DOI: 10.34101/actaagrar/2/3674

The effects of water supply on the physiological traits and yield of tomato

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SUMMARY

The SPAD value, the chlorophyll fluorescence and the canopy temperature of the leaves and fruits of tomato hybrid "H1015" were investigated under non-irrigated (I0), deficit irrigated (I50) and well-irrigated (I100) conditions. The aim of the experiments was to show which treatment effect on the examined traits affected photosynthesis, leaf temperature and yield quantity, as well as quality under water scarcity. In the control treatment (I0), the canopy temperature increased, but the SPAD decreased compared to the other two treatments (I50 and I100). Chlorophyll fluorescence produced a fluctuating result. In the end, the number of the fruits was high, but the number of the sick and green berries was increased.

Keywords: *tomato, water deficit, SPAD, chlorophyll fluorescence, canopy temperature*

INTRODUCTION

The tomato (*Lycopersicon esculentum Mill.*) is a member of the *Solanaceae*. The plant species are native to South America (Mexico) and Central America, but today people across the world have planted it especially in temperate climates and greenhouses only. The largest tomato producers were the California, USA, where 11.6 million mT, were processed, followed by Italy 4.65 million mT and China 3.8 million mT. Spain was the fourth largest producer in the world, with 2.8 million mT, in 2018. Hungary was only 106000 mT (WPTC, 2018).

The tomato is one of the most popular vegetables and one of the most important fruit crops (Brandt et al., 2003). Vegetables included an ample quantity of vitamins and nutrition that prevents various deadly diseases to human bodies (Rubatzky and Yamaguchi Mas, 1997). Tomatoes main contain lycopene, tocopherols, vitamin C, potassium and iron (Pék et al., 2014). Water management (irrigation management) plays a major role in drive processing tomato yields. Stevens and Rick (1986) considers the difficulty of water management to be the most important deterrent to high yields of high quality tomatoes.

The knowledge of the plant response to water stress is important in order to determine the timing of irrigation, the applied water amount (Fereres and Evans, 2006). Decrease in soil water content induces the stomatal closure to reduce the water loss of plants. Nevertheless, the long-term stomatal closure results not only reduction in transpiration but photosynthesis inhibition (Sing and Reddy, 2011). The photosynthetic activity of the crops is one of the important factors influencing the yield that can be monitored by the measurement of physiological traits (Song et al., 2012). The photosynthetic pigments in the leaf absorb strongly the light in the visible range, minimizing its reflectance. The light energy that is not used for the photosynthesis either as emitted fluorescence or as heat is released (Lambrev et al., 2012). Stress factors result the metabolic disturbance change in the chlorophyll content of the leaves (Carter and Knap, 2001; Knipling, 1970) and also change the leaf reflectance. Under drought stress the change in chlorophyll fluorescence (Fv/Fm) depending the genotypes (Estrada et al., 2015). Researchers found reduction in chlorophyll content under moisture deficit could be attributed to the fact that water stress damages the photosynthetic apparatus by causing changes in the chlorophyll contents and components (Kenneth et al., 2017). Reduction in moisture led to a decrease in the leaf relative water content, stomatal conductance, and fruit yield.

The aim of this study was to evaluate the influence of irrigation factors on the physiological traits and yield of processing tomato.

MATERIALS AND METHODS

In 2018, open field experiments were conducted on the Institute of Horticulture's farm at Szent István University, Gödöllő, Hungary. The type of soil was brown forest soil. The tomato cultivar distributed by Heinz was H1015 hybrid with early ripening (114 days) and had resistance to Verticillium race 1, Fusarium races 1 and 2, root-knot nematode and bacterial speck. H1015 processing tomato can be grown under both arid and humid conditions. The planting was a symmetrical arrangement: the row and plant distances were 150x18.6 cm which means the plant density was 3.58 plants m^2. The date of transplantation was May 17^{th} and the harvest date was August 27^{th}.

On the basis of crop evapotranspiration using the equation $ETc = ET_0 \times Kc$, two different irrigation treatment (I), was performed: optimum water supply (I100) and deficit irrigation (I50) where half of irrigated doses of I100 treatment was applied. Non-irrigated plots represented the rain-fed control (I0). The irrigation was done with a drip system.

Measurements of physiological traits were performed every week from the beginning of flowering. The soil moisture was measured with PT-1 (Kapacitív Kkt., Hungary), the leaf temperature using by Raytek MX4 (Raytek Corporation CA, USA) infrared remote thermometer. Chlorophyll content of leaf was measured by SPAD 502 (Minolta, UK) portable

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chlorophyll meter and it was given as SPAD values. PAM-2500 (Waltz, Germany) portable fluorometer was used to measure the chlorophyll fluorescence of leaf.

10 plants were harvested from each plot per repeat. The total biomass and yield were weighed, then the yield was classified to the marketable (ripe) and non-marketable (green and ill) fruits and measured the yield.

Data were evaluated by analysis of variance (ANOVA) using SPSS 20.0 for Windows software. The average values of treatments were compared by Duncan's Multiple Range Test at P<0.05.

RESULTS AND DISCUSSION

2018 can be considered as a dry year, but the distribution of precipitation was from 5.00 to 160.2 mm during the stages of development of tomato. Large amount of precipitation was fallen from planting to the beginning of flowering of tomato; however it was low (5.0 mm) during flowering period (*Table 1*). During fruit development, the high temperature associated with large amount of available water contributed a large yield. Total water of I100 treatment was 464.8 mm and I50 treatment was 384.8 mm from planting to harvesting stages (*Table 1*).

Table 1

Meteorological data during the growth of tomato (2018)

Date	Stages	Tmin ºC	Tmax ºC	RH %	Soil moisture at 60 cm %	Precipitation (mm)	Irrigation mm (I100)	Total water (I100) (mm)	Total water (I50) (mm)
17.05–24.06	Growing	14.98	25.78	75.1	25.6	160.2	20.1	180.3	170.3
25.06–12.07	Beginning flowering	13.69	25.11	72.2	26.2	48.6	35.1	83.7	66.2
13.07–20.07	Flowering	15.60	27.60	66.1	27.7	5.0	24.3	29.3	17.2
21.07–26.07	Flowering fruit setting	16.90	28.33	74.4	27.8	28.3	19.5	47.8	38.0
27.07–09.08	Fruit development	18.34	31.52	70.3	27.2	17.8	44.0	61.8	39.8
10.08–23.08	Fruit ripening	17.36	31.22	65.8	24.8	22.5	17.2	39.7	31.1
27.08	Harvesting	15.90	24.60	79.0		22.2	0.0	22.2	22.2
	From planting to harvesting					*304.6*	*160.2*	*464.8*	*384.8*

T min = minimum temperature; T max = maximum temperature; RH-relative humidity

During flowering and fruit setting the SPAD value was large, but it was decreased during fruit development and later began to increase during ripening period of tomato. There was high canopy temperature from the fruit setting to fruit ripening period while chlorophyll fluorescence fluctuated from 0.809 to 0.681 (*Table 2*). During this time, the physiological traits were changed by the water supply conditions (*Figures 1–3*).

Table 2

Change in physiological traits of tomato during generative stages of development (2018)

Traits[z]	Flowering	Fruit setting	Fruit development		Fruit ripening		
	VII.13	VII.20	VII.26	VIII.02	VIII.09	VIII.17	VIII.23
SPAD	51.5 a	50.6 a	48.4 b	46.3 bc	48.8 a	49.2 a	45.1 c
CT ºC	26.2 b	28.9 a	28.3 a	28.8 a	28.5 a	25.8 b	29.0 a
Fv/Fm	0.723 c	0.772 b	0.734 c	0.809 a	0.759 b	0.757 b	0.681 d

[z]CT= canopy temperature, Fv/Fm =chlorophyll fluorescence

Mean values in the column having a different letters are significantly different at P < 0.05 level using Duncan's multiple range test.

A significant effect of water supply on canopy temperature was detected during the flowering; it was the lowest for the well-irrigated plants compared to the water-stressed ones (*Figure 1*). Under water deficiency (I50), during fruit development and ripening, the canopy temperature was low and did not change significantly except during the last period of fruit ripening.

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Figure 1: **Effect of water supply on canopy temperature of processing tomato**

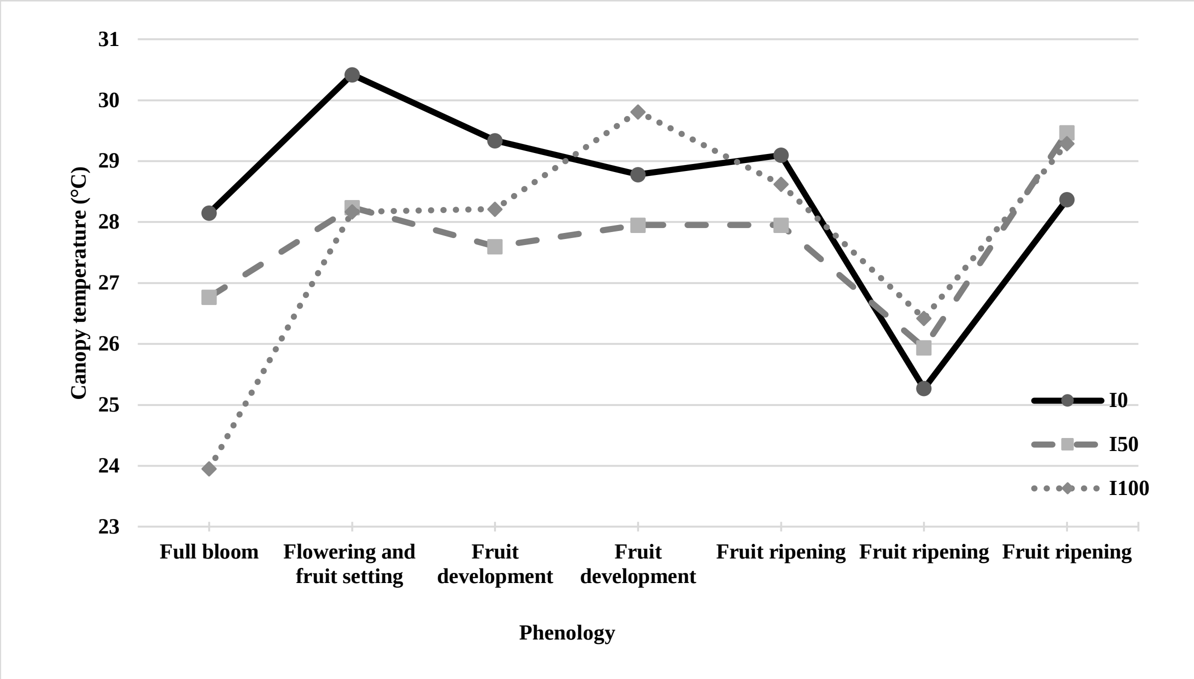
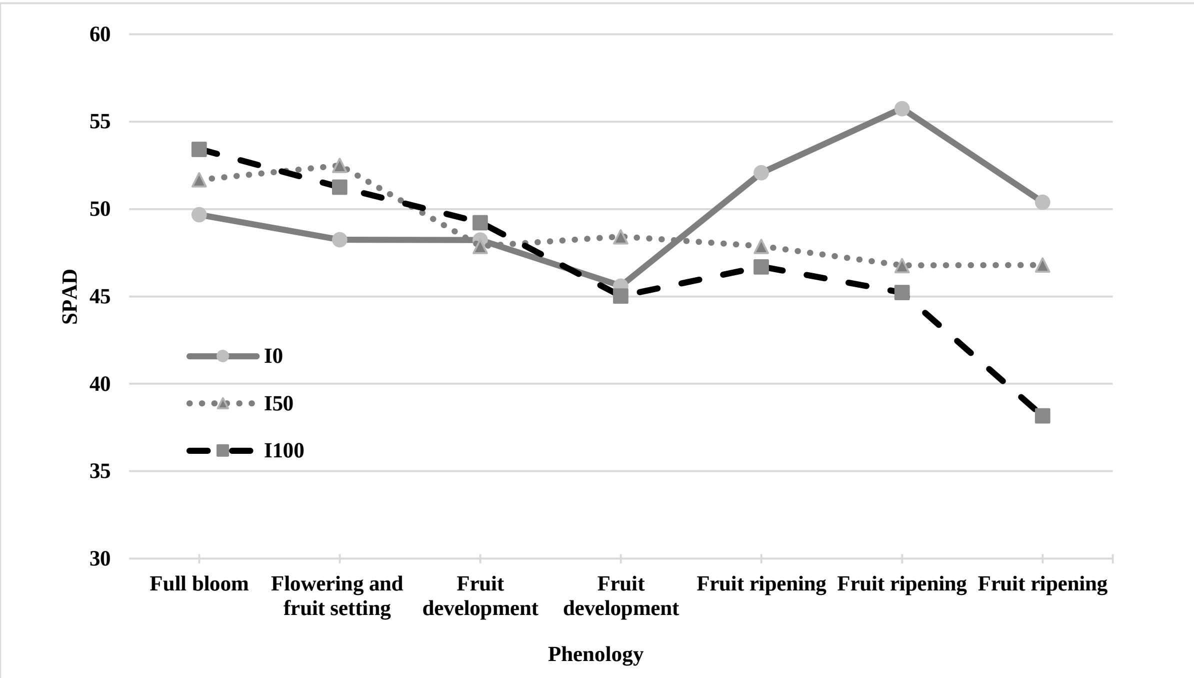


Figure 2: **Effect of water supply on SPAD value of leaves of processing tomato**



Under non-irrigated condition (I0), during flowering and fruit setting periods the SPAD value of leaf was significantly lower than that of the irrigated plants (I50, I100) (*Figure 2*). While there were no differences between the two measurements at treatment I50 in the fruit development, in the other two irrigation SPAD results have decreased. At the control, the 2nd measurement shows a protruding value in fruit ripening, while the others two SPAD results have decreased after each measurement, more spectacular in I100.

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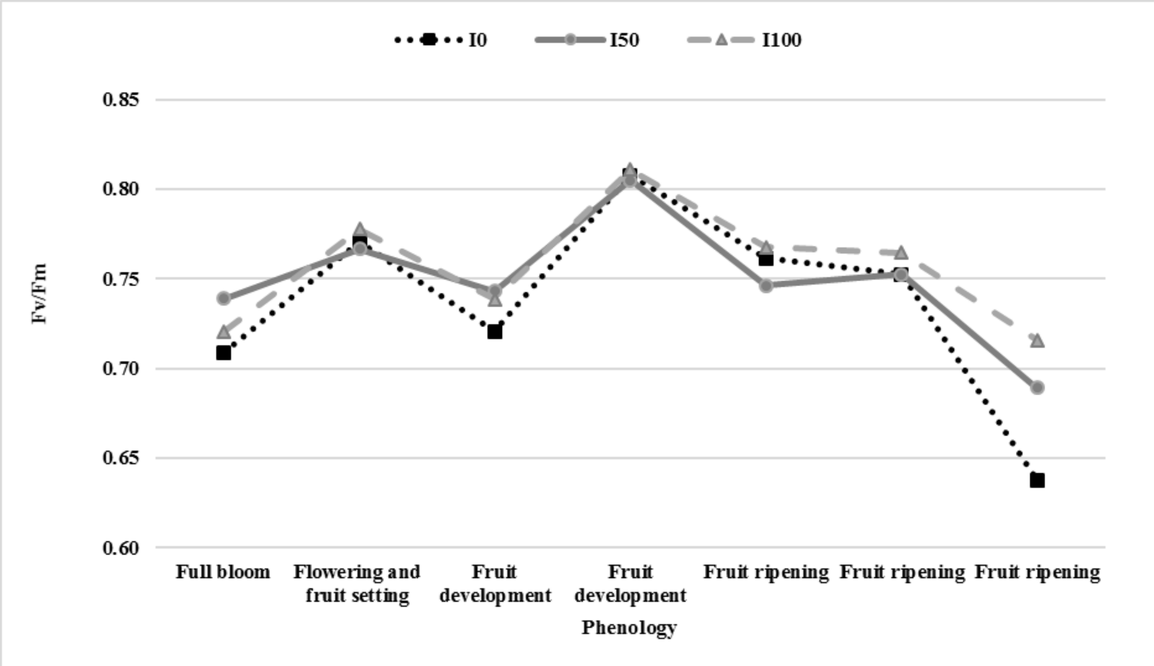
Figure 3: **Change in chlorophyll fluorescence under different water supply conditions**



Water supply did not influence significantly the chlorophyll fluorescence (Fv/Fm) except at the end of fruit ripening. In the non-irrigated treatments, the chlorophyll fluorescence was lower than that at regularly irrigation (*Figure 3*). In the end of the fruit development all results were high, then the results of the control fall sharply in the middle of the fruit ripening.

Under non-irrigated (I0) condition, high canopy temperature, SPAD values of the leaves and low chlorophyll fluorescence decreased the photosynthesis. Although the productivity of tomato decreased under this condition, the fruit quality was favourable due to the low ratio of the green and diseased, injured tomato fruits (*Table 3*). The water shortage (I50), even though the SPAD was high, did not decrease the yield due to the low canopy temperature and chlorophyll fluorescence. Under well-irrigated condition (I100), the low canopy temperature, SPAD and high chlorophyll fluorescence (Fv/Fm) contributed to the intensive photosynthesis which resulted increase in the yield of tomato but the ratio of green and others fruits also increased significantly (*Table 3*).

Table 3

Physiological traits and yield of tomato under different water supply conditions

Water supply[z]	Canopy temperature ºC	SPAD	Fv/Fm[y]	Total yield t ha^{-1}	Yield		
					Marketable	Green	Others
I_0	28.4 a	50.0 a	0.737 b	50.7 b	45.2 b	4.4 b	0.8 b
I_{50}	27.7 b	48.8 a	0.749 ab	64.9 ab	59.2 a	4.6 b	1.0 b
I_{100}	27.7 b	47.0 b	0.757 a	72.4 a	59.7 a	9.9 a	2.7 a

[z] I_0= non-irrigation, I_{50}= water deficiency, I_{100}= regularly irrigation, [y] chlorophyll fluorescence

Mean values in the column having a different letters are significantly different at $P < 0.05$ level using Duncan's multiple range test.

Tomato is considered to be a high water-demanding crop (Patané et al., 2011). The period from fruit setting to the end of fruit development is the most sensitive to water deficiency (Helyes and Varga, 1994), when the degree of water stress tolerance of cultivars can be determined by the measurement of the physiological traits. The results confirmed that these stages of development of tomato were sensitive to severe water deficiency because the canopy temperature of crop increased significantly in comparison with that of well-irrigated one. The high canopy temperature can results the degradation in the chlorophyll content, thus the absorption of light decreases in the chloroplast and the reflectance increases that presented large SPAD value. Agbna et al. (2017) found that deficit irrigation

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improved the fruit quality of tomato but it reduced the vegetative growth, photosynthesis and transpiration rate as well as fruit yield. This results also showed that moderate water deficiency (I50) on contrary to the large SPAD value did not decrease the yield but the fruit quality was favourable than that of well-irrigated plants.

Measurement of Fv/Fm has also been used to screen the heat tolerance of tomato genotypes. Zhou et al. (2015) established, that heat tolerant tomato genotypes have higher Fv/Fm did not alter the net photosynthesis rate, but increased the stomatal conductance under heat stress comparing with the control. According to the result, the chlorophyll fluorescence (Fv/Fm) decreased significantly under non-irrigated plants in compared to the well-irrigated ones. This value was higher than in the work of Mishra et al. (2012) wherein a low (0.45) Fv/Fm was measured under drought stress condition.

According to Cselőtei and Helyes (1988) and Helyes (1990) irrigation was effected at foliage temperature and yield of tomato. Differences doses and time of irrigation were reflected the development of plants very well.

CONCLUSION

During flowering and fruit setting periods of tomato, severe water deficit increased significantly the canopy temperature while SPAD value of leaf was low in comparison with the well-irrigated plants. Chlorophyll fluorescence fluctuated independently the water supply during the growth of tomato. Significant difference in between the SPAD and Fv/Fm has been shown at the end of fruit ripening when the SPAD values increased, but Fv/Fm decreased under non-irrigated condition. Under water deficiency (I50), in contrary the high SPAD value of the total yield did not decrease due to the low canopy temperature and chlorophyll fluorescence during the growth of tomato. Under regularly irrigation, the low canopy temperature and SPAD and high Fv/Fm contributed to an intensive photosynthesis that resulted large yield, but the amount of green and diseased injured fruits of tomato increased.

ACKNOWLEDGEMENTS

This research was supported by the Higher Education Institutional Excellence Program (1783-3/2018 FEKUTSTRAT) awarded by the Ministry of Human Capacities within the framework of water related researches of Szent István University and grant number EFOP-3.6.3-VEKOP-16-2017-00008”.

REFERENCES

Agbna, G. H. D.–Dongli, S.–Zhipeng, L.–Elshaikh, N. A.–Guangcheng, S.–Timm, L. C. (2017): Effects of deficit irrigation and biochar addition on the growth, yield, and quality of tomato. Sci. Hortic. 222: 90–101.

Brandt, S.–Lugasi, A.–Barna, É.–Hóvári, J.–Pék, Z.–Helyes, L. (2003): Effect of the growing methods and conditions on the lycopene content of tomato fruits. Acta Alimentaria, 32.3: 269–278.

Carter, G. A.–Knap, A. K. (2001): Leaf optical properties in higher plants: linking spectral characteristics to stress and chlorophyll concentrations. Am. J. Bot. 88: 677–684.

Cselotei, L.–Helyes, L. (1988): The possibility of determining irrigation requirements by means of plant temperature. Acta Horticulturae 220: 353–358.

Estrada, F.–Escobar, A.–Romero-Bravo, S.–González-Talice, J.–Poblete-Echeverría, C.–Caligari, P. D. S.–Lobos, G. A. (2015): Fluorescence phenotyping in blueberry breeding for genotype selection under drought conditions, with or without heat stress. Sci. Hortic. 181: 147–161.

Fereres, E.–Evans, R. G. (2006): Irrigation of fruit trees and vines: an introduction. Irrigation Sci. 24: 55–57.

Helyes, L. (1990): Relations among the water supply, foliage temperature and the yield of tomato. Acta Horticulturae 227: 115–121.

Helyes, L.–Varga, Gy. (1994): Irrigation demand of tomato according to the results of three decades. Acta Hortic. 376: 323–328.

Kenneth, O.–Tembe, G. N.–Ambuko, C. J.–Owino, W. (2017): Effect of water stress on yield and physiological traits among selected African tomato (Solanum lycopersicum) land races. Int J Agron Agri R. 10.1: 78–85.

Knipling, E. B. (1970): Physical and physiological basis for the reflectance of visible and near-infrared radiation form vegetation. Rem Sens Environ. 1: 155–159.

Lambrev, P. H.–Miloslavina, Y.-Jahns, P.–Holzwarth A. R. (2012): On the relationship between non-photochemical quenching and photoprotection of photosystem II.Biochim. Biophys. Acta Bioenerg.1817: 760–769.

Mishra, K. B.–Iannaconeb, R.–Petrozza, A.–Mishra, A.–Armentano, N.–La Vecchia, G.–Trtilek, M.–Cellini F.–Nedbal L. (2012): Engineered drought tolerance in tomato plants is reflected in chlorophyll fluorescence emission. Plant Science 182: 79–86.

Patanè, C.–Tringali, S.–Sortino O. (2011): Effects of deficit irrigation on biomass, yield, water productivity and fruit quality of processing tomato under semi-arid Mediterranean climate conditions. Sci. Hortic. 129: 590–596.

Pék, Z.–Szuvandzsiev, P.–Daood, H.–Neményi, A.–Helyes, L. (2014): Effect of irrigation on yield parameters and antioxidant profiles of processing cherry tomato. Cent. Eur. J. Biol. 9.4:383–395.

Rubatzky, V. E.–Yamaguchi, Mas (1997): World vegetables: principles, production and nutritive values, Second edition, International Thomson publishing, New York. 3–6.

Sing, S. K.–Reddy, K. R. (2011): Regulation of photosynthesis, fluorescence, stomatal conductance and water-use efficiency of cowpea (Vigna unguiculata (L.) Walp.) under drought. J. Photoch Photobiol B 105: 40–50.

Song, H.–Gao, J. F.–Gao, X. L.–Dai, H. P. P.–Zhang, P.–Feng, B. L.–Wang, P. K.–Chai, Y. (2012): Relations between

DOI: 10.34101/actaagrar/2/3674

photosynthetic parameters and seed yields of Adzuki bean cultivars (Vigna angularis). J Integr Agric. 11.9: 1453–1461.

Stevens, M. A.–Rick, C. M. (1986): Genetic and breeding. In: Atherion JG. and Rudich J (eds) The tomato Crop. A Scientific Basis for Improvement. Chapman & Hall, London. 35–109.

Zhou, R.–Yu, X.–Kjær, K. H.–Rosenqvist, E.–Ottosen, C. O. (2015): Screening and validation of tomato genotypes under heat stress using Fv/Fm to reveal the physiological mechanism of heat tolerance. Environ Exp. Bot. 118: 1–11.

WPTC. The World Processing Tomato Council: Tomato News Processed Tomato 2018. https://www.wptc.to/