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Research Article

Effect of irrigation on processing tomato yield and antioxidant components

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Abstract: A 2-year (2007 and 2008) open-field experiment was conducted to study the effects of irrigation on the yield parameters and main antioxidant components (lycopene, phenolic compounds, and ascorbic acid) of processing tomato. Two different treatments were applied: some plants were regularly irrigated, and some had their irrigation cut off 30 days before harvest. Both groups were compared with a rainfed control. Daily irrigation volume was calculated from the average daily temperature to reach optimum water supply. Fruits were harvested at the red-ripe maturity stage. The irrigated plants gave a significantly higher yield, and rainfed plants showed a yield loss. Irrigation had a greater effect on the average fruit weight than on fruit number. A seasonal effect was also remarkable, but was not as strong as that of irrigation. A better water supply caused a lower Brix number than that of the rainfed control. In both years, the antioxidant concentrations in tomato fruit showed a decrease with irrigation, except for the ascorbic acid content.

Key words: Antioxidant content, Brix, irrigation, tomato, yield

Introduction

Nowadays, tomato is cultivated all over the world and is one of the most widely consumed produce items. Tomatoes are a significant food crop with more than 141.4 × 10^6 t harvested in the world in 2009 (FAO 2011), and they are characterized by high consumption, year-round availability, and significant health benefits. Health qualities of the processing tomato fruit are determined by the interactions between varieties; environmental factors such as light, temperature, and water supply; and the composition of the nutrient solution and crop management (Dorais 2007).

Water supply is important for yield quantity and quality. Processing tomato cultivation is profitable above a yield of 65–70 t ha^{-1} in Hungary, but it is important to mention that profitability depends on technological elements, mainly propagation and irrigation methods (Al-Omran et al. 2010). Irrigation is essential to maintain higher yields and it is possible to increase the amount to 90–110 t ha^{-1} (Helyes and Varga 1994; Helyes et al. 1999). Water supply is limited worldwide and there is an increasing necessity to reduce the quantity of water used in irrigation practices (Zegbe-Domínguez et al. 2003; Favati et al. 2009).

Currently, there is not much literature regarding the influence of irrigation practices on the nutritional quality of tomato (lycopene, phenolic compounds, etc.). Lycopene is the main pigment of tomato

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and a well-known, colorful, and nutritionally beneficial carotenoid substance in tomato berries. Lycopene is an acyclic, biologically active carotenoid contained in different foods, and its preventive role in several cancerous diseases has been proven by epidemiological and experimental data. Its beneficial role in the maintenance of human health is related to its significant antioxidant properties (Lugasi et al. 2004). Processing can increase the bioavailability of bioactive compounds like lycopene, since the bioavailability is higher after the intake of processed tomato paste or juice than of a raw tomato (Unlu et al. 2007). Gartner et al. (1997) recorded that lycopene ingested from tomato puree had an effect 2.5 times stronger than the ingestion of the same amount of fresh tomatoes. The most important isomers of lycopene are cis- and trans-lycopene. The trans configuration makes up 95.4% of the lycopene in fresh tomatoes. During processing, a remarkable amount of trans-lycopene transforms into cis-lycopene (Barrett and Anton 2001). The lycopene content of tomato fruits is influenced by the variety and also by the cultivation methods and environmental conditions. Chlorophyll breaks down and carotenoids, mostly lycopene, accumulate during the ripening process (Brandt et al. 2006; Helyes et al. 2006). According to Helyes et al. (2003, 2007) the lycopene content of tomato fruits cultivated in Hungary ranged from 39 to 171 mg kg^{-1}.

Tomato fruits are also rich in polyphenols, which amount to the largest part of the antioxidant capacity of the soluble phase. Thermal stress induces the accumulation of phenolic compounds like flavonoids and phenylpropanoids. At 35 °C, the polyphenol level is double that produced at 25 °C (George et al. 2004). According to Helyes et al. (2006), the polyphenol content of tomato fruits did not change significantly during the ripening process.

Higher temperatures seem to be favorable for ascorbic acid synthesis. In addition, solar exposure is probably required for further ascorbic acid accumulation, but this was ambiguous during a longer ripening process (Wold et al. 2004). Dumas et al. (2003) observed that ascorbic acid increased by as much as 66% when plants with mature green fruits were moved from the shade into the sunshine.

The aim of this study was to establish the effects of irrigation on the yield parameters and main antioxidant components (lycopene, phenolic compounds, and ascorbic acid) of processing tomato.

Materials and methods

This experiment was conducted at the Experimental Farm of the Department of Horticultural Technology at Szent István University (47°35′N, 19°21′E), Gödöllő, Hungary. The site was flat, at an elevation of 204 m above sea level. Various physical properties of the soil at the experimental site are presented in Table 1.

The experimental field is composed of brown forest soil, with a mechanical composition of sand and sandy clay, and the subsoil water is below 5 m; it therefore cannot influence water turnover. Tomato is usually planted after the last spring frost around the first 10 days of May in Hungary, and so the seeds were sown in a greenhouse on 2 April 2007 and 7 April 2008 and then transplanted on 14 May 2007 and 12 May 2008. The experiment used a randomized block design, and the number of replications were 8 (2007) and 4 (2008) for each of the treatments. The Brigade F_1 variety (Seminis, Hungary) was used. Seedlings were arranged in double (twin) rows with a distance of 1.2 and 0.4 m between the rows and 0.3 m between the plants, with a plant density of 4.2 plants m^{-2}. For

Table 1. Textural status, field capacity, wilting point, and bulk density at different layers of the soil profile.

Soil layers (cm)	Sand (%)	Silt (%)	Clay (%)	Field capacity (v%)	Wilting point (v%)	Bulk density (g cm^{-3})
0–32	82.3	8.4	9.3	16.8	7.3	1.57
32–75	78.1	8.6	13.2	17.5	7.7	1.64
75–138	77.7	6.8	15.5	18.4	8.2	1.73
138–150	86.1	5.0	8.9	12.9	5.8	1.54

the experiment, all of the plots were irrigated at a total amount of 40 mm before planting for good soil water status.

There were 2 different irrigation treatments. Some plants were regularly irrigated and some had their irrigation cut off 30 days before harvest, and there was a rainfed control. According to Helyes and Varga (1994), the daily potential evapotranspiration of a tomato crop can be well estimated by dividing the expected daily average temperature by 5 and expressing this in millimeters. The method for calculating the amount of irrigation is based on weather forecasting data. The temperature forecast from the Hungarian Meteorological Service (2007, 2008) for every next 2-, 2- and 3-day interval per week was used to calculate the daily potential evapotranspiration. The amount of irrigation was calculated by considering the daily potential evapotranspiration for the forecasting period corrected by amount of precipitation. If precipitation covered the irrigation demand until the next irrigation date, we did not irrigate, but if it was less than the irrigation demand, we supplied the amount of daily potential evapotranspiration. Regularly irrigated plants were irrigated with the calculated amount of water every Monday, Wednesday, and Friday morning from 4 June until 17 August in 2007 and from 26 May until 5 August in 2008. Irrigation cut-off treatment was the same for those that were regularly irrigated until 25 July 2007 and 10 July 2008; after these dates, these plants did not receive water by irrigation. In 2007, 375, 293, and 188 mm of water was usable for the plants in the 2 different irrigation treatments and the rainfed control during the season, respectively, and in 2008 there was 464, 392, and 320 mm of water for the plants in the same experimental configuration (Figures 1 and 2). Irrigation water was given out by drip irrigation equipment, using one lateral for every twin row. The spacing between the emitters was 0.3 m, and the discharge rate of the emitters was 4 L h^{-1}.

A basic nutrition supply was given to the plants when they were transplanted by using Agroblen 18-8-16 fertilizer, consisting of 29.9 g m^{-2} N, 13.3 g m^{-2} P_2O_5, and 26.6 g m^{-2} K_2O. A month after the field planting, a further 7.5 g m^{-2} N (as ammonium nitrate) was applied as top dressing.

The red fruits were measured at harvesting on 23 August 2007 and 13 August 2008.

Lycopene from homogenized tomatoes was extracted with an n-hexane–methanol–acetone (2:1:1) mixture containing 0.05% BHT. Water-free Na_2SO_4 was used to remove water traces from the

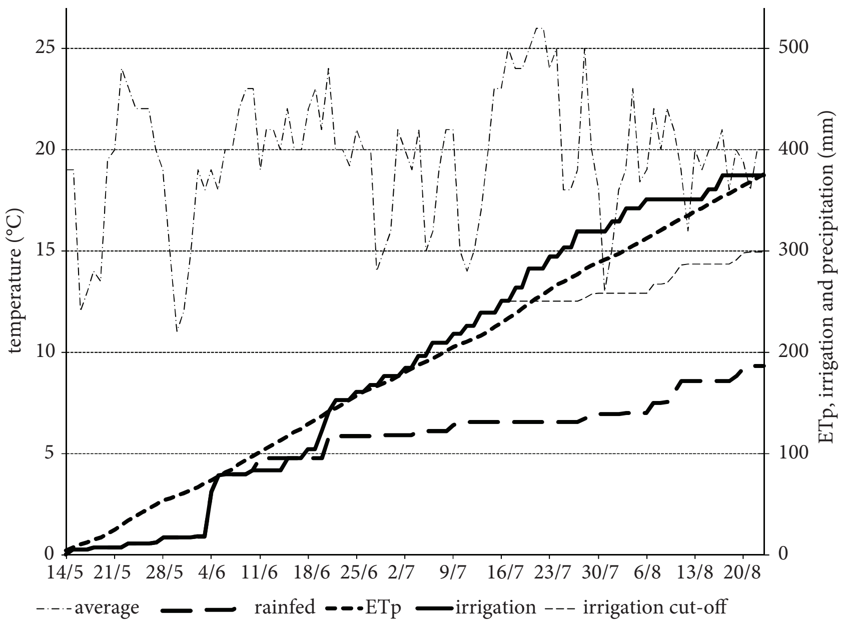

Figure 1. Average daily temperature, total evapotranspiration (ETp), irrigation, cut-off, and precipitation during the growing season in 2007.

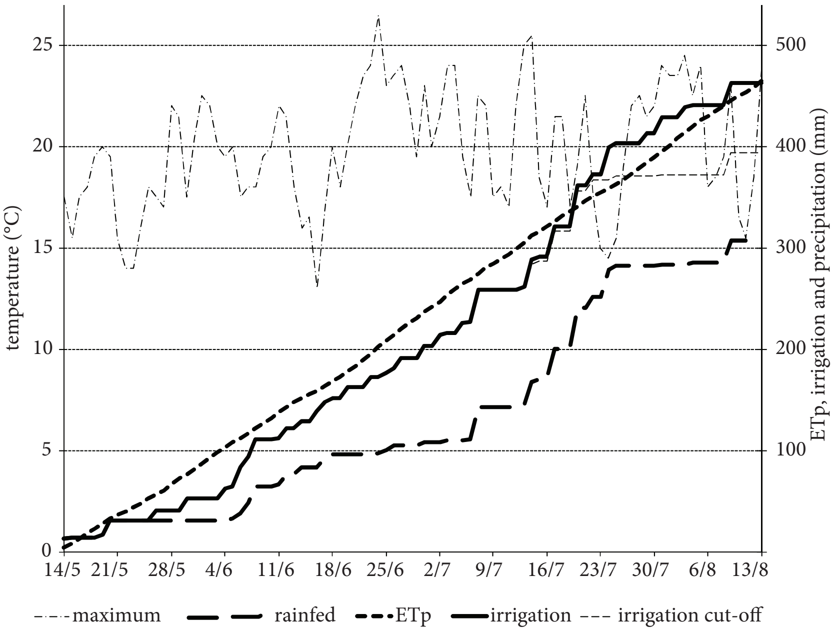

Figure 2. Average daily temperature, total evapotranspiration (ETp), irrigation, cut-off, and precipitation during the growing season in 2008.

upper part. The optical density of the hexane extract was measured spectrophotometrically at 500 nm against hexane blank (Sadler et al. 1990) with a UV-VIS Spectrophotometer Lambda 3B (PerkinElmer). The concentration of lycopene was calculated using a specific extinction coefficient (E_{1cm}1% 3150) (Merck 1989). The analyses of the total phenolics were completed spectrophotometrically according to the Folin-Denis method at 760 nm (AOAC 1990). The ascorbic acid content was measured via high performance liquid chromatography (HPLC) (Dong and Pace 1996), and the Brix degree was measured using a refractometer (AST 1230, Tokyo, Japan). Temperature was measured 6 times per hour using a Skye DataHog micrometeorological instrument, placed 2 m above the ground (Skye Instruments Ltd., Llandrindod Wells, UK) (Figures 1 and 2).

The data were analyzed by 2-factor analysis of variance (ANOVA) with repetitions and the means were separated using Student's t-test at P = 0.05. The statistical analysis was performed using Statistica 9 software (StatSoft Inc., Tulsa, OK, USA).

Results

The 2 growing seasons were totally different in weather conditions. The average temperatures of the growing periods in 2007 and 2008 were 14.9 and 19.8 °C, respectively. The total precipitation during the tomato growing period was 188 mm in 2007, which is average, and 320 mm in 2008, which is almost twice the average. The weather was remarkably cooler than average during the 2007 growing period and average in 2008. The amount of precipitation during the growing season was adequate for a medium yield in 2008, but its distribution was uneven. The percentage of the total water supply in the form of precipitation during the treatment period was 69% in 2008. The longest duration of no precipitation was 17 days in 2007, whereas it was only 14 days in 2008 (Figures 1 and 2). This characteristic of the uneven distribution of rainfall deeply affected the rainfed plants, especially when rainfall occurred in a concentrated manner from the beginning of July in 2008, which caused continuous flowering, fruit setting, and fruit development in the ripening period, resulting in many unmarketable small green fruits.

Effect of irrigation on tomato yield quantity and Brix degree

The effect of irrigation on yield quantity and quality significantly depended on the weather and especially on temperature and precipitation conditions during the growing season. The effect of irrigation increased the marketable yield by 11% and 62% in 2007 and by 133% and 124% in 2008 in the cases of cut-off and regularly irrigated plants, respectively. The irrigation treatments significantly affected the average fruit weight and number of set fruits per hectare (Table 2). Marketable fruits per hectare decreased by 10% in the cut-off group and increased by 16% in the regularly irrigated group in 2007, and also increased by 60% and 54% in 2008, respectively. In the case of average fruit weight, the effect of irrigation was more obvious: fruit weight was increased by 23% and 40% in 2007 and by 46% and 46% in 2008 in the cut-off and regularly irrigated plants, respectively.

Seasonal effect was also detectable since tomato yield is greatly affected by weather (Helyes and Varga 1994; Helyes et al. 1999). Rainfed plants produced lower yield by 16% in 2008, but cut-off and irrigated plant yields were 77% and 16% higher than in 2007.

A decrease in the soluble solid content of fruits was negligible in irrigated treatments in both years. The soluble solid content of fruits was often very high without irrigation, while other quality parameters of fruits decreased (Dumas et al. 2003).

Effect of irrigation on antioxidant components of tomato fruit

We evaluated lycopene, total polyphenols, and ascorbic acid content in relation to water supplementation in 2007 and 2008. The average lycopene concentration of the treatments ranged from 115 to 193 mg kg^{-1}. This is nearly a 70% difference. We found significant differences among the average lycopene content of the treatments. Rainfed plants gave the highest average lycopene content of all (144 and 193 mg kg^{-1} in 2007 and 2008, respectively). It is important to note that the average lycopene content was significantly higher (38%) in 2008 than in 2007. During the week preceding the harvest of 23 August 2007, the season's average daily temperature was 22.6 °C, the average maximum temperature was 29 °C, the average minimum temperature was 16.3 °C, and the maximum temperature was ≥30 °C on 4 days. However, the week preceding the harvest of 13 August 2008, the weather was cooler. During this week, the average daily temperature was only 18.5 °C, the average minimum temperature was 12.3 °C, and the maximum values were never higher than 30 °C. These lower temperatures activated the biosynthesis of lycopene during the ripening period of 2008 (Table 3).

The total polyphenol content of the regularly irrigated treatment was significantly lower in the examined years at 26% and 23%, respectively (Table 3). In our experiments, in contrast to the total polyphenol content, we measured a higher ascorbic acid content in the regularly irrigated treatments in both years, but we only found a significant difference in 2008. Irrigation or good water supply had a negative effect on the main antioxidant components.

Effect of yield parameters on fruit components

In this study, we investigated the influence of yield parameters on the Brix degree as well as antioxidant concentrations (lycopene, total polyphenol, and ascorbic acid content) of different water-supply treatments over 2 years (Table 4). We observed a positive correlation between all yield parameters (yield, number of fruits per hectare, average fruit

Table 2. Quantitative yield parameters of tomato production (cv. Brigade F_1; n = 24 in 2007 and n = 12 in 2008).

Treatments	Marketable yield (t ha^{-1})	Number of marketable fruits (10^6 ha^{-1})	Average fruit weight (g $fruit^{-1}$)
Rainfed 2007	52.0 ± 6.4^{ab}	1.27 ± 0.25^{a}	41.5 ± 5.6^{ab}
Cut-off 2007	57.5 ± 11.6^{b}	1.13 ± 0.21^{a}	51.0 ± 1.5^{b}
Regularly irrigated 2007	84.4 ± 10.3^{c}	1.47 ± 0.32^{a}	58.2 ± 5.6^{c}
Rainfed 2008	43.8 ± 10.6^{a}	1.19 ± 0.22^{a}	36.8 ± 5.6^{a}
Cut-off 2008	101.9 ± 1.9^{d}	1.90 ± 1.07^{ab}	50.9 ± 2.9^{b}
Regularly irrigated 2008	98.0 ± 9.7^{cd}	1.83 ± 0.22^{b}	53.6 ± 2.7^{b}

Data in the same column bearing the same superscript letter are not significant at P = 0.05.

Table 3. Average antioxidant concentrations and yield of marketable tomato fruits depending on irrigation regime in 2007 and 2008.

Treatments	**Ascorbic acid mg kg^{-1} FW**	**Lycopene mg kg^{-1} FW**	**Phenolic compounds mg kg^{-1} FW**
Rainfed 2007	252 ± 14.8^{a}	144 ± 16.7^{bc}	420 ± 28.1^{b}
Cut-off 2007	256 ± 11.1^{a}	115 ± 8.6^{a}	411 ± 39.8^{b}
Regularly irrigated 2007	273 ± 21.2^{a}	119 ± 17.2^{ab}	310 ± 21.9^{a}
Rainfed 2008	206 ± 23.0^{b}	193 ± 31.2^{c}	562 ± 25.2^{c}
Regularly irrigated 2008	262 ± 34.7^{a}	170 ± 33.6^{c}	435 ± 36.4^{b}

Data in the same column bearing the same superscript letter are not significant at P = 0.05.

weight) and ascorbic acid content in both years. In general, yield parameters showed negative correlations with other fruit components (Brix degree, lycopene, and phenolic compounds). Soluble solids were influenced negatively by all yield parameters in 2007 and positively in 2008.

Discussion

Irrigation has a complex effect in increasing yield. One of the main effects was the increased number of marketable fruits per hectare. Stronger and healthier plants can produce higher rates of flowering, fruit set, and ripened fruits. This effect is clearly realized but was not significant in either year, despite the uneven distribution of precipitation in 2008. The second main effect is the increased weight of fruits. The seasonal effect was also remarkable, but it was not as strong as that of irrigation. According to Helyes and Varga (1994), 2007 was a D-type year, which results in low yields without irrigation, such that a high yield can only be reached with regular irrigation. However, 2008 was a C-type year, which results in a moderate yield without irrigation; the effect of a single 40-mm irrigation at the time of flowering results in a high yield and regular irrigation produces extra-high yield.

Usually, irrigation has a greater effect on the average fruit weight than on fruit number because of the limited number of flowers in the determinate growth habit of processing tomatoes. Therefore, the yield enhancer effect comes in the form of bigger fruits (Helyes et al. 1999).

Higher temperatures mean more sunshine hours in the open field, which in turn accelerates plant production, resulting in a higher soluble solids content. The temperature effect was greater in the case of optimal water status.

Table 4. Correlation coefficients (r) according to Pearson's test between the yield (Y), number (N), average fruit weight (W) and the soluble solids and antioxidants (ascorbic acid, lycopene, and phenolic compounds).

	Soluble solids	**Ascorbic acid**	**Lycopene**	Phenolic compounds
2007	°Bx	mg kg^{-1} FW	mg kg^{-1} FW	mg kg^{-1} FW
Y (t ha^{-1})	–0.650*	0.491	–0.482	–0.395
N (10^{6} ha^{-1})	–0.304	0.031	–0.020	–0.038
W (g)	–0.693*	0.717*	–0.685*	–0.589
2008				
Y (t ha^{-1})	0.280	0.477	–0.605	–0.850**
N (10^{6} ha^{-1})	0.442	0.502	–0.730*	–0.794*
W (g)	0.031	0.428	–0.421	–0.781*

*, ** Correlation is significant at P = 0.05 and 0.01, respectively (2-tailed).

Lycopene content is determined by genetic factors (George et al. 2004) and its distribution in tomato fruits is not homogeneous in traditional processing varieties (Toor and Savage 2005). These types of tomatoes contain higher lycopene concentrations in the fruit peel than in the fruit flesh, while high-lycopene tomatoes contain lycopene almost homogeneously in the whole fruit (Ilahy et al. 2011). Environmental factors, such as a high fruit surface temperature caused by a high air temperature or direct sunlight, decrease the lycopene content in the fruit peel and also significantly decrease the lycopene content of the whole fruit (Helyes et al. 2007). Therefore, indirect factors (e.g., the shadow of a large canopy or cooler weather during the ripening period), which prevent this lycopene-degrading effect, will increase the lycopene content of tomato fruits (Pék et al. 2011).

Extreme temperature regimes have a positive effect on ascorbic acid content and phenolic compounds (Pék et al. 2011), which is a stress reaction of the fruits, and so suboptimal water supply will enhance these compounds in tomatoes (Dumas et al. 2003).

The following conclusions were drawn from this study. Many studies have demonstrated that the content of a tomato is fundamentally determined by the genetic background of its variety, but this does not exclude the fact that environmental factors also strongly affect it. Increasing water supply increased fruit yield but significantly reduced the Brix degree, lycopene, and total polyphenol content of fruits, while in the case of ascorbic acid, we measured significantly higher content with optimum water-supply conditions.

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