to the control.

Conclusion

The findings can be used to distinguish between environmental conditions as well as the quantitative and qualitative characteristics of pomegranate fruits grown under color shade nets, compared to those grown in the full sun (without shade nets). Our findings revealed that photo-selective shade nets have a significant effect on sunburn management in "Malase Saveh" pomegranate fruits. The cooling effect of the shade nets in preventing sunburn in pomegranate fruits was largely due to the lower air temperature under the shade net being adjusted over the canopy of trees, preventing direct sunlight from striking the surface of the leaves and fruits. Shade nets created a suitable microclimate for tree physiological processes including photosynthesis by reducing light intensity and temperature. Although the net of 30% PAR decreased the damaging effects of high temperature and light when compared to the control, it is not recommended because some pomegranate fruits still suffered from sunburn and had a shorter shelf life, compared to those treated with the net of 50% PAR. In general, the white shade net (50% PAR) treatment was found to be the best shading treatment (in terms of color and shading percentage) for reducing temperature and light stress. Also, it assisted in increasing RWC, controlling sunburn, producing deep red fruits, and increasing quantitative, qualitative yield, as well as total anthocyanin, total phenolics, and vitamin C. Furthermore, the application of white shade net (50% PAR) resulted in the preservation of fruit juice and quality characteristics such as TSS, TA, pH, and flavor index. Finally, the amount of proline content that increased in plants under stress conditions was lowest under the white shade net of 50% PAR, indicating a reduction in stress in the examined trees when compared to other treatment groups and the control.

Conflict of Interests

The authors indicate no conflict of interest for this work.

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