Agrociencia

QUALITY OF STRAWBERRY (*Fragaria* x *ananassa* Duch.) FRUITS FROM PLANTS CULTIVATED UNDER COLORED SHADE NETS

Luis Alberto **Aragón-Ramírez**[1], Ana María **Castillo-González**[1*], Luis Alonso **Valdez-Aguilar**[3],
María del Rosario **García-Mateos**[1], María Carmen **Ybarra-Moncada**[2],
Edilberto **Avitia-García**[1], Efrén **Fitz-Rodríguez**[4]

[1]Universidad Autónoma Chapingo. Instituto de Horticultura, Departamento de Fitotecnia. Carretera México-Texcoco km 38.5, Chapingo, State of Mexico, Mexico. C. P. 56230.
[2]Universidad Autónoma Chapingo. Instituto de Alimentos, Departamento de Ingeniería Agroindustrial. Carretera México-Texcoco km 38.5, Chapingo, State of Mexico, Mexico. C. P. 56230.
[3]Universidad Autónoma Agraria Antonio Narro. Departamento de Horticultura. Calzada Antonio Narro 1923, Buenavista, Saltillo, Coahuila, Mexico. C. P. 25315.
[4]Universidad Autónoma Chapingo. Departamento de Ingeniería Mecánica Agrícola. Carretera México-Texcoco km 38.5, Chapingo, State of Mexico, Mexico. C. P. 56230.
* Author for correspondence: anasofiacasg@hotmail.com

ABSTRACT

Strawberry (*Fragaria* x *ananassa* Duch.) fruit has a high demand worldwide for its organoleptic and nutraceutical properties that are beneficial to human health. Colored shade nets alter the light quality reaching plants, influencing specific physiological reactions and the phytochemical composition of fruits. The present study aimed to investigate how different photoselective shade nets (black, 288 photosynthetically active radiation (PAR); blue, 429 PAR; green, 271 PAR; and beige, 519 PAR) affect the physical and biochemical quality of strawberry fruits cv. Albion. The study was conducted in a glass greenhouse in the spring-winter season of 2022. Strawberry seedlings were placed in 5-L containers in an open soilless system. A completely randomized experimental design was used, with four treatments and a control (973 PAR), with nine replicates; the experimental unit consisted of one plant per pot. The concentration of total soluble sugars, total soluble solids (TSS), phenolic compounds, anthocyanins, flavonoids, ascorbic acid, and antioxidant capacity were evaluated; as well as titratable acidity (TA), pH, and TSS/TA ratio. The results showed that the fruit's response was influenced by the color of the net. Fruits from plants grown under the blue and beige nets had 42 % higher total soluble sugars, while those under blue nets had 86 % more anthocyanins compared to the control plants. TSS values were similar in the control fruits and blue and beige nets. The fruits harvested from the beige net showed an increase of 24 % in TA and 4 % more phenolic compounds than the control. The blue and beige nets could serve as an alternate production strategy to enhance the physical and biochemical parameters of strawberry fruits.

Keywords: photoselective net, anthocyanins, antioxidant capacity, phenolic compounds.

Citation: Aragón-Ramírez LA, Castillo-González AM, Valdez-Aguilar LA, García-Mateos M del R, Ybarra-Moncada MC, Avitia-García E, Fitz-Rodríguez E. 2025. Quality of strawberry (*Fragaria* x *ananassa* Duch.) Fruits from plants cultivated under colored shade nets. **Agrociencia.** https://doi.org/ 10.47163/agrociencia.v59i1.3326

Editor in Chief:
Dr. Fernando C. Gómez Merino

Received: October 15, 2024.
Approved: January 27, 2025.
Published in Agrociencia:
January 28, 2025.

INTRODUCTION

Strawberry (*Fragaria x ananassa* Duch.) is a fruit characterized by its delicate flavor and high vitamin content (Zoratti *et al.*, 2015). The plant is cultivated in several regions from the Arctic to the tropics (Hancock, 2020), and the fruit contains a diversity of organoleptic and nutraceutical properties, including ascorbic acid, anthocyanins, and phenolic compounds, which possess a strong antioxidant capacity that is beneficial for human health (Stevenson and Scalzo, 2012). Strawberries are considered a functional food (Giampieri *et al*., 2014) and are a rich source of phenolic compounds.

Shade nets in agriculture offer protection to crops from extreme radiation, winds, or pests (Shahak, 2008), birds, hail, and viral diseases transmitted by insects (Tezcan *et al*., 2023). Black shade nets alter the amount of radiation plants receive, while color or photo-selective nets can modify light quality and enhance the transmission of specific wavelengths, potentially affecting physiological responses like photosynthesis and photomorphogenesis. The color of the nets can boost photosynthetically active radiation (PAR) or photosynthetic photon flux density (PPFD) within the range of 400–700 nm (Arthurs *et al*., 2013) and increase the phytochemical and pigment content of crops.

In coriander (*Coriandrum sativum* L.), the use of black nets increased the content of total phenols, flavonoids, antioxidant activity, and ascorbic acid in the leaves (Buthelezi *et al*., 2016). Miao *et al*. (2016) covered strawberry 'Yueli' fruits with transparent polyethylene colored filter light films (red, yellow, green, blue, and white); the fruits of the red and yellow covers had a higher content of total anthocyanins than those of the white (control), and the opposite effect was observed with the green and blue covers. With the use of red, green, and black nets with 40 % shading in strawberry plants cv. Kabarla, it was observed that all the nets increased the leaf anthocyanin content compared to the control, but with black, the content was the highest (Aras and Eşitken, 2019).

Retamales *et al.* (2008) found that utilizing colored nets altered the reproductive and vegetative patterns of *Vaccinium corymbosum* L., resulting in a 44 % increase in yield with white nets, 25 % with gray nets, and 32 % with red nets. Wang and Wang (2014) discovered that as the shading percentage increased, there was a 20 % longer duration in the flowering stage and a 13 % greater maturation of strawberry fruits; however, there were no significant effects in firmness, total soluble solids, ascorbic acid, and titratable acidity. The variability in research results suggests that the physiological responses of plants to light quality and intensity depend on the type, color, and spectral composition of the net (Kotilainen *et al.* 2018).

This study aimed to examine the impact of various colored shade nets (black, blue, green, and beige) on the physical, biochemical, and nutraceutical quality of strawberry fruits cv. Albion, and evaluate if this technology could be a feasible production method to improve these fruit characteristics.

MATERIALS AND METHODS

Plant material and growing conditions

The study was conducted in a glass greenhouse during the spring-winter season of 2022. Strawberry seedlings (cv. Albion) were placed in black polyethylene containers of 5-L capacity in an open soilless system. The substrate consisted of a 70:30 v/v mixture of sphagnum peat and perlite. Plants were set at a density of 11 plants per square meter. Three times a week, plants were hand-watered with 800 mL of a nutrient solution (Steiner, 1984) (pH 6.0, electrical conductivity 1.7 dS m^{-1}). Tap water was used to prepare the nutrient solution, considering its ion composition; the nutrient solution contained 9 mEq L^{-1} NO_3^-, 0.39 mEq L^{-1} $H_2PO_4^-$, 0.26 mEq L^{-1} SO_4^{-2}, 4.43 mEq L^{-1} K^+, 5.83 mEq L^{-1} Ca^{+2}, 1.94 mEq L^{-1} Mg^{+2}, 3.24 ppm Fe-EDTA, 0.14 ppm Zn-EDTA, 0.05 ppm Cu-EDTA, 0.73 ppm Mn-EDTA, 0.05 ppm Mo-EDTA, and 0.13 ppm B-EDTA.

Temperature, relative humidity, and spectral irradiance underneath the nets

On the 25th day after transplant (dat), the plants were covered with shade nets (80 % shade) of various colors (black, green, blue, and beige), while a control group without a shade net was also set up. Nets were positioned at a height of 1.5 m above the plants. Temperature and relative humidity were recorded underneath each net using a datalogger (RC-51H, Elitech Technology, CA, USA). Spectral irradiance was recorded at 70 dat in each net at noon on a clear sky day using a multispectral radiometer (PS-300, Apogee Instruments Inc., UT, USA) (Table 1). An experimental design with four treatments and a control was implemented, utilizing 15 replications per treatment; a one-plant container was considered the experimental unit.

Table 1. Temperature, relative humidity, and spectral irradiance (μmol m^{-2} s^{-1}) measured under the colored shade nets assed.

Variable	Control (no net)	Black	Blue	Green	Beige
Air temperature (°C)†	36.53±0.7	33.20±0.5	35.45±0.6	33.10±0.5	34.95±0.4
Relative humidity (%)†	28.55±1.5	41.21±1.9	38.21±1.7	38.46±2.2	38.50±1.8
PAR (400–700 nm)	973	288	429	271	519
Ultraviolet-B (280–320 nm)	0.71	0.15	0.11	0.04	0.09
Ultraviolet-A (320–400 nm)	43.44	14.51	16.38	12.61	21.05
Blue light (400–500 nm)	293.80	90.25	71.78	82.75	150.06
Green light (500–600 nm)	343.91	01.98	151.53	97.16	185.41
Red light (600–700 nm)	335.19	96.32	105.66	90.61	183.88
Far red light (700–800 nm)	297.24	82.89	120.99	81.98	163.77

†Data are expressed as mean ± standard error of 18 replications (18 weeks). PAR: Photosynthetically active radiation.

Fruit physical characterization

Five plants were selected randomly for each treatment. All fruits were harvested when they reached a bright red color covering three-quarters of the fruit. The length and width of the fruit were measured using a digital vernier caliper (Steren®, Mexico City, Mexico). The roundness index was calculated by dividing the length by the diameter of each fruit (Martínez-Bolaños *et al*., 2008). Firmness was measured at the equatorial diameter (Martínez-Bolaños *et al*., 2008) using a penetrometer equipped with a 1.9 mm wide tip (model FT O2, Qa Supplies®).

Fruit biochemical characterization

The total soluble sugar concentration was measured using the anthrone technique (Witham *et al*., 1971) in 15 fruits (three-quarters covered in red) per treatment. A sample of 5 g of fresh fruit was prepared for each treatment replicate. The measurements were taken using a spectrophotometer (model Thermo Spectronic Genesys 10 UV, NY, USA) at a wavelength of 600 nm. The sugar concentration was calculated using a standard curve from 0 to 250 μg of glucose mL^{-1}. The total soluble solids (TSS) were measured using a digital refractometer (PAL-1 Atago®, Saitama, Japan) on 20 harvested fruits per treatment (also when three-quarters covered in red). The pH and titratable acidity (TA) of the fruit were measured from 10 fruits (in the same state of maturation mentioned above) per treatment. A sample of 10 g of fresh fruit was blended in 50 mL of distilled water for each treatment replicate. The pH was measured using a CONDUCTRONIC potentiometer (model PC45, Puebla, Mexico), and titratable acidity was evaluated using the AOAC (1980) method with acidity percentage calculated based on citric acid (mEq = 0.064). The equation used was:

$$\%\ \text{citric acid} = \frac{\text{mL NaOH } x \text{ N NaOH } x \text{ mEq citric acid } x \text{ V } x \text{ 100}}{\text{sample weight } x \text{ aliquot}}$$

The TSS/TA ratio was also calculated.

Fruit nutraceutical quantification

A methanolic extract was prepared from a sample of 15 fruits per treatment. Strawberry pulp (1 g) was crushed in 10 mL of aqueous methanol solution at 80 % v/v. The mixture was homogenized and sonicated (BRANSON 2510 sonicator, Danbury, CT, USA) for 15 min, allowed to rest for 24 h, and then centrifuged at 1400 x g for 10 min (Chang *et al*., 2002).

Phenolics compounds

An aliquot of the methanolic extract (250 μL) was mixed with 250 μL of Folin-Ciocalteu reagent (0.2 N) and 2 mL of Na_2CO_3 (0.7 M). The mixture was left to incubate for 2 h at room temperature in the absence of light. The absorbance was determined at 765 nm (Thermo Spectronic Genesys 10 UV spectrophotometer, NY, USA). The phenol concentration was determined using a gallic acid standard curve (y = 0.0060x + 0.0389;

$R^2 = 0.991$) and expressed as mg gallic acid equivalents per 100 g fresh weight (mg GAE 100 g^{-1} FW) following the Waterman and Mole (1994) technique.

Flavonoids

A 500 µL aliquot of the methanolic extract was mixed with 1.5 mL of 95 % ethanol, 100 µL of 10 % $AlCl_3$, 100 µL of CH_3COOK (1 M), and 2.8 mL of distilled water. The mixture was incubated for 30 min at room temperature, and the absorbance was measured at 415 nm. Flavonoid content was quantified using a standard curve of quercetin ($y = 0.006x - 0.0026$; $R^2 = 0.996$) as reported by Chang *et al*. (2002). The results were quantified as milligrams of quercetin equivalents per 100 grams of fresh weight (mg QE 100 g^{-1} FW).

Anthocyanins

Two test tubes were prepared with 0.1 mL of the methanolic extract. A 0.025 N KCl solution (5 mL) at pH 1 was added to one test tube, and a 0.4 M $CH_3COONa\ 3H_2O$ solution (5 mL) at pH 4.5 was added to the second test tube. The reaction was allowed to stabilize for 15 min, and then the absorbance was measured at 510 and 700 nm in both mixtures. The concentration of anthocyanins was measured in mg of cyanidin-3-glucoside equivalents per 100 g of fresh weight (mg CGE 100 g^{-1} FW) (Giusti and Wrolstad, 2001).

Ascorbic acid

The method 967.21 from AOAC (1995) was utilized. A sample of 0.5 g of fresh fruit was prepared for each treatment replicate. The concentration of ascorbic acid was calculated using a standard curve equation ($y = -0.0038x + 0.2205$; $R^2 = 0.991$) at a wavelength of 515 nm. The results were quantified in milligrams of ascorbic acid equivalents per 100 grams of fresh weight (mg ASCE 100 g^{-1} FW).

Antioxidant capacity

The antioxidant capacity was determined with the 2,2'-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) method (Re *et al*., 1999). A Trolox (6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid) standard curve ($y = -0.2274x + 0.6746$; $R^2 = 0.993$) was utilized at a wavelength of 734 nm. The results were expressed as µM Trolox equivalents per 100 g of fresh weight (µM TE 100 g^{-1} FW).

Statistical analysis

A completely randomized experimental design was used with four treatments and a control, with nine replicates for the physical, chemical, and nutraceutical characteristics of the fruit. Analysis of variance (ANOVA) and mean comparisons were performed using Tukey's test ($p \leq 0.05$) with SAS® version 9 software.

RESULTS AND DISCUSSION

Fruit physical characterization

Fruits from plants covered with colored nets exhibited significant variations in diameter, roundness index, and firmness compared to the fruits from the control plants ($p \leq 0.05$) (Table 2). Fruits harvested from colored nets had a diameter approximately 39 % smaller than those from the control group, with no significant impact on length. The decreased diameter caused a rise in the roundness index, leading to the production of elongated fruits. Fruits collected from plants under the blue and green nets had a 12 % drop in firmness compared to the control. The findings of this study do not coincide with those of Retamal-Salgado *et al*. (2017), who observed a decrease in firmness of 30 to 90 % in fruits of *Vaccinium corymbosum* L. grown in the field compared to the control group when the shade was increased using a black net, suggesting that using nets to reduce light exposure can lead to a shorter postharvest life.

Table 2. Physical characteristics in strawberry (*Fragaria* x *ananassa* Duch.) fruit cv. Albion cultivated under colored shade nets.

Color net	Equatorial diameter (mm)	Length (mm)	Roundness index	Firmness (N)
Control	39.23 ± 2.59 a	32.03 ± 0.55 a	0.88 ± 0.06 b	1.42 ± 0.03 a
Black	24.19 ± 0.55 b	32.42 ± 0.93 a	1.34 ± 0.03 a	1.34 ± 0.01 ab
Blue	24.36 ± 0.25 b	31.35 ± 0.56 a	1.28 ± 0.02 a	1.24 ± 0.03 b
Green	23.35 ± 0.58 b	30.87 ± 0.99 a	1.32 ± 0.03 a	1.26 ± 0.04 b
Beige	24.33 ± 0.39 b	31.23 ± 0.53 a	1.28 ± 0.01 a	1.35 ± 0.04 ab
HSD	4.96	2.98	0.14	0.12
CV (%)	13.60	7.01	8.50	6.80

Data are expressed as mean ± standard error of nine replications. Different letters in the same row indicate significant statistical differences (Tukey, $p \leq 0.05$). HSD: honest significant difference; CV: coefficient of variation.

Fruit biochemical characterization

Fruits from plants grown beneath blue, beige, and green nets exhibited an increase of 42, 28, and 22 % in total soluble sugars compared to those of the control ($p \leq 0.05$) (Table 3). There was no significant effect in sugar content between fruits cultivated under the black net and those grown in the control. The total soluble solids in fruits harvested from blue and beige nets was similar to that of the control group ($p \leq 0.05$) and 23 % higher than in fruits harvested with black and green nets. All fruits harvested from the nets, regardless of color, had a greater titratable acidity in comparison to fruits from the control treatment. The titratable acidity of fruits obtained from the beige net was 24 % higher than that from the other nets ($p \leq 0.05$). The pH of fruits from the control and blue nets was similar, while the fruits under the black and green nets were 5 and

Table 3. Chemical characteristics in strawberry (*Fragaria* x *ananassa* Duch.) fruits cv. Albion cultivated under colored shade nets.

Color net	Total soluble sugars (g 100 g^{-1} FW)	TSS (%)	TA (%)	pH	TSS/TA ratio
Control	2.63±0.16c	7.00±0.09a	1.00±0.03c	2.58±0.04a	7.07±0.31a
Black	2.62±0.12c	5.63±0.07b	1.11±0.01b	2.44±0.03bc	5.06±0.06c
Blue	3.73±0.13a	6.94±0.13a	1.10±0.01b	2.50±0.02ab	6.25±0.15b
Green	3.21±0.12b	5.60±0.07b	1.08±0.02b	2.35±0.02c	5.15±0.06c
Beige	3.36±0.07ab	6.78±0.06a	1.24±0.01a	2.48±0.01b	5.47±0.06c
HSD	0.49	0.34	0.07	0.09	0.64
CV (%)	11.76	3.99	4.89	2.83	8.31

Data are expressed as mean ± standard error of nine replications. Different letters in the same column indicate significant statistical differences (Tukey, $p \leq 0.05$). FW: fresh weight; TSS: total soluble solids; TA: titratable acidity; TSS/TA: TSS/TA ratio; HSD: honest significant difference; CV: coefficient of variation.

9 % more acidic than the control, respectively. Fruits from beige, green, and black nets had, on average, a TSS/TA ratio 26 % lower than control fruits, whereas fruits from blue nets had a ratio 11 % lower ($p \leq 0.05$).

In 'Hayward' kiwifruit vines under blue, white, red, and grey nets, it was observed that the red and white nets increased the size of the fruit and concentration of total soluble solids during cold storage, while the blue and grey nets decreased fruit size and concentration of total soluble solids compared with the control (Basile *et al*., 2012). Zoratti *et al*. (2015) found a 12 % decrease in the yield of *Vaccinium corymbosum* L. fruits when grown under a black net (90 % shade) compared to the control group. Fruits collected from green and black nets had the lowest total soluble solids levels in this study, possibly due to the lower photosynthetic rate caused by the decrease in the radiation intensity reaching the plants.

This study demonstrates that fruits produced under nets exhibited more titratable acidity compared to the control plants (Table 3). The readings fall within the range specified by Hancock (2020) of 0.29 to 1.24 % citric acid in strawberry. Fruits grown under black, green, and beige nets exhibited a lower pH compared to the control and blue net fruits; in general, the use of nets yielded acidic fruits, due to the state of ripeness of the fruit in which it was harvested (when they reached a bright red color covering three-quarters of the fruit). The pH measured in this study was lower than the range of 3.4 to 3.7 reported by Nunes *et al*. (2021) for various strawberry fruit cultivars. Gunness *et al*. (2009) stated that pH plays a crucial role in the sensory characteristics of strawberry fruit by influencing the impression of sweetness, especially when the pH is less acidic. Simkova *et al.* (2024) found that the total soluble solids, titratable acidity, and the sugars/acid ratio are highly correlated with the ripening of strawberry as sugars increase and titratable acidity decreases as the fruit matures.

The data indicates a correlation between the far-red light passing through colored nets (Table 1) and the levels of total soluble sugars, total soluble solids, and pH in strawberry fruit. These parameters showed an increase with greater exposure to far red light, reaching a peak near 200 μmol m^{-2} s^{-1} before decreasing (Figures 1A–1E). However, titratable acidity (Figure 1C) and the TSS/TA ratio (Figure 1E) consistently increased even when far red light exceeded 200 μmol m^{-2} s^{-1}. Kim *et al*. (2020) found in tomato fruits (*Solanum lycopersicum* L.) that the combination of far-red wavelength and red lighting enhanced total soluble solids and titratable acidity, as opposed to red light alone; the authors suggested that this may be due to alterations in the phytochrome system and the functioning of the enzyme sucrose phosphate synthase as the fruit

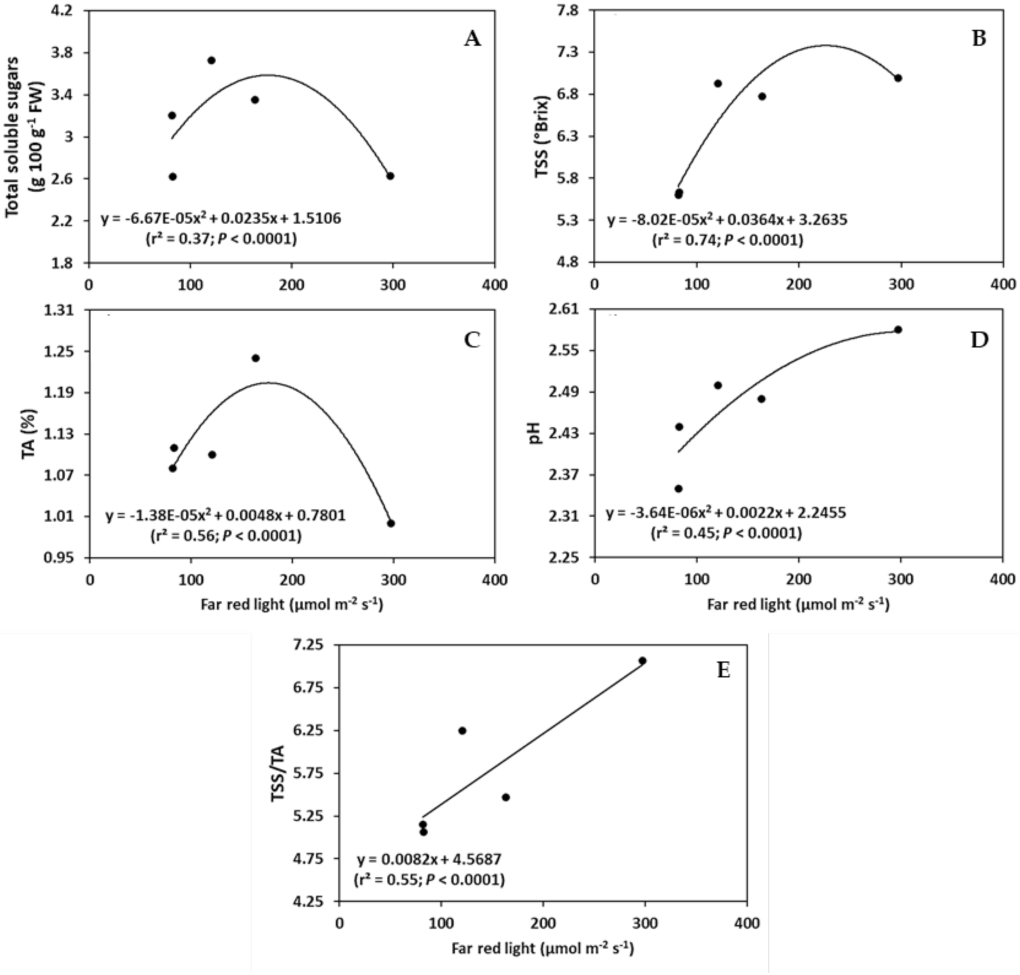

Figure 1. Chemical characterization of strawberry (*Fragaria* x *ananassa* Duch.) fruit cv. Albion cultivated under colored shade nets as influenced by far red light (700–800 nm). A: total soluble sugars; B: total soluble solids (TSS); C: titratable acidity (TA); D: pH; E: TSS/TA ratio. FW: fresh weight.

develops. Zhen *et al*. (2022) noted a synergy between far-red light photons and short-wavelength photons.

Studies have shown that far-red photons from LED light can enhance the photochemical efficiency and photosynthetic rate when combined with red/blue or white light (Zhen and van Iersel, 2017). In this study, a synergistic effect probably occurred in the control, beige, and blue net fruits that were exposed to a higher level of far-red wavelength light (Table 1). This exposure may have resulted in increased carbohydrate production and translocation to the fruits, leading to elevated total soluble solids, as suggested by Kim *et al*. (2020) in tomato.

Fruit nutraceutical quantification

Differences in nutraceutical concentrations in strawberry fruits were observed between treatments (Figure 2). The total content of phenolic compounds in fruits grown with beige nets was 4 % higher than that of the control and 5 % higher than that of fruits grown with black and blue nets ($p \leq 0.05$) (Figure 2A). The total phenols measured in this study were within the range reported by Nunes *et al.* (2006) for different strawberry cultivars grown in the field (110, 70, and 90 mg de GAE 100^{-1} g for cv. Chandler, Oso Grande, and Sweet Charlie, respectively). However, it was lower than the concentration observed by Ornelas-Paz *et al*. (2013) for organically cultivated fruits of cv. Albion (209 mg de GAE 100^{-1} g). In both studies, the fruits were harvested when three-quarters of the fruit had become red.

There were no significant differences in flavonoid concentrations between the control and net fruits; however, fruits from the beige and green nets were around 41 % higher in flavonoids than the blue net (Figure 2B). These results suggest that the strawberry plants cultivated under beige and green nets may have experienced stress conditions due to the quantity and ratio of UV-A and blue light that they received. Although the plants grown under the blue net received a high intensity and quantity of short wavelength light (UV-A and blue), the fruits did not demonstrate a high flavonoid content but a lower concentration, implying that these compounds were in the leaves. Zoratti *et al*. (2014) found that intense solar radiation, particularly in the blue spectrum (400–500 nm), alters flavonoid production in fruits. However, this response may vary depending on the interaction between light conditions and environmental factors. Additionally, Falcone et al. (2012) stated that exposure to UV-B radiation (280–320 nm) not only affects plant growth and development but also results in the production of reactive oxygen species. In response to this UV-B radiation, plants synthesize flavonoids to absorb it and to counteract the reactive oxygen species.

The anthocyanin concentration in fruits produced with the blue net was 86 % bigger than the control, 54 % higher than the beige net, and 95 % higher than the green and black nets. ($p \leq 0.05$) (Figure 2C). This may be due to the excessively high blue radiation may have caused photo-oxidative stress in the plants, resulting in increased production of antioxidants for protection, as indicated by Alrifai *et al*. (2019), and the increase in anthocyanin levels in the fruits. Qian *et al*. (2016) observed that the

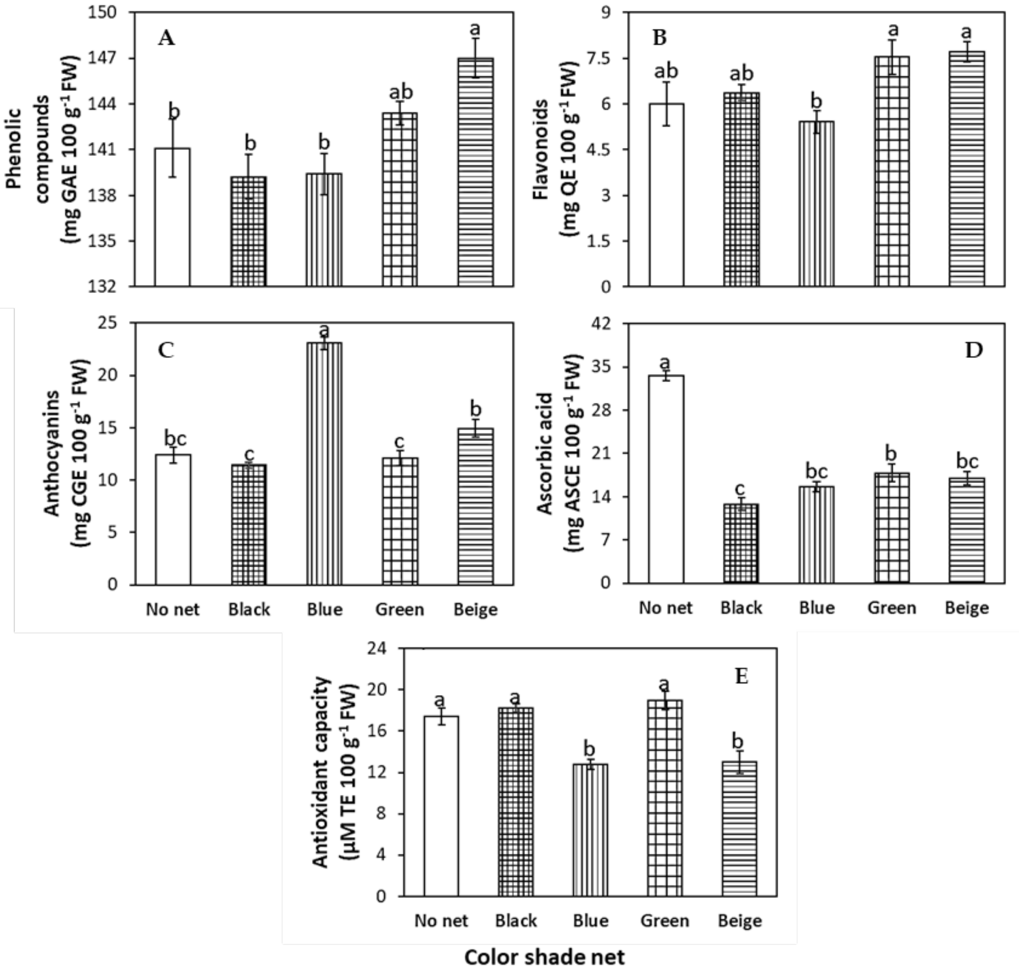

Figure 2. Antioxidant concentration in strawberry (*Fragaria* x *ananassa* Duch.) fruit cv. Albion cultivated under varying colored shade nets. A: phenolic compounds; B: flavonoids; C: anthocyanins; D: ascorbic acid; E: antioxidant capacity. Data are expressed as mean ± standard error of nine replications. Different letters on the bars indicate significant statistical differences (Tukey, $p \leq 0.05$). FW: fresh weight; GAE: gallic acid equivalents; QE: quercetin equivalents; CGE: cyanidin-3-glucoside equivalents; ASCE: ascorbic acid equivalents; TE: Trolox equivalents.

accumulation of anthocyanin in fruits is influenced by light as it is required for their synthesis, and that light spectral quality can affect the process. Short wavelengths in the blue and UV spectrum are reported to enhance anthocyanin concentration when fruits are ripening (Zoratti *et al.*, 2015).

The color of the nets did not promote the buildup of ascorbic acid in the fruits; these levels were half of those found in the control fruits (Figure 2D). According to Flieger et al. (2021), stressful conditions lead to the production of reactive oxygen species in plants, which are responsible for damaging biomolecules such as membrane lipids, proteins, and nucleic acids. Plants have developed a defensive mechanism against these reactive oxygen species by creating antioxidant substances like ascorbic acid to neutralize the negative impact of free radicals. The present study showed that the control fruits contained the highest level of ascorbic acid, indicating that these plants were experiencing stressful conditions. However, the use of colored shade nets alleviated such stressful conditions caused by high solar intensity, temperature, and low relative humidity, as their use was associated with a 3 °C drop in temperature and a 37 % increase in relative humidity when compared to the control. Temperature and relative humidity are environmental conditions that significantly impact the growth of strawberries (Hancock, 2020).

The antioxidant capacity of fruits from plants grown under black and green nets was similar to that of the control and 29 % higher than those under blue and beige nets (Figure 2E). Fruits' antioxidant activity refers to the capacity they have to counteract or decrease oxidation produced by atoms or groups of atoms with unpaired electrons that steal electrons from stable molecules, known as free radicals (Niki, 2011). The results obtained suggest that the plants from the control, black net, and green net produced fruits with greater capacity to neutralize free radicals because they contained higher levels of certain antioxidants.

The antioxidant capability observed in the control may be linked primarily to the stress induced by the intense light and high temperature that the plants were subjected to in comparison to plants under the colored nets, since the control exhibited a high quantity of ascorbic acid. The fruits collected from plants grown under blue and beige nets exhibited a lower antioxidant capacity compared to those collected using black and green nets; however, phenolic compounds and anthocyanins were the main contributing chemicals in the beige (Figure 2A) and blue (Figure 2C) nets, respectively. Warner *et al*. (2021) comment that the secondary metabolites that are predominant in strawberry fruit and influence antioxidant capacity are phenolic compounds. This activity varies depending on the cultivar and maturation stage of the fruit (Hwang *et al.,* 2019). The present study suggests that the antioxidant capacity of fruits obtained using colored nets may not be solely due to the concentration of a specific compound, and additional determinations like the FRAP and DPPH methods were necessary.

CONCLUSIONS

Fruit quality was affected by the color of the shade nets. Fruits harvested from plants grown under the blue and beige nets showed higher total soluble sugars, and with the blue net, the highest concentration of anthocyanin was presented, whereas those harvested with the beige net had increased concentrations of titratable acidity and phenolic compounds. The study suggests that using blue and beige nets could serve as an alternate production strategy to enhance the quality and nutritional properties of 'Albion' strawberry fruit. Using other methods is recommended to accurately assess the antioxidant capacity.

AKNOWLEDGEMENTS

This work was supported by the Horticulture Institute at Chapingo Autonomous University and the Secretariat of Science, Humanities, Technology, and Innovation (SECIHTI).

REFERENCES

Alrifai O, Hao X, Marcone MF, Tsao R. 2019. Current review of the modulatory effects of led light on photosynthesis of secondary metabolites and future perspectives of microgreen vegetables. Journal of Agricultural and Food Chemistry 67 (22): 6075–6090. https://doi.org/10.1021/acs.jafc.9b00819

AOAC (Association of Official Analytical Chemists).1980. Official methods of analysis (12th edition). Association of Official Analytical Chemists: Washington, DC, USA. 1018 p.

AOAC (Association of Official Analytical Chemists). 1995. Official methods of analysis (16th edition). Association of Official Analytical Chemists: Washington, DC, USA. 2490 p.

Aras S, Eşitken A. 2019. Physiological effects of photoselective nets in strawberry plant. KSU Journal of Agriculture and Nature 22: 342–346. https://doi.org/10.18016/ksutarimdoga.vi.552218

Arthurs SP, Stamps RH, Giglia FF. 2013. Environmental modification inside photoselective shadehouses. HortScience 48 (8): 975–979. https://doi.org/10.21273/hortsci.48.8.975

Basile B, Giaccone M, Cirillo C, Ritieni A, Graziani G, Shahak Y, Forlani M. 2012. Photo-selective hail nets affect fruit size and quality in Hayward kiwifruit. Scientia Horticulturae 141: 91–97. https://doi.org/10.1016/j.scienta.2012.04.022

Buthelezi MND, Soundy PP, Jifon J, Sivakumar D. 2016. Spectral quality of photo-selective nets improves phytochemicals and aroma volatiles in coriander leaves (*Coriandrum sativum* L.) after postharvest storage. Journal of Photochemistry and Photobiology B: Biology 161: 328–334. https://doi.org/10.1016/j.jphotobiol.2016.05.032

Chang CC, Yang MH, Wen HM, Chern JC. 2002. Estimation of total flavonoid content in propolis by two complementary colorimetric methods. Journal of Food and Drug Analysis 10 (3): 178–182. https://doi.org/10.38212/2224-6614.2748

Falcone F, Rius ML, Casati PSP. 2012. Flavonoids: Biosynthesis, biological functions, and biotechnological applications. Frontiers in Plant Science 3: 1–15. https://doi.org/10.3389/fpls.2012.00222

Flieger J, Flieger W, Baj J, Maciejewski R. 2021. Antioxidants: Classification, natural sources, activity/capacity measurements, and usefulness for the synthesis of nanoparticles. Materials 14 (15): 4135. https://doi.org/10.3390/ma14154135

Giampieri F, Alvarez-Suarez JM, Battino M. 2014. Strawberry and human health: Effects beyond antioxidant activity. Journal of Agricultural and Food Chemistry 62 (18): 3867–3876. https://doi.org/10.1021/jf405455n

Giusti MM, Wrolstad RE. 2001. Characterization and measurement of anthocyanins by UV-visible spectroscopy. Current Protocols in Food Analytical Chemistry 0 (1): F1.2.1–F1.2.13. https://doi.org/10.1002/0471142913.faf0102s00

Gunness P, Kravchuk O, Nottingham SM, D'Arcy BR, Gidley MJ. 2009. Sensory analysis of individual strawberry fruit and comparison with instrumental analysis. Postharvest Biology and Technology 52 (2): 164–172. https://doi.org/10.1016/j.postharvbio.2008.11.006

Hancock JF. 2020. Strawberries. CABI Publishing: New York, NY, USA. 275 p.

Hwang H, Kim Y, Shin Y. 2019. Influence of ripening stage and cultivar on physicochemical properties, sugar and organic acid profiles, and antioxidant compositions of strawberries. Food Science and Biotechnology 28 (6): 1659–1667. https://doi.org/10.1007/s10068-019-00610-y

Kim H, Yang T, Choi S, Wang Y, Lin M, Liceaga AM. 2020. Supplemental intracanopy far-red radiation to red LED light improves fruit quality attributes of greenhouse tomatoes. Scientia Horticulturae 261: 108985. https://doi.org/10.1016/j.scienta.2019.108985

Kotilainen T, Robson TM, Hernández R. 2018. Light quality characterization under climate screens and shade nets for controlled-environment agriculture. PLoS ONE 13 (6): e0199628. https://doi.org/10.1371/journal.pone.0199628

Martínez-Bolaños M, Nieto-Angel D, Téliz-Ortiz D, Rodríguez-Alcazar J, Martínez-Damian MT, Vaquera-Huerta H, Carrillo-Mendoza O. 2008. Comparación cualitativa de fresas (*Fragaria x ananassa* Duch.) de cultivares mexicanos y estadounidenses. Revista Chapingo Serie Horticultura 14 (2): 113–119.

Miao L, Zhang Y, Yang X, Xiao J, Zhang H, Zhang Z, Wang Y, Jiang G. 2016. Colored light-quality selective plastic films affect anthocyanin content, enzyme activities, and the expression of flavonoid genes in strawberry (*Fragaria* x *ananassa*) fruit. Food Chemistry 207: 93–100. https://doi.org/10.1016/j.foodchem.2016.02.077

Niki E. 2011. Antioxidant capacity: Which capacity and how to assess it? Journal of Berry Research 1 (4): 169–176. https://doi.org/10.3233/jbr-2011-018

Nunes MCN, Brecht JK, Morais AM, Sargent SA. 2006. Physicochemical changes during strawberry development in the field compared with those that occur in harvested fruit during storage. Journal of the Science of Food and Agriculture 86 (2): 180–190. https://doi.org/10.1002/jsfa.2314

Nunes G, Teixeira F, Schwarz K, Kopanski CC, Tadeu VRJ, Freitas E, Callegari FB, Novello D. 2021. Influence of genetic variability on the quality of strawberry cultivars: Sensorial, physical-chemical and nutritional characterization. Acta Scientiarum, Agronomy 43: e46862. https://doi.org/10.4025/actasciagron.v43i1.46862

Ornelas-Paz J de J, Yahia EM, Ramírez-Bustamante N, Pérez-Martínez JD, Escalante-Minakata M del P, Ibarra-Junquera V, Acosta-Muñiz C, Guerrero-Prieto V, Ochoa-Reyes E. 2013. Physical attributes and chemical composition of organic strawberry fruit (*Fragaria x ananassa* Duch. cv. Albion) at six stages of ripening. Food Chemistry 138 (1): 372–381. https://doi.org/10.1016/j.foodchem.2012.11.006

Qian H, Liu T, Deng M, Miao H, Cai C, Shen W, Wang Q. 2016. Effects of light quality on main health-promoting compounds and antioxidant capacity of Chinese kale sprouts. Food Chemistry 196: 1232–1238. https://doi.org/10.1016/j.foodchem.2015.10.055

Re R, Pellegrini N, Proteggente A, Pannala A, Yang M, Rice-Evans C. 1999. Antioxidant activity applying an improved ABTS radical cation decolorization assay. Free Radical Biology and Medicine 26 (9–10): 1231–1237. https://doi.org/10.1016/S0891-5849(98)00315-3

Retamales JB, Montecino JM, Lobos GA, Rojas LA. 2008: Colored shading nets increase yields and profitability of highbush blueberries. Acta Horticulturae 770: 193–197. https://doi.org/10.17660/actahortic.2008.770.22

Retamal-Salgado J, Vásquez R, Fischer S, Hirzel J, Zapata N. 2017. Decrease in artificial radiation with netting reduces stress and improves rabbit-eye blueberry (*Vaccinium virgatum* Aiton) ’Ochlockonee’ productivity. Chilean Journal of Agricultural Research 77 (3): 226–233. https://doi.org/10.4067/S0718-58392017000300226

Shahak Y. 2008. Photo-selective netting for improved performance of horticultural crops. A review of ornamental and vegetable studies carried out in Israel. Acta Horticulturae 770: 161–168. https://doi.org/10.17660/ActaHortic.2008.770.18

Simkova K, Veberic R, Hudina M, Grohar MC, Pelacci M, Smrke T, Ivancic T, Weber NC, Jakopic J. 2024. Non-destructive and destructive physical measurements as indicators of sugar and organic acid contents in strawberry fruit during ripening. Scientia Horticulturae *327*: 112843. https://doi.org/10.1016/j.scienta.2024.112843

Steiner AA. 1984. The universal nutrient solution. *In* Proceedings 6th International Congress on Soilless Culture. International Society for Soilless Culture: Wageningen, Netherlands, pp: 633–650.

Stevenson D, Scalzo J. 2012. Anthocyanin composition and content of blueberries from around the world. Journal of Berry Research 2 (4): 179–189. https://doi.org/10.3233/JBR-2012-038

Tezcan NY, Taspinar H, Kormaz C. 2023. Effects of shade nets on the microclimate and growth of tomato. Journal of Agricultural Sciences 29 (2): 443–454. https://doi.org/10.15832/ankutbd.1073156

Wang J, Wang H. 2014. Effects of shade on strawberries in hydroponic cultivation. Acta Horticulturae 1049: 733–736. https://doi.org/10.17660/ActaHortic.2014.1049.114

Warner R, Wu BS, MacPherson S, Lefsrud M. 2021. A review of strawberry photobiology and fruit flavonoids in controlled environments. Frontiers in Plant Science 12: 611893. https://doi.org/10.3389/fpls.2021.611893

Waterman PG, Mole S. 1994. Analysis of phenolic plant metabolites. Blackwell Scientific Publications. Oxford. K. 238 p.

Witham FH, Blaydes DF, Devlin RM. 1971. Experiments in plant physiology. Van Nostrand Reinhold Company: New York, NY, USA. 245 p.

Zhen S, van Iersel MW. 2017. Far-red light is needed for efficient photochemistry and photosynthesis. Journal of Plant Physiology 209: 115–122. https://doi.org/10.1016/j.jplph.2016.12.004

Zhen S, van Iersel MW, Bugbee B. 2022. Photosynthesis in sun and shade: The surprising importance of far-red photons. New Phytologist 236 (2): 538–546. https://doi.org/10.1111/nph.18375

Zoratti L, Karppinen K, Escobar AL, Häggman H, Jaakola L. 2014. Light-controlled flavonoid biosynthesis in fruits. Frontiers in Plant Science 5: 534. https://doi.org/10.3389/fpls.2014.00534

Zoratti L, Jaakola L, Häggman H, Giongo L. 2015. Modification of sunlight radiation through colored photo-selective nets affects anthocyanin profile in *Vaccinium* spp. berries. PLoS ONE: 10 (8): e0135935. https://doi.org/10.1371/journal.pone.0135935