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# Effect of polycarbonate and agricultural film on production and biochemical compounds of tomato fruits

**Efeito de policarbonato e filme agrícola na produção e compostos bioquímicos de frutos de tomate**

**Efecto del policarbonato y la película agrícola sobre la producción y compuestos bioquímicos de frutos de tomate**

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**Abstract**
Tomato production has been enhanced significantly by management using intervention of temperature and radiation control in a protected environment. The use of plastic and/or polycarbonate covers changes the dynamics of production in tropical climate regions. The present study aimed to compare the following covered cultivation conditions: 1) polycarbonate plate (10 mm) box-shaped polycarbonate with a twin wall with anti UV-A and B (P), 2) agricultural film (AF) anti UV-A and UV-B, and 3) open field (OF) on the productivity and quality of Italian hybrid tomatoes. The study was carried out at Embrapa Agrossilvipastoril located in Sinop, Mato Grosso, Brazil. Four tomato hybrids and 03 distinct environments were used in a randomized block design in a subplot setup with five replications. The main factor was hybrid traits, and the subplots were environments with different covers. The highest productivity occurred in the P environment, with the hybrids Fascinio and Vedette with 66.64 and 55.84 t ha-1, respectively. The highest plant yield obtained was in the P environment, with an average of 3.15 kg per plant. Among the evaluated hybrids, the highest antioxidant potential was observed in Shanty, and for the content of carotenoids, lycopene, and vitamin C, no significant difference was observed between the evaluated hybrids. We can conclude that the use of

polycarbonate plates box shaped with a twinwall or agricultural film in a protected tomato cultivation system under high temperature conditions increases the yield and qualitative potential of the Fascinio and Vedette hybrids.
**Keywords:** *Solanum lycopersicum* (L.); Protected cultivation; Tropical horticulture; Polycarbonate box shape twinwall.

**Resumo**
A produção de tomate tem sido aprimorada significativamente pelo manejo com intervenção de controle de temperatura e radiação em ambiente protegido. O uso de coberturas plásticas e/ou de policarbonato altera a dinâmica de produção em regiões de clima tropical. O presente estudo teve como objetivo comparar as seguintes condições de cultivo coberto: 1) placa de policarbonato (10 mm) policarbonato em forma de caixa com parede dupla com anti UV-A e B (P), 2) filme agrícola (AF) anti UV-A e UV-B, e 3) campo aberto (OF) sobre a produtividade e qualidade de tomates híbridos italianos. O estudo foi realizado na Embrapa Agrossilvipastoril localizada em Sinop, Mato Grosso, Brasil. Foram utilizados quatro híbridos de tomateiro e 03 ambientes distintos em delineamento de blocos casualizados em uma configuração de subparcelas com cinco repetições. O principal fator foram as características híbridas, e as subparcelas foram ambientes com coberturas diferentes. A maior produtividade ocorreu no ambiente P, com os híbridos Fascinio e Vedette com 66,64 e 55,84 t ha$^{-1}$, respectivamente. A maior produtividade de plantas obtida foi no ambiente P, com média de 3,15 kg por planta. Entre os híbridos avaliados, o maior potencial antioxidante foi observado no Shanty, e para o teor de carotenóides, licopeno e vitamina C, não foi observada diferença significativa entre os híbridos avaliados. Podemos concluir que o uso de placas de policarbonato em forma de caixa com parede dupla ou filme agrícola em sistema de cultivo protegido de tomate sob condições de alta temperatura aumenta a produtividade e o potencial qualitativo dos híbridos Fascinio e Vedette.
**Palavras-chave:** *Solanum lycopersicum* (L.); Cultivo protegido; Horticultura tropical; Parede dupla em forma de caixa de policarbonato.

**Resumen**
La producción de tomate se ha mejorado significativamente mediante la gestión mediante la intervención del control de la temperatura y la radiación en un entorno protegido. El uso de cubiertas de plástico y/o policarbonato cambia la dinámica de producción en las regiones de clima tropical. El presente estudio tuvo como objetivo comparar las siguientes condiciones de cultivo cubierto: 1) placa de policarbonato (10 mm) policarbonato en forma de caja con pared doble con anti UV-A y B (P), 2) película agrícola (AF) anti UV-A y UV-B, y 3) campo abierto (OF) sobre la productividad y calidad de los tomates híbridos italianos. El estudio fue realizado en la Embrapa Agrossilvipastoril situado en Sinop, Mato Grosso, Brasil. Se utilizaron cuatro híbridos de tomate y 03 ambientes distintos en un diseño de bloques al azar en una configuración de subparcelas con cinco repeticiones. El factor principal fueron los rasgos híbridos, y las subparcelas fueron ambientes con diferentes coberturas. La mayor productividad se presentó en el ambiente P, con los híbridos Fascinio y Vedette con 66,64 y 55,84 t ha$^{-1}$, respectivamente. El mayor rendimiento de plantas obtenido fue en el ambiente P, con un promedio de 3,15 kg por planta. Entre los híbridos evaluados, el mayor potencial antioxidante se observó en Shanty, y para el contenido de carotenoides, licopeno y vitamina C, no se observó diferencia significativa entre los híbridos evaluados. Podemos concluir que el uso de placas de policarbonato en forma de caja con doble pared o película agrícola en un sistema de cultivo de tomate protegido en condiciones de alta temperatura aumenta el rendimiento y el potencial cualitativo de los híbridos Fascinio y Vedette.
**Palabras clave:** *Solanum lycopersicum* (L.); Cultivo protegido; Horticultura tropical; Pared doble en forma de caja de policarbonato.

## 1. Introduction

Tomato is characterized as a high-risk crop, particularly in tropical regions, with a high demand for investments principally to reduce the interference of temperature in production. One of the strategies in an attempt to minimize the impact of high temperatures on tomato cultivation has been to select hybrids with adaptations to these regions (Bazgaou, *et al.,* 2018; Seabra Junior, *et al.,* 2022). However, integrated management with different covers can aid tomato cultivation to reduce physiological stresses in tomato plants and corroborate to maximize great yields. One of the most widespread materials for covering greenhouses in tropical climates is the use of plastic film, but it can cause physiological disorders that lower productivity (Otoni, *et al.,* 2012; Ahemd, *et al.,* 2016; Bazgaou, *et al.,* 2018).

High temperature and UV indices are important environmental stress factors that cause physiological problems such as flower and fruit abortion. Stress can also modify the physical, chemical, and biochemical characteristics of fruits (Tilahun, *et al.,* 2017; Mariz-Ponte, *et al.,* 2019). Thus, it is necessary to use materials that contribute to the reduction of the thermal load of the protected environment structure (Harel, *et al.,* 2014; Florido & Álvarez, 2015).

The use of covered structures has the ability to influence plant growth, development, and production due to the modification of some meteorological variables (Beckmann, *et al.,* 2006; Kidus, *et al.,* 2020). With advanced technologies in the development of plastics, the production design of protected environments has been able to adopt new materials for environmental coverage (Kwon, *et al.,* 2017).

There are strategies that can be adopted for the cooling of the protected environment and thus provide more favorable microclimatic conditions for cultivation (Abdel-Ghany, *et al.,* 2015). The use of near infrared radiation (NIR) reflective roofing materials can contribute to the reduction of thermal load in protected environment structures in tropical climate regions and thereby increase the productivity of vegetables (Mutwiwa, *et al.,* 2017).

Different NIR filtering methods can influence climatic and cultural parameters (Hemming, *et al.,* 2005). The use of polycarbonate can be considered an alternative for covering greenhouses due to its light weight, high light transmittance in combination with UV protection, and long-term stability (Kwon, *et al.,* 2017; Mogharreb & Abbaspour-Fard, 2019).

The adoption of new types of materials allows more favorable conditions that can increase productivity and quality conditions of high temperatures and rainfall. This study aimed to determine the effect of polycarbonate coating, agricultural film and uncoated (field culture) on yield and biochemical compounds of Italian tomato hybrids under high temperature conditions.

## 2. Methodology

The study was carried out at Embrapa Agrossilvipastoril located in the city of Sinop, Mato Grosso (latitude 11°52'12.62"S, longitude 55°35'54.61"O, altitude 364 m) during the growing season 2019-20. The Köppen climatic classification of the area is tropical (Aw) (Nogueira, *et al.,* 2010). The soil is characterized as dystrophic red–yellow latosol (EMBRAPA, 2013).

A randomized block design was used with a subdivided plot arrangement evaluating three environments in each plot and four hybrids in each subplot, with five replications and seven plants per plot. The hybrid cultivars of Italian tomato used were Fascínio (Feltrin®), Anny and Shanty (Házera®) and Vedette (Feltrin®). The environments studied were as follows: 1) Agricultural Film (AF) - chapel-like protected environment, transparent polyethylene agricultural film of 150 μm as cover; 2) Polycarbonate plates (10 mm) box shape polycarbonate with a twinwall with Anti UV-A and B (P); 3) Open Field (OF) - environment without protection.

Both the P- and AF-environment-type gable rigid frames evaluated presented dimensions of 6.4 m x 20 m with a side height of 3.5 m and a center height of 4.8 m. Lateral closure was performed with a light reflector aluminet® with 30% shading.

The experimental plots were composed of 4 7 plants spaced evenly within an area of 0.35 m x 1.25 m at a density of 22,000 plants $ha^{-1}$. Hybrid tomato seeds were sown in 300 milliliter containers in the commercial substrate Vivato® into a greenhouse with anti UV-A and UV-B film. Transplanting occurred after 50 days.

Soil acidity and fertilization were performed by applying dolomitic limestone and adding 40 ton $ha^{-1}$ cattle manure and 3,400 kg $ha^{-1}$ single superphosphate (18% $P_2O_5$) thirty days before the experiment was established. Top dressing fertilization was executed by applying 120 g $plant^{-1}$ of calcium nitrate (15% N and 19% Ca), 40 g $plant^{-1}$ of potassium sulfate (48% $K_2O$ and 15% $SO_4$), 30 g $plant^{-1}$ of monoammonium phosphate (12% N and 61% $P_2O_5$), 110 g $plant^{-1}$ of potassium nitrate (13% N, 44% $K_2O$ and 1.5% S), and 70 g $plant^{-1}$ magnesium sulfate (9% Mg and 12% S) under intervals of seven days by fertigation (Ribeiro, 1999). Irrigation was carried out by applying a mean of 3.5 mm in all environments, compensating for the daily evapotranspiration average obtained. (Valeriano, *et al.,* 2017).

Disease and pest control was carried out according to conventional recommendations for the culture. The agrometeorological conditions of each cultivation environment were monitored from December 2019 to April 2020 by means of ONSET® HOBO® U30 Station weather stations, which recorded temperature, relative humidity, global radiation and photosynthetically active radiation every 20 minutes between 6:00 and 18:00 hours. During the experiment, the accumulated precipitation was 2115 mm.

To evaluate productive characteristics, all fruits at stage 6 (intense red color) were collected, classified and quantified, with the following parameters calculated: total production - TP (kg $plant^{-1}$), commercial production - CP (kg $plant^{-1}$), fruit mass - FM (g $fruit^{-1}$), mass of nonmarketable fruits - MNMF (kg $plant^{-1}$), percentage of fruit loss - FL (%), soluble solids - SS (°Brix), pH, titratable acidity - A (%), texture - T (N), chroma - *C**, *hue* angle – h°, lycopene (mg 100 $g^{-1}$), β-carotene (mg 100 $g^{-1}$), vitamin C (VC) (mg 100 $g^{-1}$), total phenols (FT) (mg 100 $g^{-1}$) and antioxidant activity (DPPH) (μmol $g^{-1}$) for all three treatments.

The classification of fruits in commercial production was performed according to weight characteristics and visual damage presence according to the recommendation of the Programa Brasileiro de Modernização da Horticultura - PBMH, (2003). The productivity calculation was performed by projecting the production of 22,000 plants $ha^{-1}$ according to the useful area ocuped by each plant.

For qualitative analyses, the fruits were harvested mature in stage 6 (intense red color) and were classified and standardized for 12 samples collected per repetition. The fruits were sanitized by immersion in chlorinated water and distilled water. Tomato samples were crushed in a juicer (Philips Walita) and separated into triplicates. Fresh samples were used for the physicochemical analyses, and samples for biochemical analysis were frozen.

The fruit firmness analysis was performed by using a micro system texture analyzer® model TA HD Plus with a tip of 6 mm at a depth of 9 mm. The total soluble solids (SST) content expressed in °Brix was measured using the ATAGO® refractometer model PAL-BX/IR.

For the color parameter, the Colorimeter of the Hunter Lab® brand and the Color Quest XE model were used, and the readings were performed in the L*a*b system, in which the calculations of chromaticity $C° = (a^2+b^2)^1/2$ and hue angle were performed with the data (b/a). The ascorbic acid content was determined by the Tillman titulometric method, which is based on the reduction of the sodium salt dye 2,6-indophenol dichlorophenol by an acid solution containing oxalic acid (AOAC, 2000).

A juice extractor was used to extract fruit juice for total acidity analysis based on the method of Maul et al. (2000) with the aid of a potentiometric titer (Hanna Instruments® model HI901), and acidity (expressed as a percentage of citric acid) was calculated using the following formula:

$$\text{Acidity (\%)} = \frac{Titled\ x\ fc\ x\ 0{,}0064\ (Citric\ Acid\ Factor)}{g}\ x\ 100$$

Where Titrated = volume (ml of NaOH); fc= 0.887469; *and g* (grams).

This function determines the concentrations of lycopene β-carotene, according to Nagata and Yamashita (1992). The analysis of total phenolic compounds was performed according to the Folin-Ciocalteau method (Singleton & Rossi, 1965).

Antioxidant capacity was evaluated in the same extract obtained for the quantification of total phenolic compounds using the assay with 1,1-difenil-2-picrilhydrazil-DPPH (Brand-Williams, *et al.*, 1995). All determinations were accompanied by a control, without the samples after 30 minutes of rest. The result was expressed in equivalent antioxidant capacity in Trolox - TEAC (μmol $g^{-1}$).

The data were submitted to the normality test and analysis of variance (F test), and the means were compared by the Schott Knot test with $p<(0.05)$ with SISVAR® Pt-BR version 5.6 software (Ferreira, 2019). All laboratory and field procedures were performed in triplicate (*n*=3).

## 3. Results

There was a significant interaction regarding productivity between the environment and hybrid. Polycarbonate (P) cover provided higher productivity for all hybrids grown (Table 1). In the environment covered with agricultural film, there was a difference in productivity only for the Fascínio hybrid, and in the open field, the lowest overall tomato yield was obtained. Under a polycarbonate cover, the Fascínio and Vedette hybrids obtained higher productivity than Anny and Shanty. Fascínio obtained productivity that was 29% and 39.8% higher than Anny and Shanty, respectively. Vedette was 15% and 27.9% higher than Anny and Shanty, respectively (Table 1).

**Table 1.** Productivity (t $ha^{-1}$) and number of marketable fruits - NMF (unit $plant^{-1}$) of tomatoes of the hybrids Fascínio, Anny, Shanty and Vedette grown in open field (OF) and protected environments with agricultural film covering (AF) and polycarbonate (P).

| | | Environment | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Prod[1]. (t. $ha^{-1}$)** | | | **NMF (unit $plant^{-1}$)[2]** | | |
| | | **P** | **AF** | **OF** | **P** | **AF** | **OF** |
| Hybrids | Fascínio | 66.80 aA | 38.40 aB | 13.80 aC | 17.40 aA | 14.60 aA | 4.60 aB |
| | Anny | 47.40 bA | 46.00 aA | 14.60 aB | 12.60 bA | 16.60 aA | 3.80 aB |
| | Shanty | 40.20 bA | 35.00 aA | 18.80 aB | 10.80 bA | 13.60 aA | 5.60 aB |
| | Vedette | 55.80 aA | 44.20 aA | 16.00 aB | 15.20 aA | 17.60 aA | 4.20 aB |
| | | **F calculated** | | | | | |
| | Env. (E) | 173.05* | | | 83.16* | | |
| | Hybrid. (H) | 1.04 ns | | | 1.41ns | | |
| | H x E | 2.06* | | | 2.37* | | |
| | CV1 | 9.53 | | | 14.29 | | |
| | CV2 | 15.74 | | | 13.22 | | |

CV1- environment; CV2- environment x Hybrids. Means followed by the same letters, upper case in the row and lower case in the column do not differ by Scott–Knott test ($p<0.05$). [1]Considering a population of 22000 plants $ha^{-1}$. [2] Data transformed to $Y=\sqrt{x+0.5}$. Source: Authors, (2022).

When comparing hybrids within each environment, Fascínio under polycarbonate was 73.95% and 480.05% more productive compared to agricultural film and open field, respectively. The production of Anny in OF conditions was lower (Table 1), with P and AF environments higher by 324.65% and 315.06%, respectively. Another Hybrid “Shanty” was similar to Anny, showing increases in P and AF of 213.82% and 186.17%, respectively. The hybrid Vedette production was increased under P and AF by 348.75% and 276.25%, respectively, compared to OF. These results indicate the significance of genetic input regarding tomato adaptability and potential to cultivation conditions between different environments.

The production of marketable fruits was higher under covers than under OF (Table 1). In relation to hybrids evaluated, Anny and Shanty showed the lowest production under the P environment. The fascínio hybrid exhibited a higher NMF under P and AF, with 17.40 and 14.60 units per plant, respectively. OF was lower than both, with a mean of 4.60 units $plant^{-1}$ (Table 1).

The increase in NMF in P and AF in comparison to OF was 378.20 and 315.06%, respectively. For the “Anny” hybrid, NMF developed under AF and P conditions verified increases of 331.6% and 242.8%, respectively. For Hybrid Shanty, NMF under P and AF conditions increased by 361.9% and 436.8%, respectively, in relation to OF. The “vedette” hybrid NMF under P and AF conditions increased by 419% and 192.8%, respectively, when compared to OF.

In relation to total and commercial production (PT and CP), there was a significant difference for the environment, in which the polycarbonate cover provided production of 3.25 kg $plant^{-1}$, which represented an increase of 325% in relation to OF (Table 2).

**Table 2.** Total production - TP (kg $plant^{-1}$), commercial production - CP (kg $plant^{-1}$), fruit mass - FM (g $fruit^{-1}$), mass of nonmarketable fruit - MNMF (kg $plant^{-1}$) and percentage of fruit loss - FL (%) of tomatoes from the hybrids Fascínio, Anny, Shanty and Vedette grown in a protected-environment chapel type with polycarbonate cover (P), agricultural film (AF) and open field (OF).

| | | PT[2] | CP[2] | FM | MNMF[2] | FL[2] |
|---|---|---|---|---|---|---|
| Hybrids | Fascínio | 2.66 a | 1.86 a | 111.13 a | 0.60 a | 25.00 a |
| | Anny | 2.26 a | 1.73 a | 121.66 a | 0.40 a | 22.06 a |
| | Shanty | 1.93 a | 1.40 a | 99.20 b | 0.40 a | 22.73 a |
| | Vedette | 2.26 a | 1.86 a | 103.53 b | 0.53 a | 23.20 a |
| Environments | P | 3.25 a | 2.30 a | 106.65 a | 0.80 a | 24.10 a |
| | AF | 2.60 b | 1.95 b | 103.60 a | 0.65 a | 25.00 a |
| | OF | 1.00 c | 0.90 c | 116.40 a | 0.10 b | 20.65 a |
| **F calculated** | | | | | | |
| Env. (E) | | 95.74* | 96.33* | 2.64 ns | 31.00* | 1.61 ns |
| Hybrids. (H) | | 2.21 ns | 1.75 ns | 3.04* | 1.02 ns | 0.28 ns |
| (H) x (E) | | 1.12 ns | 1.36 ns | 0.12 ns | 0.56 ns | 1.56 ns |
| CV (%) 1 | | 10.08 | 7.90 | 16.87 | 18.47 | 14.66 |
| CV (%) 2 | | 12.95 | 14.55 | 20.07 | 20.71 | 18.35 |

CV1- environment; CV2- environment x hybrids. Equal lowercase letters in the column do not differ by the Scott–Knott test ($p<0.05$). * There was a significant difference within the analyzed factor. ns Not significant within the analyzed factor. [1] Population of 22,000 plants per hectare. [2] Transformed data ($Y=\sqrt{x+0.5}$). Source: Authors, (2022).

Analyzing another environment, AF was observed to produce 260% more than OF. For total and commercial production, there was no difference between the hybrids analyzed. CP evaluation in the environment covered by P and AF provided an increase of 255 and 216.66% higher than OF, respectively (Table 2).

In the fresh mass (FM) evaluation, there was a significant difference between hybrids, in which the highest means were observed in Anny and Fascínio, with 121.66 and 111.13 g per fruit, respectively (Table 2). Shanty and Vedette hybrids exhibited lower FM than Anny and Fascínio hybrids, with means of 99.20 and 103.53 g $fruit^{-1}$, respectively.

The fresh mass of nonmarketable fruits (MNMF) in the P and AF environments was 0.80 and 0.65 kg per plant, respectively, and that in the OF was 0.10 kg $plant^{-1}$. These values can be explained by the fact that more productive environments tend to obtain greater losses in general; however, the loss in the open field represented 10% of the total fruit production.

To verify the FL, these values were not significant but varied between hybrids from 22.1 to 25.0% and between environments of 20.6 and 25.0%. The losses in the OF were relatively higher due to infestation with whitefly (*Bemisia tabaci* Hemiptera: Aleyrodidae) and thrips (Thysanoptera), common insect pests of tomatoes.

There was a significant interaction between environment and hybrids for biochemical variables, which are shown in Table 3. For soluble solids (SS), there was only a significant difference for the environment and interaction environment and hybrids. AF was higher than P and OF, with means of 5.05, 4.51 and 4.06 °Brix, respectively.

**Table 3.** Soluble solids content - (Brix°), pH, titratable acidity (%), *ratio*, texture (N), chroma C*, L- brightness and hue angle - h° of tomato hybrids Fascínio, Anny, Shanty and Vedette produced in a protected environment with polycarbonate cover (P), agricultural film (AF) and open field (OF).

| | | **Soluble solids** | | | **pH** | | | **Titratable Acidity [1]** | | | ***Ratio*** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Environments** | | | | | | | | | | | |
| | | P | AF | OF | P | AF | OF | P | AF | OF | P | AF | OF |
| Hybrids | Fascínio | 4.50 aA | 4.73 bA | 4.33 aA | 4.05 aA | 4.00 aB | 4.0 aB | 0.28 bB | 0.47 bA | 0.28 aB | 16.07 aA | 10.06 bB | 15.46 aA |
| | Anny | 4.33 aB | 4.80 bA | 3.91 aB | 4.00 aA | 4.00 aA | 4.0 aA | 0.28 bB | 0.35 cA | 0.30 aB | 15.46 aA | 13.71 aA | 13.03 aA |
| | Shanty | 4.60 aB | 5.33 aA | 3.93 aC | 4.00 aA | 4.00 aA | 4.0 aA | 0.39 aB | 0.64 aA | 0.36 aB | 11.79 bB | 8.32 cC | 10.91 aA |
| | Vedette | 4.58 aB | 5.33 aA | 4.00 aC | 4.00 aA | 4.00 aA | 4.0 aA | 0.30 bB | 0.44 bA | 0.30 aB | 15.26 aA | 12.11 aB | 13.30 aB |
| | | **F calculated** | | | | | | | | | | | |
| | Env. (E) | | 3327.45* | | | 0.78ns | | | 20.79* | | | 4.29* | |
| | Hy. (H) | | 2.51ns | | | 0.60ns | | | 26.00* | | | 4.86* | |
| | H x E | | 2.41* | | | 0.67* | | | 5.92* | | | 7.39* | |
| | CV1 | | 1.00 | | | 2.25 | | | 19.00 | | | 40.0 | |
| | CV2 | | 11.00 | | | 1.89 | | | 9.00 | | | 20.0 | |
| | | **Texture** | | | ***Croma*** | | | **Brightness** | | | **Angle *hue*°** | | |
| | | **Environments** | | | | | | | | | | | |
| | | P | AF | OF | P | AF | OF | P | AF | OF | P | AF | OF |
| Hybrids | Fascínio | 7.44 bA | 7.26 bA | 7.88 bA | 66.46 aB | 64.30 aB | 69.53 aA | 41.80 bB | 40.96 bB | 47.16 aA | 51.80 aA | 52.43 aA | 41.73 bB |
| | Anny | 7.32 bB | 9.40 aB | 11.08 aA | 68.40 aA | 65.90 aB | 69.65 aA | 42.20 bB | 41.10 bB | 45.65 bA | 50.45 aB | 53.00 aA | 44.35 aC |
| | Shanty | 9.07 aA | 6.60 bB | 7.44 bB | 67.48 aA | 67.00 aA | 67.60 aA | 42.84 bB | 41.90 bB | 44.92 bA | 49.52 bB | 51.76 aA | 45.36 aC |
| | Vedette | 5.94 bB | 5.36 bB | 7.88 bA | 68.00 aA | 68.93 aA | 65.08 bB | 43.90 aA | 43.66 aA | 44.76 bA | 48.70 bA | 50.93 aA | 44.16 aB |
| | | **F calculated** | | | | | | | | | | | |
| | Env. (E) | | 2.53ns | | | 2.02ns | | | 111.18* | | | 214.80* | |
| | Hy. (H) | | 10.06* | | | 0.87ns | | | 3.29* | | | 3.86ns | |
| | H x E | | 4.14* | | | 4.95* | | | 8.36* | | | 2.44* | |
| | CV1 | | 59.00 | | | 9.00 | | | 4.00 | | | 6.00 | |
| | CV2 | | 40.00 | | | 7.00 | | | 4.00 | | | 7.00 | |

CV1- environment; CV2- environment x hybrids. Equal lowercase letters in the column and uppercase letters in the row do not differ significantly among hybrids by Scott–Knott test ($p<0.05$). [1]Transformation ($\sqrt{(y+0.5)}$). Source: Authors, (2022).

For the chroma and acidity interaction, the Anny, Shanty and Vedette hybrids showed the same result from the effect of each environment, with the highest production in AF when compared to P and OF (Table 3). These results had higher values for these hybrids in AF when compared to the other treatments. Analyzing the hybrids, Fascínio was indifferent to the effect of the environment and showed hybrids widely adapted to all conditions.

Regarding pH, there was only an effect on the interaction between chroma and acidity (Table 3), with only Fascínio having a change in pH. The P environment showed the highest pH of 4.05, followed by the AF and OF environments, each with a mean of 4.00.

Titratable acidity (TA) is an important indicator of the quality of tomato fruits. In our study, there was a significant independent effect for hybrids, environments and the interaction between both (Table 3). In relation to hybrids, the highest acidity was found in Shanty, followed by Vedette, Fascínio and Anny, with means of 0.46%, 0.34%, 0.34, and 0.28%, respectively. In relation to the environments, it was found that AF induces a higher acidity than P and OF. This higher acidity observed in AF may be related to a greater effect of cellular respiration, and from the technological point of view, it is important for applicability in industry because higher acidity is required to maintain or establish lower pH.

When analyzing the interaction between H x E, the highest mean of TA was found in AF when compared to P and OF, respectively (Table 3). Thus, when analyzing hybrid behavior according to environments, the highlight for P was the Shanty hybrid, with an average of 0.39%. Shanty showed the highest levels of FA, with a mean of 0.64%, followed by Fascínio, Vedette and Anny, with means of 0.47%, 0.44%, and 0.35%, respectively. In OF, there was no difference between the hybrids.

The ratio of SS/TA is an important attribute for tomatoes because it refers to palatability (acid or sweet). For this attribute, there was a difference between A and the H x E interaction (Table 3). In relation to the environments, both OF and P were superior to AF. In the P and AF environments, Shanty was inferior to the other hybrid, showing a more acidic characteristic. In OF, all materials showed no differences. These data show that in both P and AF, solar radiation, temperature, and RH were dominant for equalization between SS and AT (Neugart & Schreiner, 2018; Mariz-Ponte, *et al.,* 2019).

Another important factor as an attribute in tomato is the texture (T). There was a difference for H and the interaction between H x E. Anny, Shanty and Fascínio had the highest with averages of 9.26, 7.72 and 7.51 N, respectively. The worst result observed was for Vedette with 6.43 N. It was observed in P that Shanty had better firmness than Fascínio, Anny and Vedette, with averages of 9.07, 7.44, 7.32 and 5.94 N, respectively. In the AF treatment, Anny had the highest, followed by the Fascínio, Shanty and Vedette hybrid, with averages of 9.40, 7.26, 6.60 and 5.36 N, respectively.

In OF, the response was similar to that in AF, particularly for Anny. Although the fruits were harvested at stage 6 (ripe), the potential for maintaining firmness was shown. When unfolding the behavior of the hybrid according to the environment, the Fascínio hybrid showed no difference between environments. For the Anny hybrid, the highest firmness was observed, followed by the AF and P environments, with averages of 11.08, 9.40 and 7.32 N. In the Shanty hybrid, the highest texture value was observed in P, with an average of 9.60, followed by the ac and AF environments, with averages of 7.40 and 6.60 N, respectively. The hybrid Vedette was similar in behavior to the Anny, and the OF obtained the highest firmness, followed by the AF and P environments, with averages of 7.88, 5.94 and 5.36, respectively.

The chroma (C*) values refer to the proportion of the predominant pure tone; the closer to zero, the greater the pallor. Thus, the chroma values obtained were quite high and far from zero; however, the polycarbonate cover reduced the chroma values in the hybrid Fascínio. Under plastic film, there was a reduction in chroma values for the Fascínio and Anny hybrids, and in the open field, only the hybrid Vedette had a reduction in this parameter.

The *hue angle* by both hybrids and the environment in the cultivation with agricultural film had the highest averages for the interaction between the factors. In the cultivation under polycarbonate, the Fascínio and Anny hybrids presented the highest averages, and the interaction between the environment and hybrid was more promising for Fascínio, with an average hue angle of 51.8 (Table 3). In the open field, the hybrid with the lowest performance was Fascínio, with no significant difference between the others; however, in this environment, Fascínio provided the lowest averages for this parameter.

Regarding the chemical parameters of quality, there was a significant interaction between environment versus hybrid for lycopene, β-carotene, vitamin C, total phenols and antioxidant activity (DPPH) (Table 4).

**Table 4.** Lycopene (µg $g^{-1}$), β-carotene (µg $g^{-1}$), vitamin C (mg.100 $g^{-1}$), total phenols (FT) (mg.100 $g^{-1}$) and antioxidant activity (DPPH) (µmol.$g^{-1}$) in tomatoes of the hybrids Fascínio, Anny, Shanty and Vedette grown in open field (OF) and protected environments with agricultural film covering (AF) and polycarbonate (P).

| | | **Licopene¹** | | | **β-carotene¹** | | | **Vitamin C¹** | | | **Total Phenols** | | | **DPPH** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Environments** | | | | | | | | | | | | | | |
| | | **P** | **AF** | **OF** | **P** | **AF** | **OF** | **P** | **AF** | **OF** | **P** | **AF** | **OF** | **P** | **AF** | **OF** |
| Hybrids | Fascínio | 4.33 aA | 4.0 aA | 3.33 aA | 0.66 aA | 0.20 aA | 0.33 aA | 25.8 aA | 31.8 aA | 28.0 aA | 35.8 aA | 35.4 aA | 37.8 aA | 17.0 bA | 19.8 aA | 21.4 aA |
| | Anny | 2.83 bA | 3.6 aA | 3.25 aA | 0.01 bA | 0.01 aA | 0.25 aA | 30.0 aA | 32.6 aA | 31.8 aA | 31.8 aA | 24.4 aA | 35.2 aA | 16.6 bA | 17.2 aA | 19.2 aA |
| | Shanty | 3.44 bA | 1.8 bB | 2.40 aB | 0.01 bA | 0.40 aA | 0.20 aA | 42.0 aA | 28.2 aA | 36.4 aA | 37.2 aA | 33.4 aA | 35.4 aA | 25.8 aA | 21.8 aA | 22.4 aA |
| | Vedette | 1.57 cB | 2.8 bA | 2.60 aA | 0.14 bB | 0.80 aA | 0.01 aB | 41.8 aA | 27.4 aA | 35.8 aA | 30.0 aA | 32.8 aA | 31.4 aA | 15.8 bA | 19.2 aA | 18.0 aA |
| | **F calculated** | | | | | | | | | | | | | | | |
| | Env. (E) | 0,328$^{ns}$ | | | 0,456$^{ns}$ | | | 0,41$^{ns}$ | | | 0,97$^{ns}$ | | | 0,25$^{ns}$ | | |
| | Hybrids (H) | 10,29* | | | 2,54* | | | 0,93$^{ns}$ | | | 1,48$^{ns}$ | | | 4,14* | | |
| | H x E | 3,47* | | | 2,57* | | | 0,84$^{ns}$ | | | 0,50$^{ns}$ | | | 4,14* | | |
| | CV1 | 11,80 | | | 30,97 | | | 28,58 | | | 23,73 | | | 32,94 | | |
| | CV2 | 14,57 | | | 26,17 | | | 21,46 | | | 27,47 | | | 26,06 | | |

CV1- environment; CV2- environment x hybrids. * There was a significant difference within the analyzed factor. $^{ns}$ There were no significant differences within the analyzed factor. ¹Transformation (√(y+0.5)). Source: Authors, (2022).

The fruits of the hybrid Fascínio showed a higher concentration of lycopene when cultivated under polycarbonate; however, when agricultural film was used as a cover, the hybrid Anny presented averages similar to Fascínio. In open-field cultivation, the lycopene content was reduced only in the shanty hybrid due to the interaction between the environment and hybrid (Table 4).

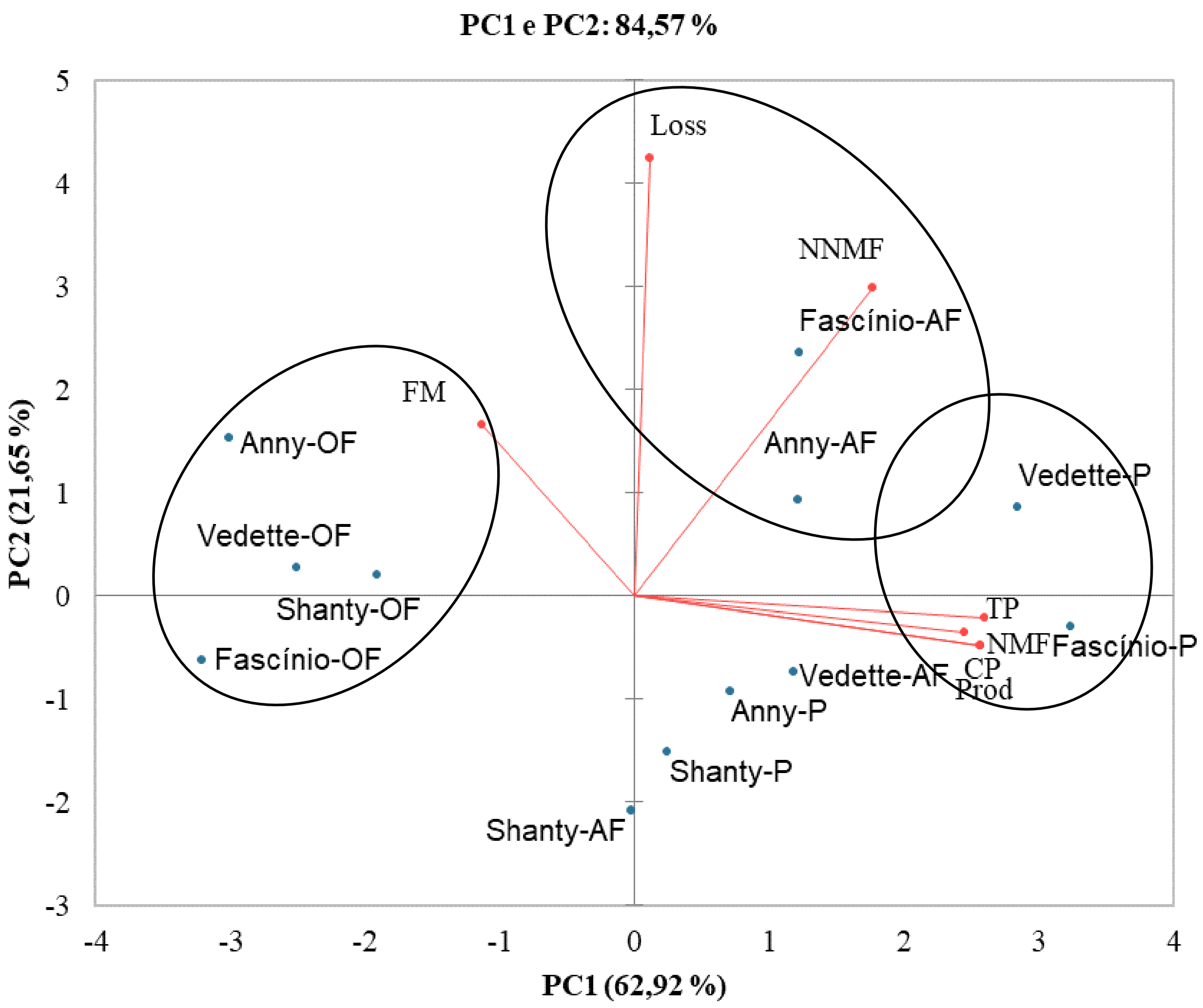
The β-carotene had a reduction in the fruits of the Anny and Shanty hybrids when cultivated under polycarbonate and in the hybrid Vedette in open-field cultivation, in the unfolding of the environment versus hybrid (Table 4). Due to its antioxidant properties, β-carotene is increasingly desirable in tomato hybrids (Seabra Junior, *et al.*, 2022)

The content of total phenolic compounds ranged from 24.4 to 37.8 mg 100 $g^{-1}$ fresh weight. For the P, AF and OF environments, the averages were 21.50, 22.70 and 24.95, respectively. Regarding hybrids, the means were 26.33, 20.46, 35.33 and 31.40 mg 100 $g^{-1}$ for Fascínio, Anny, Shanty and Vedette, respectively. There was no influence of the interaction between the environment and the hybrid on vitamin C and total phenols, and all combinations were interesting in the production of these compounds.

Regarding antioxidant activity (DPPH), there was no significant difference for the effect of hybrids and the interaction of the environment as a function of hybrids (Table 4). Among the hybrids evaluated, the highest antioxidant potential was observed in the Shanty hybrid, with an average of 23.333, followed by the Fascínio, Anny and Vedette hybrids, with averages of 19.40, 17.66 and 17.66 µmol 100 $g^{-1,}$ respectively.

In this study, we can infer that those plants grown in the open field, regardless of the hybrid used, presented lower productive performance for agronomic characteristics (Tables 1 and 2), except for fruit mass (FM), grouped in PC1, through principal component analysis (PCA), which explains 84.57% of the data (Figure 1). However, 'Vedette' and 'Fascínio' when cultivated in a polycarbonate (P) environment showed better productive performance for most of the evaluated characteristics (Prod., PT, CP, NMF and NNMF) and were grouped in PC1+.

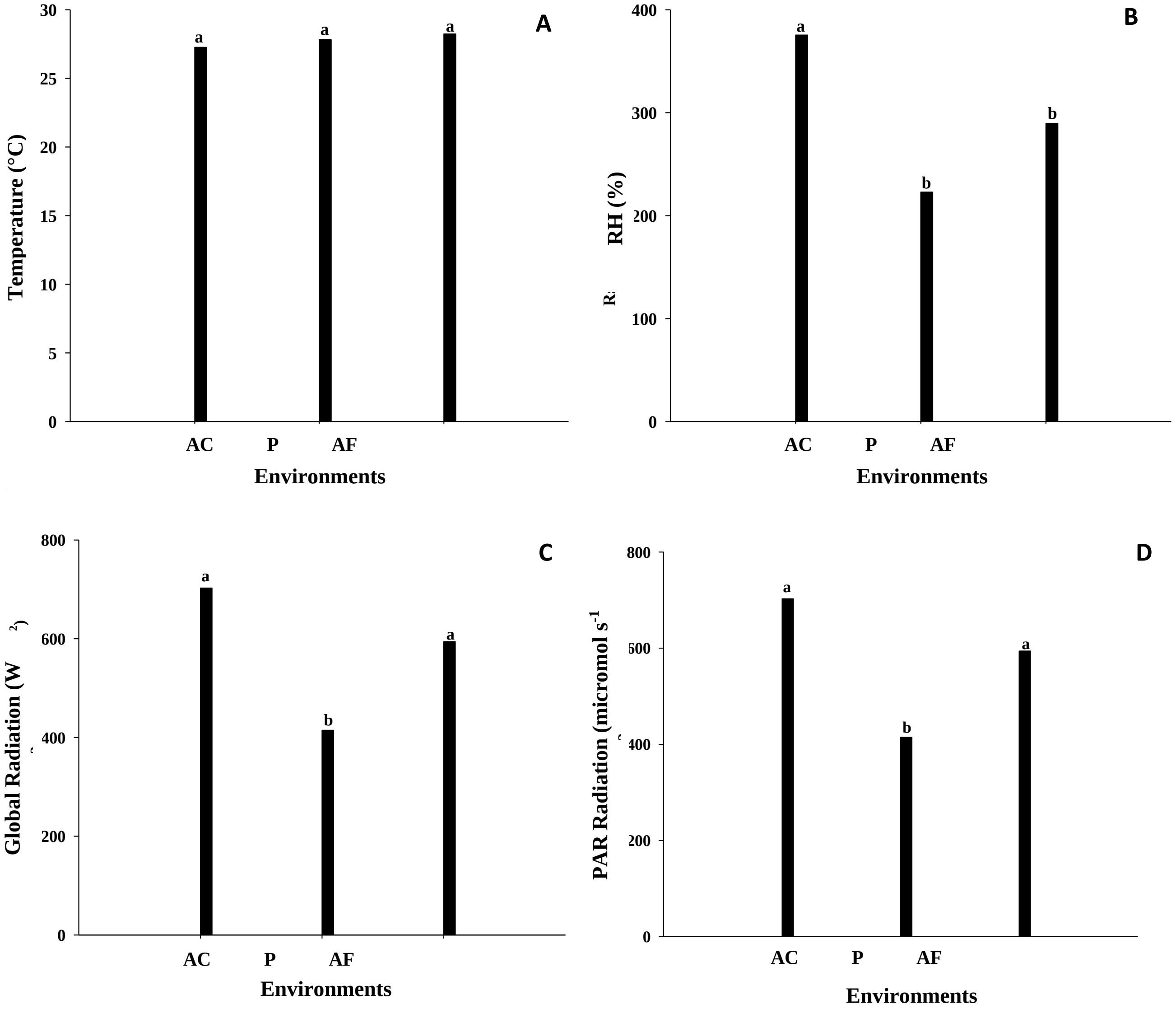
**Figure 1.** Bidimensional projection and score of the productive characteristics (productivity - Prod., total production - TP, commercial production - CP, fruit mass - FM, number of marketable fruits - NMF, mass of nonmarketable fruits - NNMF and loss) of tomatoes of the hybrids Fascínio, Anny, Shanty and Vedette produced in open field (OF) and protected environments gagle rigid frame with agricultural film covering (AF) and polycarbonate (P).




Source: Authors, (2022).

In PC2+ (21.65%), 'Fascínio' and 'Anny' were grouped, which, when produced in an environment covered by AF, presented higher NNMF and loss (Figure 1), but this response did not affect the high production obtained by the Fascínio hybrid (Table 1).

**Figure 2.** Net average temperature (°C) (A), relative humidity (%) (B), global radiation (W $m^{-2}$) (C) and PAR radiation (micromol $s^{-1}$ $m^{-2}$) (D). Different letters between the bars differ significantly between environments by Scott–Knott test ($p<0.05$). The rainfall precipitation was 2115 mm.




Source: Authors, (2022).

## 4. Discussion

Tomato is considered an expensive crop due to the technology and labor required to grow the crop. The adoption of hybrids that are easier to manage, without the need for pruning, could help mitigate production costs (Seabra Junior, *et al.*, 2022).

The evaluation in summer conditions showed that OF plants completed their growing season earlier than those in the other two groups due to induced disease by climate conditions. The AF and P environments showed the best productive performance when compared to the OF conditions. Several studies have related best performances in greenhouse conditions during the summer season by ameliorating inner developed conditions to plant growth (Trento, *et al.*, 2021; Seabra Junior, *et al.*, 2022)

In addition, the crop does not tolerate wet leaves, making a protected environment more productive in terms of reducing the incidence of diseases, foliar damage and impaired fruit quality. In this study, a higher yield of tomato hybrids was obtained when the crop was grown under a protected environment, but the effects between cover types varied between hybrids. Evaluating environmental conditions, P>AF>OF to higher production. In relation to the hybrids evaluated, Fascínio and Vedette followed the same behavior, such as the environments. Other authors, such as Abdel-Gha et al. (2015); Kwon et al. (2017); Mutwiwa et al. (2017); and Kidus et al. (2020), have shown that hybrid material and different compounds convert changes in physiological and biochemical compounds that corroborate better development.

According to Mariz-Ponte et al. (2019), effects such as solar radiation, nutrition and RH are conditioning factors that interfere with the dynamics of sugars in fruits. The higher productivity and biochemical compounds in both protected environments were higher than those in FO due to the microclimatic conditions being unfavorable for tomato cultivation at this time of year, with high levels of rainfall and a high incidence of diseases.

The use of a protected environment can influence meteorological variables such as air temperature, relative humidity, and solar radiation, allowing viable cultivation in the off-season (Beckmann, *et al.,* 2006). The enhancement of new cover technology associated with height in summer conditions can change yield concepts. In our study, temperature and RH did not change (Figure 2A e B). Global radiation was lower in P and FA. PAR radiation was lower only in the P environment. The present study recognizes the need for protected cultivation to enable production in regions that have such environmental conditions because high temperature and high precipitation are factors that limit production. Fascínio and Vedette were the most productive hybrids when grown under polycarbonate with yields of 66.80 and 55.80 t $ha^{-1}$, which were 66% and 79% higher than when grown without protection, respectively (Table 1).

Tomato plants produced under polycarbonate had yields that were 18% to 47% higher than those produced with agricultural film. This is attributed to the higher incidence of diffuse radiation provided by the polycarbonate plate twinwall. This structure produces a multidirectional internal reflection of radiation that ameliorates the inner canopy and stimulates photoassimilate production of radiation (Radin, *et al.,* 2003; Mogharreb & Abbaspour-Fard, 2019). This hypothesis supports our results. The highest NMF was obtained in plants grown in a protected environment. This was observed for all hybrids (Table 1).

Temperature and luminosity are relevant factors in fruit harvest, where high temperatures can reduce the number of fruits per plant; therefore, when compared to the number of fruits produced by tomato plants grown in other regions, they can present more fruits than the number of fruits obtained in this study, as identified in the studies by Reis et al. (2013) with 21.5 fruits $plant^{-1}$ and Kwon et al. (2017) with 13.5 fruits $plant^{-1}$. The cause of this behavior may be the regional average temperatures, as temperatures above 29°C can reduce the development of anthers and thus reduce pollen viability, reducing productivity (Harel, *et al.,* 2014; Bazgaou, *et al.,* 2018).

Protected cultivation is an efficient technique for reducing the effect of high precipitation on tomato, but no differences were observed between average temperature and relative humidity (Figure 2 A and B). The reduction in the number of fruits in the open field (> 67%) may be related to the reduction in the plant cycle due to the incidence of disease pests and the accumulated rainfall of 2115 mm.

Increases in global radiation were 41% and 23% in P and AF environments, respectively, when compared to the open field (Figure 2 C). When solar radiation is excessively high, there may be an increase in the transpiration rate of the plant, resulting in stomatic closure and decreased photosynthesis (Andriolo, 2000). This causes lower photoassimilate production and productivity.

One of the most important components of solar radiation is photosynthetically active radiation (PAR). It was observed that productivity in the P was higher than that in other environments (Table 1) despite having low PAR radiation readings between the environments (Figure 2 D). Although the supply of diffuse radiation in the polycarbonate treatment was not measured, it is believed that the behavior of polycarbonate presents a better diffusion of light and consequently better penetration inside the canopy contributing to an increase in productivity, corroborating this statement the data obtained in the study developed by Mogharreb and Abbaspour-Fard. (2019).

One of the main challenges in greenhouse design is producing a suitable microenvironment during hot climatological periods with high levels of solar radiation. High radiation levels combined with high temperature can promote physiological damage, such as photorespiration, photoinhibition, and accelerated evapotranspiration, and provide conditions for a higher incidence of pests and diseases (Otoni, *et al.,* 2012). Thus, the methods of cooling greenhouses need to be further explored (Ahemd, *et al.,* 2016).

When the global radiation level and PAR were evaluated in the different environments (Figure 2 C and D), it was observed that under polycarbonate, the radiation was lower, with an average of 414.55 μmol $s^{-1}$ $m^{-2}$, which supports the hypothesis of a more efficient diffusion of radiation reaching the canopy. This improves photosynthesis and is near the optimal range for tomato production (Nakayama, *et al.*, 2021)

The active radiation range for photosynthesis in tomatoes is between 400 nm and 700 nm (Castilla, 2013). This shows that both P and AF increased productivity. Greenhouses equipped with polycarbonate plates provide an ideal active photosynthetic region for plant growth, allowing the passage of radiation with wavelengths of 400 nm to 600 nm (Mogharreb & Abbaspour-Fard, 2019; Subin, *et al.,* 2020).

The luminous saturation in tomato plants ranges from 700 to 1,500 μmol $s^{-1}$ $m^{-2}$ (Rocha, 2007; Papadopoulos & Hao, 1997); thus, the increase in irradiance can directly influence the production of photoassimilates, directly contributing to plant growth and fruit production (Andriolo, 2000), possibly due to better capture of light energy at the ideal length. This trend was observed in other studies (Radin, *et al.,* 2003; Kwon, *et al.,* 2017; Mogharreb & Abbaspour-Fard. 2019).

Tomato plants have higher efficiency in the use of photosynthetically suitable radiation when it has lower availability of incidence under the crop (Radin, *et al.,* 2003). This was supported by the productivity data (Table 1), in which the P and AF environments obtained the best yield averages for each hybrid but received lower radiation levels than CA (Figure 2D).

The transmittance of radiation in terms of the cover material is significant. A polyethylene cover of 120 μm thickness has an average transmittance of 62% (Reis, *et al.*, 2013). In polycarbonate, the average transmittance is approximately 85% (Kwon, *et al.*, 2017).

## 5. Conclusion

This study shows that the use of protected environments with either polycarbonate cover or agricultural film for the cultivation of Italian-type tomatoes in a humid tropical climate with high temperature and rainfall increases the productive and qualitative potential of tomatoes. Fascínio and Vedette hybrids showed the best adaptations in polycarbonate and AF, respectively.

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## References

Abdel-Ghany, A. M., Picuno, P., Al-Helal, I., Alsadon, A., Ibrahim, A., & Shady, M. (2015). Radiometric characterization, solar and thermal radiation in a greenhouse as affected by shading configuration in an arid climate. *Energies, 8* (12), 13928-13937.

Ahemd, H. A., Al-Faraj, A. A., & Abdel-Ghany, A. M. (2016). Shading greenhouses to improve the microclimate, energy and water saving in hot regions: a review. *Scientia Horticulturae, 201*, 36-45. https://doi.org/10.1016/j.scienta.2016.01.030

Andriolo, J.L. (2000). Fisiologia da produção de hortaliças em ambiente protegido. *Horticultura Brasileira, 18*, 26-33.

Association of Official Analytical Chemists. (2000). *Official Methods of Analysis of AOAC International*. (17.ed.). Arlington, v.2.

Bazgaou, A., Fatnassi, H., Bouhroud, R., Gourdo, L., Ezzaeri, K., Tiskatine, R., Demrati, H., Wifaya, A., Bekkaoui, A., Aharoune, A., & Bouirden, L. (2018). An experimental study on the effect of a rock-bed heating system on the microclimate and the crop development under canarian greenhouse. *Solar Energy*, (176), 42-50. https://doi.org/10.1016/j.solener.2018.10.027

Beckmann, M. Z., Duarte, G. R. B., Paula, V. A. D., Mendez, M. E. G., & Peil, R. M. N. (2006). Radiação solar em ambiente protegido cultivado com tomateiro nas estações verão-outono do Rio Grande do Sul. *Ciência Rural*, 86-92.

Brand-Williams, W., Cuvelier, M. E., & Berset, C. L. W. T. (1995). USE of a free radical method to evaluate antioxidant activity. *LWT-Food science and Technology*, 28(1), 25-30.

Castilla, N. (2013). *Greenhouse Technology and Management*. Ed. 2. (pp. 335). Boston: Cabi Publishing.

EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária). (2013). *Sistema brasileiro de classificação de solos. Centro Nacional de Pesquisa de solos* (p. 353). Rio de Janeiro.

Ferreira, D. F. (2019). SISVAR: A computer analysis system to fixed effects split plot type designs. *Revista brasileira de biometria, [S.l.], 37* (4), 529-535. doi: https://doi.org/10.28951/rbb.v37i4.450.

Florido, B. M., & Álvarez, G. M. (2015). Aspectos relacionados con el estrés de calor en tomate (*Solanum lycopersicum* L.). *Cultivos Tropicales, 36*, 77(19).

Harel, D., Fadida, H., Alik, S., Gantz, S., & Shilo, K. (2014). The effect of mean daily temperature and relative humidity on pollen, fruit set and yield of tomato grown in commercial protected cultivation. *Agronomy, Suíça, 4*, 167-177.

Hemming, S., Kempkes, F., Van Der Braak, N., Dueck, T., & Marissen, N. (2005). Filtering natural light at the greenhouse covering-Better greenhouse climate and higher production by filtering out NIR?. **In:** V International Symposium on Artificial Lighting in Horticulture 711. 411-416.

Kidus, T., Areya, T., & Tesfay, W. (2020). Proportional Enactment of Tomato (Solanum Lycopersicum L. Mill) Varieties under Greenhouse Production Systems of Tigray Biotechnology Center, Ethiopia. *International Journal of Research in Agriculture and Forestry, 7*, 01-11.

Kwon, J. K., Khoshimkhujaev, B., Lee, J. H., Yu, I. H., Park, K. S., & Choi, H. G. (2017). Growth and yield of tomato and cucumber plants in polycarbonate or glass greenhouses. *Horticultural Science and Technology, 35(1)*, 79-87. https://doi.org/10.12972/kjhst.20170009

Mariz-Ponte, N., Martins, S., Gonçalves, A., Correia, C. M.; Ribeiro, C., Dias, M. C., & Santos, C. (2019). The potential use of the UV-A and UV-B to improve tomato quality and preference for consumers. *Scientia Horticulturae, 246*, 777-784. DOI: https://doi.org/10.1016/j.scienta.2018.11.058

Maul, F.S.A., Sargent, C.A., Sims, E.A., Baldwin, M.O., & Balaban D.J. (2000). Tomato flavor and aroma quality as affected by storage temperature. *J. Food Sci., 65*, 1228-1237.

Mogharreb, M. M., & Abbaspour-Fard, M. H. (2019). Experimental study on the effect of a novel water injected polycarbonate shading on light transmittance and greenhouse interior conditions. *Energy for Sustainable Development, 52*, 26-32. https://doi.org/10.1016/j.esd.2019.07.002.

Mutwiwa, U. N., Tantau, H. J., Von Elsner, B., & Max, J. F. (2017). Effects of a near infrared-reflecting greenhouse roof cover on the microclimate and production of tomato in the tropics. *Agricultural Engineering International: CIGR Journal*, 19 (3), 70-79.

Nagata, M., & Yamashita, I. (1992). Simple method for simultaneous determination of chlorophyll and carotenoids in tomato fruit. *Nippon Shokuhin Kogyo Gakkaishi, 39* (10), 925-928.

Nakayama, M., Fujita, S. I., Watanabe, Y., Ando, T., Isozaki, M., & Iwasaki, Y. (2021). The effect of greenhouse cultivation under a heat insulation film covering on tomato growth, yield, and fruit quality in a subtropical area. *The Horticulture Journal,* UTD-249. https://doi.org/10.2503/hortj.UTD-249.

Neugart, S., & Schreiner, M. (2018). UVB and UVA as eustressors in horticultural and agricultural crops. (2018). *Scientia Horticulturae, 234*, 370-381. https://doi.org/10.1016/j.scienta.2018.02.021.

Nogueira, S. F., Grego, C. R., Quartaroli, C. F., Andrade, R. G., Holler, W. A., & Vital, D. M. (2011). Estimativa de estoque de carbono em sistema de produção de soja na região norte mato-grossense. In: *Congresso Brasileiro De Ciência Do Solo*, Uberlândia, MG. 33.

Otoni, B. D. S., Mota, W. F. D., Belfort, G. R., Silva, A. R. S., Vieira, J. C. B., & Rocha, L. D. S. (2012). Produção de híbridos de tomateiro cultivados sob diferentes porcentagens de sombreamento. *Revista Ceres, 59*, 816-825.

Papadopoulos, A. P., & Hao, X. (1997). Effects of three greenhouse cover materials on tomato growth, productivity, and energy use. *Scientia Horticulturae, v. 70*, 165-178.

PBMH - Programa Brasileiro Para Modernização da Horticultura. Norma de Classificação do Tomate. Centro de Qualidade em Horticultura. CQH/CEAGESP. São Paulo. 2003. (CQH, Documentos, 26).

Pereira, C., Marchi, G., & Silva, E. C. (2000). Produção de tomate-caqui em Estufa. *Série extensão.* Lavras: UFLA, 26p.

Radin, B., Bergamaschi, H., Junior, C.R., Barni, N.A., Matzenauer, R., & Didoné. I.A. (2003). Eficiência de uso da radiação fotossinteticamente ativa pela cultura do tomateiro em diferentes ambientes. *Pesquisa Agropecuária Brasileira. 38*. 1017-23.

Reis, L. S., Azevedo, C. A. V. D., Albuquerque, A. W., & Junior, J. F. S. (2013). Índice de área foliar e produtividade do tomate sob condições de ambiente protegido. *Revista Brasileira de Engenharia Agrícola e Ambiental, 17*, 386-391. https://doi.org/10.1590/S1415-43662013000400005

Ribeiro, A.C. (1999). Recomendações para o uso de corretivos e fertilizantes em Minas Gerais: 5. Aproximação. Comissão de fertilidade do solo do estado de Minas Gerais.

Rocha, R. C. (2007). Uso de diferentes telas de sombreamento no cultivo protegido do tomateiro. 105 p. Tese (Doutorado em Agronomia) – Faculdade de Ciências Agronômicas, Universidade Estadual Paulista "Julio Mesquita Filho", Botucatu.

Singleton, V. L., & Rossi, J. A. (1965). Colorimetry of total phenolics with phosphomolybdic phosphotungstic acid reagents. *American Journal of Enology and Viticulture, 16* (3), 144-158.

Seabra Junior. S., Casagrande, J. G., Toledo, C. A. L., Ponce, F. S., Ferreira, F.S., Zanuzo, M.R., Diamante, M.S., & Lima, G.P.P. (2022). Selection of thermotolerant Italian tomato cultivars with high fruit yield and nutritional quality for the consumer taste grown under protected cultivation. *Scientia Horticulturae*, 291. https://doi.org/10.1016/j.scienta.2021.110559

Subin, M. C., Karthikeyan, R., Periasamy, C., & Sozharajan, B. (2020). Verification of the greenhouse roof-covering-material selection using the finite element method. *Materials Today: Proceedings, 21*, 357-366. https://doi.org/10.1016/j.matpr.2019.05.462

Trento, D. A., Antunes, D. T., Fernandes Júnior, F., Zanuzo, M. R., Dallacort, R., & Seabra Júnior, S. (2021). Desempenho de cultivares de tomate italiano de crescimento determinado em cultivo protegido sob altas temperaturas. *Nativa, 9*(4), 359-356. https://doi.org/10.31413/nativa.v9i4.10945

Tilahun, S., Park, D. S., Seo, M. H., & Jeong, C. S. (2017). Review on factors affecting the quality and antioxidant properties of tomatoes. *African Journal of Biotechnology, 16*, 1678-1687.

Valeriano, T. T. B., Santana, M. J., De Souza, S. S., Pereira, U. C., & Campos, T. M. (2017). Lâmina ótima econômica para o tomateiro irrigado cv. Andréa e cultivado em ambiente protegido. *Innovative Science & Technology Journal, 3* (2),13-19.