EFFECT OF WATER SUPPLY ON YIELD AND STOMATAL CONDUCTANCE OF PROCESSING TOMATO

PhD thesis

ANDRÁS BŐCS

Gödöllő

2018

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INTRODUCTION AND OBJECTIVES

Tomato (*Lycopersicon esculentum* Mill.) is cultivated all over the World and is one of the most consumed vegetables in recent times, with a huge production area and a high yield.

Hungary's moderate climate, excellent agricultural land and water resources make it possible to grow high quality tomatoes with excellent nutritional value (Terbe et al., 2010). After a few years decline in processing tomato production, it has become an increasingly important crop again in Hungary, owing to increasing farm sizes, intensive technology, precise irrigation systems and the use of modern hybrids, resulting in 80-100 t/ha yields and thus tomato growers have become stable partners of the processing industry (FruitVeb, 2017; KSH-STADAT, 2017).

Tomato has low calorie (22 kcal/100g), and high carotenoid content (Helyes, 1999a), which has antioxidant and health-preserving effects, proved in many clinical trials (Pernice et al., 2010; Li et al., 2013; Riahi és Hdider, 2013). One of the main antioxidants in tomato is Lycopene, resulting in tomatoes being the main source of lycopene in the human diet (Clinton, 1998; Giovannucci et al., 2002; Lugasi et al., 2004). The red color of tomatoes is determined by their lycopene content, which is one of the most important internal value metrics and the basic quality requirement for the processing industry (Stevens és Rick, 1986; Helyes, 1999a).

The dry matter content is influenced by a number of factors, depending on variety, fruit ripeness and environmental parameters (temperature, radiation, fertilization and water supply, year type) (Helyes and Varga, 1994; Sass-Kiss et al., 2005).

In Hungary, drought is one of the most important barriers to production during the vegetation period. In terms of climate change, forecasts are extremely uncertain, but it is almost certain that there will be more spatial and temporal expansion of drought, and the likelihood of extreme rainfall will be greater. The future possibilities for crop production will be determined by the level of adaptation to climate change, which means more efficient water management (Láng et al., 2007; Jolánkai and Birkás, 2010; Birkás et al., 2015).

The water demand of plants can be characterized by the amount of water they use and their need of soil moisture, which should be examined in the process of their formation in order to better understand and continuously promote the balance between water consumption and water loss (Cselőtei, 1993, Zegbe-Domínguez et al 2003, Favati et al., 2009).

The critical period of water supply for processing tomatoes lasts from the middle of June until the beginning of August (Balázs, 1985). Among the climatic conditions of Hungary, irrigation is an indispensable part of modern and economic vegetable production, and is one of the most profitable drought protection investments.

The effect of irrigation can be evaluated by crop yield, crop development, maturation dynamics, and nutritional constituents. Late start irrigation and overwatering result in decreased yields (Helyes, 1999a).

It is important that irrigation planning is based on objective information, to ensure both the highest yield and to avoid the decrease of quality in the point of view of economic cultivation. However, planning is difficult due to weather variability, so it is important to use methods based on plant parameters to continuously monitor the water supply of the plants during the growing period to optimize irrigation.

My research was focused on exploring and quantifying the influence of the most important abiotic and biotic factors affecting the production of processing tomato and its constituents. From the plant characteristics of water shortage stress determination, non-destructive methods of stomatal conductance and foliage temperature were examined.

Stomatal closure is a substantial plant adaptation reaction to water loss, which involves the limitation of photosynthesis during daylight hours. The prolonged decline in the intensity of photosynthesis slows down plant growth and limits biomass production, resulting in decreased yeilds. Characterization of stomatal activity enables the optimum cultivation conditions and the characterization of stress factors. The foliage temperature also defines the plant's water supply (Cselőtei és Helyes, 1988; Helyes, 1999b).

Both stomatal conductance and leaf surface temperature can predict the irrigation need (Bőcs et al., 2010a; Helyes et al., 2010; Bőcs és Pék, 2011; Bőcs et al., 2011).

My scientific research objectives covered the following topics:

- For four consecutive years, assessing the effect of different water supplies on stomatal conductance and foliage temperature of processing tomato.
- Study the combined effect mechanisms of environmental factors, year type and water supply on the most important crop parameters of the processing tomato (yield, number of fruits per hectare, fruit average and Brix°).

MATERIALS AND METHODS

Experimental conditions

The experiments were carried out in Gödöllő, at Szent István University's Horticultural Institute (47°35′N, 19°21′E), between 2008 and 2011, on processing tomato.

Description of experimental methods

During the first three years (2008-2010) a „cut off" system was used, with an irrigated control (K) plant stock, an optimal water supply (RÖ) and a Cut off (CO) treatment, which means irrigation was stopped 30 days before the expected harvest. In the 4th year (2011), Regulated Deficit Irrigation was used with 50%-, 75%- and 100% irrigation treatments.

Daily irrigation water was calculated from the average daily air temperature, according to the National Meteorological Institute weather forecast, from which I deduced the potential evapotranspiration (ET_{pot}) of the plants in mm. This was carried out three times a week, corrected with the amount of precipitation. The formula was as follows:

$$I_d = \left(\frac{T_{min} + T_{max}}{2}\right) / 5 .$$

Table 1. lists the main technological elements of the 4-year cultivation period I have examined:

1. table The main technological elements of the growing season of each year

	2008	2009	2010	2011
Hybrids	Brigade F_1	Brigade F_1	Brixsol F_1	Uno Rosso F_1
Sowing date	7. April	25. March	29. March	1. April
Planting date	12. May	5. May	12. May	29. April
Cultivated area	Row spacing: 120+40cm Spacing within row 30cm	120+40cm +30cm	120+40cm +30cm	120+40cm +30cm
Nutrient supply	NPK 18-8-16 + 2MgO + NH_4NO_3 + KNO_3			NPK 15-15-15 + NH_4NO_3 + KNO_3 + microelement supplement
Water supply	K: 297 mm CO: 369 mm RÖ: 441 mm	K: 156 mm CO: 296 mm RÖ: 416 mm	K: 408 mm CO: 549 mm RÖ: 564 mm	K: 162 mm 50%: 330 mm 75%: 414 mm 100%: 498 mm
Harvest date	12. August	17. August	1. September	22. August

Comments: K = Kontroll, CO = Cut off, RÖ = Regularly irrigated treatment

During the growing season, nutrition supply, irrigation, and plant protection followed recommendations for commercial tomato production in the region (Helyes and Varga, 1994).

Statistical analysis

The results were expressed on average, showing the deviation values (standard deviation, ± SD). To perform the statistical tests, I used the data analysis module of Microsoft Excel 2010 Analysis Toolpak (Microsoft Corp., Redmond, USA).

After performing the variance analysis (ANOVA), statistically significant differences were detected at $P=0.05$. The correlation studies were performed by regression and correlation analysis using the MicroSoft Excel 2010 application regression analysis module. When analyzing yield parameters, significant differences from the control were determined with Duncan test. When using the Duncan test, the columns marked with different letters differ significantly from $P \leq 0.05$ probability levels.

- I calculated foliar - air temperature differences every year,
- I looked for correlation between foliage - air temperature index and cumulative stomatal conductance,
- I compared the annual marketable yield with fruits per hectare, average weight, Brix° and Brix yield.

RESULTS

Relationship between water supply and marketable yield

The 4 years' data (2008-2011) can be used to quantify the effect of precipitation + irrigation water on the harvested yield. An accumulated water volume of 330-430 mm from irrigation and natural precipitation produced the most yield, and more or less water had a damaging effect on cultivation. The strongest correlation was in the dry year of 2009 (r^2=0,89), but there was also a strong correlation in 2011 (r^2=0,83).

In the rainy year of 2008 (r^2=0,57) the linear equation showed a moderately strong significant relationship. It can be seen in 2010, that non irrigated treatments were similar to that of regularly irrigated treatments in other years. However, the uneven distribution of precipitation in 2010 contributed to low yields, which distorted the relation in the 4 years' average.

Relationship between water supply and Brix°

The water soluble dry matter (Brix°) was influenced differently by the amount of water from irrigation and natural precipitation. Depending on the treatment and year type, Brix° varied between 4,7 and 9,0. Better water supply resulted in higher yields but reduced the water-soluble dry matter content of the fruits (r^2=0,66). However, yield per hectare of dry matter was significantly increased. We have found close correlations in 3 years, except in 2010. The equation of linear regression ($y = -0{,}0084x + 9{,}1182$) for aggregated data suggests that 119 mm water surplus caused 1 Brix ° decrease in the average of the 4 years.

Relationship between water supply and stomatal conductance

The relationship between water supply and transpiration was close in 2008 (r^2=0,94), in 2009 (r^2=0,98) and also in 2011 (r^2=0,95), but not significant in 2010, due to the extreme humid weather. However, the four years' joint evaluation data showed close correlation (r^2=0,47), which was significant at 95% probability level.

Relationship between water supply and foliage temperature

The real necessity of irrigation is evident in dry years. The value of the determination coefficient calculated from the polynomial equation was the strongest in 2009 (r^2=0,99) and 2011 (r^2=0,97). The close negative relationship between water supply and foliage temperature (r^2=0,74), can be seen from the equation ($y = -0{,}0113x + 4{,}5139$).

Relationship between stomatal conductance and foliage-air temperature difference

Both stomatal conductance and leaf surface temperature can predict the irrigation need. Examining these two variables, it can be stated that stomatal conductance 99% determined the foliar temperature in 2009, 98% in 2011, and 83% in 2008. In 2010 this ratio was only 57%, becauseof the great volume of precipitation and high humidity.

In the joint assessment of the years, there was a high degree of linearity (r^2=0,61), which shows that stomatal conductivity determined the foliage-air temperature difference by 61%.

NEW SCIENTIFIC RESULTS

1. Based on the experimental results of four years, I have determined that production volume and quality of processing tomatoes are significantly influenced by the year type effect (mainly air temperature and precipitation).
2. I proved that water supply has a close negative correlation (R^2=0,66; n=52) with water-soluble dry matter content (Brix°). Linear regression showed that 119 mm of water surplus meant 1 Brix° decrease.
3. My results clearly demonstrated that water supply is closely related (R^2=0,47; n=58) to the cumulated stomatal conductance of processing tomato.
4. According to my results it can be concluded that the water supply has a close negative correlation (R^2=0,74; n=58) with the difference between foliar- and air temperature.
5. As a result of the previous two correlations, I found a close negative (R^2=0,61; n=58) relationship between the cumulative stomatal conductance and the difference of foliar- and air temperature.
6. Comparison of yield parameters showed a close positive correlation between marketable yield and Brix yield (R=0,95; R^2=0,9; n=52), the number of fruits harvested per hectare (R=0,89; R^2=0,79; n=52) and the average fruit weight (R=0,83; R^2=0,68; n=52).
7. On the basis of the four years' study, I came to the conclusion that "cut-off method" is an irrigation technology element that can not be successfully used in cultivation practice under hungarian conditions.

CONCLUSIONS AND SUGGESTIONS

From a meteorological point of view, the four examined years differed significantly from each other. The humid year of 2008 was followed by the exceptionally arid 2009, while 2010 was extremly wet, with low temperatures and high relative humidity. The arid 2011 was the opposite of the previous year.

These different weather conditions greatly influenced the quantity and quality of the crop. The amount of available water determined the yield by over 83% and the soluble dry matter content above 73%, similar to the results of other authors (Patanè és Cosentino, 2010; Patané et al., 2011; Pék et al., 2015).

In terms of water soluble solids (Brix°), the irrigated plant stocks gave lower values in all examined years (2008-2011), but the yield of dry matter per hectare increased. This entirely concurs with expectations and the results of domestic and international experiences (Cahn et al., 2001; Zegbe-Domínguez et al., 2003; Machado et al., 2005; Barbagallo et al., 2013; Pék et al., 2015).

In three of the years (2008, 2009 and 2011), irrigation was absolutely necessary to produce good yields, while in 2010 the yield was low despite the water supply, due to the cold weather and the uneven distribution of rainfall. In cool, rainy weather, irrigation comes with undesirable consequences, like slowing fruit growth and maturation, decreasing dry matter content and dry matter yield, and also increasing the possibility of the occurrence of disease.

This concurs with the results of Helyes and Varga (1994), who found that irrigation is needed in 75-80% of the years in Hungary, along with appropriate timing and quantity. It is also confirmed by the climate forecasts, which predict the drying of the Carpathian basin (Jolánkai és Birkás, 2011).

The "cut off" irrigation system, used in 2008-2010, can not be effectively applied in our region due to the unpredictability of the weather, but the regulated water deficit irrigation system (RDI), introduced in 2011, already provides a designable and efficient water supply to maximize yields with favorable Brix°. This can be accomplished by inducing mild water deficit stress, maintaining stomatal activity at an appropriate level and avoiding excessive water loss from transpiration, in a way that is optimal for photosynthesis.

The relationship between water supply and transpiration can be concluded by measuring stomatal conductance, which showed a close correlation during the four years (r^2=0,47), which was significant at 95% probability level. In this regard, several authors have come to similar conclusions (Casson és Hetherington, 2010; Torres-Ruiz et al., 2013; Osakabe et al., 2014; Clauw et al., 2015; Nemeskéri et al., 2015).

In terms of water supply and foliar temperature, the equation for aggregated data showed a close negative relationship on average over the four years (r^2=0,74), with similar results from other authors (Helyes, 1991; 1999b; Wang et al., 2010; Helyes et al., 2015).

As a result of the previous two correlations, I found a close negative (r^2=0,61) relationship between cumulative stomatal conductance and the difference of foliar- and air temperature of the plant stock during the 2008-2011 period, which showed a more significant correlation in drought years (r^2=0,99; r^2=0,98).

Since the need of irrigation can be predicted from stomatal conductance and plant foliar temperature, these relationships can be utilized in the irrigation planning of processing tomato, which is confirmed by numerous international publications (Fereres és Soriano, 2007; Prichard et al., 2008; Papenfuss és Black, 2010; Navarro et al., 2015; Grilo et al., 2017).

It can be concluded that the year type effect significantly affects the quantitative and qualitative parameters of processing tomato, but this effect can be reduced by further optimizing the water supply stages, which can improve the yield and optimize the dry matter content.

LIST OF RELATED PUBLICATIONS

Approved articles in English:

HELYES L., DIMÉNY J., **BŐCS A**., SCHOBER GY., PÉK Z. (2009): The effect of water and potassium supplement on yield and lycopene content of processing tomato. *Acta Horticulturae* 832:103-108.

HELYES L., **BŐCS A**., PÉK Z. (2010): Effect of water supply on canopy temperature, stomatal conductance and yield quantity of processing tomato (*Lycopersicon esculentum* Mill.*).* *International Journal of Horticultural Science*, 16 (5) 13-15.

PAKSI A., **BŐCS A**., HELYES L., DIMÉNY J., PÉK Z. (2010): Changes in colour and antioxidants during vine and postharvest ripening process of tomato fruits. *Acta Horticulturae*, 858: 239-242.

BŐCS A., PÉK Z., HELYES L. (2011): Simultaneous impact of the different water supply and year type on processing tomato yield. *International Journal of Horticultural Science*, 17 (1-2): 79-81.

HELYES L., **BŐCS A**., LUGASI A., PÉK Z. (2012): Tomato antioxidants and yield as affected by different water supply. *Acta Horticulturae*, 936: 213-218.

Approved articles in Hungarian:

BŐCS A., PÉK Z., HELYES L. (2010): A vízellátottság hatása az ipari paradicsom sztómakonduktanciájára, levélfelület-hőmérsékletére és termésmennyiségére. *Kertgazdaság*, 42 (1): 3-9.

BŐCS A., PÉK Z. (2011): Az öntözés hatása az ipari paradicsom termésmennyiségére és minőségére. *Kertgazdaság*, 43 (2): 3-9.

Proceedings /Conference papers:

In English:

BŐCS A., HELYES L., DIMÉNY J., PAKSI A., PÉK Z. (2008): Effect of ecological conditions on fruits colour and ingredients during the ripening process. *Cereal Research Communications*, 36: 519-522.

BŐCS A., PÉK Z., NEMÉNYI A., KOMJÁTHY L., HELYES L. (2009): Effect of water supply on canopy temperature and stomatal conductance of processing tomato. *Cereal Research Communications*, 37: 113-116.

BŐCS A., HELYES L., PÉK Z., LUGASI A. (2010): Spectrophotometrically measured colour and lycopene content of normal and high lycopene tomato varieties. *Pigments in Food*, 6: 136-139.

In Hungarian:

OMBÓDI A., SAIGUSA M., **BŐCS A**., HELYES L. (2009): Szabályozott tápanyagleadású kálium műtrágya hatása ipari paradicsom termésmennyiségére és minőségére. Lippay János - Ormos Imre - Vas Károly Tudományos Ülésszak: Összefoglalók. Kertészettudomány, 330-331.

Participation in scientific conferences:

VII. Alps-Adria Scientific Workshop, Stara Lesna, Slovakia, 2008.04.28.-05.02.

Bőcs A., Helyes L., Dimény J., Paksi A., Pék Z.: Effect of ecological conditions on fruits colour and ingredients during the ripening process.

VIII. Alps-Adria Scientific Workshop, Neum, Bosnia-Herzegovina, 2009.04.29-05.02.

Bőcs A., Pék Z., Neményi A., Komjáthy L., Helyes L.: Effect of water supply on canopy temperature and stomatal conductance of processing tomato.

Lippay János – Ormos Imre – Vas Károly Tudományos Ülésszak, Budapesti Corvinus Egyetem, Budapest, 2009.10.28-30.

Ombódi A., Masahiko S., Bőcs A., Helyes L: Szabályozott tápanyagleadású kálium műtrágya hatása ipari paradicsom termésmennyiségére és minőségére.

6th International Congress on Pigments in Food: Chemical, Biological and Technological Aspects. Budapest, 2010.06.20-06.24.

Bőcs A., Helyes L., Pék Z.: Spectrophotometrically measured colour and lycopene content of normal and high lycopene tomato varieties.

28th Interntional Horticultural Congress, Lisboa, 2010.08.22-27.

Helyes L., Bőcs A., Lugasi A., Pék Z. (2010): Tomato antioxidants and yield as affected by different water supply.

Bőcs A., Pék Z., Helyes L. (2010): Tomato yield as affected by different irrigation regime.