Effect of water supply and season on the productivity and carotenoid content of cherry type processing tomato

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Abstract: The weather, the growing conditions and the genetic background of the varieties determine the efficiency of processing tomato growing. During years Strombolino a cherry type tomato hybrid with determinate growth habit was investigated to show the effect of unirrigated and regularly irrigated treatments on the yield quantity and phytonutrients content under open field conditions. Too much water (precipitation + irrigation) was disadvantaged for the productivity and yield quality of cherry tomato hybrid because the amount of diseased yield increased while the soluble solids content (°Brix) and lycopene content of tomato fruit decreased. In the mildly wet year, irrigation had positive effect on the marketable yield, the β-carotene and zeaxanthin content of tomato fruit but the ratio of diseased fruit increased. In the dry years smaller weighed fruits were produced but the regular irrigation significantly increased the marketable yield, °Brix, β-carotene and cis lycopene content of fruit.

Keywords: cherry tomato; irrigation; yield; phytonutrients

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Introduction

Frequently occurance of high temperature and low precipitation due to global warming (Spinoni et al. 2015) decreases the productivity of vegetables crops grown in open field conditions and unfavourably influence unfavourably the yield quality (Bisbis et al. 2018). The damage caused by drought can be mitigated using irrigation technology, but the efficiency of irrigation was influenced by the time and dose of irrigation (Helyes et al. 2018), the water use efficiency of the varieties (Nemeskéri et al. 2015, 2018) and the weather of the years (Molnár et al. 2012).
In recent years, the focus of research has been on the bioactive substances of different vegetable species, especially tomatoes (Duc et al. 2017; Pék et al. 2012 and 2013). Tomato is one of the most water-demanding crops. Water deficiency affects the physiological processes, growth and yield of tomato. Nevertheless, the water deficit can benefit the tomato quality due to the accumulation of high level of soluble solids affecting the taste, aroma and water content of fruit (Barbagallo et al. 2013; Klunklin and Savage 2017). The amount of marketable yield, the soluble solids (°Brix) and lycopene content of fruit are important parameters for the preparation of various tomato purée in the processing industry (Berki et al. 2014). Nevertheless, the soluble solids content of tomato fruit depends on the variety, growing and weather conditions (Helyes and Varga 1994; Sass-Kiss et al. 2005; Pék et al. 2019). Under good water supply conditions, the tomato varieties produced high yield with low Brix value but the Brix yield per hectare increased (Pék et al. 2015). Lycopene content of tomato fruits depends on the variety and environmental conditions including temperature, and water supplies (Brand et al. 2006; Helyes et al. 2006; Petrović et al. 2019).

Tomato is classified as a functional food because of high levels of lycopene and carotenoids that are responsible for the red colour of the fruits (Rocha et al. 2013; Díaz et al. 2020). Its consumption helps prevent chronic diseases such as cancer and cardio-

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vascular diseases and it has favourable effects on the human health due to the phytonutrients of fresh fruits such as phenolic compounds, flavonoids, carotenoids and vitamins (Agarwal and Rao 2000). Lycopene comprisess 64-80% of the carotenoids depending the varieties in addition the amount of β-carotene, lutein and zeaxanthin is remarkable in the tomato (Lugasi et al. 2004; Chaudhary et al. 2018; Helyes 2014). Lutein and zeaxanthin is considered to retard the development of eye diseases such as age-related macular degeneration (Frede et al. 2017) and they have antioxidant properties because they take part in the scavenging of free radicals in the cells (Steiner et al. 2018). The accumulation of phytonutrients in tomato is influenced by the genotype, thefruit ripening and environmental factors. An increase in lycopene content of cherry type tomato varieties was detected using deficit irrigation but it decreased in large fruited cultivars (Dumas et al. 2003). Although there have been a number of studies conducted on the effect of irrigation on the yield of tomato the knowledge about the responses of cherry type tomato to water deficiency under field condition is scarce.

The aim of the present study was to investigate the effect of water supply on the productivity, the distribution of yield and phytonutrients of small sized processing cherry tomato.

Materials and Methods

Experimental design

During four years (from 2012 to 2015) the productivity and yield quality of early ripening Strombolino F_1 processing cherry tomato was investigated under regularly irrigated and non-irrigated conditions in open field experiments at the Experimental Farm of the Institute of Horticulture of Szent István University, Gödöllő. Tomato seedlings have been propagated in greenhouse and the four-week-old seedlings were transplanted ton the field on 8 to 11 of May depending on the weather of the years. Tomato seedlings were planted in twin rows, with 40 cm spacing inside the row and 120 cm between adjacent twin rows. The space between the plants in the rows was 30 cm with a plant density of 4.2 plants m^{-2}. The irrigation treatments were arranged in a randomized complete block design with four repetitions. Regular irrigation (RI) was used to provide the optimal water demand of plants using meteorological data to determine the dose of irrigation as described by Helyes at al. (2018). In non-irrigated plots the plants were grown only under natural precipitation conditions. The irrigation method was drip irrigation and was performed three times per week and it was finished 19 days before the harvest.

Analysis of yield quantity and quality

Ten and twenty plants were selected and harvested from each repetition between the 8th and 11th of August depending on the year. After harvest the fruit yield of selected plants was weighed and classified. The marketable group contained the healthy red coloured tomato fruits. The healthy green coloured fruits were classified into the second group and the third group comprised of the diseased fruits.

Five tomato fruit of red marketable yield from each repetition was used to determine the content of total soluble solids (°Brix) using a Krüss DR201-95 handheld refractometer (A. Krüss Optronic GmbH, Hamburg, Germany). Identification and measurement of carotenoids was performed using HPLC analysis as described by Daood et al. (2014).

Data were evaluated by two-way analysis of variance (ANOVA) using SPSS 20.0 (IBM Hungary Ltd, Budapest, Hungary) Windows software. The average values of treatments were compared by Tukey test at $p < 0.05$.

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Table 1. Total amount of precipitation and irrigated plots water during the growth of Strombolino F_1 cherry type processing tomato

Water supply mm	Years							
	2012		2013		2014		2014	
	until flowering	total	until flowering	total	until flowering	total	until flowering	total
Precipitation	118.6	219.4	144.9	166.2	129.5	380.7	116.5	175.6
Irrigation	159.9	337.0	169.8	351.7	184.5	447.7	154.8	438.1

Results

On the basis of precipitation shown in Table 1, the weather was dry in years 2013 and 2015 and it was mildly wet in 2012 and rainy in 2014. Processing tomato requires at least 400 mm rainfall for undisturbed growth (Battilani et al. 2012) that was ensured by regular irrigation in the dry 2015 year. During the growth of tomato, the distribution of precipitation was different in the years which influenced the fruits setting and fruit development. From planting to the flowering, the amount of precipitation was similar 116 and 145 mm, respectively, both in wet and dry years. Nevertheless, a significant difference in the precipitation between the years was detected during fruit development and fruit ripening; a lot of rain fell in the wet years, but it was 19 mm and 57 mm in the dry years of 2013 and 2015 respectively.

In mildly wet (2012) and moderate dry (2015) years the total yield was larger than in the very dry (2013) and rainy (2014) year. Nevertheless, the amount of marketable and green yield originating in the individual productivity of plants was determined by the water supply together with the year (Table 2). In mildly wet (2012) year, a high productivity of plants was shown by large number of fruits and fruit weight per plant. In this year the irrigation was event efficient; regular irrigation resulted in a significantly increase in the weight of red fruit and marketable yield, but the rate of diseased fruits was high. In the rainy (2014) year the plants used a large proportion of available water to develop their vegetative organs rather than for the yield production. This was proven by the low fertility which resulted in the fewer larger sized matured red and green tomato fruits. In a rainy year the irrigation had no impact on the weight of red tomato fruits, but it significantly increased the amount of diseased yield in comparison with the non-irrigated plants (Table 2.). In dry (2013 and 2015) years, the plants produced generally smaller sized red fruits than in wet years however the water supply had significant influence on the fertility of plants i.e. fruit number per plant (Table 2). The largest soluble solids content (°Brix) of tomato fruit was measured in the very dry 2013 year and it was the lowest in rainy 2014. Irrigation had a negative effect on soluble solids content (°Brix) of fruit in the moderate dry (2015) and mildly wet (2012) year. It can be said that in dry years regular irrigation significantly increased the weight of tomato fruits when compared with the non-irrigated plants however the extent of increase was related to the intensity of drought which affected the marketable yield.

Under non-irrigated conditions, independently of the years, a low marketable yield (15-21 t ha^{-1}) has been produced (Figure 1ab). In dry years, under non-irrigated conditions more uniform and healthy yield was detected than in wet years. In dry years use

Table 2. Water supply on the yield components, distribution of yield and soluble solids content (°Brix) of fruit of Strombolino F_1 processing tomato

Traits	Water supply	Wet years† 2012	2014	Wet years†† 2013	2015
Fruit nr. plant^{-1}	NI	130.09a	93.31b	123.77a	76.01c
	RI	184.83a*	99.25c	84.32c*	149.10b*
Total fruit kg plant^{-1}	NI	0.93a	0.74b	0.73b	0.35c
	RI	1.89a*	0.89c*	0.74d	1.56b*
Red fruit weight g	NI	7.48b	8.85a	6.15c	5.05d
	RI	10.28a*	9.88a	9.63a*	10.78a*
Green fruit weight g	NI	6.15a	4.18b	1.48d	2.68c
	RI	2.63c*	4.05b	2.55c*	7.73a*
Diseased fruit weight g	NI	6.90a	6.75a	7.10a	4.38b
	RI	11.83a*	8.40c*	9.73b*	9.75b*
Total yield t ha^{-1}	NI	38.73a	30.80b	26.63c	21.90d
	RI	78.93b*	37.00d*	57.33c*	97.43a*
Marketable yield t ha^{-1}	NI	15.63c	14.65c	25.55a	18.53b
	RI	57.45b*	14.38c	53.93b*	85.27a*
Green yield t ha^{-1}	NI	9.85a	1.48c	0.38d	2.23b
	RI	1.03d*	1.48c	1.68b*	5.43a*
Diseased yield t ha^{-1}	NI	13.28a	8.20b	0.73d	1.13c
	RI	20.45a*	15.78b*	1.75d*	6.68c*
°Brix	NI	6.93a	4.60c	6.60b	7.35a
	RI	5.05b*	4.40c	6.03a	4.53c*

Value in the rows following different letters indicates the significant difference at P<0.05 level using Tukey test * significant difference between non-irrigation (NI) and regular irrigation (RI) in the year. †2012 mildly wet, 2014 rainy year, ††2013 very dry 2015 moderate dry year.

of regular irrigation increased the marketable red yield and low green and diseased yields were produced (Figure 1a). In wet years the relatively low marketable yield was due to the low fruit setting however the regular irrigation significantly increased the amount of diseased and green yields in comparison with the non-irrigation (Figure 1b).

It can be established that in dry years (2013 and 2015) the amount of marketable yield was increased by irrigation while the rate of diseased yield can be maintained at low level, but too much water (precipitation + irrigation) can decrease the marketable yield and increase the diseased yield of cherry tomato.

During the fruit development and ripening stages of tomato the water supply conditions, and temperature influence the synthesis of secondary metabolites and phytonutrient compounds (Table 3). The largest content of zeaxanthin and lowest of β-carotene in fruits was measured in the dry (2013) year. The regular irrigation resulted in an increase in the β-carotene and cis lycopene contents of fruits in the dry year however in the mildly wet (2012) year an increase in the accumulation of zeaxanthin and β-carotene could be detected. The finding showed that regular irrigation depending on the weather of the

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Table 3. Water supply on the phytonutrients content of Strombolino F_1 cherry type tomato

Phytonutrients μg g^{-1}	Water supply	Years 2012	2014	2013
Total carotenoids	NI	168.67a	121.16b	64.14c
	RI	159.94a	126.56b	56.05c*
β-carotene	NI	3.63a	1.63b	3.83a
	RI	5.75a*	2.95b*	4.17a
Lycopene	NI	150.20a	101.82b	53.51c
	RI	140.70a*	109.39b	46.01c*
cis lycopene	NI	8.02a	7.35a	2.03b
	RI	7.45b	9.05a*	3.10c*
Zeaxanthin	NI	0.39b	0.63a	0.37b
	RI	0.49a*	0.27b*	0.48a*

Value in the rows following different letters indicates the significant difference at $P<0.05$ level using Tukey test * significant difference between non-irrigation (NI) and regular irrigation (RI) in the year.

years enhanced the accumulation of zeaxanthin into the fruit, except in a very dry year, when it decreased.

It can be established that abundant water was unfavourable on the nutritional quality of cherry tomatoes because the soluble solids content (°Brix) and lycopene content of fruit decrease. In mildly wet year the effect of irrigation on the β-carotene and zeaxanthin content of fruit was favourable however the best nutritional quality of cherry tomato fruit including high β-carotene and cis lycopene could be reached in the dry years.

Discussion

During the reproductive stage of development of tomato, the water supply influence the fruits number and weight of plants which determine the final yield and its morphological distribution (Pék et al. 2019). The impact of water deficiency on the yield and quality depends on the genotype, the duration and intensity of water stress occurring during the fruit development stage (Riggi et al. 2008, Ripoll et al. 2014). It was shown that long-term water deficit decreased a greater extent the fresh mass and fruit diameter of cherry tomatoes than in large fruited ones but the reduction of fruit growth of cherry tomato could be compensated by improving fruit nutritional value (Petrović et al. 2019, Duc et al 2017). Others (Coyago-Cruz et al. 2019) also found that water stress reduced the fruit weight and number per cluster of cherry tomato (Coyago-Cruz et al. 2019). According to our results both water supply and years influence the yield components, yield fraction and accumulation of phytonutrients of Strombolino F_1 processing cherry tomato.

In mildly wet and moderate dry years the regular irrigation more efficiently improved the fruit setting (fruit number per plant) and the weight of fruits than in marginal wet and arid years (Table 2). Therefore, the total yield increased (78.83 and 97.38 t ha^{-1} respectively) in these years however the distribution of yield was different. Others (Bőcs et al. 2011) also found a strong positive effect of water supply on the marketable yield and average fruit weight of tomato with large fruit size was detected. The result concern-

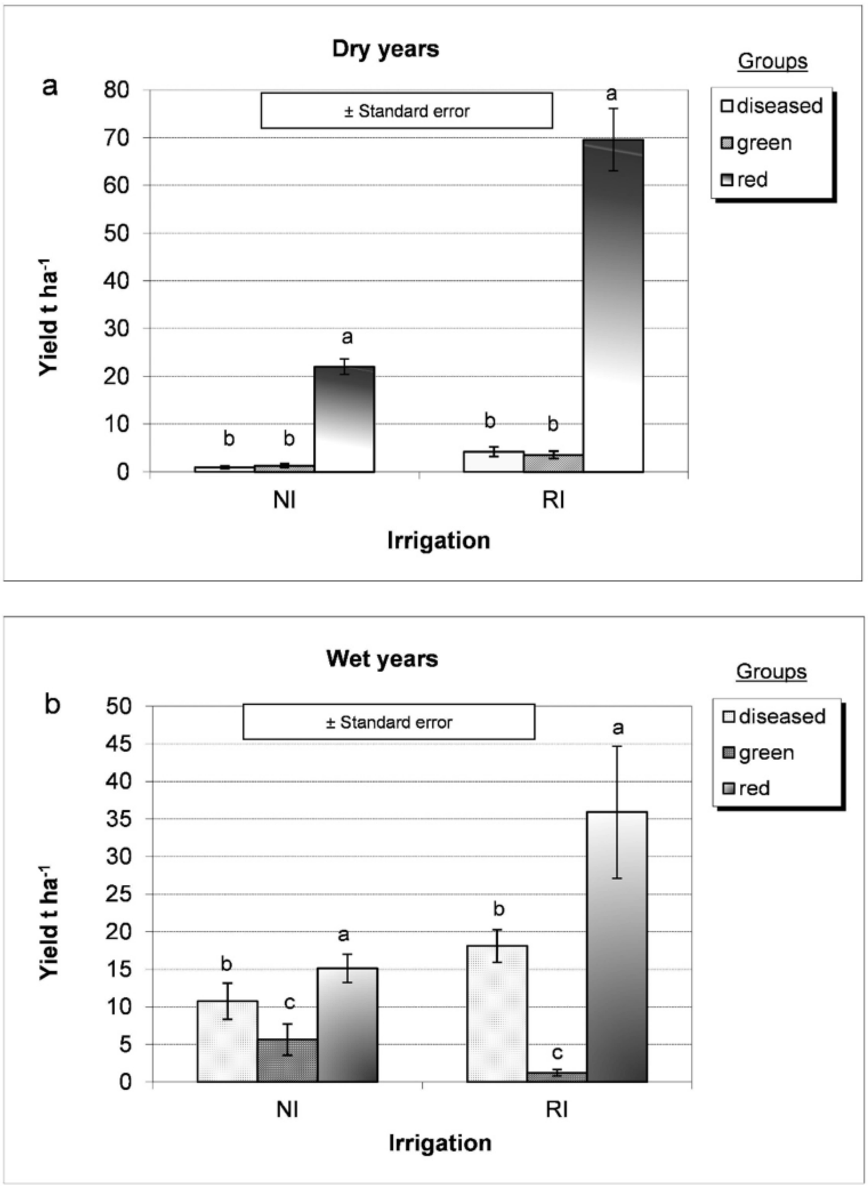

Figure 1. Effect of water supply on the yield quantity of Strombolino F_1 cherry tomato in dry (a) and wet (b) years. Means following different letters are significant difference at P<0.05 level using Tukey test NI=non-irrigated RI= regularly irrigated conditions

ing the cherry type tomato was similar to that of Bőcs et al (2011) but the effect of irrigation was modified by the weather of years. In rainy year the plants increased the green biomass rather than to the fruit development while the amount of diseased yield was increased. In dry years the irrigated plants produced healthier marketable yield than in rainy years.

Prior to harvest the irrigation and precipitation strongly influence the tomato yield quality (Helyes et al. 2012). During this period the soluble solids contents including sugars, amino acids, organic acids are accumulating into the tomato fruits to provide the flavour aroma and water content of fresh fruits. The soluble solids content (°Brix) of tomato fruit is determined by the genetic attributes of the

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varieties. A higher Brix value was found in cherry type tomato varieties than in traditional weighed fruit ones (Lapushner et al. 1990) however the weight of fruits can be changed by water supply conditions. Helyes et al. (2018) published that in a moderate dry year using regular irrigation the Brix value of Uno Rosso F_1 processing tomato with larger size fruit decreased by 52% in comparison with that of non-irrigated plants (8.0 °Brix). According to the results in the moderate dry (2015) year, under irrigated condition the decrease in the Brix value was lower (38%) for cherry type Strombolino F_1 tomato compared to the non-irrigated plants but it did not change in the very dry (2013) year (Table 2). Lycopene and β-carotene accumulate in the final ripening stage of tomato and are responsible for the deep-red colour and β-carotene for the orange colour of the fresh fruits (Brandt et al. 2006). During this period the effect of drought stress influences the lycopene content however the results concerning lycopene synthesis are rather contradictory. Riggi et al. (2008) showed that drought stress decreased the lycopene content of fruits but Sánchez-Rodriguez et al. (2012) pointed out that the moderate water stress induced an increase in the lycopene content of tomatoes. Nevertheless, lycopene content of fruits is determined by the genetic background of cultivars. Pék et al. (2014) reported that small-fruited cherry tomatoes had higher lycopene content than large-fruited cultivars. Petrović et al. (2019) also established that independently of the water supply conditions the fruit of cherry tomato had higher total carotenoids than in larger fruits mainly due to higher content of lycopene. They also reported that the effect of drought was more favourable on the accumulation of β-carotene than on lycopene of tomatoes. The results partly confirmed this statement; in very dry year, despite of irrigation lycopene content of fruits of Strombolino F_1 tomato did not change but it was the lowest in a rainy year.

Conclusions

Strombolino F_1 processing cherry tomato responded sensitively to water stress under different weather conditions. Under water abundance few and large weighed fruits per plant were produced that had low nutritional quality including low °Brix and lycopene while the diseased yield increased significantly. In a mildly wet year the good fertility of plant is further increased by irrigation therefore the marketable yield significantly increased and the fruit nutritional quality was improved with increasing F_1 and cis lycopene and less decreased °Brix value but lycopene content of fruit decreased significantly while the amount of diseased yield increased. Contrary to smaller weighed fruits that were produced in dry years, the marketable yield was increased significantly by irrigation and their nutritional quality improved due to rising °Brix, F_1 and cis lycopene content of fruit while diseased yield was minimal.

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