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Effect of irrigation and fertilisation on the biologically active components of tomato

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ABSTRACT

A three-year (2016–2018) open field experiment was conducted to study the effect of irrigation, fertilisation, and seasonal variation on the main bioactive components, such as carotenoids (lycopene and β-carotene), total polyphenols, antioxidant capacity, and tocopherols of processed Uno Rosso F1 tomato. The statistical evaluation of measurements proved that the multi-year data set cannot be evaluated as combined data set; the values obtained in different years must be evaluated separately. The impact of irrigation on the content of bioactive components varied from year to year. The correlation was negative between irrigation and α-tocopherol content in 2016 and 2018 (r = –0.567 and –0.605, respectively), polyphenol content in 2016 (r = –0.668), γ-tocopherol content in 2017 (r = –0.662), while positive correlation was observed between concentration of vitamin C (r = 0.533) in 2017, lycopene content (r = 0.473) in 2018 and irrigation intensity. A weak correlation was proved between K levels and concentrations of lycopene and polyphenols in 2016 (r = 0.301 and r = 0.392, respectively).

KEYWORDS

tomato, bioactive metabolites, irrigation, fertilisation

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1. INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most popular, widely grown, and economically important food crops produced worldwide. Tomato is the second most important solanaceous crop after potato, its cultivation is estimated at 180 millions of tons worldwide, and it is a popular vegetable in Hungary as well (FAOSTAT, 2019). The importance of tomato cultivation has grown steadily in recent decades due to its health promoting effects.

Tomato is a significant source of lycopene, which is associated with several health benefits. Lycopene has biological and chemical properties that explain its high antioxidant activity, and especially help in the deactivation of singlet oxygen and the scavenging of free radicals. Therefore, the consumption of foods with higher contents of lycopene reduces the risks of several inflammations, cardiovascular diseases, and cancer (Rao et al., 2018).

In addition, tomato contains considerable amounts of other essential components that have vitamin activity, such as ascorbic acid, β-carotene, tocopherols, and phenolics. These components with different sugars, organic acids, and amino acids in tomatoes improve both the organoleptic and health-promoting qualities. The phenols, vitamin C, and tocopherols play key roles in plant protection against pathogens and UV-B radiation, and these components are highly reactive antioxidants, reducing the risk of several chronic diseases (Aono et al., 2021).

Irrigation and fertilisation are key agrotechnical parameters for improving the quality and yield of vegetables (Ronga et al., 2020; Takács et al., 2020). Although the amount of bioactive metabolites in tomato is also affected by genotype (Vlaisavljević et al., 2019.) and the stages of maturity (Valšíková-Frey et al., 2017), several studies have shown that cultivation conditions also affect these components. There are several researches showing that irrigation (Pék et al., 2014) and fertilisation (Stoyanova and Kuneva, 2019) also have significant effects on the concentration of bioactive metabolites in tomatoes.

Water supply is limited worldwide, and there is a growing need to reduce the amount of water used for irrigation due to the increase in crop production and population growth. Previous studies also showed that the response of different tomato cultivars to irrigation, cultivation conditions, and water or drought stress is different, so irrigation and fertilisation must be optimised for the cultivation area, fertilisation- and genotype (Pék et al., 2014).

The aim of our research was to monitor the effect of irrigation and fertilisation on the bioactive compounds in tomatoes over several years.

2. MATERIALS AND METHODS

2.1. Plant material and treatments

The experiment was conducted in 2016 and 2017 on the sandy soil open field of the Vegetable Crop Research Department, National Agricultural Research and Innovation Centre, Kecskemét, Hungary, and in 2018 on silty loam open field of the Department in Kalocsa. Irrigation was carried out regularly at 50, 75, and 100% calculated from water capacity, the control (0%) was not irrigated. Fertiliser quantities (50, 75, and 100%) were calculated for 100 t ha^{-1} yield with special attention to K supply, and fertilisation was achieved weekly via drip irrigation system, where control (0%) was not supplied with K during the growing seasons. Tomato cultivar Uno Rosso F1 (United Genetics, Italia) was planted between 15 and 20 May and harvested between 25 and 30 August.

For each analysis, tomato fruits were harvested from five plants at fully mature stages and divided into 3 replicate batches for each analysis. Tomato fruits were homogenised using a Waring blender, and the samples were stored at –20 °C until analysis.

Concentrations of vitamin C, β-carotene, lycopene, α and γ-tocopherols, and total polyphenols, antioxidant capacities and their composition depending on seasonal variation, irrigation, and fertilisation were evaluated in 2016, 2017, and 2018.

2.2. Chemicals

Standards, as ascorbic acid, lycopene, β-carotene, tocopherol standard solutions (of α, β, γ, and δ), Folin–Ciocalteu reagent, gallic acid, DPPH (2,2-diphenyl-1-picrylhydrazyl), and Trolox (6-hydroxy-2,5,7,8-tetra-methylchroman-2-carboxylic acid) were purchased from Sigma-Aldrich Ltd. (Budapest, Hungary). HPLC and analytical grade organic solvents (methanol, 1,2-dichloroethane, acetonitrile, hexane, ethanol, and acetone) and other chemicals (quartz sand, KH_2PO_4, anhydrous Na_2SO_4, metaphosphoric acid, and Na_2CO_3) were purchased from VWR (Budapest, Hungary).

2.3. Analytical methods

Total polyphenol content was quantified using the Folin–Ciocalteu method (Singleton et al., 1999).

DPPH radical-scavenging method of Brand-Williams et al. (1995) was used to assess the antioxidant capacity.

Ascorbic acid content was measured using RP-HPLC method with UV detection by Nagy et al. (2015).

Separation and analysis of carotenoids was performed according to method of Daood et al. (2014) with RP-HPLC method.

The extraction, saponification and analysis of tocopherols were performed by NP-HPLC method according to Abushita et al. (1997).

A Waters Alliance liquid chromatographic instrument consisting of a Model 2696 Separation Module and a Model 2695 photodiode-array detector was used for HPLC analysis. Operation and data processing were performed by Empower software.

2.4. Statistical analysis

Spectrophotometric and HPLC analyses were done in triplicates for all samples. All data in the tables are presented as the average (n = 3) and plus/minus standard deviations. IBM SPSS Statistics (USA, SPSS) software was used for normality analysis (Kolmogorov–Smirnov and Shapiro–Wilk test), Pearson’s correlation analysis (Table 4), and discriminant analysis (Figures 1, 2 and 3).

3. RESULTS AND DISCUSSION

3.1. Effect of irrigation

According to Berki et al. (2014), irrigation of tomatoes increases yield but results in lower carotenoid and polyphenol levels. Pék et al. (2014) found that water supply had a positive effect

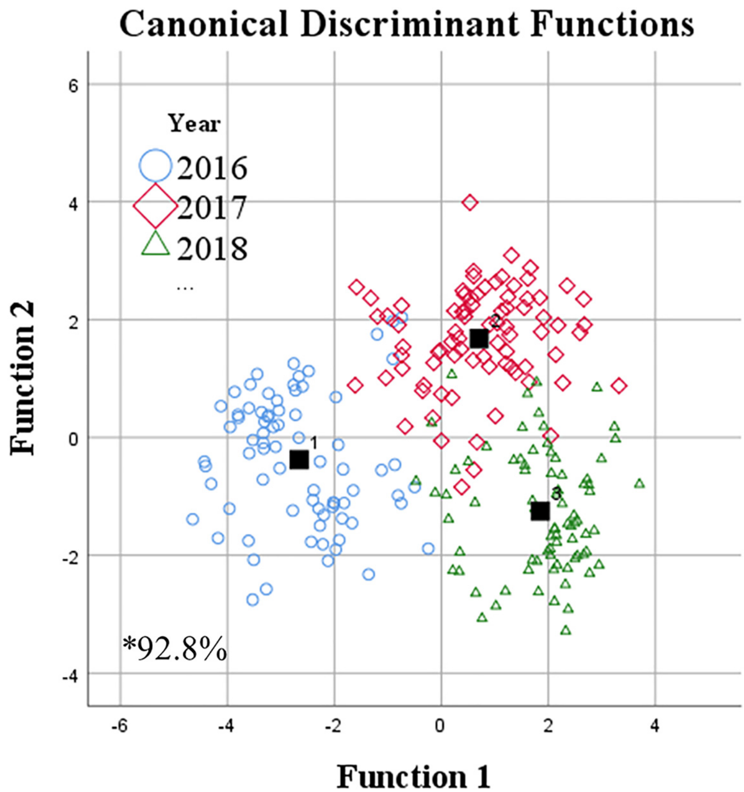

Fig. 1. Discriminant analysis of data obtained in years 2016–2018.*: Predicted group membership

on the composition of carotenoids. Optimal water treatment resulted in lower lycopene content, and a negative correlation was found between the rutin and antioxidant concentrations and irrigation for cherry tomato. The tocopherol concentration was significantly higher in irrigated plants.

The results of the statistical evaluation of obtained data were not consistent with the data in the literature. According to Pearson's correlation results of the summarised data for the 3 years studied, irrigation had no clear effect on any of the bioactive components, in contrast to the literature data (Pék et al., 2014; Ronga et al., 2020; Takács et al., 2020). Discriminant analysis (Fig. 1) showed that the results of the 3 years can be significantly distinguished from each other. 92.8% of the samples could be classified according to the examined components, revealing that the year of cultivation had significant effect on the bioactive metabolites of tomatoes. Regarding the effect of irrigation, only 50% of the samples could be correctly classified by discriminant analysis (Fig. 2).

The effect of irrigation on bioactive components was examined separately for each year (Tables 1, 2 and 3). Figure 2 shows that the canonical discriminant analysis could correctly classify the differently irrigated groups with a 70–80% probability. The results of Pearson's correlation analysis of the samples per year show that the amount of γ-tocopherol increased in

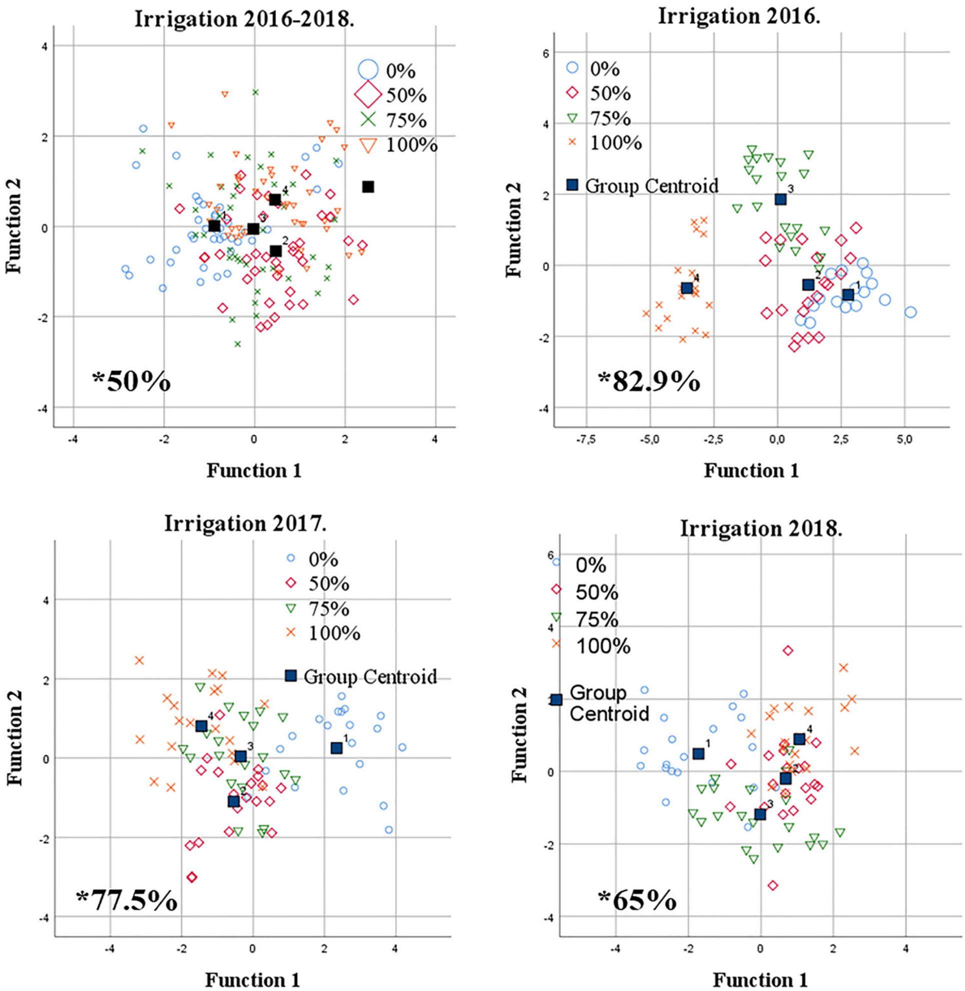

Fig. 2. Discriminant analysis of irrigation in different years (2016–2018, 2016, 2017, and 2018). *: Predicted group membership

2016 (r = 0.588), while the amounts of α-tocopherol and polyphenols decreased (r = –0.567 and –0.668, respectively) by the increasing intensity of irrigation (Table 4). The highest γ-tocopherol concentration (2.43) was measured at 75% and the lowest (0.3 $\mu g\,g^{-1}$) at 0% irrigation. The amounts of α-tocopherol ranged from 9.05 to 18.59 $\mu g\,g^{-1}$ and that of polyphenols ranged from 295.7 to 475.7 mg GAE/kg (Tables 1, 2 and 3).

In 2017, the amount of γ-tocopherol decreased with the increasing intensity of irrigation (r = –0.662), and weak positive correlation was found between the vitamin C concentration of tomatoes (r = 0.533) and irrigation intensity. The amounts of γ-tocopherol ranged from 0.35 $\mu g\,g^{-1}$ (75% irrigation) to 1.61 $\mu g\,g^{-1}$ (0% irrigation), while the amounts of vitamin C

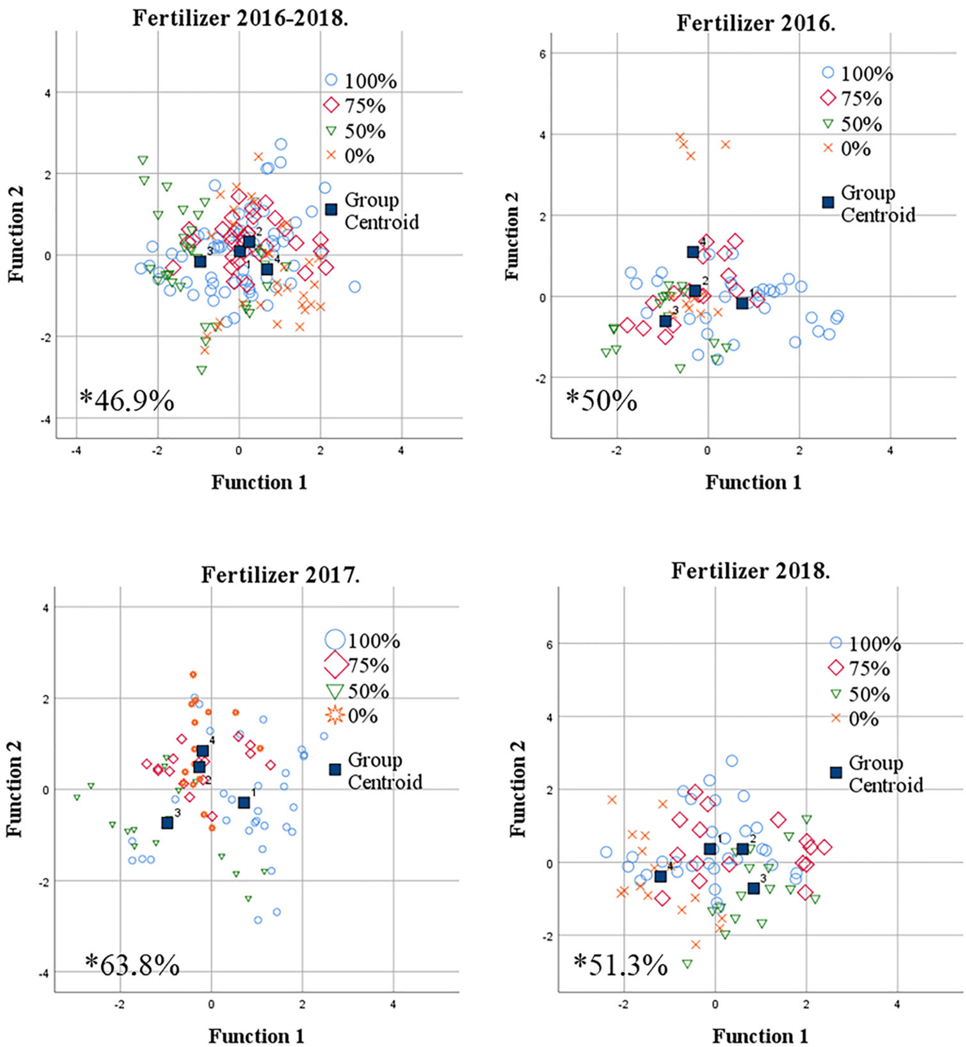

Fig. 3. Discriminant analysis of fertilisation in different years (2016–2018, 2016, 2017, and 2018). *: Predicted group membership

ranged from 90.7 to 269.6 μg g^{-1} (0% and 75% irrigation, respectively). During that year, irrigation had no significant effect on the concentrations of α-tocopherol and polyphenols. Similarly to 2016, in 2018, the statistical evaluation showed a moderate effect of water supply. The amount of α-tocopherol was reduced by irrigation (r = –0.604), while the amount of lycopene increased but correlation was not strong (r = 0.473) (Table 4). The amounts of α-tocopherol ranged from 6.00 μg g^{-1} (100% irrigation) to 13.15 μg g^{-1} (0% irrigation), while the amounts of vitamin C ranged from 35.86 μg g^{-1} (0% irrigation) to 51.85 μg g^{-1} (100% irrigation).

Table 1. Changes in concentrations of bioactive compounds of Uno Rosso F1 tomato cultivar as an effect of different irrigation and fertilisation intensities in 2016

Irrigation (%)	Fertilisation (%)	α-Tocopherol (μg g^{-1})	γ-Tocopherol (μg g^{-1})	Antioxidant capacity (mM Trolox/kg)	Polyphenol (mg GAE/kg)	Lycopene (μg g^{-1})	β-carotene (μg g^{-1})
0	100	17.48 ± 0.31	0.39 ± 0.03	1.66 ± 0.19	**475.7** ± 36.2	35.59 ± 1.3	3.67 ± 0.1
	75	17.73 ± 0.49	0.4 ± 0.02	1.16 ± 0.12	382.5 ± 18.9	32.36 ± 1.15	**3.98** ± 0.07
	50	15.73 ± 0.54	0.34 ± 0.02	**1.88** ± 0.11	414 ± 17.5	29.94 ± 0.33	3.25 ± 0.03
	0	NS	NS	NS	NS	NS	NS
50	100	14.18 ± 0.3	**0.3** ± 0.03	1.45 ± 0.16	413 ± 6.7	**44.64** ± 1.63	3.52 ± 0.05
	75	17.01 ± 0.45	0.37 ± 0.04	1.27 ± 0.08	363.5 ± 22.5	29.78 ± 0.79	2.95 ± 0.04
	50	**18.59** ± 0.65	0.43 ± 0.07	1.45 ± 0.19	391 ± 5.1	22.99 ± 0.77	3.5 ± 0.17
	0	17.76 ± 0.57	0.89 ± 0.07	1.75 ± 0.12	407.7 ± 27.8	28.06 ± 1.79	2.8 ± 0.13
75	100	18.46 ± 0.57	0.81 ± 0.05	1.44 ± 0.09	356.5 ± 23.6	30.28 ± 1.33	3.06 ± 0.13
	75	15.61 ± 0.5	**2.43** ± 0.09	1.72 ± 0.15	407 ± 26.3	27.1 ± 0.53	2.6 ± 0.04
	50	17.67 ± 0.55	1.22 ± 0.06	1.49 ± 0.24	352.2 ± 9.3	30.37 ± 1.35	2.95 ± 0.13
	0	14.28 ± 0.32	1.97 ± 0.02	**0.91** ± 0.11	337 ± 25.5	**19.1** ± 1.64	**2.28** ± 0.11
100	100	**9.05** ± 0.23	0.75 ± 0.02	1.26 ± 0.07	348.5 ± 30.2	31.2 ± 0.84	2.6 ± 0.03
	75	10.03 ± 0.46	0.9 ± 0.06	1.4 ± 0.09	**295.7** ± 24.1	26.21 ± 1.91	2.94 ± 0.18
	50	14.46 ± 0.49	1.81 ± 0.05	1.27 ± 0.12	312 ± 14.5	30.26 ± 1.31	3.03 ± 0.14
	0	13.05 ± 0.39	1.2 ± 0.07	1.16 ± 0.11	321.7 ± 12.7	31.09 ± 1.62	3.68 ± 0.22

NS: no sample; minimum and maximum values within a column are written in bold.

Table 2. Changes in concentrations of bioactive compounds of Uno Rosso F1 tomato cultivar as an effect of different irrigation and fertilisation intensities in 2017

Irrigation (%)	Fertilisation (%)	α-Tocopherol (µg g^{-1})	γ-Tocopherol (µg g^{-1})	Antioxidant capacity (mM Trolox/kg)	Polyphenol (mg GAE/kg)	Lycopene (µg g^{-1})	β-carotene (µg g^{-1})	Vitamin C (µg g^{-1})
0	100	11.79 ± 0.49	**1.61** ± 0.11	**2.02** ± 0.06	432.2 ± 18.0	51.2 ± 1	3.95 ± 0.3	157.4 ± 16.4
	75	10.1 ± 0.29	1.5 ± 0.19	1.86 ± 0.12	397.8 ± 21.9	51.83 ± 1.45	5.28 ± 0.15	128.5 ± 14.4
	50	8.92 ± 0.38	0.69 ± 0.08	1.29 ± 0.19	431.8 ± 91.4	**54.5** ± 1.83	3.33 ± 0.29	**90.7** ± 6.4
	0	11.1 ± 0.38	1.58 ± 0.06	1.25 ± 0.25	446.5 ± 78.9	50 ± 2.24	3.2 ± 0.12	113.5 ± 4.4
50	100	**5.56** ± 0.28	0.8 ± 0.03	1.59 ± 0.14	355.5 ± 38.6	47.15 ± 1.8	3.83 ± 0.11	121.6 ± 3.2
	75	10.02 ± 0.18	0.94 ± 0.05	1.61 ± 0.21	317 ± 16.4	44.88 ± 1.47	3.43 ± 0.16	185.6 ± 15
	50	8.49 ± 0.2	0.57 ± 0.04	1.08 ± 0.31	310.4 ± 56.3	52.68 ± 1.68	3.43 ± 0.19	220.2 ± 23.3
	0	12.87 ± 0.44	0.57 ± 0.04	0.95 ± 0.21	372.4 ± 49.8	42.2 ± 1.35	4.15 ± 0.23	250.2 ± 17.9
75	100	**13.57** ± 0.48	0.57 ± 0.02	**0.9** ± 0.3	317.7 ± 89.7	47.53 ± 0.68	4 ± 0.31	190.9 ± 15.9
	75	10.24 ± 0.27	**0.35** ± 0.03	1.51 ± 0.1	491.2 ± 98.3	53.18 ± 2.71	3.58 ± 0.15	219.6 ± 16.5
	50	9.55 ± 0.22	0.56 ± 0.02	1.32 ± 0.29	452.3 ± 62.5	**38.7** ± 1.3	3.7 ± 0.07	204.5 ± 10.3
	0	9.37 ± 0.37	0.81 ± 0.03	1.43 ± 0.32	**524.5** ± 51.2	53.65 ± 1.46	**6.25** ± 0.11	**269.6** ± 14.3
100	100	10.82 ± 0.3	0.37 ± 0.03	1.39 ± 0.23	514.1 ± 60.3	50.53 ± 1.63	3.68 ± 0.08	183 ± 13.4
	75	10.64 ± 0.44	0.36 ± 0.04	1.64 ± 0.16	427.9 ± 49.9	40.83 ± 0.97	3.35 ± 0.11	242.6 ± 14.6
	50	7.01 ± 0.24	0.97 ± 0.06	2 ± 0.2	**300.8** ± 54.2	54.28 ± 1.43	3.28 ± 0.11	132.4 ± 7.6
	0	9.46 ± 0.3	0.37 ± 0.05	**2.16** ± 0.3	405.0 ± 21.5	44.13 ± 1.84	**3.13** ± 0.08	189.4 ± 14.8

Minimum and maximum values within a column are written in bold.

Table 3. Changes in concentrations of bioactive compounds of Uno Rosso F1 tomato cultivar as an effect of different irrigation and fertilisation intensities in 2018

Irrigation (%)	Fertilisation (%)	α-Tocopherol (μg g^{-1})	γ-Tocopherol (μg g^{-1})	Antioxidant capacity (mM Trolox/kg)	Polyphenol (mg GAE/kg)	Lycopene (μg g^{-1})	β-carotene (μg g^{-1})	Vitamin C (μg g^{-1})
0	100	6.84 ± 0.17	**0.34** ± 0.03	0.97 ± 0.04	475 ± 35.3	42.61 ± 1.3	2.51 ± 0.06	269.6 ± 13.4
	75	**13.15** ± 0.42	1.22 ± 0.06	0.89 ± 0.17	457 ± 33.8	37.91 ± 0.2	3.1 ± 0.03	234.1 ± 5.7
	50	6.2 ± 0.28	2.4 ± 0.18	1.27 ± 0.18	459.5 ± 28.8	41.04 ± 1.43	2.55 ± 0.09	139.4 ± 10.1
	0	11.82 ± 0.34	1.72 ± 0.06	0.69 ± 0.14	477.2 ± 16.4	**35.86** ± 2.54	3.85 ± 0.27	171.8 ± 12.8
50	100	9.6 ± 0.27	**3.47** ± 0.09	0.84 ± 0.1	441 ± 18.7	43.88 ± 1.48	4 ± 0.19	220.9 ± 8.8
	75	8.76 ± 0.36	1.51 ± 0.06	1.12 ± 0.2	467 ± 58.0	48.9 ± 1.76	3.96 ± 0.21	214.1 ± 1.9
	50	8.6 ± 0.29	2.25 ± 0.1	0.95 ± 0.26	409 ± 33.2	45.8 ± 1.73	4.44 ± 0.26	216.9 ± 5.2
	0	7.15 ± 0.2	2.11 ± 0.06	1.39 ± 0.17	521 ± 28.5	37.21 ± 2.49	3.18 ± 0.24	**296.1** ± 1.9
75	100	7.6 ± 0.22	2.72 ± 0.12	1.19 ± 0.2	454.2 ± 46.2	44.36 ± 1.53	3.52 ± 0.17	156.3 ± 2.2
	75	6.32 ± 0.23	2.86 ± 0.08	1.05 ± 0.19	430.5 ± 13.1	40.81 ± 1.83	3.68 ± 0.22	240.6 ± 2.9
	50	6.38 ± 0.21	1.97 ± 0.09	0.57 ± 0.09	**382.2** ± 19.2	40.37 ± 2.78	**1.97** ± 0.16	147.8 ± 1.7
	0	7.49 ± 0.3	1.17 ± 0.04	**0.55** ± 0.13	391.2 ± 31.6	42.69 ± 1.39	3.79 ± 0.18	205.7 ± 4.8
100	100	6.92 ± 0.26	0.83 ± 0.02	**1.83** ± 0.19	**528.5** ± 15.8	42.78 ± 1.49	3.27 ± 0.14	280.6 ± 5.0
	75	**6.00** ± 0.2	2.12 ± 0.11	1.32 ± 0.17	474.5 ± 25.2	46.36 ± 0.96	3.41 ± 0.05	**113.0** ± 2.0
	50	6.4 ± 0.28	1.23 ± 0.07	0.62 ± 0.19	503.7 ± 27.7	**51.85** ± 1.26	**4.8** ± 0.19	215.2 ± 4.4
	0	8.61 ± 0.33	1.98 ± 0.04	0.76 ± 0.16	497.7 ± 39.6	40.39 ± 2.07	3.6 ± 0.18	234.9 ± 4.8

Minimum and maximum values within a column are written in bold.

Table 4. Pearson's correlation coefficients between irrigation, fertilisation and investigated components (α-tocopherol, γ-tocopherol, antioxidant capacity, polyphenol, lycopene, β-carotene, and vitamin C contents)

	2016		2017		2018	
	Irrigation	Fertilisation	Irrigation	Fertilisation	Irrigation	Fertilisation
α-Tocopherol	–0.567**	–0.099	0.020	0.077	–0.605**	–0.158
γ-Tocopherol	0.588**	–0.189	–0.662**	–0.129	0.128	–0.016
Antioxidant capacity	–0.383**	0.180	0.159	–0.021	0.084	0.317*
Polyphenol	–0.668**	0.301*	0.037	–0.054	0.052	0.037
Lycopene	–0.282*	0.392**	–0.314**	0.112	0.473**	0.061
β-Carotene	–0.257*	–0.194	–0.172	–0.103	0.352*	–0.191
Vitamin C	ND	ND	0.533**	–0.262*	0.077	–0.019

**: Correlation is significant at the 0.01 level (2-tailed); *: Correlation is significant at the 0.05 level (2-tailed); ND: No data.

Antioxidant capacity and β-carotene content were not affected by irrigation intensity in any of the investigated years. Although significant differences were found between treatments, values did not correlate with irrigation. Our results are consistent with observations of Marti et al. (2018), who examined the effect of controlled deficit irrigation on the accumulation of carotenoids, polyphenols, and L-ascorbic acid in different tomato cultivars. The authors found that irrigation had no significant effect on the accumulation of carotenoids, while it increased the levels of chlorogenic and ferulic acids, rutin, and L-ascorbic acid. Their final conclusion was that a combination of best genotype and growing area with irrigation would offer high quality products. Semel et al. (2007) found no difference in the metabolite compositions of irrigated and non-irrigated plants, and the results of Lu et al. (2021) demonstrated that the effect of irrigation is influenced by the soil and tomato cultivars together.

3.2. Effect of fertilisation

Similarly to irrigation, the effect of fertilisation could not be evaluated by examining the summarised results of the 3 years, as the discriminant analysis was only able to classify the samples into the appropriate group with a probability of 46.9% (Fig. 3).

No better results were obtained with the annual statistical analysis, results of the parcels fertilised with different K doses could be divided with a probability of 50% in 2016, 63.8% in 2017, and 51.3% in 2018 (Fig. 3).

A weak correlation between the level of fertilisation and lycopene content was found only in year 2016. The amount of lycopene (r = –0.392) decreased with increasing nutrient replenishment intensity (Table 4). This result indicates an effect opposite to that observed by Delazari et al. (2019), who found significant positive effect of fertilisation on lycopene content in Carina tomato variety. They obtained maximum content of lycopene by applying 200% of the fertiliser's dose and 50% of the irrigation depth, which is similar to our results in year 2016. The maximum lycopene content (44.64 $\mu g\ g^{-1}$) was measured at 100% K replenishment and minimum (19.1 $\mu g\ g^{-1}$) lycopene content at 50% irrigation intensity. No correlations were found between the amounts of bioactive component analysed and fertilisation in 2017 and 2018.

4. CONCLUSIONS

Similarly to literature data, our results also proved that not only the interaction of variety, fertilisation, and irrigation can influence the composition of bioactive components in tomatoes, but year as well. Several components may behave differently under the same cultivation parameters but different weather conditions. No general conclusion can be drawn from the results, as the same genotype behaves differently in succeeding years. The results show that amounts of some bioactive components, such as polyphenols, tocopherol derivatives, or lycopene, may decrease with increasing irrigation intensity. These components may be formed under abiotic stress, so optimal irrigation does not promote their formation.

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