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Photoselective Shade Netting in a Sweet Pepper Crop Accelerates Ripening Period and Enhances the Overall Fruits Quality and Yield

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ABSTRACT

Photoselective nets are used to protect horticultural plants from sunburn and prolong the cropping period in conditions of excess light. In this work, we studied the influence of four photoselective shading nets (Pearl 30, Red 30, Silver 30, Red 40), a standard black-colored net (Black 35), and a control (no cover) on the evolution of color during the ripening of two types of pepper, namely, Lamuyo and California. For this purpose, the evolution of the colors of the fruit was followed from the beginning of their formation until the harvest, and was correlated with the total radiation and the temperature. The plant material used were peppers of the California type -cultivars Bendigo and Cayetano- and of the Lamuyo type, cultivars Alcudia and Pompeo. The results showed that the rate of change of the pepper coloration depended on the net used in the greenhouse. The speed of the change in color from green to red was more dependent on the cultivar and the total radiation, as conditioned by the different photoselective nets, than on the type of pepper. The greatest differences were between the control (without a net) and the black net, the increase in the red color of the peppers being faster in the former. Radiation values below 75 W m^{-2} or greater than 110 W m^{-2} negatively affected the yield. The temperature below the net was not affected significantly by the type of net, and thus its effect on the different cultivars was similar.

Keywords: CIELAB, ΔE, Radiation, Sweet pepper color.

INTRODUCTION

There is a worldwide trend towards greater consumption of fruit and vegetables, mainly motivated by a growing desire for a more balanced diet. This is coupled with a rising demand for superior quality, both externally and internally. This quality is a complex perception of many attributes that are simultaneously evaluated, objectively or subjectively, by the consumer. According to the color of the fruit, the consumer assesses whether it is immature and lacks a good taste, texture, or aroma. This coloration has to be uniform, without spots or parts that are darker or lighter than others.

Globally, peppers are one of the most grown and consumed crops (López-Marín *et al.*, 2016). Peppers can be marketed in a great diversity of colors (red, yellow, and orange), although the most commercialized are the red ones.

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Sweet pepper is one of the most important horticultural crops in the Mediterranean area, and in southeast Spain, one of the main production areas of sweet pepper in Europe, 10,260 ha of sweet pepper were grown in greenhouses in the province of Almería and 1,600 ha in the provinces of Murcia and southern Alicante, in 2019 (MAPA, 2019).

Cultivation of pepper for fresh consumption is carried out almost entirely in protected areas within greenhouses. However, prolonged high temperatures (35-40°C), as a result of high solar radiation, can increase the incidence of abiotic disorders in crop plants, and this problem is likely to intensify as the climate changes (López-Marín *et al.*, 2017, 2019, 2021). In recent years, mobile and fixed systems have been used to reduce the radiation and temperature within greenhouses, however, reducing access to light can modify many physiological processes in growing plants (Oliveira *et al.*, 2018; Kong *et al.*, 2012; Wojciechowska and Siwek, 2006), and delays in fruit ripening (Goren *et al.*, 2011; Galvez *et al.*, 2020).

With the new designs of nets for use in greenhouses, and the use of high-quality plastics, environments that favorably influence cultivation of horticultural crops such as peppers can be created (Ayala-Tafoya *et al.*, 2011). Photoselective colored nets provide various mixtures of natural, unmodified, and scattered light - that is, spectrally modified light (Shahak, 2008, Shahak *et al.*, 2009; Rajapakse and Shahak, 2007) - depending on the pigmentation of the net thread and the design of the fabric with different fibers and densities to create specific tone indices (Castellano *et al.*, 2008; Appling, 2012).

Photoselective nets are also used to protect horticultural plants from sunburn and to prolong the harvest in conditions of excess light (Castellano *et al.*, 2008).

The evolution of fruit color in different cultivars of pepper grown in the open-air has been studied by different authors, such as Gomez-Ladron de Guevara and Pardo-Gonzalez (1996), but this has not been done for crops grown under different photoselective shading nets. Therefore, in this work, we used different shading nets for the greenhouse cultivation of four cultivars of pepper. In particular, we determined the evolution of the fruit color of the pepper cultivars under different colored nets, as well as the evolution of the total radiation and temperature under the nets and its influence on the color and yield of the peppers.

MATERIAL AND METHODS

Plant Material

The assays were carried out on the experimental farm of the IMIDA at Torreblanca, located at 37º 45' north (longitude) and 0º 59' west (latitude), in the Campo de Cartagena area of the region of Murcia (Spain). The pepper plants used were of the California type -cultivars ‘Bendigo’ (Enza Zaden Spain SL) and ‘Cayetano’ (Enza Zaden Spain SL)- and the Lamuyo type, cultivars ‘Alcudia’ (Semillas Fitó SA) and ‘Pompeo’ (Nunhems Spain, SA).

Experimental Design and Growth Conditions

The experiment was carried out in 2016 and 2017. The plants were grown in single rows 1 m apart, with 40 cm between plants in a given row (plant density of 25,000 plants ha^{-1}). In 2016, the plants were transplanted on April 4th, the crop cycle ended on August 16th, and in 2017, the plants were transplanted on April 7th, and the crop cycle ended on August 18th, after three harvests. Localized irrigation was used, with a line of drippers for each row of plants. Its nominal flow was 2.2 L h^{-1}. Fertilizer was distributed by fertigation.

The experiments were carried out in two Kyoto-model tunnels. Each unit of cultivation or tunnel was 5.55 m wide, 18.00 m long, and 2.70 m high in the roof ridge, giving a usable area of 100 m^2. The greenhouses were independent, being 5 m apart. Experimental design was a randomized complete block with three replications and five colored shade treatments (four colored nets and an open air (no cover). In each tunnel a different photoselective net was installed, except in one of them (the control), which was left open, without a net. The treatments were open air (no cover); a black shade net providing 30% shade, Polysack LTD (Black 35); Chromatinet Pearl, 30% shade, Polysack LTD (Pearl 30); Chromatinet Red, 30% shade, Polysack LTD (Red 30); Chromatinet Silver, 30% shade (Silver 30); and Chromatinet Red, 40% shade (Red 40) and were within the optimal shade level (30% to 46% shade) for bell pepper (Díaz-Pérez, 2014).

Temperature and Radiation Measurements

The radiation and air temperature in each unit were monitored during the growing cycle. The total radiation was measured using an LI-1400 instrument (LI-COR Inc., Lincoln, Nebraska, USA). The air temperature was recorded using a Hobo U12 temperature data logger (Onset, Massachusetts, USA), located at a height of 1.5 m in the centre of tunnel.

The nets were characterized in terms of the quantity and quality of the transmitted radiation (Table 1), for which measurements of the solar radiation flux spectrum were made in a total band of 350 to 1,050 nm wavelength (total solar radiation: RT), at 1-nm intervals, by means of a BLACK-Comet-SR UV-VIS-NIR spectrometer (StellarNet Inc., USA), with a Dual Blaze 40-mm-diameter concave grating with aberration correction. Measurements were taken at 12:00 midday (GMT).

Color Measurements

Each year, evolution of the fruit was followed from 20 days after the beginning of their formation until the harvest of the red fruit (20, 24, 27, 32, 38, 43, 47 DAFS). The external color of the fruit was measured with a CM-700d portable spectrophotometer, using a view angle of 10º, standard illuminant D65, and a CIELab color space. The L*, a*, and b* data were used to determine differences in color. Twenty fruits per variety and shading treatment were measured throughout the evolution of the fruit.

Three readings were taken in the equatorial zone of each fruit. In each reading, the colorimetric coordinates **L***, **a***, and **b*** were measured. The **L*** color coordinate measures lightness (100 for white and 0 for black L*). The **a*** color coordinate corresponds to the green-red axis, where the negative values correspond to green and the positive to red (-60 green, +60 red) (Hutchings, 1994; MacDougall, 2002), and the **b*** color coordinate measures variations from blue to yellow (-60 blue, +60 yellow). Any decrease in the chlorophyll content of the fruit is associated with colorimetric coordinate **a*** (Kidsome *et al.*, 2002; Manera *et al.*, 2012).

Table 1. Characterization of the different nets studied, regarding total radiation. AR, UVA, blue light, red light, far red light, and IRC (W m^{-2}).

	Total radiation (350-1050 nm)	PAR (400-700 nm)	UVA (350-400 nm)	Blue light (400-500 nm)	Red light (600-700 nm)	Far red light (700-800 nm)	IRC (800-1050 nm)
Pearl 30%	469.1	204.8	10.3	69.0	120.5	66.6	373.1
Red 30%	501.6	217.7	11.3	71.1	131.3	68.2	312.9
Silver 30%	479.2	211.3	11.1	71.1	124.8	66.0	298.1
Red 40%	439.6	190.8	9.9	59.7	118.4	66.3	299.2
Black 35%	465.1	200.2	10.8	68.7	116.6	58.0	291.4
No cover	828.8	370.2	17.6	126.8	214.8	106.0	383.8

The Chroma C_{ab} (**C**) was calculated as **C**= $(a^2+b^2)^{1/2}$ and represents the hypotenuse of the triangle created by the union of the points (0, 0), (**a***, **b***), and (**a***, 0). The Hue angle (h_{ab}*) is defined as the angle between the hypotenuse and 0º on the **a*** (bluish-green/red-purple) axis. It was calculated as h_{ab}*= Arc tg (**b*/a***) (Little, 1975; McGuire, 1992). This indicates how much green and yellow the fruit color has. It is commonly used in English-speaking countries, while the **a*** coordinate is more common in Mediterranean countries. Therefore, both variables were used in this research work.

Color differences, expressed as ΔE_{ab}, were calculated using **L***, **a***, and **b*** as geometric coordinates in the following formula:

$$\Delta E_{ab}= [(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2]^{1/2}$$

Values above 3 indicate that the color perceived by the human eye is different (Manresa and Vicente, 2007).

The evolution of the colorimetric coordinate a* and its relationship with the total accumulated radiation, under the different types of net, as well as the behavior of the Chroma and Hue angle during the ripening of the peppers, were analyzed.

Yield

Number and weight of marketable, nonmarketable, and total (marketable+ nonmarketable) fruit were determined and expressed on a per hectare basis.

Statistical Analysis

The results were analyzed using the SPSS Statistics 24 program. The differences among the nets and cultivars ($P< 0.05$) for the different parameters studied were evaluated by Analysis Of Variance (ANOVA), followed by Tukey's test of comparison of means. Regressions were used to analyze, the effect of temperature and radiation on coordinate **a*** and total yield.

RESULTS AND DISCUSSION

Evolution of the Colorimetric Coordinates

The evolution of color was similar in the different cultivars studied. Figure 1 shows the evolution of the colorimetric coordinates of the outer surface of the pepper fruit for the variety Alcudia under the different treatments, throughout the period of maturation. As can be seen, the values of the coordinates were quite stable while the fruits were green, but once they began to turn red, the values of coordinate **a*** changed from negative (green) to values between 20 and 25 (red). Therefore, **a*** is a representative colorimetric coordinate in fruits or juices whose color is between green and reddish (Brown and Walker, 1990; Tsantili, 1990). The **b*** coordinate hardly varied, since only a small decrease was observed - from values close to 15 to values around 10 (yellow). Similar trends were found for the **b*** coordinate in other cultivars of pepper (Perez-Lopez *et al.* 2007). Finally, the **L*** coordinate underwent a decrease, but had almost recovered at the end of the fruit ripening process.

The study of ΔE was applied here to verify if the variations observed in the colorimetric coordinates implied that there were visually appreciable color differences among the cultivars and treatments used. Previously, ΔE was used to show the differences in color perceived by the human eye among different cultivars of grapefruit (Porras *et al.*, 2014) and lemon (Porras *et al.*, 2015).

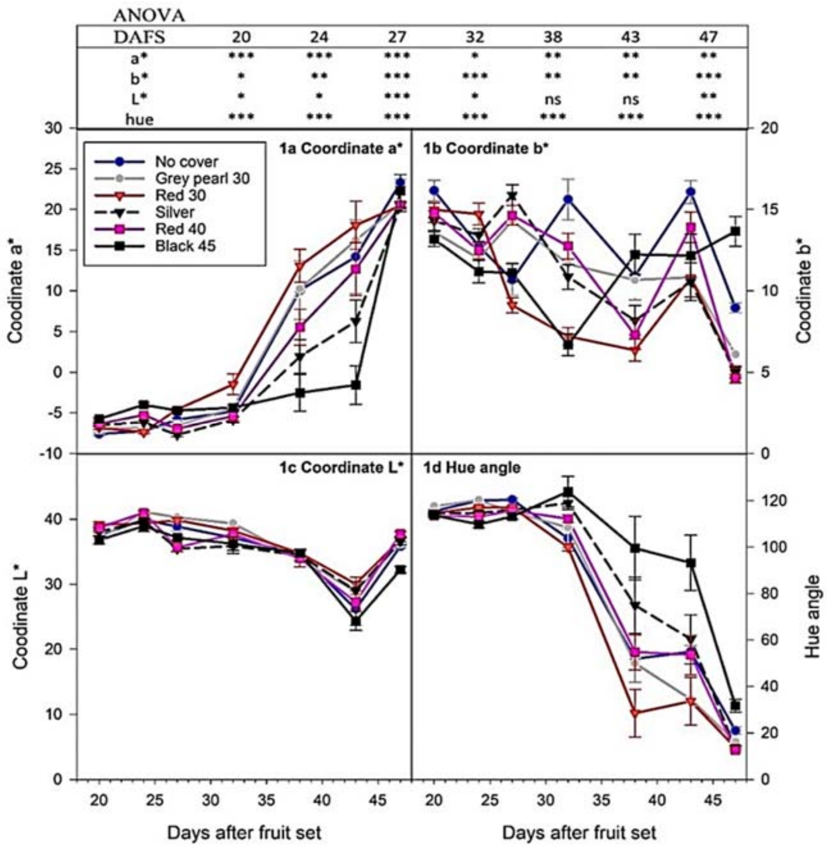

Figure 1. Evolution of the coordinates a*, b*, and L* and of the Hue angle of the cultivar Alcudia under the different nets. The values are the averages of the two crop seasons. ***, **, * and 'ns' indicate significant differences at P< 0.001, P< 0.01, P< 0.05 and non-significant differences respectively.

In each of the maturation cycles of the fruit of the distinct cultivars and treatments, a similar evolution was observed. As an example, Figure 2 shows the evolution of ΔE during the fruit growth and maturation of the cultivars Alcudia and Bendigo, under the Red 40 net. As a result, values greater than 3 indicate that the difference is visible to the naked eye (Manresa and Vicente, 2007). As in most of the comparisons, color differences were not noticeable until the number of Days After Fruit Set (DAFS) exceeded 30; from this point onwards, the evolution of the two cultivars was somewhat different and this could be seen with the naked eye. These differences diminished in the final stage, when the peppers were already red.

Table 2 shows the influence of the different nets on the coloration of the fruit of the different cultivars of pepper at 47 DAFS, considering the greenhouse without a net as the reference. The differences in color, measured as ΔE, once the coloration process had started, from 32 DAFS onwards, were evident throughout the maturation (coloration) process, with values greater than 3 for the vast majority of combinations. This means that, for the same cultivar, the difference in color of the fruit growing under two different nets was visible to the naked eye (Mokrzycki and Tatol, 2011; Witzel *et al*., 1973). However, these differences had practically disappeared on the last day of data collection, 47 DAFS (Table 2), when the peppers were already red and the differences were limited mainly to those between the control "No cover" and Black 35 and the other treatments. In fact, in cultivars

Cayetano and Alcudia, the only visual differences were between No cover and the rest of the treatments. In Bendigo, in addition to No cover, the Silver 30 n*et al*so produced visually perceptible differences with respect to the other treatments. Finally, for Pompeo, the Pearl 30 net also gave some visual differences with respect to the other treatments.

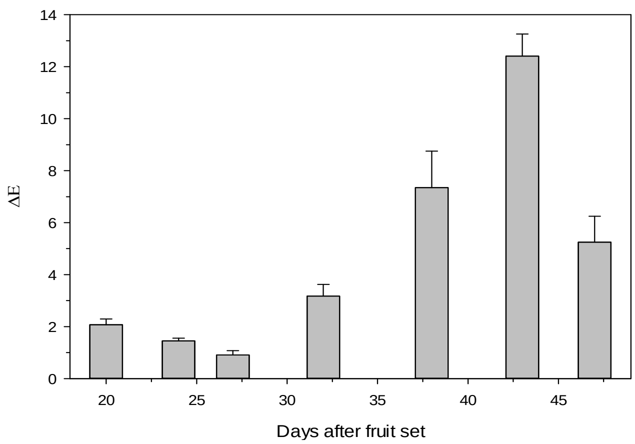

Figure 2. Evolution of ΔE from 20 days after fruit set, for the cultivars Alcudia and Bendigo grown under the Red 40 net (Mean±standard error of the two crop seasons).

Table 2. Values of ΔE at 47 days after fruit set (Mean±standard error of the two crop seasons).

	Pearl 30	Red 30	Silver 30	Red 40	Black 35
Alcudia					
No cover	3.9±0.41	4.9±0.48	5.02±0.89	5.49±0.47	6.01±1.82
Pearl 30		1.22±0.17	1.22±1.55	2.13±0.5	8.7±1.72
Red 30			0.33±2.04	1±1.03	9.92±1.87
Silver 30				1.23±1.1	9.91±0.11
Red 40					10.74±0.69
Bendigo					
No cover	2.11±0.87	1.29±0.98	3.38±1.48	1.36±2.92	7.1±2.84
Pearl 30		0.85±0.19	4.73±0.3	1.49±1.86	7.29±1.97
Red 30			4.19±0.73	1.09±2.19	7.07±2.33
Silver 30				3.25±0.63	10.26±0.31
Red 40					8.05±0.16
Cayetano					
No cover	2.72±0.71	3.82±0.9	5.07±0.3	3.7±0.61	2.84±1.19
Pearl 30		1.71±0.41	2.62±0.41	1.51±0.2	5.14±0.58
Red 30			1.47±0.85	0.42±0.26	6.43±0.18
Silver 30				1.41±0.55	7.47±0.03
Red 40					6.22±0.06
Pompeo					
No cover	4.06±1.46	1.93±1.24	3.45±1.39	3.87±2.81	8.31±2.89
Pearl 30		3.33±1.12	3.31±1.69	4.08±0.67	8.81±0.78
Red 30			1.62±0.33	1.98±0.74	9.72±0.82
Silver 30				1.22±1.35	10.59±0.95
Red 40					11.56±0.89

Pepper Coloration

Since the coordinate **a*** is the one that shows the color change from green to red, it is analyzed below. Figure 3 shows the evolution of coordinate **a*** for the cultivars Alcudia, Bendigo, Cayetano, and Pompeo under each of the treatments. The color change, from green to red, of the peppers started between 27 and 32 DAFS and ended at 47 DAFS.

In the evolution of the coordinate **a***, the differences were greatest when the peppers were changing color, between 38 and 43 DAFS. Before and after this period, the differences were small. In the absence of a cover (No cover), there were practically no differences in the evolution of the color among the cultivars. At the beginning, the unshaded treatment had the smallest (more negative) a* value such as occurred in Bell pepper (Díaz-Pérez *et al*., 2020). However, this treatment gave higher values of **a***; they were especially high in cultivars Bendigo and Pompeo, and relatively high in Alcudia and Cayetano. The Black 35 net gave the lowest values for all cultivars, especially Alcudia and Bendigo, for which the values of **a*** took much longer to begin to change. However, the color change occurred more quickly under the Black 35 net, all the cultivars reaching very similar values on the day of the last data collection. The Pearl 30 net also gave quite high values, the highest being in Cayetano. Finally, the values for the Red 40 net were lower than or similar to those of Red 30, but never higher.

The color evolution of the peppers was different from that found when other cultivars were grown in a polyethylene greenhouse and outdoors, those grown in the greenhouse having less color (Gomez-Ladrón de Guevara *et al*., 1996).

Visually, the greatest differences were between DAFS 38 and 43, Figure 3 shows the average values of the coordinate **a***, with their respective standard errors, for those days. In addition, the existence of significant differences, according to the Tukey test, is indicated for each cultivar and for each net.

From Figure 3 and Table 1 it can be deduced that it was between 38 and 43 DAFS when coordinate **a*** evolved more rapidly. Furthermore, the higher values of coordinate **a*** depended more on the cultivar than on the type of radiation under the net. Thus, the value of coordinate **a*** increased faster in Alcudia, Bendigo, and Cayetano than under No cover and with the Red 30 and Pearl 30 nets, where the PAR was between 204.8 and 370.2 W m^{-2} and the red light was between 120.5 and 214.8 W m^{-2}. For the rest of the nets (Silver 30, Red 40, and Black 45), with smaller wavelengths in the PAR and red light, the color evolution was slower and depended on the cultivar. The behavior of the cultivar Pompeo was different from that of the other cultivars: the increase in the red color (coordinate **a***) was quickest with No cover, with high values of PAR (370.2 W m^{-2}) and red light (214.8 W m^{-2}), and was much slower with all the studied nets.

Regarding the Chroma index, the “L a b” (CIELab) color diagram, Figure 4, shows that 20 DAFS all cultivars had similar values, with a Hue angle around 120º in the second quadrant, which indicates that, on that date, the peppers were green, regardless of the cultivar and type of tunnel net. The color change from green to red started between 32 and 38 DAFS, when the Chroma values passed from the second quadrant to the first quadrant; the Hue angles were already less than 90º at 32 DAFS.

As can be seen, at 43 DAFS, there were differences among the nets regarding the beginning of the color change of the peppers from green to red. With the Red 30 net, the red color of the pepper skin appeared earlier (Figure 4) in the cultivars Alcudia (Hue 28.51º) and Bendigo (Hue 53.55º). With the Pearl 30 net, the red color in the cultivar Cayetano (Hue 27.79º) appeared earlier, and only in the tunnel without a net did the red coloration begin earlier in the cultivar Pompeo (Hue 48.74º).

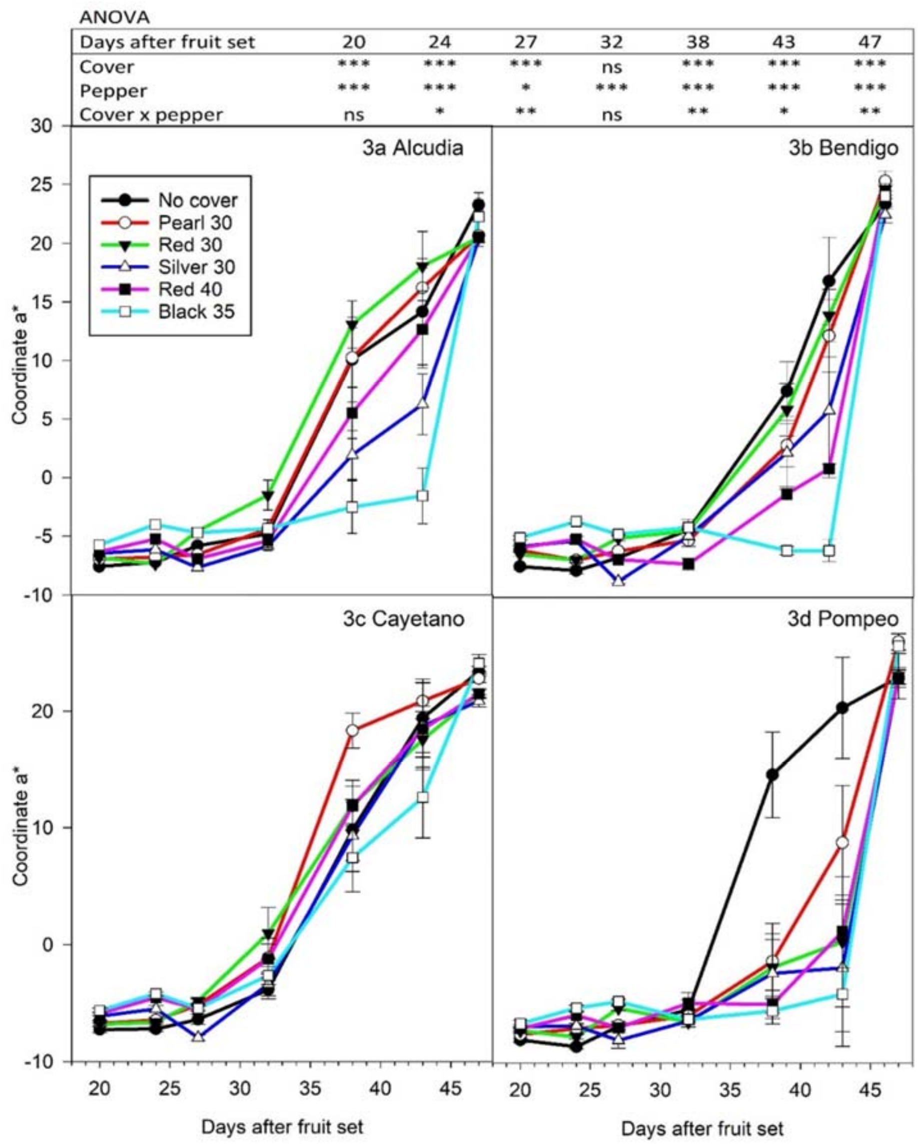

Figure 3. Evolution of the a* coordinate for each cultivar [(3a) Alcudia, (3b) Bendigo, (3c) Cayetano, and (3d) Pompeo]. The data are average values (±standard error) for each date and for each of the nets. ***, **, * and 'ns' indicate significant differences at P< 0.001, P< 0.01, P< 0.05 and non-significant differences respectively.

Temperature and Radiation

Figure 5 shows the evolution of the average daily temperature and total radiation recorded throughout the two growing cycles (2016 and 2017) under the different nets. As can be observed, on all days, the tunnel without a net was the one with the highest radiation, followed by the Silver 30 and Pearl 30 tunnels, independently of the atmospheric conditions. The radiation was lower under the Red 40 and Black 35 nets, the tunnel under the latter receiving the least radiation.

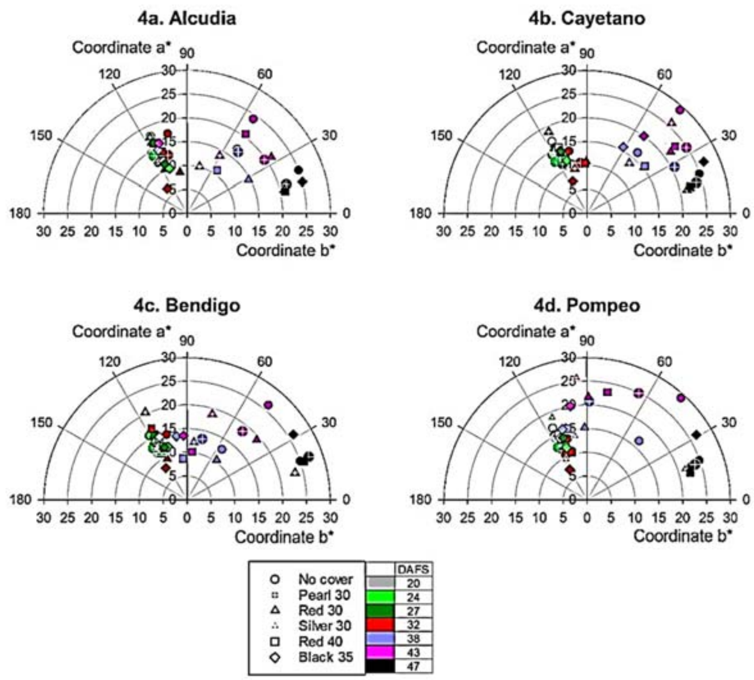

Figure 4. The "L a b" (CIELab) color diagram. Evolution of the Chroma index and Hue angle of the color of the skin of the different cultivars of peppers in tunnels with different nets or without a net (No cover).

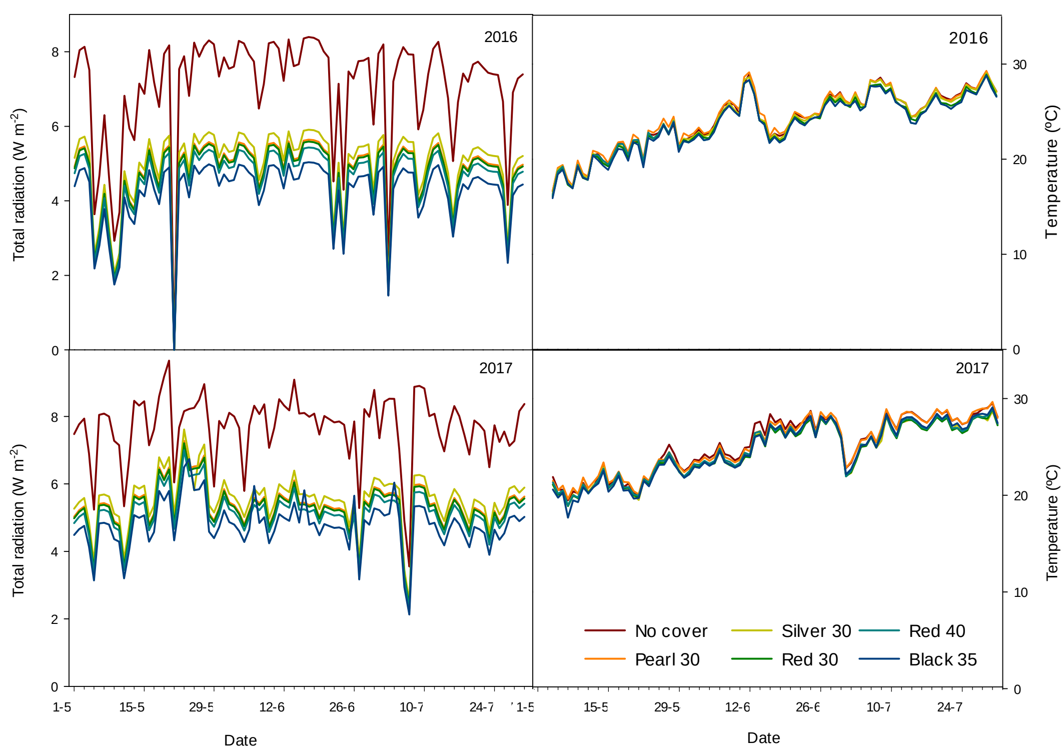

Figure 5. Evolution of the radiation and average temperature under the different nets in 2016 and 2017.

However, the average temperatures recorded in the tunnels were similar among the treatments. Ferreira *et al.* (2014) showed a similar behavior with regard to temperature in a study on pepper cultivation, with no differences between a 40% shade alumina mesh and the open field. Although the cultivation conditions in the case of Ferrerira were in a greenhouse covered with plastic, in this tunnel-type experiment, it could be due to the tunnel being completely covered by the net. The maximum and minimum temperatures were similar between the shading treatments, presenting minor differences with open field (Data not shown).

Evolution of Fruit Color *vs* Radiation and Temperature

Figure 6 shows the correlations between the value of coordinate a* at 43 DAFS and the total radiation accumulated after the starting date of the pepper coloration process. The correlations are very high, which allows us to state that the total radiation influenced the color of the peppers. If we correlate the temperature, independently with the data obtained in the 30% shading nets and the open air (Table 3), these relationships are high, being even higher when we relate by percentage of shading, in the case of the red net.

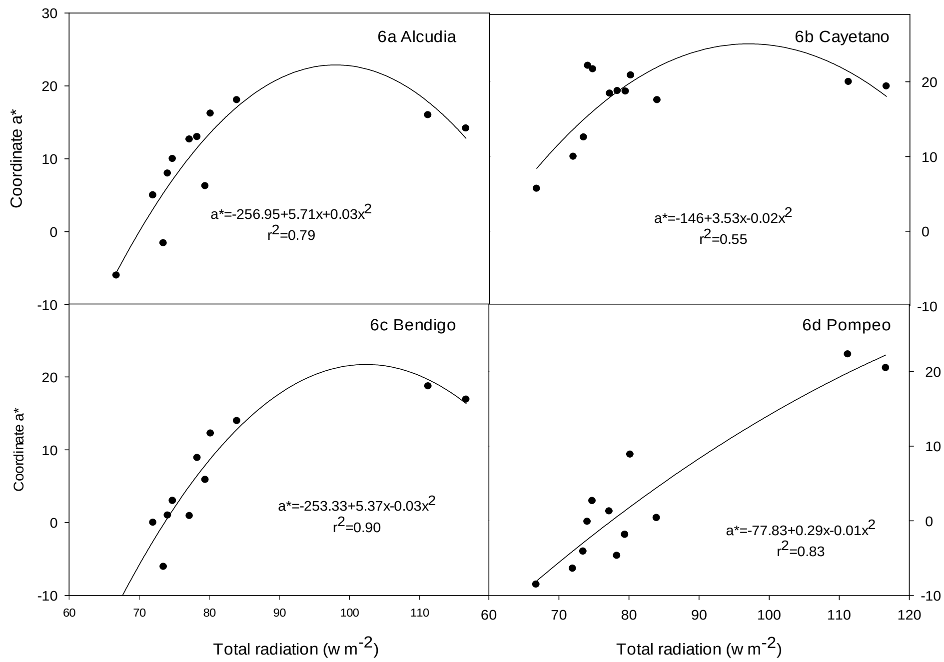

Figure 6. Correlations between coordinate a* at 43 days after fruit set and total accumulated radiation, for each cultivar, under the different nets or without a net (No cover).

Table 3. Quadratic regression between the coordinate a* (y) and the global radiation (x) of the covers at 30% and the control, and the red covers and the control.

	30%*		Red**	
	Regression	r^2	Regression	r^2
Alcudia	$y= -0.0202x^2+3.9781x-175.66$	0.5240	$y= -0.253x^2+4.9322x-218.1$	0.9486
Bendigo	$y= -0.0268x^2+5.4558x-255.05$	0.9342	$y= -0.0231x^2+4.523x-223.75$	0.9079
Cayetano	$y= 0.0092x^2-1.7886x+103.42$	0.5320	$y= -0.0144x^2+2.8521x-118.49$	0.6874
Pompeo	$y= 0.0059x^2-0.5723x+9.6359$	0.8262	$y= -0.0022x^2+1.0533x-71.047$	0.9515

*: Red, Pearl, Grey and Open field, **: Red 30%, Red 40 % and Open field.

Yield

Table 4 shows the total, commercial, and non-marketable yield by net type and cultivar. In general, all the cultivars had higher yields under these types of net than when grown in the control tunnel without a net. The results are similar to those of Shahak *et al.* (2008), who used red, yellow, and pearl colored nets giving 30 to 40% shade, and those of Fallik *et al.* (2009), who found that bell pepper grown in an arid region with red and yellow shade nets had better yields than when grown without a net. But, significant increases in leaf chlorophyll content, stomatal conductivity and photosynthesis rate have been reported by shading (50%) under conditions where the light intensity exceeds 250 μmol m^{-2} s^{-1} in tomato cultivation (Özer, 2017).

The Pearl 30 net generally gave the highest commercial yield for all the cultivars, ranging between 43,366 kg ha^{-1}, for Alcudia, and 38,956 kg ha^{-1}, for Cayetano. Next in the order of yield was the Red 30 net, with commercial yields ranging between 35,212 kg ha^{-1}, for Pompeo, and 29,422 kg ha^{-1} for Berlingo. The No cover treatment and Black 35 net gave the lowest commercial yields, the lowest of all being in "no cover" for the cultivars Cayetano and Pompeo: 12,258 and 20,348 kg ha^{-1}, respectively. There was no influence on the yield of the noticeable red light value of the Red 30 net (Table 1) since the highest yield was obtained with the Pearl 30 net, which had a red light value below those of Red 30 and Silver 30.

In general, all cultivars had lower commercial yields, and greater losses (non-marketable yields), when grown in the open air than when cultivated under a net; the exception was Pompeo, for which the loss was 20.24% in open-air cultivation and 22.58% under the Pearl 30 net. The losses were lower under the nets and ranged from 30.22%, for Cayetano grown under the Pearl 30 net, to 13.83%, for Pompeo grown under the Red 40 net.

Yield *vs* Radiation

Figure 7 shows the relationship between the total yield for each of the nets and the total accumulated radiation for each cultivar. In each case, the 12 points indicate, for each net, the total cumulative radiation between 27 and 43 DAFS and the yield per hectare. According to this figure, high radiation implies low yields, as was the case of the tunnel without a net, with the highest radiation and lowest yields. On the other hand, very low radiation also implies low yields, as in the case of the Black 35 net. In the case of correlating radiation with different colors and with the same percentage of shading, or different percentages of shading in the case of the red mesh, the relationships are higher in the latter case (Table 5).

High radiation ends up damaging the peppers. In fact, in almost all the cultivars, the loss of yield was greater with open-air cultivation than under any of the nets. In general, the mean yield increased with increases in radiation, up to a threshold value of radiation from which yield began to fall. Fallik *et al.* (2009) found that bell pepper grown in an arid region with red and yellow shade nets had significantly higher yields of fruit of export quality, compared to a black net giving the same level of shading. Díaz-Pérez *et al*. (2020) report that shade nets increase fruit yield and quality in bell pepper compared with fruit produced in unshaded conditions. Also, Kittas *et al*. (2012) showed a significantly increase in total yield of tomato, with Red and pearl colored shadecloths (40%), in Greece. Furthermore, there is an agreement with the results obtained in blueberry (*Vaccinium corymbosum L*) by Rtamates et al. (2018)"

Table 4. The total, commercial, and non-marketable yields (kg ha^{-1}), and the non-marketable yield expressed as the percentage loss of the total yield, of all cultivars when grown without a net (No cover) and under the different nets.^{A}

Alcudia	Total yield	Commercial yield	Non-marketable yield	Loss (%)
No cover	35,530±4,506^{a}	26,822±2,395^{a}	8,708±465^{bc}	24.51
Pearl 30%	53,861±2,265^{b}	43,366±1,038^{b}	10,495±457^{c}	19.49
Red 30%	36,839±3,234^{a}	29,544±1,823^{a}	7,295±54^{abc}	19.80
Silver 30%	38,714±5,362^{a}	29,734±2,108^{a}	8,980±1,146^{bc}	23.20
Red 40%	37,312±7,292^{a}	30,390±3,449^{a}	6,921±1,280^{ab}	18.55
Black 35%	31,798±4,467^{a}	27,183±2,820^{a}	4,615±119^{a}	14.51
Berlingo				
No cover	39,182±2,579^{b}	27,467±2,144^{a}	11,715±436^{c}	29.90
Pearl 30%	47,056±2,245^{c}	35,389±2,624^{b}	11,667±423^{c}	24.79
Red 30%	38,140±224^{ab}	29,422±155^{ab}	8,718±163^{b}	22.86
Silver 30%	35,608±131^{ab}	26,521±588^{a}	9,087±719^{b}	25.52
Red 40%	31,887±526^{a}	25,835±365^{a}	6,051±161^{a}	18.98
Black 35%	33,448±24^{ab}	26,858±377^{a}	6,590±391^{a}	19.70
Cayetano				
No cover	23,702±1,677^{a}	12,258±1,304^{a}	11,444±437^{b}	48.28
Pearl 30%	55,825±2,738^{d}	38,956±1,830^{c}	16,869±908^{c}	30.22
Red 30%	44,663±927^{c}	30,293±799^{b}	14,370±766^{c}	32.17
Silver 30%	39,842±1,478^{bc}	24,779±1,538^{b}	15,064±70^{c}	37.81
Red 40%	38,942±1,710^{bc}	28,896±1,543^{b}	10,047±551^{ab}	25.80
Black 35%	36,616±1,376^{b}	28,103±759^{b}	8,513±644^{a}	23.25
Pompeo				
No cover	25,513±2,998^{a}	20,348±2,956^{a}	5,165±43^{a}	20.24
Pearl 30%	47,545±75^{ab}	36,810±246^{c}	10,735±309^{b}	22.58
Red 30%	44,468±1,331^{b}	35,212±841^{c}	9,256±923^{b}	20.81
Silver 30%	30,211±1,953^{ab}	24,415±2,481^{ab}	5,796±537^{a}	19.19
Red 40%	38,235±1,095^{b}	32,946±935^{c}	5,289±766^{a}	13.83
Black 35%	38,143±2,274^{b}	31,931±1,944^{bc}	6,212±715^{a}	16.28
ANOVA				
Cover	***	***	***	
Pepper	ns	***	***	
Cover×Pepper	***	***	***	

^{A} Values with different letters in the same column differ significantly at the 95% level, according to Tukey's HSD test.

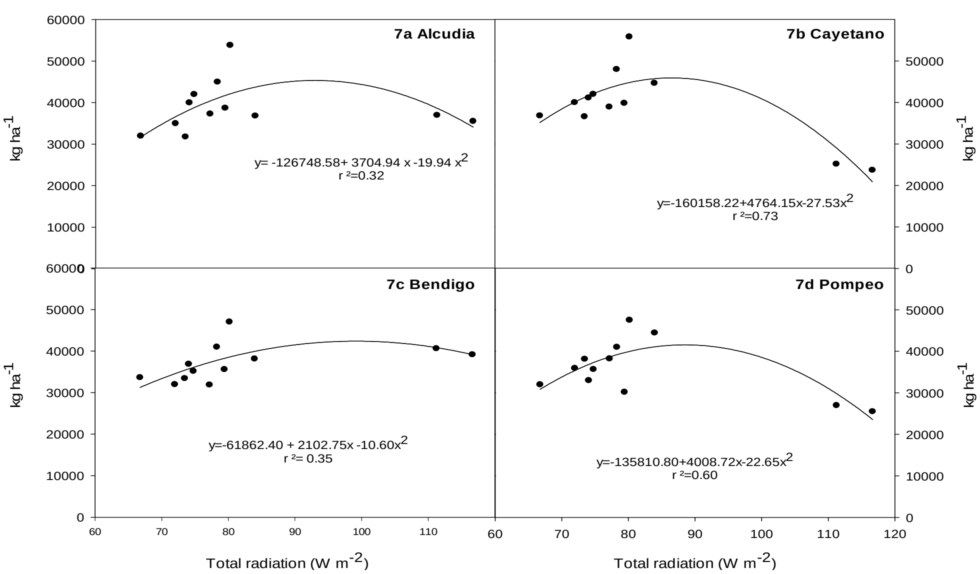

Figure 7. The relationship between the yield (for each net) and the cumulative total radiation between 27 and 43 days after fruit set, for each of the cultivars under study. The values of the x axis are in thousands.

Table 5. Quadratic regression between the production (y) and the global radiation (x) of the covers at 30% and the control, and the red covers with the control.

	30%[a]		Red[b]	
	Regression	r^2	Regression	r^2
Alcudia	$y= -5.8475x^2+940.73x+4998.9$	0.3620	$y= -8.196x^2+1586.4x-32550$	0.031
Bendigo	$y= -12.029x^2+2339.6x-70386$	0.2670	$y= -12.851x^2+2576.6x-86715$	0.5674
Cayetano	$y= -26.661 x^2+4557.5x-148063$	0.7903	$y= -21.089x^2+3543.1x-104932$	0.8924
Pompeo	$y= -33.126x^2+6039.3x-231052$	0.6163	$y= -24.514x^2+4332.x-148598$	0.9251

[a] Red, Pearl, Grey and Open field, [b] Red 30%, Red 40 % and Open field.

CONCLUSIONS

The speed of coloration of the pepper fruit depended on the net used in the tunnel greenhouse. It was fastest in the tunnel without a net, followed by the Red 30 and Pearl 30 treatments, and was slowest with the Black 35 net. The speed of the color change from green to red also depended on the cultivar: it was fastest in Cayetano, for all nets, and slowest in Pompeo. In the tunnel with no cover, there were no differences in the evolution of the color among the cultivars. According to the ΔE measurements, the perceivable differences in color between treatments increase, once the color changing process had begun, and decrease at the end of the process, when the fruit has reached their characteristic red color.

The correlations between radiation and pepper color were very high, which allows us to affirm that total radiation influenced the evolution of color. However, since there were no significant differences in temperature among the different nets, the influence of temperature was the same for the different cultivars regardless of the net.

The influence of the different types of net on the pepper yields depended on the cultivar grown: the Pearl net improved the yields of the cultivars Alcudia and Pompeo, so, this type of net seems to be favorable for the cultivation of cultivars of type Lamuyo. In the case of the cultivar Cayetano (California type), the Red 30 net gave higher yields. The yield was affected by the radiation, low and high radiation values resulting in lower yields per hectare, while moderate values corresponded to higher yields. The velocity of the change in fruit color from green to red was related to the type of net used. The higher the radiation received, the earlier the appearance of the red coloration.

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توری سایه‌دار فتوسلکتیو(Photoselective) در محصول فلفل شیرین، دوره رسیدن را تسریع می‌کند و کیفیت کلی و عملکرد میوه را بهبود می بخشد

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چکیده

توری‌های فتوسلکتیو برای حفاظت از سبزیجات و گیاهان باغی در برابر آفتاب سوختگی استفاده شده و به طولانی شدن دوره کشت در شرایط نور زیاد منجر می شود. در این پژوهش، ما تأثیر چهار شبکه سایه‌انداز فتوسلکتیو (Pearl 30, Red 30, Silver 30, Red 40)، یک شبکه استاندارد سیاه‌رنگ (Black 35 سیاه 35)، و یک شاهد (بدون پوشش) را بر تکامل رنگ محصول طی دوره رسیدن میوه دو نوع فلفل، یعنی لامویو(Lamuyo) و کالیفرنیا (California) بررسی کردیم. به این منظور، تکامل رنگ میوه ها از ابتدای شکل گیری تا زمان برداشت پایش شد و با تابش کل و دما همبست شد(correlated). مواد گیاهی مورد استفاده فلفل از نوع کالیفرنیا - ارقام Bendigo و Cayetano - و از نوع Lamuyo، ارقام Alcudia و Pompeo بود. نتایج نشان داد که نرخ تغییر رنگ فلفل به (نوع) توری استفاده شده در گلخانه وابسته بود. سرعت تغییر رنگ از سبز به قرمز بیشتر به رقم و تشعشع کل ، که مشروط به توری‌های فتوسلکتیو مختلف بود، بستگی داشت تا به نوع فلفل. بیشترین تفاوت بین تیمار شاهد (بدون تور) و توری مشکی بود، افزایش رنگ قرمز فلفل ها در اولی سریعتر بود. مقادیر تشعشع زیر 75 وات بر مترمربع یا بیشتر از 110 وات بر مترمربع تأثیر منفی بر عملکرد داشت. دمای زیر توری به‌طور معنی‌داری تحت تأثیر نوع توری قرار نگرفت و در نتیجه تأثیر آن بر ارقام مختلف مشابه بود.