



Research Article

A SCITECHNOL JOURNAL

Quality's Attributes of Tomato Conducted under Greenhouse in Relation to Climatic Conditions

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Abstract

Three greenhouses' horticultural covers, Celloclim/Polyane 4D and double cover were tried using a culture of tomato, *Solanum lycopersicum*, cv Durinta harvested 12 and 28 weeks after transplanting. While Polyane 4D permitted the most enlightened conditions, the double cover ensured the greatest means of diurnal and nocturnal temperature. Fruits maturity was firstly recorded under the greenhouse covered by Celloclim. Produced fruits were the heaviest, largest, richest on dry matter content and both potassium, calcium and magnesium; and the sweetest (high savor's index) under the greenhouse covered by Polyane 4D. However, they presented the most elevated content on nitrogen and antioxidant compounds (lycopene, β-carotene, polyphenols, anthocyanine, vitamin C) when harvested from the greenhouse covered by the double cover. Fruits gathered under this last cover were the most impaired by the drastic increment of temperature recorded at the second sampling's date by showing the least fruits' size yet the highest antioxidant activity and proline concentration considered as a defense mechanism.

Keywords

Horticultural cover; Greenhouse; Climatic conditions; Tomato; Production; Quality

Introduction

International market is more sophisticated and consumers are becoming more discerning in their purchasing behavior. As the same, a particular attention was paid to the nutritive quality [1,2,3,4] and the flavor particularly that they are recently dissatisfied with modern selected varieties [3,5,6,7]. Flavor refers to taste (sweetness and sourness), aroma and volatile compounds [8,9,10].

Tomato (*Solanum lycopersicum L.*) is the second most cultivated vegetable in the world after the potato [3]. It's great consumption is due to its healthy beneficial effects seeing its high content on health-promoting compounds such as antioxidants including polyphenols and vitamins [1,2,5,8,11,12]. Among polyphenols, flavonoids [5,13], such as anthocyanins, defensive against oxidative stress [14]. As an antioxidant, ascorbic acid directly eliminates superoxide, hydroxyl radicals and oxygen singlet radicals [3]. Besides, epidemiological studies have proved its wealth on carotenoids namely lycopene and β-carotene with a notable capacity to eliminate active oxygen species (AOS), associating the fruit with the prevention of cardiovascular

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Received: March 03, 2016 Accepted: March 25, 2016 Published: March 31, 2016

diseases and certain cancer [2,5,8]. The aforementioned intrinsic quality's attributes were closely affected by interplay of genetic factors, cultural practices and climatic conditions [8,9,10]. Among climatic factors, Adams, et al. [15] and Hewett [9] indicated that temperature and solar radiation are fundamental in intensive cultivation greenhouses as those heated and irrigated by geothermic water. Leonardi et al. [16] have quoted the effect of relative humidity too.

Sustainability of the commercial horticulture depends on the compliance of products with quality and food safety [9], the strong market competitiveness highlights the need to increase the quality of horticultural products through better control of greenhouse's climatic conditions [17]. In Mediterranean greenhouses, control of inner climatic conditions is hard seeing the special climate [18]. Therefore, unfavorable climatic conditions are established and, thus, stimulate anti-oxidant mechanisms [3] and accumulation of osmoprotectors such as proline [19]. In order to ensure this control and avoid stress situations, high-technology greenhouses are being developed in the Mediterranean region based on automatic control of inner climate and a pertinent choice of covers. Indeed, climatic conditions inside greenhouses are established by a set of energy exchanges through the cover in relation to the imposed external conditions [20]. Therefore, the present study was conducted to determine how three horticultural covers affect the main climatic favors (solar radiation, temperature and relative humidity) under geothermic greenhouses and both gustative and nutritional quality of tomatoes [21].

Material and Methods

Plant material and growth conditions

Three juxtaposed Vermako greenhouses developed at the geothermic society "SANLUCAR" located in Hamma Gabes (Eastern South of Tunisia) and oriented in North/South were considered. They were covered by three types of horticultural covers: i) Polyane 4D, ii) Celloclim and iii) double cover that associated Polyane 4D and Polyane 4TT (Table 1). Seedlings of tomato (*Solanum lycopersicum*) cv. Durinta grafted on Heman rootstock were transplanted at 20/09/2012 in Perlite-filled sacks (90 cm long, 33 L in volume) with a planting scheme of 3.41 plants m⁻². Fertilization was realized automatically with both pH and EC as 6.00 and 3.50 dS.m⁻² respectively. To avoid salt accumulation in the potting media, plants were over watered once a week with geothermal water without nutrients. Trusses were pruned to five fruits after anthesis.

The climatic conditions under greenhouses were monitored automatically using the multi-probe system. Heating was applied from November to April and usually has been affected between 17 h

Table 1: Main characteristics of covering materials.

	Thickness (micron)	Light transmission (%)	Diffuse light (%)	Thermicity (%)	Type
Celloclim	215	>82	<70	>84	Mico- bubbles thermal
Polyane 4D	200	>88	<50	>83	Thermal spreading
Polyane 4TT	200	>90	<20	>84	Thermal colorless

and 7 h. Aeration was done through openings at the ridge. Regulation of both relative humidity and temperature was managed using a brumization system. Over the entire crop cycle, temperature (diurnal, nocturnal, maximum and minimum) and air humidity were measured automatically. They were quantified each 10 min recording the average value for every three measurements over 30 min. The solar radiation under greenhouses was measured using a luxmeter 200 000 L C.A813.

Fruits were produced weekly from January to June. They were sampled 12 and 28 weeks after transplantation corresponding respectively to the precocious and non-precocious production. Five samples of fresh tissue from the exocarp part were used to analyze the parameters described below.

Fruit analysis

The fruits' juice was used to determine pH, EC and soluble solids (SS) estimated respectively by an electronic pH, conductive meter and a refractometer. Titratable acidity (TA) was measured by titration of 25 ml of homogenate juice as described by Haddad [16]. Contents on citric and malic acids were estimated referring to CTIFL (2000). The soluble sugars (glucose and fructose) were quantified by high performance liquid chromatography (HPLC) using Acetonitrile "SIGMA-ALDRICH" solvent. Obtained concentrations were used to calculate the savor's index as indicated by Rosales [12]:

$$\text{Savor's index} = (1^*[\text{Glucose}]) + (2.3[\text{Fructose}]) + (1.35[\text{Sucrose}]).$$

Vitamin C content was determined by HPLC method. Lycopene and β-carotene were extracted from the exocarp fractions with acetone / hexane (4:6). Concentrations were determined referring to the method of Nagata and Yamashita (1992). They were quantified using subsequent equations:

$$[\text{Lycopène}] (\mu\text{gml}^{-1}) = -0.0458 A_{663} + 0.204 A_{645} + 0.372 A_{505} - 0.0806 A_{453}$$

$$[\beta\text{-Carotène}] (\mu\text{gml}^{-1}) = 0.216 A_{663} - 1.220 A_{645} - 0.304 A_{505} + 0.452 A_{453};$$

Where A_{663} , A_{645} , A_{505} and A_{453} are the absorbance at 663, 645, 505 and 453 nm, respectively.

Anthocyanin content was determined according to Lange et al. [22]: fruit skins were homogenized in propanol-HCl-H₂O (18:1:81) and further extracted in boiling water for 3 min. The content was calculated as: $A = A_{535} - A_{650}$; where A_{535} and A_{650} correspond to the absorbance at 535 and 650 nm respectively. Antioxidant activity was measured in the exocarp fraction using the Ferric Reducing Ability of Plasma (FRAP) assay as reported by Rosales et al. [12]: the FRAP assay was performed with FRAP reagent, i.e. 1 mmol L⁻¹ 2,4,6-tripyridyl- 2-triazine (TPTZ) and 20 mmol L⁻¹ ferric chloride in 0.25 mol L⁻¹ sodium acetate (pH 3.6). An aliquot of 100 μL of tomato extract (10 g L⁻¹ in methanol) was mixed with 2 mL of FRAP reagent and left for 5 min at ambient temperature. Then, absorbance at 593 nm was measured. Calibration was against a calibration curve (25–1600 μmol L⁻¹ ferrous ion) constructed using freshly prepared ammonium ferrous sulfate. This activity was estimated, too, via the 2,2-diphenyl-1-picrylhydrazyl (DPPH) free-radical scavenging effect was performed according to Hsu and Lo [18]. Aliquots of 0.5 mL of methanolic tomato extract and 2.5 mL of freshly prepared 0.1 mmol L⁻¹ DPPH methanolic solutions were thoroughly mixed and kept for 60 min in both cold and dark. It was calculated as following:

$$\text{Scavenging effect (\%)} = [1 - (A_{517} \text{ sample}/A_{517} \text{ blank})] \times 100;$$

Where blank solution corresponds to a methanol solution (0.5 mL).

Samples were digested with nitric acid in order to determine their contents on K, Ca and Mg using a spectrophotometer. To analyze nitrogen, N, and phosphorus, P, samples were digested in sulphuric acid and nutrients were determined by automatic colorimeter [16]. The contents were expressed in term of dry matter (% DM) [23,24,25].

Statistical Analysis

Statistical analysis is computed as ANOVA test to assess the significance of treatment means. The differences between means of each treatment (type of cover) at each sampling period, also the means at two different periods were compared using the least significant difference (LSD) and Duncan's multiple-range test (DMRT) at the 0.05 probability level.

Results and Discussion

Effect of cover on climatic conditions

The double cover displayed the most drastic limitation of exterior solar radiation, severely at the 16th week after transplantation when recording 516.53 J.cm⁻² (Figure 1) seeing its least solar radiation transmission (Table 1). Until the fifth week after transplantation, maximum air temperatures means were the greatest under the greenhouse covered by Polyanne 4D with average of 29.79 °C. Henceforth, the double cover greenhouse showed the most elevated values (Figure 2b). Moreover, this cover ensured more clement nights by ascertaining greater minimal temperatures (Figure 2c, d) in conformity with findings of Driss Becheur [7]. This superiority could be explained by its high thermicity and light diffusion that stop the transmission of long infra-red radiations. Therefore, heating efficiency was affected: indeed, the double cover ensured an economy of 1 hour and 20 minutes and 53 minutes of heating by geothermal water respectively comparing with Polyanne 4D and Celloclim. [26,27]. Elsewhere, a high humidity was monitored under the greenhouse covered by Polyanne 4D where a peak of 96.41 % was reached ten weeks after transplantation (Figure 3).

Effect of cover on production

Fruits maturity was recorded at first inside the greenhouse covered by Celloclim. 3 and 7 days later it was noted for the greenhouses covered respectively by Polyanne 4D and double cover. Superiority of Celloclim seems being attributed to its humidity medium values of that Iraqi et al. [19] and Mortensen [28,29,30] have confirmed this attribution. However, the non-significant delay in maturity under the two other covers can be explained by their greater temperatures as it

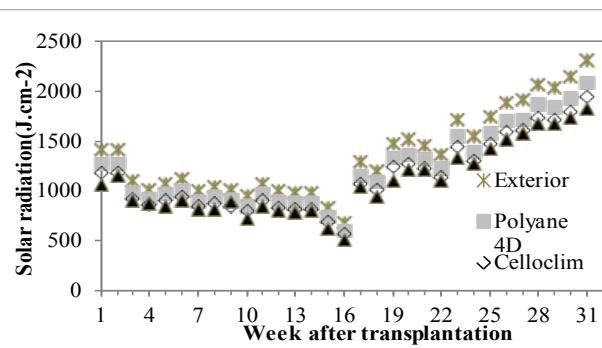


Figure 1: Limitation of exterior solar radiation by (*) Celloclim (◊), Polyanne 4D (■) and the double cover (▲).

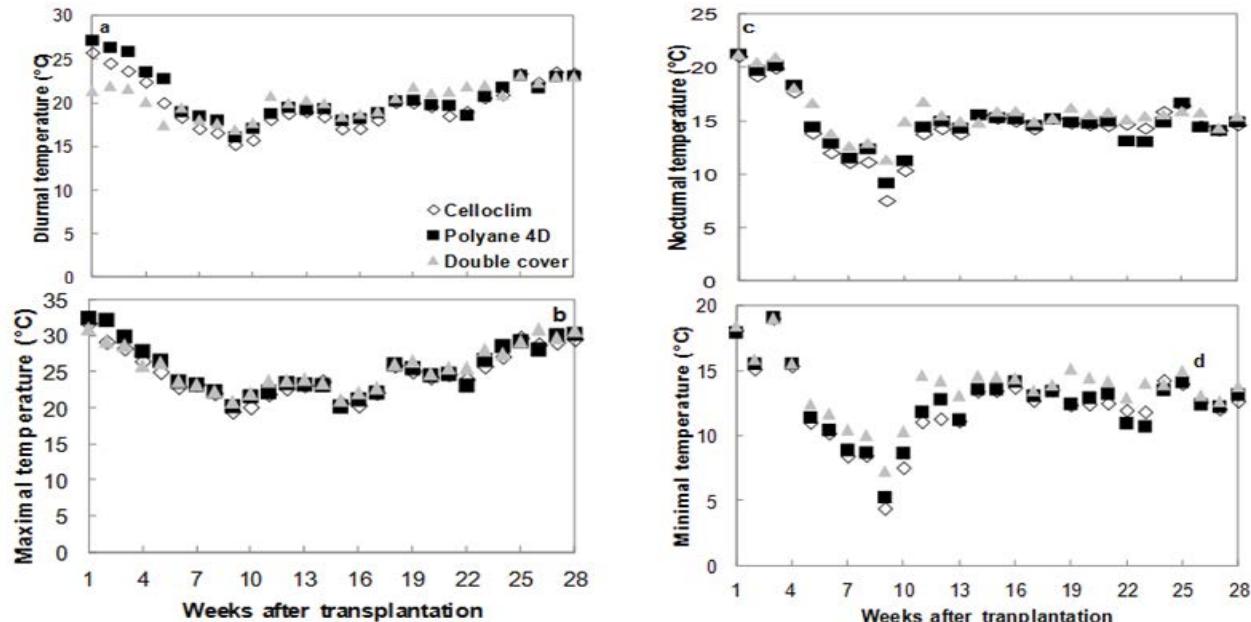


Figure 2: Values of diurnal (a), maximal (b), nocturnal (c) and minimal (d) temperature inner the greenhouse covered by Celloclim (\diamond), Polyane 4D (\blacksquare) and double cover (\triangle).

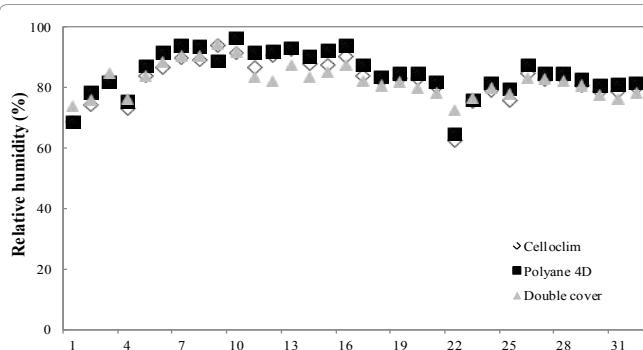


Figure 3: Relative humidity under greenhouses covered by Celloclim (\diamond), Polyane 4D (\blacksquare) and double cover (\triangle).

was adopted by Bertin [2]. The lower effect of the double cover was in conformity with works of Driss-Bécheur [7].

Produced fruits were the heaviest and the largest under the greenhouse covered by Polyane 4D with averages of 150.5 g and 6.81 cm (Table 2). Inferiority of fruits' weight under Celloclim corroborates the findings of Wacquant et al. [17] and Maul et al. [6]. These authors have remarked a negative correlation between earliness and fruit's size. The smallest fruits were harvested under the double cover. This finding can be justified by the high values of temperature under this cover (Figure 2) that limit fruit's growth [20,31,32,33]. This justification is affirmed by the significant reduction of fruit sizes during the second period of harvest consequently to obvious increasing temperatures (Figure 2). This impairment was about 33.68, 20.67 and 34.77% for $p < 0.001$ for weight and about 13.37, 13.2 and 16.51 % for diameter under greenhouses covered by Celloclim, Polyane 4D and double cover respectively (Table 3). With respect to yield (kg.m^{-2}), it was of 27.21; 20.98 and 26.05 respectively under the greenhouse covered by Celloclim, Polyane 4D and double cover.

Difference seems being attributed more to fruits' number (data not shown) than to fruit's dimension. Our data disagree with those of Adams et al. [1] who reported yield losses in tomato plants when air temperatures exceeded 26 °C.

Effect of cover on quality's traits

Gustative quality: Regarding fruit gustative quality, only the acidity revealed a significant difference. An adequate acidity has been noted under Celloclim (Table 2). This finding is in opposite to literature reported by Wacquant et al. [17] indicating that acidity parameters (pH's juice, citric and malic acids) are not affected by climatic conditions. However, they were not significantly affected by climatic conditions of the second period (Table 3). At exception with fruits produced 12 weeks after transplantation under the greenhouse covered by the double cover which presented a dry matter content of 3.88%, all harvested fruits have presented a content of dry matter higher than 5%. Referring to Turhan and Vedat [28], these values reflect good maturity. For both dates of harvest, Polyane 4D was the most suitable for the dry matter's accumulation (Table 2 and 3) owing to its great solar radiation transmission that Massot et al. [24], Escobar et al. [10] and Ghorbani et al. [14] have confirmed its positive effect. This attribution is affirmed by increment of this content at the second date of harvest simultaneously with amelioration of lightening conditions. This increase was about 7.32; 25.22 and 31.7 % respectively under greenhouses covered by Celloclim, Polyane 4D and double cover. In addition, great differences on diurnal/nocturnal temperature and higher humidity under Polyane 4D can justify this discrepancy as it was adopted by Gent and Ma [13] and Leonardi et al. [23] respectively.

Reducing sugars assay in fruits has shown that the content of fructose was more important than that of glucose [34]. This finding agrees with those of Mikkelsen [27] and Rosales et al. [31]. Table 2 shows that the composition on reduced sugar was the most important for fruits harvested under the greenhouse covered by

Table 2: Effect of cover on quantitative and qualitative production.

Mineral composition (%DW)	N	9.85 ^a ± 6.78	5.83 ^b ± 5.94	8.93 ^a ± 4.11
Na	0.3 ^a ± 0.01	0.12 ^b ± 0.01	0.17 ^a ± 0.005	
P	0.97 ^a ± 0.018	0.7 ^b ± 0.03	0.8 ^b ± 0.02	
K	2.65 ^a ± 0.056	3.02 ^a ± 0.04	2.48 ^a ± 0.037	
Ca	1.35 ^a ± 0.012	1.73 ^a ± 0.016	0.98 ^a ± 0.02	
Mg	0.55 ^{ab} ± 0.016	0.75 ^a ± 0.011	0.46 ^a ± 0.009	

Table 3: Effect of sampling's period on quantitative and qualitative production of tomato conducted under three greenhouses' shelters.

	Celloclim	Polyane 4D	Double cover
Fruit weight (g)	- ; **	- ; **	- ; **
Fruit diameter (cm)	- ; "	- ; "	- ; **
DM (%)	+ ; "	+ ; "	+ ; **
EC (dS.m ⁻¹)	+ ; **	+ ; **	+ ; "
IR (%)	+ ; *	+ ; **	+ ; NS
Fructose (mg.g ⁻¹ FM)	+ ; *	+ ; ***	+ ; *
Glucose (mg.g ⁻¹ MF)	+ ; *	+ ; **	+ ; *
Savor index	+ ; *	+ ; ***	+ ; *
Vitamine C (µg.g ⁻¹ FM)	+ ; *	+ ; *	+ ; ***
Polyphénols (mg rutine.g ⁻¹ MF)	+ ; *	+ ; *	+ ; ***
Anthocyanine (abs 535 nm g ⁻¹ MF)	+ ; ***	+ ; **	+ ; *
Lycopène (µg.g ⁻¹ MF)	+ ; **	+ ; **	+ ; **
β-Carotène (µg.g ⁻¹ MF)	+ ; *	- ; Ns	+ ; *
Reduced power (abs 700 nm.g ⁻¹ MF)	+ ; "	+ ; p= "	+ ; "
P	- ; **	- ; **	- ; **
Ca	- ; "	- ; "	- ; **
Mg	- ; "	- ; "	- ; **

Polyane 4D coinciding with conditions of high solar radiation (**Figure 1**). In fact, Massot et al. [24] have specified that fruits exposed to light showed 15% of reduced sugar more than those maturing at shading condition. This attribution was affirmed by the increase of both reducing sugar contents at the second period of sampling (**Table 3**). This enhancement seems being far more pronounced in the tomatoes collected under Polyane 4D ($p < 0.001$). The lower content on reducing sugars of fruits produced under the double cover can be explained, added to its lowest solar radiation, to its lower difference between diurnal and nocturnal temperatures [9]. This composition has considerably affected the savor's index which was the greatest under the greenhouse covered by Polyane 4D at the two samplings dates with values of 88.87 and 116.04 (**Table 2** and **3**). This superiority seems being proportional to the significant content on fructose that Rosales [30] has indicated that it is more determined than glucose in the taste of tomato [35].

Nutritional quality

Under our experimental conditions, we have found that the double cover has allowed significant accumulation of antioxidant compounds obviously lycopene, polyphenols and anthocyanine (**Table 2**). Studying similar conditions, Grolier et al. [17] and Dumas et al. [8]; Escobar et al. [10] and Ghorbani et al. [14] have found, respectively, that lycopene and polyphenols are stimulated by condition of higher light. Nevertheless, other findings recorded at the second period confirmed these aforementioned literature reports. Comparing the three covers, we found that tomatoes cultivated in the greenhouse covered by the double cover had a high content of vitamin C at the two dates of harvest but not significantly, coinciding with its pertinent solar radiation (**Figure 1**) as indicated by Dumas et al. [8]. Increment of this content at the second sampling's date

(**Table 3**) agrees with works of Gautier et al. [12] who have remarked that the ascorbate content increased under conditions of high temperature as an antioxidant response. Augment of accumulation of the aforementioned antioxidants has positively affected the antioxidant activity which was more elevated at the second sampling's date than the first on (**Table 3**). This increase was correlated to increment of temperature and surge of relative humidity which triggered such metabolic responses as remarked by Rosales et al. [31]. The greatest values were of 89.33%.g⁻¹ FM (DPPH) and 0.97 abs 700 nm.g⁻¹ FM (reducing power) recorded under the greenhouse covered by the double cover. Superiority of the double cover effect could be probably caused by the highest temperatures that it established (**Figure 2**). This activity seems being the most dependant on the composition on polyphenols in conformity with findings of Yasunori and Iki [36] who have enunciated its power antioxidant effect. However, Smirnoff [32] has affirmed that vitamin C is the most effective antioxidant. Given that glucose is the main precursor of ascorbate and carotenoids and that fructose is, also, included in antioxidant synthesis [37], it seems that lower contents on these elements under the greenhouse covered by the double cover is attributed to their contribution in the mechanisms of the fruit antioxidant defense by supplying precursors of antioxidant compounds. In addition to antioxidant compounds, arising of proline content at the second date of production implying stressed environmental conditions as noted by Claussen [5]. Therefore, the highest proline accumulation in tomato fruits grown under the greenhouse covered by the double cover clearly indicates the occurrence of heat stress conditions.

Tomato fruits subjected to elevated air temperatures under the greenhouse covered by the double cover showed the greatest contents on nitrogen by accumulating 8.93 and 6.32 % DM 12 and 28 weeks after transplantation. This superiority could be probably due to its lower precocity that Grolier et al. [15] have indicated that it favors the absorption of this element.

This result was in contradiction to findings of Iraqi et al. [19] who have indicated that this mineral accumulation is empowered by greater solar radiation. However, fruits grown under Polyane 4D were the richest on potassium and calcium drastically in the second sampling's period with 1.92 and 1.12 % DM (**Table 2** and **3**). This composition may be due most likely to discrepancy on humidity. Indeed, lower humidity remarked under the greenhouse covered by the double cover and during the second period of harvest (**Figure 3**) seems justifying their lower values on potassium, calcium and magnesium (**Table 3**) as cited by Iraqi et al. [19]. In relation to solar radiation, higher content on potassium under Polyane 4D is in opposition with the research of Kosobrukhanov et al. [21].

In conclusion, our results indicate that climatic conditions established by Celloclim prompt the fruits' maturity, hence precocious production, and ensure the greatest yield. Whereas, Polyane 4D permitted, owing to its best conditions of lightening and humidity, the most expansion and sweetness taste of fruits assigning them a higher market quality. For the double cover, it was the most pertinent for accumulation of antioxidant compounds. The content on qualitative and nutritional compounds was more important at the second period proportionally to increment of temperature which even it generates a fruit size decrease, it notably improved the nutritional quality of tomatoes and thus considerably boosting their commercial value. In this framework, Gautier et al. [12] have noted that fruits quality is largely dependent on the lycopene content.

Although more research is needed, these covers effects could be helpful in the horticultural covers selection thereby avoiding plants

several damages resulting from unsuitable climatic conditions. More climatic conditions control is advised to create equilibrium between quantitative and qualitative parameters.

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