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Effect of irrigation on yield parameters and antioxidant profiles of processing cherry tomato

Research Article

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Abstract: A two-year (2010 and 2011) open field experiment was conducted to study the effect of drip irrigation and seasonal variation on the yield parameters and main bioactive components, carotenoids (mainly all trans, cis lycopene, and β-carotene), polyphenols (chlorogenic acid, caffeic acid, gallic acid, quercetin, rutin, naringin, etc.), and tocopherols of processing Strombolino F1 cherry tomatoes. The irrigated plants (STI) gave a higher marketable yield (61% and 101% respectively), and rain fed plants showed a yield loss. Water supply had a strong positive (R^2=0.98) effect on marketable yield in 2011, but weak (R^2=0.69) in 2010. In both years, the antioxidant concentration (all carotenoids, total polyphenols, tocopherols) showed a decrease with irrigation. Water supply affected the composition of carotenoids to a considerable extent. The optimum water supply treatment gave a lower proportion of lycopene than the rain fed control (STC) treatment. We observed significant negative correlation between rutin concentration and irrigation. The α-tocopherol concentration was significantly higher in STC treatments. Irrigation negatively influenced antioxidant concentrations of cherry tomato fruits, but higher yield could account for the concentration loss of individual fruits by higher antioxidant production per unit area.

Keywords: *Water supply • Carotenoids • Phenolics • Tocopherols • Processing cherry tomato*

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1. Introduction

FAO of the United Nations and the World Health Organization (WHO) stress the role of foods and nutrition in the prevention of non-communicable diseases and point to a role for plant-derived phytochemicals in the prevention of cancer and heart disease. WHO places low vegetable and fruit intake sixth on its list of 20 risk factors for mortality worldwide [1].

Tomato cultivation and its importance has been growing rapidly in the last decades in the world. Processing tomato has a great importance in the food industry, basically because of its health promoting features [2].

Water supply is limited worldwide and there is an increasing necessity to reduce the quantity of water used during irrigation practices [3]. The practice of partial root zone drying in irrigation increases water use efficiency of processing tomato without significant negative effects on yield [4]. Furthermore poor water quality and water deficit are the main factors affecting yield and tomato quality in terms of nutritional value and food safety [5]. Nutrient composition of tomatoes is complex and very difficult to assess. Plant metabolites levels are strongly affected by genetic and environmental factors as well as transportation and storage conditions [6].

Several authors report on the effect of irrigation on tomato yield, fruit soluble solids and dry matter content. Pernice *et al.* [7] report that tomatoes cultivated in the experimental field produced an average yield of almost 100 t ha^{-1}. Yield was highly influenced by the water regime; in particular, a strong increase was observed in average yield when comparing no irrigation to the reduced irrigation condition (+45.7%). While tomato yield increase from reduced irrigation to normal irrigation was only 11.0%. Similar results were observed

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by Liu *et al.* [8] when compared to nonirrigation, drip irrigation increased tomato fruit size by 32%. This marked influence of irrigation on tomato fruit size was also reported by others [9]. Irrigation also increased total fruit yield by 66% and marketable fruit yield by 127%, while it decreased soluble solids content by 19% [8]. The negative influence of irrigation on soluble solid levels of tomato fruit and dry matter was also observed in other experiments [10]. Thus the greatest effect of increasing soil water deficit is the rise in fruit firmness, soluble solids and total solids and a decrease in fruit size and yield [9].

Colour is one of the most important quality traits of tomato fruits. The predominant carotenoid of tomato is lycopene, which causes red coloration of fruits. Recently, lycopene has been studied intensively in vitro and in vivo with epidemiological methods because of its marked antioxidant characteristics and potential role in prevention of several diseases [11]. Lycopene exhibits a high physical quenching rate of singlet oxygen, which is directly related to its antioxidant activity [12]. During the ripening process the chlorophyll breaks down and carotenoids, mostly lycopene, accumulate [13-15].

Liu *et al.* [8] found that drip irrigation decreased lycopene content by 8% compared to nonirrigation, with no effects on dry biomass of stems and leaves. While according to the findings of Riggi *et al.* [16], higher amounts of lycopene were measured in the well watered treatment, regardless of the ripening stage, or the parameter unit used (dry or fresh matter). They also reported that water stress had a positive on β-carotene content when expressed, respectively, on a dry and fresh weight basis. While water stress also influenced the β-carotene/lycopene ratio mostly in the first 2 ripening stages. They suggested that, under soil water deficit conditions, especially at the beginning of the fruit ripening process, the carotenoid biosynthetic pathway is more 'β-carotene accumulation' oriented. Favati [10] also reports on the lycopene and b-carotene concentration of tomatoes with regard to the influence of irrigation management. They also found that the lycopene and β-carotene concentration was higher in less irrigated, than that observed in tomatoes well irrigated.

Tomato fruits are also rich in polyphenols, which give the largest part of the antioxidant capacity of the soluble phase. Phenolics play a role in protection against UV radiation and cold acclimation. External stimuli such as temperature, chemical stressors, ultraviolet radiation, and microbial infection induce their synthesis [17]. Helyes and Lugasi [18] found that during the ripening process the total polyphenols content of the tomato fruits did not change significantly.

The dynamic balance between the antioxidant pattern and polyphenol oxidase activity under water stress conditions resulted in fruits with increased antioxidant activity (+12%), due to a decline in enzyme activity (-48%) and a rise in vitamin C (+20%) and total phenolic (+13%) contents [19-21].

Like lycopene, vitamin E belongs to the lipophilic fraction of the tomato fruit. The tocopherols of certain vegetables (turnip greens, celery, carrots) are almost 100 % in the α-form. The tocopherols in legumes, for example peas, contain practically no α-form, while in other vegetables α-tocopherol represents from 50 to 80 % of the total tocopherols. Several studies point to high levels of vitamin E in the processed tomato product [22,23]. Tomatoes at the ripening stage contain a-tocopherol and g-tocopherol at the average concentration of 3.5 and 1.2 mg g^{-1}, respectively [24].

Genetic and environmental factors modulate the physiology and secondary metabolism of tomato [25,26], but it is not clearly stated for cherry tomatoes how the genetic and abiotic factors (cultivar and water supply) would affect its natural antioxidant composition (carotenoids, and phenolic compounds). It is important to understand the influence of varietal and environmental factors and their interactions on the natural antioxidants of cherry tomato, if the purpose is the production of cherry tomato fruits rich in health-promoting substances.

The main target of the present study was to evaluate the influence of environmental factors (irrigation and seasonal variation) on the content of carotenoids (β-carotene, lycopene and its isomers), phenolic compounds (flavonoids and phenolic acids) and tocopherol content and composition in processing cherry tomato.

2. Experimental Procedures

2.1 Plant material and experimental design

The experiment was conducted on the Experimental Farm of the Institute of Horticulture, Szent István University, in Gödöllő, Hungary. The experimental field is on brown forest soil, with mechanical composition of sand and the subsoil water is below 5m, therefore it cannot influence the water turnover. Basic nutrition supply was applied when plants were transplanted with 320 kg ha-1 of Agroblen 18-8-16 fertilizer (Everris International B.V., The Netherlands). Strombolino F_1 (cherry type) seeds were sown on the 2nd of April in 2010 and 7th of April in 2011 in a greenhouse and transplanted on the 14th of May 2010 and 12th of May in 2011. Strombolino F1, an American variety (United Genetics Seeds Co.) belongs to the cherry type processing tomato cultivars, which are unique and new for the processing tomato industry.

Regularly irrigated (STI) crop was compared with rain fed control (STC). STI plants were irrigated to daily

potential evapotranspiration of tomato. The amount of daily irrigation demand was estimated from expected daily average temperature (in °C) divided by five expressed in millimeter according to a previous study $I_d = \left(\frac{T_{\min} + T_{\max}}{2} \right) / 5$ [27].

The amount of irrigation supplied was calculated based on weather forecasting data of the Hungarian Meteorological Service [28]. Temperature, averaged over 2- and 3- day intervals each week were used to calculate the daily potential evapotranspiration (ET_0). The amount of irrigation was calculated by ET_0 for the forecasting period corrected by the amount of precipitation. If precipitation was less than irrigation demand, we supplied the amount of ET_0, but if it covered the irrigation demand until the next irrigation date we did not irrigate. STI plants were irrigated by the calculated amount of water on every Monday, Wednesday and Friday mornings from planting to harvesting. Water availability of 500 and 352 mm in 2010 and 489 and 154 mm in 2011 were usable for plants in the irrigation treatment and non-irrigated control respectively during the vegetation period (Figure 1 and 2). Irrigation was applied by drip irrigation, one lateral for every twin rows, with discharge rates of 4 L h^{-1}.

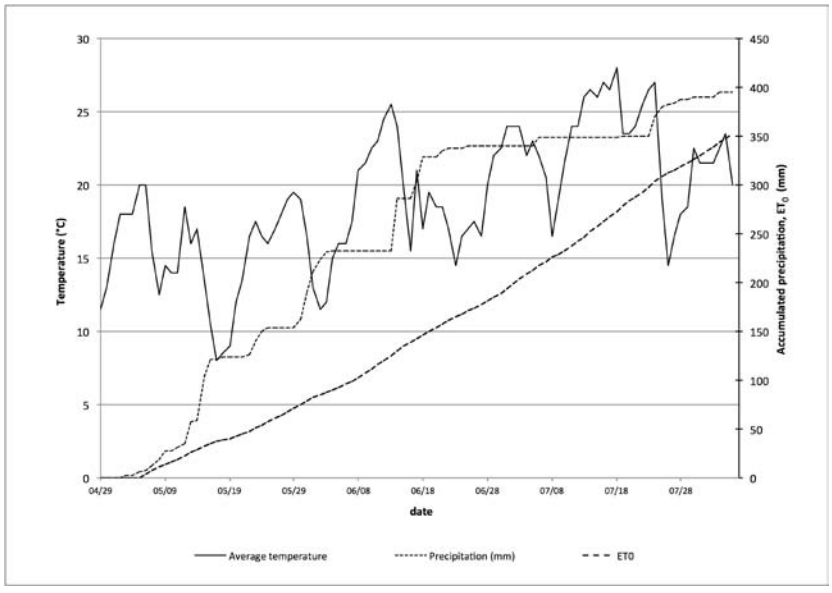

Figure 1. Meteorological and irrigation volume data during tomato growing season in 2010.

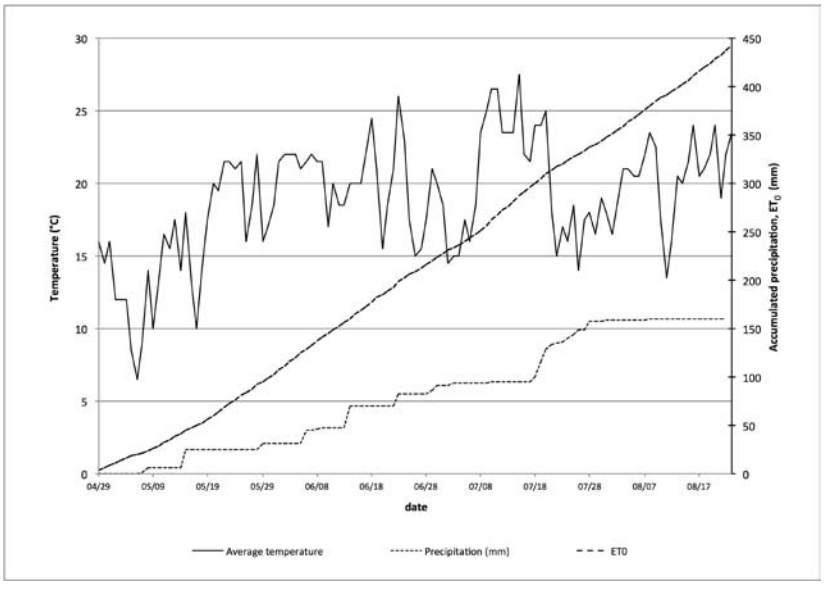

Figure 2. Meteorological and irrigation volume data during tomato growing season in 2011.

The experimental design was randomized block, with three replications for each treatment. Tomato plants were arranged in twin rows with a distance of 1.2 and 0.4 m between the rows and 0.3 m between the plants. Crop density was 4.2 plant m^{-2}. Red ripened, green and non-marketable fruits were measured at harvesting on the 6th of August in 2010. There was a single harvest date in 2010 due to the excess precipitation.

In 2011, red ripened marketable fruit sample was taken on the 26th of July and red ripened, green and non-marketable fruits were harvested on the 26th of August. The reason for the low number of replications (3) chosen, was because of the significant manual labour involved in the evaluation of fruit yield and parameters (a total of 40 000 fruits were handled manually per harvest).

Total carotenoid, total polyphenol and tocopherol concentration and their composition depending on seasonal variation and irrigation treatment were also evaluated in 2010 and 2011. There were two different sampling dates to establish an optimal harvest date for better antioxidant concentration of tomato fruits in 2011, only one in 2010 because of the very high precipitation during the harvest period. During the week preceding the 26th of July harvest, the average maximum and minimum temperature was 23°C and 15.1°C and every day was rainy and cloudy. In contrast the week preceding the 26th of August harvest was much warmer, the average daily, maximum and minimum temperature was 23.3°C, 31.5°C and 15°C and the maximum temperature reached was at or above 30°C six times.

2.2 Measurement of environmental parameters

During the experiment the air temperature (°C), precipitation (mm) (Fig. 1-2.) and relative humidity (RH %) was recorded. Temperature and relative humidity were measured every 10 min using a SKYE DataHog micrometeorological instrument, placed at a height of two meters (Skye Instruments Ltd, Llandrindrod Wells, UK).

2.3 Determination of carotenoids, tocopherols

Five grams of well homogenized (10 marketable fruits per replications) tomato fruit were crushed in a crucible mortar in the presence of 1 g quartz sand and 0,5 g ascorbic acid. The extraction procedure started with the binding of water with methanol according to a previously described procedure [29] followed by extraction of carotenoids by 1,2-dichloroethan in a liquid-liquid partitioning. The polar and non-polar phases were separated by addition of 1 mL of distilled water and mechanical shaking for 15 min. The lower non-polar phase was separated in a separating funnel, dried through anhydrous Na_2SO_4 and evaporated at 30°C under vacuum. The residue was re-dissolved in High Performance Liquid Chromatography (HPLC) grade acetone and filtered through a 0.45 µm teflon (polytetrafluoroethylene) syringe filter before injection.

2.4 Instrument and HPLC conditions

A Waters Alliance liquid chromatographic instrument consisting of a Model 2696 Separation Module (Gradient pump, auto-sampler and column heater) and a Model 2695 photodiode-array detector was used for the analysis of carotenoids and polyphenols. Operation and data processing were performed by Empower software. For tocopherol analysis, a combination of a Beckman 114M isocratic pump, a model RF-535 Shimadzu fluorometric detector, and a Waters-740 Data Module integrator was used.

Separation of carotenoids was performed on Nucleodur ISIS, 3 µm, 15 cm x 4.6 mm, column with gradient elution of (A) water and (B) acetone, according to Daood *et al.* [30].

Peak identification was based on comparison of retention time, spectral characteristics and mass spectrum data with those of available standards (lycopene, β-carotene and zeaxanthin purchased from Sigma-Aldrich Ltd., Budapest, Hungary) or with data from literature. External standards were used for the quantification of lycopene, β-carotene and zeaxanthin. Other carotenoids were quantified as either lycopene- or β-carotene-equivalent.

To analyze tocopherol concentration, the tomato lipid fraction obtained by the same procedure used for carotenoid extraction was saponified and extracted by n-hexane according to procedure described by Abushita *et al.* [24].

The separation was performed on Nucleosil 5 mm (250 4.6 mm i.d.) with a mobile phase consisting of 99.5:0.5 n-hexane:ethanol. The fluorometric detector was set at 295 and 320 nm as the excitation and emission wavelength, respectively [31].

Tocopherols were identified by injection of standard solutions (external standard) of α, β, γ, δ homologues (from Sigma-Aldrich Ltd., Budapest, Hungary) under the same condition used for the samples.

The phenolic compounds were determined by HPLC. Tomato sample was homogenized with a warring blender and 5.0 g well homogenized samples were mixed with 25 ml 2% acetic acid in methanol. After 20 min of shaking, the flasks were left at 4°C overnight. The samples were again shaken for 5 min and then filtered through filter paper (Macherey-Nagel folded filter paper, FiFo MN 619 G ¼, 15.0 cm). The residues were washed twice with 2.5 ml solvent. The filtrates were further cleaned by passing through a 0.45 µm

HPLC syringe filter before injection into HPLC column for analysis of phenol compounds.

Chromatographic separation and compounds identification as well as quantification of phenols was performed on EC NUCLEODUR Sphinx RP, 3 µm, 150 x 4.6 analytical column using gradient elution using a procedure previously described [32].

For quantitative determination the compounds were detected at their absorption maxima (335, 324, 326, 275, 323 nm for apigenin, caffeic acid glucoside, chlorogenic acid, sinapic acid glucoside and ferulic acid respectively).

Calibration curves of the standard materials were prepared by plotting peak area and concentration of the working solutions of concentrations between 0 and 100 µg ml^{-1} for each one. The calibration curves were used for quantification of phenolic compounds identified in this work.

2.5 Statistical analysis

The results were expressed as the average plus/minus standard deviations. The data were analysed by two-factor analysis of variance (ANOVA) with repetitions and the means separated using the Student's test at p=0.05. Regression analysis was performed using Statistica 9 software (Statsoft Inc., Tulsa, OK)

3. Results and Discussion

3.1 Weather conditions

The two years were significantly different in precipitation, because 2010 was the rainiest year in the last hundred years in Hungary, which resulted in water excess, not typical during the growing season of processing tomato in Hungary [27]. There was a major drought in 2011. Average daily precipitation was almost three times higher (4.1 mm) in 2010, than in 2011 (1.4 mm) during the crop season. The rainfall would have been sufficient for tomato plants, but the distribution and intensity of precipitation were unfavourable in 2010. Temperature between the 25th of June and the 25th July, was warmer and less rainy (12.1 mm precipitation) than average. During this period the daily average temperature exceeded 25°C on five days, and the daily maximum reached 34°C on seven days. While in 2011, during the whole month of August there was only 1 mm of precipitation. The average monthly maximum temperature in June, July and August was above 25°C, and in mid-July the daily maximum reached or exceeded 34°C on eleven days.

ET_0 showed more precisely the seasonal difference between the two years, 332 mm and 426 mm respectively (Figure 1 and 2). Amount and distribution of precipitation in the first year almost covered the water demand of STC tomato plants, because of the low evaporative demand, but STI plants possibly experienced supra-optimal (slightly above optimal) water conditions in 2010 (Figure 1). STC plants suffered water shortage (198 mm), from the higher evaporative demand and lower precipitation mainly in 2011 (Figure 2).

3.2 Effect of irrigation on tomato yield

During the two-year experiment, we found that lower yields were harvested without irrigation (Table 1), which is in agreement with previous studies of conventional (non-cherry) type processing tomato [19,20]. The effect of water supply increased the marketable (red and green) yield by 61% in 2010 and 101% in 2011.

Irrigation effect on processing tomato is complex; first it increases the number of fruits per plant through the number of flowers and the percentage of fruit set, and then enlarges the size of fruits [33]. Hence, we evaluated, how the two main quantity parameters, number of fruits and average fruit weight influenced yield (Figure 3). Linear regression analysis proved that both parameters had positive effect on marketable yield, but number of fruit per hectare increases yield at a higher rate than average fruit weight. Every 0.08 M fruits ha^{-1} resulted in 1 t ha^{-1} yield, while every increase of 0.13 g average fruit

		Yield (t ha^{-1})			Number of fruits (M fruits ha^{-1})			Average fruit weight (g)		
Year	Treatments	ripened	non-ripened	non-marketable	ripened	non-ripened	non-marketable	ripened	non-ripened	non-marketable
2010	STI[d]	31.0±4.5b	15.9±3.4b	6.7±1.7a	3.0±0.5b	1.7±0.3b	0.6±0.1a	10.4±0.4b	9.4±0.8c	11.5±0.5c
2010	STC[e]	23.2±0.7a	6.0±2.6a	4.8±0.6a	2.8±0.2a	1.0±0.3a	0.5±0.2a	8.3±0.6a	5.7±0.8ab	10.6±3.0b
2011	STI	57.8±3.5c	6.9±3.4a	22.0±5.9c	5.2±0.5c	1.2±0.5a	1.8±0.6b	11.1±1.3b	5.8±0.5b	12.0±0.5c
2011	STC	24.2±2.4a	8.1±2.5a	12.3±0.9b	2.8±0.2a	1.6±0.5a	2.1±0.5b	8.5±1.0a	4.9±0.3a	5.9±1.4a

Table 1. Yield parameters of cherry tomato under different water supply in 2010 and 2011 (n=4, ±SD).

Values are reported as the mean ± standard deviation. Data in the same column bearing the same letter are not significant at P=0.05.
STI- regularly irrigated, STC- unrrigated control

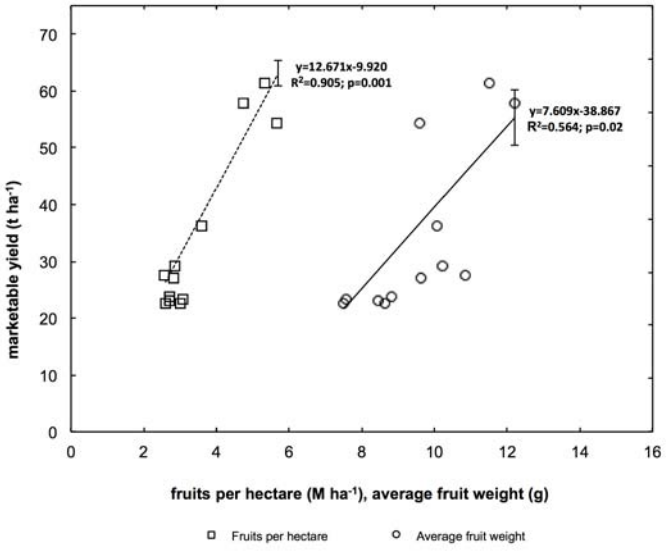

Figure 3. Correlation between yield parameters and yield of processing cherry tomato in 2010 and 2011 (n=12). Vertical bars represent the standard error of regression.

weight caused 1 t ha^{-1} more yield. Correlation coefficient of fruits ha^{-1} showed higher impact (R^2=0.91, P=0.001) on yield, than average fruit weight (R^2=0.56, P=0.02), which is the opposite of findings by Bőcs *et al.* [34] in normal type processing tomato.

The main reason for grading nonmarketable yield was because of fruit cracking, especially in 2010 where the average weight of non-marketable fruits was higher in both treatments. Cherry tomato is more susceptible to cracking because crack appearance is limited to the ripening process and its fruit growth did not cease at the mature green stage, but continued until the overripe stage [35]. Our results demonstrate that supra-optimal water supply increased fruit weight causing fruit cracking of bigger fruits, which resulted in more non-marketable yield.

The total amount of water supply in STI was almost the same, 500 and 489 mm, in 2010 and 2011, respectively, while the two years were totally different because of the extraordinary weather conditions. The proportion of rainy and cloudy days in 2010 possibly decreased the metabolic efficiency of plants, which resulted in yield loss.

3.3 Effect of irrigation on average antioxidant concentration and antioxidant composition

3.3.1 Carotenoids

Total carotenoid concentration of the tomato fruits ranged from 63.3 to 112.1 mg kg^{-1} (Figure 4). STC gave higher total carotenoid concentration at all harvest dates, and the difference between STC and STI was not significant only in the second harvest in 2011, meaning that irrigation decreased total carotenoid concentration. STC gave the highest total carotenoid concentration (112.1 mg kg^{-1}) in July 2011, because of the cooler weather conditions, which is in agreement with Tomes [36] and Dumas *et al.* [37].

In the examined tomato samples, we could identify seven components of carotenoids including the following: zeaxanthin, lycoxanthin, *all-trans*-lycopene, *cis*-lycopene, β-carotene, γ-carotene and phytoene. The identified carotenoid components gave about 95% of total carotenoid concentration. Red colour is caused by lycopene, the most abundant carotenoid in ripe tomatoes. Cherry type tomatoes contain significantly higher lycopene concentration than large fruited cultivars [38,39]. Our results demonstrate that lycopene accounts for 82-92 % of the total carotenoid concentration depending on season and treatment (Table 2). Lycopene concentration of tomato fruits ranged between 54-103 mg kg^{-1}, but this is a much lower concentration than previous results of growing seasons from 2007 to 2008 in the same experimental place using normal fruit sized processing tomatoes grown under nearly optimal conditions [20].

It is well known that lycopene synthesis is inhibited, but β-carotene is only slightly inhibited at temperatures above 30°C [40]. Our results confirmed this effect in 2011 (Table 2), see above mentioned temperature conditions before fruit harvest. Overheating of fruit surface temperature by direct intense solar radiation

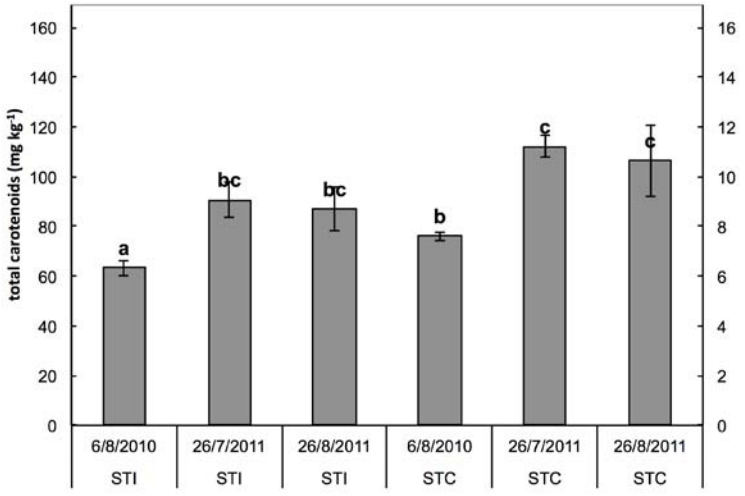

Figure 4. Concentration of total carotenoids (FW) of cherry tomato under different water supply (n=4, ±SD).

Harvest date	Treatments	Zeaxanthin	Lycoxanthin	Lycopene (*all-trans*)	Lycopene (9Z+13Z, *cis*)	β-carotene	γ-carotene	Phytoene
6.8.2010.	STI	0.47±0.07c	1.05±0.07ab	48.38±4.78a	4.55±0.74a	3.63±0.5b	0.32±0.04bc	2.02±0.21b
6.8.2010.	STC	0.57±0.01c	1.49±0.06b	62.65±2.77b	2.98±1.21a	3.27±0.17b	0.28±0.02b	1.69±0.13a
26.7.2011	STI	0.28±0.1b	0.86±0.20a	73.5±15.8bc	8.3±1.66b	2.77±0.23a	0.24±0.01a	1.61±0.19a
26.7.2011	STC	0.18±0.03a	1.55±0.23b	95.8±10.2c	7.5±1.93b	2.4±0.31a	0.21±0.03a	1.51±0.07a
26.8.2011	STI	0.24±0.01ab	0.78±0.28a	57.3±19.4ab	13.6±0.32c	3.45±0.26b	0.25±0.04ab	2.76±0.32c
26.8.2011	STC	0.41±0.07c	1.53±0.42b	72.1±24.5abc	19.57±1.85d	3.7±0.79b	0.48±0.11c	2.55±0.57c

Table 2. Carotenoid components (mg kg^{-1} FW) of cherry tomato under different water supply in 2010 and 2011 (n=4, ±SD)

Values are reported as the mean ± standard deviation. Data in the same column bearing the same letter are not significant at P=0.05. STI- regularly irrigated, STC- unirrigated control

could cause significant lycopene degradation, which resulted in lower lycopene concentration of fruits [40]. Riga *et al.* [41] found that temperature has a greater effect on tomato fruit quality than photosynthetically active radiation. Lycopene in the pulp and seed fractions were far lower than those present in the skin in traditional cultivars [42], but not in the newly developed high lycopene concentration processing tomato cultivars [43]. Previous research results showed that small-fruited tomatoes, like cherry type, had significantly higher lycopene concentration than the larger fruit sized cultivars. This could be attributed to the higher fruit surface area/volume ratio of the small-fruited cultivar when compared with the larger fruit sized cultivars [44].

Irrigation also decreased lycopene concentration, so Sánchez-Rodríguez *et al.* [45] suggest moderate water stress to improve fruit yield and lycopene concentration of cherry tomatoes. Irrigation probably indirectly affected lycopene concentration by inducing more and larger fruits (R^2=0.84, p=0.01; data not shown), and thus had a dilution effect on ingredients. The higher yield could account for the concentration loss of individual fruits by higher lycopene production per unit area [20].

Irrigation affected lycopene isomerization more than season. The *all-trans* form of lycopene of STI fruits was, higher while *cis*-isomers of lycopene were lower in all of the three harvests. The average *cis*-lycopene concentration was significantly higher in 2011 than in 2010, and it was nearly two-fold higher at the second harvest date in 2011. Because all other climatic parameters except for temperature were the same, it would seem probable that the warmer temperatures

and a better light supply activated the biosynthesis of *cis*-isomers of lycopene in 2011 (Table 2), which is in agreement with Kuti and Konuru [38]. This effect is very similar to the production of heat processed tomato products. There is evidence that processing treatments can have a large impact on both lycopene bioavailability and texture of tomato products [46].

3.3.2 Phenolics

We also analysed phenolic compounds of tomato samples. Tomato fruits are rich in phenolics, but few scientific experiments used processing cherry tomatoes. While several thousand phenolic compounds were isolated and determined during the last decade, these are usually classified into two groups, flavonoids and phenolic acids [47]. In the examined tomato samples we could identify twelve components of phenolics, in which quercetin-glucoside, rutin, catechin and naringin belong to flavonoids, while neoclorogenic acid, clorogenic acid, clorogenic acid-derivatives, caffeic acid, coumaric acid derivatives, ferulic acid, ferulic acid derivatives and gallic acid belong to phenolic acids (Table 3-4).

Table 3 shows the effect of irrigation and season on total phenolics, flavonoids and phenolic acids concentrations of cherry tomato fruits. Total phenolics concentration ranged between 578.8-845.3 mg kg^{-1} in fresh weight (FW), which is in agreement with Fu *et al.* [48], who found 735 mg kg^{-1}, which is higher than in cherry tomatoes grown hydroponically in the greenhouse. Riga *et al.* [41] found strong negative correlation between cumulative temperature during the 45 days before harvest and total phenolic concentration in beef type tomatoes under greenhouse conditions. Also lower phenolics content of fresh tomato fruit was reported at higher temperatures [49], and our results could confirm this temperature effect. Probably seasonal variation of phenolic compounds is also closely correlated with the temperature regime during the fruit development period of cherry tomato.

Total phenolics concentration with optimum water supply (STI) treatments were lower in all of the three samples, and significantly differed from STC harvests in August in both years, meaning that irrigation decreased total phenolics concentration.

We found lower flavonoid concentration in irrigated fruits in all of the three harvests, which is contradictory to the findings of Sánchez-Rodríguez *et al.* [45], who grew cherry tomato under near optimal environmental conditions in a growth chamber.

Phenolic acids results showed the same pattern as flavonoids and ranged between 65.9-154.1 mg kg^{-1}. STI gave lower values, but the differences were not significant at the second harvest in 2011. This is in agreement with Sánchez-Rodríguez *et al.* [45] who found lower phenolic acids concentration of fruits under moderate water stress.

Rutin produced the largest concentration from among the identified components of flavonoids (Table 4), similar to the findings of Gundogdu *et al.* [50]. Rutin is sometimes referred to as vitamin P, although not strictly a vitamin. In our experiment, the average rutin concentration ranged from 41.7 to 98.8 mg kg^{-1}. In all samples, the rutin concentration showed significant decrease with irrigation. Contrary to these findings, well watered tomato plants produced more rutin in fruits under controlled environment [45].

The second largest concentration found was chlorogenic acid (22.6-84.3 mg kg^{-1}). Chlorogenic acid and its derivatives are usually the main phenolics besides flavonoids in tomatoes [47]. It shows large seasonal variability [51], which is induced by temperature [52]. Our results demonstrate this, because the two highest values were measured in the first harvest in 2011, when daily maximum temperatures were also high. In all cases, significantly higher chlorogenic acid values were obtained from STC fruits (Table 4). Wilkens *et al.* [53] have reported that cherry type tomato plants grown in greenhouse under high light conditions, produced

Harvest date	Treatments	Flavonoids	Phenolic acids	Total phenolics
6.8.2010	STI	81.5±16.2b	65.9±8.2a	578.8±37.1a
6.8.2010	STC	106.9±5.3c	78.3±3.7b	680.8±17.3b
26.7.2011	STI	58.6±4.3a	109.0±15.5c	751.0±17.1c
26.7.2011	STC	69.0±6.4b	154.1±19.4d	753.5±30.6c
26.8.2011	STI	81.0±11.0b	101.1±12.7c	719.1±50.20bc
26.8.2011	STC	120.1±20.4c	112.5±20.2c	845.3±66.4d

Table 3. Concentration of polyphenols (mg kg^{-1} FW) of cherry tomato under different water supply (n=4, ±SD).

Values are reported as the mean ± standard deviation. Data in the same column bearing the same letter are not significant at P=0.05.
STI- regularly irrigated, STC- unirrigated control

Harvest date	Treat-ments	quercetin-glucoside	rutin	catechin	naringin	neochlorogenic acid	chlorogenic acid	chlorogenic acid-deriv.	caffeic acid	coumaric acid deriv.	ferulic acid	ferulic acid deriv.	gallic acid
6.8.2010.	STI	13.6±2.18a	46.6±10.01ab	6.0±2.09c	15.3±1.57c	11.9±1.35a	26.6±3.17a	-	19.7±2.55d	-	3.1±0.26a	-	4.7±0.68cd
6.8.2010.	STC	12.8±0.49a	68.1±2.48c	10.4±1.38d	15.5±0.84c	20.5±0.84c	30.2±0.95b	-	19.4±1.11d	-	3.6±0.28a	-	4.5±0.40c
26.7.2011	STI	13.2±0.95a	41.7±1.89a	3.3±0.38b	0.3±0.03a	13.3±1.81ab	45.8±6.99c	8.6±0.92a	6.3±0.57a	13.7±2.23a	5.8±0.55b	12.5±1.74c	3.0±0.40b
26.7.2011	STC	13.4±1.85a	52.2±4.89b	3.0±0.40b	0.4±0.05b	12.0±1.39a	84.3±12.35d	7.0±1.05a	8.0±0.75b	23.7±1.49b	7.1±0.50c	10.7±1.32c	1.2±0.13a
26.8.2011	STI	13.2±1.16a	65.5±9.20bc	2.0±0.33a	0.4±0.06b	15.0±1.36b	22.6±2.93a	21.0±2.80b	11.4±1.77c	-	9.5±1.84d	6.2±0.91b	6.5±0.72d
26.8.2011	STC	18.1±3.40b	98.8±16.15d	2.7±0.43ab	0.4±0.05b	28.9±4.24d	31.5±3.02b	25.6±3.12b	13.1±2.98c	-	12.6±4.55d	3.2±0.69a	6.5±1.24d

Table 4. Concentration of main polyphenols (mg kg^{-1} FW) of cherry tomato under different water supply (n=4, ±SD).

Values are reported as the mean ± standard deviation. Data in the same column bearing the same letter are not significant at P=0.05.
STI- regularly irrigated, STC- unirrigated control

two-fold greater soluble phenols concentration (rutin and chlorogenic acid) than plants growing under low-light conditions.

3.3.3 Tocopherols

Vitamin E is a term used to define a family of related compounds (tocopherols and tocotrienols). The average summa tocopherols concentration of the treatments ranged from 8.9 to 14.7 mg kg^{-1} (Figure 5), which is double to ten times higher than the values reported by Abushita *et al.* [24]. Its seasonal variation was not as great as in carotenoids. In all cases the non-irrigated treatments (STC) gave the highest values, but only in the second harvest was the difference significant (65 %) in 2011 (Figure 6).

Four components of tocopherols were identified in the examined tomato samples including: α-tocopherol, γ-tocopherol, β-tocopherol and γ-tocotrienol in descending percentage respectively. α-tocopherol represented 48-70% of total tocopherols, and the proportion of γ-tocopherol was between 22-38% depending on treatment, while the remaining two were lower than 10% (Figure 4). STC plants gave higher average α-tocopherol concentration: 7.14, 7.69, and

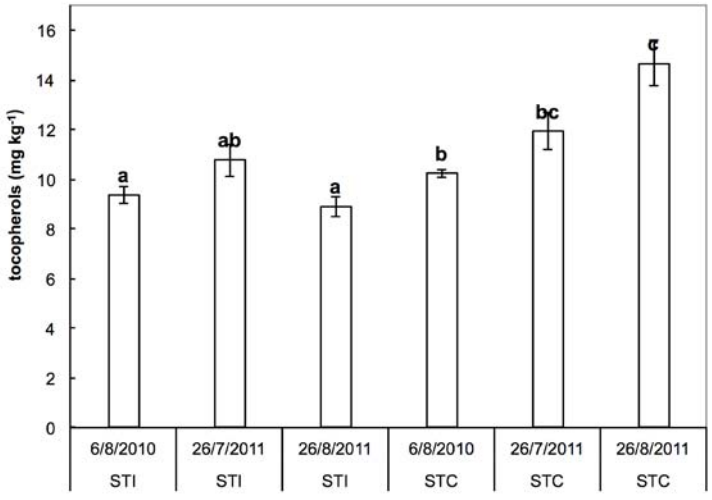

Figure 5. Concentration of tocopherols (FW) of cherry tomato under different water supply (n=4, ±SD).

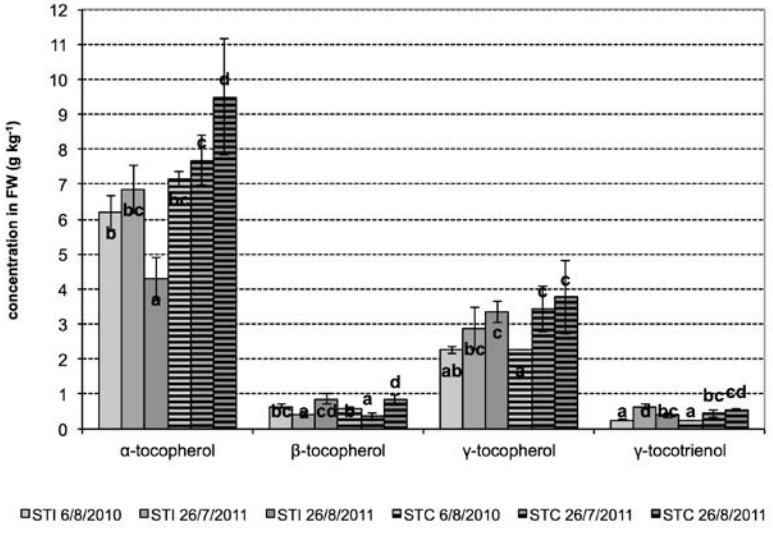

Figure 6. Concentration of tocopherol components (FW) of cherry tomato under different water supply (n=4, ±SD).

9.49 μg g^{-1} in FW respectively (Figure 6), which is in agreement with Hwang *et al.* [54]. Irrigation (STI) induced only minor effect at the second harvest in 2011; it decreased α-tocopherol and increased γ-tocopherol ratio of tocopherol concentration.

4. Conclusions

We can summarize that irrigation could increase processing tomato yield measurably. Cherry tomato fruit number showed greater effect on yield, than average fruit weight. Temperature had a great effect on lycopene, and caused significant lycopene degradation resulting in lower lycopene concentration of fruits. Irrigation also decreased lycopene concentration of individual fruits by inducing more and larger fruits, and by its dilution effects. The higher yield could account for the concentration loss of individual fruits by higher lycopene production per unit area. Higher temperature promoted *cis*-lycopene formation compared to *all-trans* lycopene, and it produced its effect during the ripening or processing procedures also. The two main phenolic compounds of cherry tomatoes are rutin from flavonoids and chlorogenic acid from phenolic acids. α-tocopherol is the most abundant tocopherol in cherry tomato fruits. Irrigation usually decreased its concentration possibly through the dilution effect of enlarged fruits.

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