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**Research Article**

# Elucidating how the chemical-nutritional composition of tomato is affected by the environment, season, and growing system

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## Abstract

Tomatoes play an important nutritional role due to the chemical-nutritional composition of this fruit, and its common use in dishes and food products. Its fruits provide pronounced antioxidant properties to the human diet, because of the presence of vitamin C, carotenogenic compounds such as lycopene and *β*-carotene, and phytochemicals such as flavonoids. Despite this, the antioxidant function and carotenoid levels in tomato may present significant differences depending on the system of cultivation, growing season, and environment in which this vegetable is cultivated. In light of this, this study aimed to assess the effects of the cultivation system known as "Viçosa", in relation to traditional tomato cultivation systems, over two seasons. This assessment was done both under field conditions and in a controlled environment. The nutritional aspects of the fruits, such as the levels of phenolic compounds, lycopene, beta-carotene, and antioxidant activity, were analyzed. The controlled environment in the autumn-winter season, associated with the Viçosa cultivation system, facilitated increases in the lycopene content. Furthermore, field cultivation provided an increase of 68% and 38% in the total phenolic concentration in tomato fruits, in the spring-summer and autumn-winter seasons, respectively. Field cultivation also provided an increase of 31% in the antioxidant activity of the fruits, compared with that of the controlled cultivation, in the autumn-winter season. The increase in the levels of total phenolics and antioxidant activity of fruits due to cultivation in the field represents an advantage as cultivation in this environment has a lower cost than cultivation in a controlled environment. The cultivation systems did not influence the chemical-nutritional aspects of fruits; moreover, the Viçosa system brings together aspects such as high productivity and profitability, without compromising the chemical-nutritional aspects of the fruits, thereby configuring a promising system for tomato production.

***Keywords:*** bioactive compounds; carotenoids; cultivation system; lycopene; *Solanum lycopersicum*

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## Introduction

The tomato (*Solanum lycopersicum* L.) is the second most economically important vegetable, second only to the potato. It is cultivated and appreciated worldwide for its organoleptic and nutritional properties, with a production of approximately 182 million tons, in an area of 4 .8 million ha (FAOSTAT, 2020).

In recent decades, tomatoes have been classified as a functional food. The nutritional importance of this vegetable is largely explained by its various health-promoting compounds, including the vitamins C and E, carotenoids, and phenolic compounds, which provide high levels of antioxidant activity (Martín *et al.*, 2016; Li *et al.*, 2018). Furthermore, tomatoes are the main source of lycopene in the human diet (Tan *et al.*, 2021). This carotenoid gives tomato its characteristic red color (which can reach approximately >80%), and is beneficial in preventing many chronic diseases, such as lung diseases and cancers (Rakic and Wang, 2020; Mirahmadi *et al.*, 2020). In addition to lycopene, tomatoes also contain *β*-carotene, a precursor to vitamin Aand is present in tomato fruits in lower concentrations (Salomon *et al.*, 2020).

Lycopene is known for presenting pronounced levels of antioxidant activity (Vasconcelos *et al.*, 2017), and is considered the most efficient carotenoid in the sequestration of the reactive singlet oxygen species (Nimse and Pal, 2015). In line with this, several studies have associated the antioxidant activity provided by the consumption of tomato fruits with the prevention of degenerative diseases, certain cancers, and cardiometabolic diseases (Kong *et al.*, 2010; Perveen *et al.*, 2015). Furthermore, studies have attributed the protective chemical action of lycopene mainly to its ability to protect cells against free radicals and reactive species (Aidoud *et al.*, 2014). Similarly, *β*-carotene is known for presenting pronounced pro-vitamin A activity (Bohn *et al.*, 2019), in addition to antioxidant activity (Jayedi *et al.*, 2018). In light of this, it is pertinent to mention that the pro-vitamin A activity of carotenoids is conditioned by the presence of ringed forms called *β*-ionone in their structures, and by the presence of polyene chains (Rodriguez-Amaya, 2005). *β*-Carotene, with two *β*-ionone rings and a polyene chain, presents the highest pro-vitamin A activity compared with other carotenoids that have only one *β*-ionone ring, such as *α*-carotene and *β*-cryptoxanthin.

After lycopene, *β*-carotene is the most abundant carotenoid in tomato fruits, ranging from 0.1-1.2 mg 100 $g^{-1}$ of the fresh mass (Martí *et al.*, 2016). Although the levels of *β*-carotene found in tomato fruits are low, tomato is one of the most commonly consumed vegetables. In a striking example of this, in carrying out the characterization of the household purchase of vegetables in Brazil, Canella *et al.* (2018) highlighted that tomato was the most commonly purchased vegetable among households, representing 29.2%. Thus, similarly to what happens in other countries, tomato consumption is very common in the diet of the Brazilian population, constituting an important source of pro-vitamin A. On the other hand, polyphenols have a different structure composed of components in which at least one hydroxyl group (-OH) is attached to one or more benzene aromatic rings ($C_6H_5$), thereby forming the structure known as a phenol ($C_6H_5OH$). These components consist of a heterogeneous group involved in different functions, such as mediation of plant/environment interaction, reproduction, and defense mechanisms, and are widely known for their antioxidant function.

Tomato fruit quality and metabolite biosynthesis are affected by plant growth conditions (Fara *et al.*, 2019; Hou *et al.*, 2020). Therefore, there is concern that near-future estimates of climate change indicate an increase in temperature, which can affect crop yields due to reduced fruit set, and change fruit quality (Ruiz-Nieves *et al.*, 2021). Growing tomato plants at higher temperatures (increasing the temperature from 25/14 °C to 30/12 °C, day/night, respectively) increases the dry matter content of tomato fruits (Rosales *et al.*, 2010). The same authors also reported that these changes in dry matter content caused changes in sugar content, which increased at high temperatures (30-35 °C) while organic acids decreased. Dannehl *et al.* (2012) reported that the lycopene content in tomatoes increases with increasing temperature and reaches its maximum concentration at 25 °C. Furthermore, temperatures below 12 °C strongly inhibit lycopene biosynthesis, whereas temperatures above 32 °C interrupt this process (Dumas *et al.*, 2003), thereby affecting the activities of enzymes in the metabolic pathway, and, consequently, the carotenoid composition of the fruit (Gautier *et al*., 2008). Likewise, phenolic compounds (chlorogenic acid, rutin, and naringenin) increase with increasing average temperatures (Dannehl *et al*., 2012).

For these reasons, crop management and cultivation strategies should be constantly updated. In keeping with this recommendation, a new tomato cultivation system was developed, called the Viçosa system. The Viçosa cultivation system and its adaptations provided promising results and are very well accepted in the horticultural community for providing greater insulation and aeration to plants. Moreover, it markedly reduces the incidence of phytopathogens in the culture, which is crucial in reducing the volume of pesticides applied to tomato crops, and the problems of their residual effect, while providing greater productivity and profitability (Almeida *et al*., 2015).

In light of this, the objective of this study was to evaluate the effects of the Viçosa system and its adaptations in relation to the traditional tomato cultivation systems, in two growing seasons (spring-summer and autumn-winter), under field conditions and in a controlled environment. This was performed, to elucidate the influence of different environments and cultivation systems on the chemical-nutritional aspects of tomato fruits. The results obtained can help to establish the effects of daytime temperatures on tomato quality and composition. Therefore, it is essential to acquire this knowledge, as seasonal variations can have different effects on the quality of tomato fruits.

## Materials and Methods

### *Experimental area*

The study was carried out at the Federal University of Viçosa (UFV), in Viçosa, Minas Gerais (MG), Brazil, under the coordinates 20° 45' 14" S, 42° 52' 55" W and an altitude of 693 m. The climate in the region is Cwb (Alvares *et al*., 2013), with an average annual temperature of 19.4 °C and an annual precipitation amount of approximately 1,200 mm.

### *Plant resources*

The commercial hybrid Pegasus® was used, which has indeterminate growth and produces Santa Cruz-type fruits. It is resistant to Fusarium Wilt (race 1 and 2), nematodes, the Tobacco Mosaic Virus, Geminivirus, and Verticillium Wilt.

### *Planning and execution of research*

This study comprised two experiments. One experiment was carried out in the field and the other was done in a controlled environment. The experiment in the controlled environment was carried out under an arch-type structure of 210 $m^2$, covered with SunCover Blue® agricultural film and with a citrus side screen in two seasons. Experiment I corresponded to a spring-summer period of cultivation and was carried out from July 2014 to January 2015; whereas Experiment 2 corresponded to an autumn-winter period of cultivation carried out from March to October 2015.

The soil in the experimental areas is a Red-Yellow Argisol and the region had a flat topography. Soil preparation was done with a plow and harrow. Soil chemical analyses were carried out, in both Experiments 1 and 2, in the field (Table 1) and in the controlled environment (Table 2). Fertilization was performed based on the results of the soil chemical analysis and recommendations from the Fertilization Manual for The State of Minas Gerais, Brazil (Ribeiro *et al*., 1999).

**Table 1**. Chemical characteristics of the soil (0–20 cm) from the field experiments (I and II)

| Exp. | pH | P | K | $Ca^{2+}$ | $Mg^{2+}$ | $Al^{3+}$ | H + Al | SB | T | V | MO | | P-rem |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $H_2O$ | -----mg/$dm^3$----- | | ---------------- $Cmol_c/dm^3$ ----------- | | | | | | % | dag/kg | | mg/L |
| I | 6.0 | 98 | 112 | 2.2 | 0.5 | 0 | 2.5 | 2.7 | 5.2 | 51 | 2.6 | | 24.5 |
| II | 5.8 | 110 | 98 | 3.1 | 0.6 | 0 | 2.8 | 3.7 | 6.5 | 57 | 2.8 | | 26.1 |

P and K available, extracted with Mehlich-1; Ca, Mg, and Al extracted with KCl 1 mol $L^{-1}$; Potential acidity at pH 7.0 with calcium acetate, obtained using 1 mol $L^{-1}$.

**Table 2**. Chemical characteristics of the soil (0-20 cm) from the experiments under controlled environment, experiments (I and II)

| Exp. | pH | P | K | $Ca^{2+}$ | $Mg^{2+}$ | $Al^{3+}$ | H + Al | SB | T | V | MO | P-rem |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $H_2O$ | -----mg/$dm^3$----- | | ---------------- $Cmol_c/dm^3$ ----------- | | | | | | % | dag/kg | mg/L |
| I | 5.7 | 132 | 151 | 3.2 | 0.6 | 0 | 3.63 | 4.2 | 7.8 | 54 | 2.6 | 22.8 |
| II | 5.9 | 145 | 162 | 2.8 | 0.7 | 0 | 3.52 | 4.2 | 7.7 | 54 | 2.4 | 25.2 |

P and K available, extracted with Mehlich-1; Ca, Mg, and Al extracted with KCl 1 mol $L^{-1}$; Potential acidity at pH 7.0 with calcium acetate, obtained using 1 mol $L^{-1}$.

The sowing was carried out in polystyrene trays and the seedlings were transplanted to the beds when they had four definitive leaves (30 days after sowing). Manual weeding was performed weekly, and pests and diseases were controlled by applying pesticides when they reached a level of economic damage.

Irrigation and fertilization (Fertigation) were carried out using a drip system. Water demand was calculated based on meteorological data (temperature, radiation, relative humidity, and wind speed) collected from a Vantage Pro2 automatic weather station, (Davis, US). From these data, the reference evapotranspiration (ETo) was calculated, while the coefficients of the crop (kc), localized irrigation (kl) and soil (ks), and crop evapotranspiration (ETc) were obtained as previously described by Guimarães *et al.* (2019).

### *Treatments*

Four tomato cropping systems were evaluated under field conditions and in a controlled environment (Figure 1).

I – Vertical (V): plants were supported vertically with polypropylene ribbon, and guided with one stem, in a spacing of 1.2 × 0.5 m (16,667 plants $ha^{-1}$).

II – Crossed fence (CF): a system similar to the first, but plants were supported with bamboo supports.

III – Viçosa (Vi): plants were grown in 2 × 0.2 m spacing (25,000 plants $ha^{-1}$), supported with polypropylene ribbon, and inclined at approximately 75° in relation to the ground. They were also arranged alternately to one side and the other, from the inside to the outside of the row of cultivation, forming a "V". The plants were conducted with one stem, with the inflorescences above the eighth raceme removed, leaving nine leaves above this, and removing the lower leaves up to the third raceme. Fruit thinning was performed by maintaining four to six fruits per raceme, when they were 2-3 centimeters in diameter. Fruits that were uneven, defective, or had phytosanitary problems were also removed.

IV – Dense Viçosa (DV): similar to the Viçosa system, but in this treatment the plants were grown in 1.6 × 0.1 m spacing (62,500 plants $ha^{-1}$).

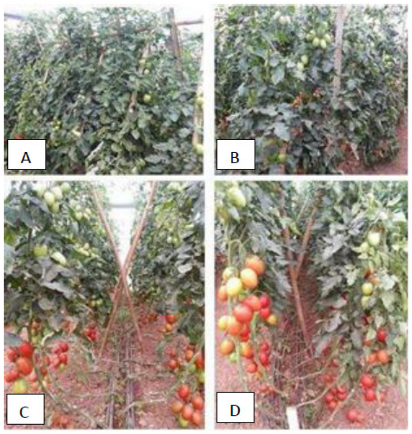

**Figure 1**. Tomato cultivation systems: Cross Fence (A), Vertical (B), Viçosa (C), Dense Viçosa (D)

*Characteristics analyzed*

Weather data

The meteorological data, comprising measurements of radiation, temperature, relative humidity, and precipitation, were recorded daily in two automatic weather station Vantage Pro2 (Davis) instruments installed in the controlled environment and in the field.

Total phenolic content

A 1 g sample of fresh fruit pulp was homogenized with 10 mL of aqueous methanol (60:40 v $v^{-1}$) and stirred (180 rpm) for 15 min at room temperature (23 °C). The sample was centrifuged at 3500 rpm for 5 min, and the supernatant was collected and used to obtain the extracts used in the assays of total polyphenols and antioxidant activity. Total polyphenols were measured using the Folin-Ciocalteu assay, which was modified as per a previous report (Li *et al.*, 2015). The results were expressed as milligram of gallic acid equivalent (GAE) per gram of dry weight (mg GAE/g DW).

Determination of carotenoid content

Carotenoids were extracted with acetone and petroleum ether, according to the method of Rodriguez *et al.* (1976), with slight modifications. Briefly, the carotenoid content was determined under the chromatographic conditions developed by Pinheiro-Sant'Ana *et al.* (1998), using a high-performance liquid chromatograph (Shimadzu) equipped with an RP-18 Phenomenex C18 chromatographic column (250 × 4.6 mm; 5 µm). The mobile phase – methanol: ethyl acetate: acetonitrile was 50:40:10, with an isocratic elution and mobile phase flow of 2.0 mL $min^{-1}$. Elution was detected using a diode array detector (Shimadzu SOD-M10 AVP), with the wavelength set to 450 nm and 469 nm for *β*-carotene and lycopene, respectively.

The carotenoids were identified by comparing the retention times between the standards and the samples, which were analyzed under the same conditions. Furthermore, the absorption spectra of the pattern and the peaks of interest in the samples were compared using the diode array detector.

Quantification was performed by external standardization with standard solutions of different concentrations of *β*-carotene and lycopene, which were isolated from concentrated tomato extracts. This was done via open column chromatography, according to the method of Rodriguez-Amaya (1999).

Determination of antioxidant activity

Antioxidant activity was determined using DPPH assays (Tan *et al.*, 2016). In this study, measurements were performed in triplicate and the antioxidant capacity was expressed in percentage.

### *Experimental design and statistical analysis*

A randomized block design was used in a double factorial scheme (2 environments × 4 cultivation systems) with nine replications. Statistical analyses were performed using Sisvar statistics. Normality was tested using the Kolmogorov–Smirnov test and the homogeneity of variance was tested using Levene's test. One-way analysis of variance (ANOVA), followed by Tukey's test at 5% probability, was used when the data were normally distributed and the variance was homogeneous.

## Results and Discussion

### *Weather data*

In general, considering the two growing seasons, there were no variations in temperature and relative humidity between the controlled and field environments. However, due to the presence of the agricultural film, the radiation in the controlled environment was much lower than that observed in the field in the two growing seasons (Figure 2, A and B). Temperature, precipitation, and solar radiation during the spring-summer cultivation period (Experiment 1) were higher than those in the autumn-winter period (Experiment 2). This is an expected result for the region where the study was carried out.

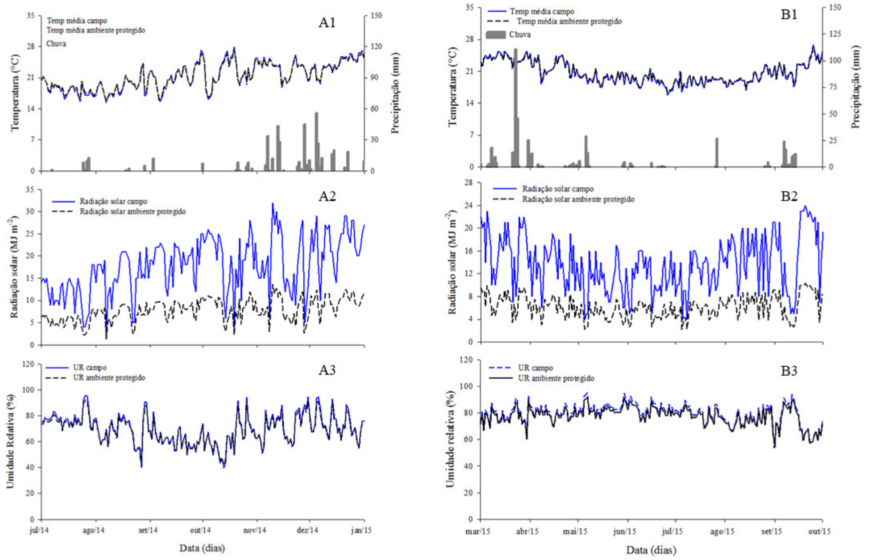

**Figure 2**. Monthly means of air temperature, radiation, and relative humidity in the controlled environment and in the field, during the spring-summer growing season – Experiment 1 (A1, A2, and A3) and autumn-winter season Experiment 2 (B1, B2, and B3)

### *Total phenolic content of fruits in different environments, seasons, and growing systems*

The analysis of the chemical-nutritional aspects of the fruits revealed that the cultivation environments influenced the bioactive compounds and the antioxidant activity. The total phenolic content of the fruits grown in the field was 68% higher than that of the fruits grown in the controlled environment in the spring-summer growing season and 38% higher than that of those grown in the autumn-winter season (Table 3). In contrast, the cultivation systems did not influence the total phenolic concentration of the fruits in any of the two growing seasons (Table 4).

The accumulation of phenolic components in plants has been associated with stress conditions such as high solar radiation and temperature (Dixon *et al*., 1995). Regarding nutrition and human health, one of the main interests in the study of the presence and levels of polyphenols in plants and fruits, stems from the possible association of these components with protection against different types of cancers, such as breast, stomach, and colorectal cancer (Bosetti *et al.*, 2005; Rossi *et al.*, 2006; Long *et al.*, 2021). Araújo *et al.* (2011) cited the anti-metastasis action, via cellular apoptosis, and the anti-inflammatory or antioxidant mechanisms of polyphenols as possible causes for the protective chemical action of these components against cancers.

**Table 3.** Total phenolic compounds (TF), lycopene, *β*-carotene, and antioxidant activity (radical scavenging capacity, RSC) of tomato fruits grown in a controlled environment (CE) and in the field in the two growing seasons spring-summer (S-S) and autumn-winter (A-W)

| Season | Environment | TF | Lycopene | *β*-carotene | RSC |
|---|---|---|---|---|---|
| | | (mg GAE 100 g$^{-1}$) | (mg 100 g$^{-1}$) | (mg 100 g$^{-1}$) | (%) |
| S-S | CE | 15.61$^{b}$ | 15.51$^{a}$ | 0.482$^{a}$ | 11.18$^{a}$ |
| | Field | 26.28$^{a}$ | 16.90$^{a}$ | 0.552$^{a}$ | 9.08$^{a}$ |
| | CV (%) | 15.46 | 32.94 | 35.19 | 29.44 |
| A-W | CE | 12.36$^{b}$ | 4.92$^{a}$ | 0.458$^{a}$ | 9.51$^{b}$ |
| | Field | 17.03$^{a}$ | 4.36$^{b}$ | 0.614$^{a}$ | 12.53$^{a}$ |
| | CV (%) | 18 | 33.22 | 24.95 | 13.25 |

Means followed by the same letter in the column do not differ using the Tukey's test ($p < 0.05$).

**Table 4.** Total phenolic compounds (TF), lycopene, *β*-carotene, and antioxidant activity (radical scavenging capacity, RSC) of tomato fruits grown in four cultivation systems (CS) in the two growing seasons spring-summer (S-S) and autumn-winter (A-W)

| Seasons | CS | TF | Lycopene | *β*-carotene | RSC |
|---|---|---|---|---|---|
| | | (mg GAE 100 g$^{-1}$) | (mg 100 g$^{-1}$) | (mg 100 g$^{1}$) | (%) |
| S-S | V | 22.67$^{a}$ | 16.62$^{a}$ | 0.470$^{a}$ | 11.22$^{a}$ |
| | CF | 23.67$^{a}$ | 12.62$^{a}$ | 0.486$^{a}$ | 10.32$^{a}$ |
| | Vi | 21.27$^{a}$ | 19.38$^{a}$ | 0.610$^{a}$ | 8.63$^{a}$ |
| | DV | 16.19$^{a}$ | 16.21$^{a}$ | 0.498$^{a}$ | 10.36$^{a}$ |
| | CV (%) | 30.80 | 26.30 | 22.16 | 30.98 |
| A-W | V | 16.05$^{a}$ | 5.22$^{a}$ | 0.478$^{a}$ | 10.93$^{a}$ |
| | CF | 13.28$^{a}$ | 4.48$^{a}$ | 0.458$^{a}$ | 11.83$^{a}$ |
| | Vi | 13.73$^{a}$ | 5.09$^{a}$ | 0.654$^{a}$ | 10.73$^{a}$ |
| | DV | 15.71$^{a}$ | 3.77$^{a}$ | 0.556$^{a}$ | 10.57$^{a}$ |
| | CV (%) | 19.76 | 23.01 | 20.89 | 19.54 |

Means followed by the same letter in the column do not differ using the Tukey's test ($p < 0.05$).

Genetic breeding has been a frequently used strategy to increase the levels of protective chemical components important to human health, such as carotenoids, vitamins, and polyphenols, in different plant species (Leva-Brondo *et al.*, 2012; Machado Júnior *et al.*, 2017); however, it is still incipient for components such as polyphenols. In this way, the modulation of environmental conditions can configure an alternative for the increase in the contents of components such as polyphenols.

In the present study, the highest concentrations of total phenolics in fruits grown in the field, in both growing seasons, may be mainly associated with the greater intensity of solar irradiation on the plants grown in the field (Figure 2). Similar to what was observed in the present study, when evaluating the profile of phenolic components in fruits grown in two growing seasons, Marsic *et al.* (2018) also reported higher levels of phenolic components in the fruits grown in the growing season with higher temperatures.

### *Carotenoid content in fruits*

Lycopene represents the majority of the total carotenoid content of tomato fruits, giving the reddish color to ripe fruits (Martí *et al*., 2018). As expected, lycopene was the carotenoid found in the highest concentrations, and in the autumn-winter growing season it expressed a significant increase of 12% in the controlled environment when compared with the values from the field (Table 3).

The cultivation systems were not found to significantly affect the lycopene content, although the content of this carotenoid tended to increase in the fruits cultivated in the Viçosa cultivation system (53%), compared with that of the fruits grown in the cross fence, in the spring-summer season (Table 4). No significant differences were observed for the *β*-carotene content in relation to the environment, season, or cultivation system (Tables 3 and 4).

The synthesis of carotenogenic compounds in fruits involves the expression of several genes, which is associated with a series of factors, such as the genetic background of the cultivated varieties, region of cultivation, and stage of maturation, in addition to agronomic practices such as irrigation and fertilization (Ilahy *et al*., 2011). In addition to these factors, the cultivation environment exerts considerable influence on the carotenoid content. Consistent with similar studies, the results observed in this study also demonstrated higher levels of carotenoids (except *β*-carotene) in tomato fruits grown under higher temperature conditions (Ruiz-Nieves *et al*., 2021). A similar result was also reported in round-type cherry tomatoes, whose lycopene concentration increased when the temperature during the fruit ripening stage increased from 15 °C to 20.3 °C in autumn and from 18 °C to 22 °C in spring (Krumbein *et al*., 2006).

Temperature can exert contrasting effects on the carotenoid content, as previously reported by Dorais *et al.* (2008), and extremes temperatures (both above 32 °C and below 12 °C) may lead to a decrease in carotenoid content (Dumas *et al*., 2003). In our study, the average temperature differences were small and close to the ideal conditions of 22-26 °C. Thus, the synthesis of lycopene and other carotenoids was not inhibited.

### *Antioxidant activity in fruits*

In the autumn-winter season, the antioxidant activity increased by 31% when comparing that of the fruits from the controlled cultivation environment with that of the fruits from the field cultivation (Table 3). However, there was no difference in the antioxidant activity of the fruits between the controlled and field environments in the spring-summer season (Table 3). Furthermore, the cultivation systems did not facilitate any difference in the antioxidant activity of the fruits (Table 4).

The antioxidant activity of vegetables is an important index for evaluating the functional properties (Padayatty *et al*., 2013). In this sense, Tan *et al.* (2021) reported that there was an association between the antioxidant activity of fortunella fruits and the health benefits resulting from their consumption. Additionally, it is well documented that antioxidant activity is closely related to the total phenolic content (Sun *et al*., 2015). Therefore, the climatic conditions of plants grown in the field in the spring-summer season, which were previously reported for the total phenolic content, may partly explain the results of the antioxidant activity observed in this study. Nevertheless, it is important to note that the total phenolic content in fruits is also influenced by climate, plant density, and agronomic techniques. Together with the genetic background, these are the main factors that determine the accumulation of antioxidant compounds during fruiting (Dumas *et al*., 2003).

### *Implications of the results for tomato production*

It was observed that the seasons and the cultivation systems did not influence the concentration of total phenolics in the fruits, nor did it affect the content of *β*-carotene, under the conditions in Viçosa, MG. However, the results did show that field cultivation increased the concentration of total phenolics by 68% and 38% in the spring-summer and autumn-winter seasons, respectively. The field cultivation also provided an increase of 31% in the antioxidant activity of the fruits, compared to that in the controlled cultivation, in the autumn-winter season.

The fact that the growing seasons did not influence the concentration of total phenolics and the content of *β*-carotene in tomato fruits under the conditions in Viçosa, MG, demonstrates the stability of the content of these components in the fruits throughout the year. This stability favors the diet and health of the populations that consume tomato fruits produced under the local conditions of Viçosa, Brazil. The conditions under field cultivation facilitated an increase in the total phenolic content and antioxidant activity of the fruits. This represents an advantage as field cultivation has a lower cost than cultivation in a controlled environment.

Therefore, in verifying that the cultivation systems did not influence the chemical-nutritional aspects, the present study demonstrated that cultivation systems such as Viçosa combine the aspects of high productivity and profitability, without compromising the chemical-nutritional aspects of the fruits. Taken together, the results obtained in the present study are fundamental in guiding tomato production with a view to optimize the chemical-nutritional aspects of the fruits in tomato production.

## Conclusions

Compared to the controlled environment, field cultivation provided an increase of 68% and 38% in the total phenolic concentration in tomato fruits, in the spring-summer and autumn-winter seasons, respectively. Field cultivation also provided an increase of 31% in the antioxidant activity of the fruits, compared with that of the controlled cultivation, in the autumn-winter season. Seasons and cultivation systems did not influence the concentration of total phenolics in the fruits, nor did it affect the content of *β*-carotene, under the conditions in Viçosa, MG. The increase in the levels of total phenolics and antioxidant activity of fruits due to cultivation in the field represents an advantage as cultivation in this environment has a lower cost than cultivation in a controlled environment. The growing seasons had no influence on the concentration of total phenolics or the content of *β*-carotene in the fruits. This demonstrates the stability of the content of these components in the fruits throughout the year, which favors the diet and health of the populations that consume the locally produced tomatoes. The cultivation systems did not influence the chemical-nutritional aspects of fruits; moreover, the Viçosa system brings together aspects such as high productivity and profitability, without compromising the chemical-nutritional aspects of the fruits, thereby configuring a promising system for tomato production.

## Authors' Contributions

Conceptualization, Methodology, Software, and Writing original draft: VSA. Writing and review of original draft: EDP and RSG. Investigation, review of original draft, and editing: NMA, RICC, HCXS, CFA. Conceptualization, Fund Acquisition, Project Management, and review of original draft: DJHS.

All authors read and approved the final manuscript.

## **Ethical approval** (for researches involving animals or humans)

Not applicable.

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## Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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