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EFFECT OF THE AGE AND PLANTING AREA OF TOMATO (*SOLANUM LICOPERSICUM* L.) SEEDLINGS FOR LATE FIELD PRODUCTION ON THE PHYSIOLOGICAL BEHAVIOR OF PLANTS

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Abstract

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In a field experiments were tested variants of seedlings with different age - 20-25-, 30-35- and 40-45-day old, grown in 40-, 66- and 104-cell containers providing a planting area for one seedling of 44, 28 and 17 cm^2 respectively. It was established that the use of biologically younger seedlings was a precondition for a greater physiological potential of the transplants during the vegetative stage. The parameters of the leaf gas exchange, biological yield and the economic photosynthetic productivity reached their highest values for the 20-25-day old seedlings grown in 66-cell containers with 28 cm^2 planting area per transplant.

Key words: tomatoes, seedlings, biological yield, net photosynthetic productivity, leaf gas exchange, plastid pigments

Abbreviations: A-photosynthetic rate, E-transpiration intensity, G_S-stomatal conductance, PP-Photosynthetic potential, NPP-Net photosynthetic productivity, CPP- Economic photosynthetic productivity, CEE-Coefficient of economic efficiency, CBE-Coefficient of biomass efficiency

Introduction

The use of high quality seedlings is an important condition for the realization of the biological potential of field grown tomatoes and for obtaining good economic results (Markovic et al., 1997). Growing seedlings in containers is an advanced technological variant winning strong recognition in the field production of vegetables. Its undeniable biological and ecological advantages are the main criterion for its topicality (Varvina and Arenas, 1997; Zhao and Chen, 2004). In the Republic of Bulgaria, research on container-grown tomato seedlings is scanty (Simidchiev and Kanazirska, 1986) and no studies are done on the late field production of tomatoes. No scientific data are to be found on the changes of the physiological status of the plants during the vegetative period when using container-grown seedlings. A series of essential issues are still unclarified – the parameters of the containers and the seedlings' biology, the size of the provided planting area in the container and its effect on the tomato photosynthetic productivity during the vegetative growth as well as on some physiological features pertaining to the quantity of the synthesized economically important phytomass.

The purpose of present investigation was to establish the influence of the age and planting area of the seedlings for late field tomato production, cultivated in containers with different cell size on the physiological behaviors, photosynthetic intensity and productivity of tomato plants.

Material and Methods

The experimental work was done during the 2011-2012 period with tomato cultivar Opal F_1. The sowing of seeds was done on 14 May, 25 May and 3 June. In styrofoam containers of 40, 66 and 104 cells, providing planting area per seedling of 44, 28 and 17 cm^2 respectively, 20-25-, 30-35- and 40-45-day old seedlings were grown. We used 20-25-day old seedlings for control, grown in a transplanting bed at a rate of 2 g/m^2, the number of transplants being 350-380/m^2 by applying thinning during the second true leaf stage. The physiological measurements were carried out at the first fruit development stage as well as at first fruit reddening stage. The study target was the leaf gas exchange featuring the photosynthetic rate (A), transpiration intensity (E)

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and stomatal conductance (G_s) determined by means of the photosynthetic system LCA-4 (ADC, England). The photosynthetic pigments were extracted with the help of 80% acetone. Using a spectrophotometer Helios, the extinction of the extract was measured, by applying the method of Pochinok (1976). The biological yield, composed of stalk, leaves and fruits, was determined by drying at 105°C until reaching the constant weight.

Based on the results of the biometric measurements, the chemical and physiological analyses, some indexes related to the photosynthetic productivity of the plants were determined, such as: 1. Photosynthetic potential (PP) – according to Nichiporovich (1961); 2. Net photosynthetic productivity (NPP), calculated by using the classic formula of Briggs et.al. (1920); 3. Economic photosynthetic productivity (EPP) according to Vasev (1977); 4. Coefficient of economic efficiency (CEE), representing the correlation between the dry fruit mass and the biological yield; 5. Coefficient of biomass efficiency (CBE), representing the average daily increase of the dry matter of the fruit of kg/da dimensions. The mathematical processing of the data was done by using standard software SPSS – Duncan's Multiple Range Test (Duncan, 1955) and BIOSTAT.

Results and Discussion

The crucial element underlying the productivity of a particular crop is the rate of phytomass accumulation. The photosynthetic activity of the leaves is the main source of accumulation of organic matter in the plant organism or for the formation of the so-called biological yield (Barnes, 1977). The tested variants differed in many of the main productivity elements (Table 1). There were differences in the accumulation of the overall as well as of the economically important phytomass. The comparison of the mean results showed that the highest biological yield was obtained when using 20-25-day old seedlings. The maximal values for the latter were reported for the 66-cell variant. During both experimental years, it surpassed all the rest of the variants, the differences being of a good statistical reliability. That same variant had advantages in the other two age groups as well. The fruit dry mass quantity also changed depending on the age of the seedlings and the number of cells. A trend, similar to the established one for the biological yield, was detected. Again, the variant of 20-25-day old seedlings grown in 66-cell containers providing 28 cm^2 of planting area per plant stood out.

It considerably surpassed all the other variants, including the control, which in turn, was inferior only to variant 7. The obtaining of a high economic yield is closely connected with the formation of a high biological yield, the dependence not being strictly linear. A crucial role is played by the economic productivity coefficient, which represents the correlation between the fruit dry matter and the overall plant dry matter and serves as a characteristic of the balance between the photosynthetic apparatus and

Table 1
Photosynthetic productivity indexes of one plant during the growing season

Variant №	Number of cells, plant area, cm^2	Biological yield (stem + leaves + fruits), g				Dry phytomass of the fruits, g				Average for 2 years				
		2011	2012	average		2011	2012	average		CEE	CBE	PP, m^2	NPP	EPP, g/m^2/24h
				g	%			g	%					
40-45 day seedlings														
1	40 (44)	207 de	167 ef	187	93.5	99 bc	77 f	88	95.6	0.47	0.78	18.00	10.39	4.89
2	66 (28)	219 bc	175 cde	197	98.5	98 bcd	80 ef	89	96.7	0.45	0.79	18.20	10.82	4.89
3	104 (17)	208 de	172 def	190	95.0	90 d	86 cde	88	95.6	0.42	0.78	16.20	11.73	5.43
30-35 day seedlings														
4	40 (44)	223 b	163 f	193	96.5	94 cd	78 ef	86	93.5	0.44	0.76	18.00	10.72	4.78
5	66 (28)	225 b	185 bc	205	102.5	98 bcd	82 def	90	97.8	0.44	0.80	18.60	11.02	4.84
6	104 (17)	202 e	171 def	183	91.5	91 cd	81 def	86	93.5	0.42	0.76	17.50	10.46	4.91
20-25 day seedlings														
7	40 (44)	238 a	192 ab	215	106.5	105 b	95 b	100	108.7	0.46	0.89	18.70	11.50	5.35
8	66 (28)	244 a	200 a	222	112.5	116 a	110 a	113	122.8	0.49	1.04	19.90	11.16	5.68
9	104 (17)	214 bcd	182 bcd	198	99.0	91 cd	89 bcd	90	97.8	0.45	0.80	18.70	10.59	4.81
10	Control	211 cde	189 b	200	100.0	93 cd	91 bc	92	100.0	0.46	0.82	17.60	11.36	5.23

Legend: a,b,c.. Duncan's multiple range test ($P<0.05$)

the nutrient-storing organs (fruits). The data showed that coefficient to be highest in variant 8, followed by variant 1. The fact indicated that in variant 8 the distribution of the biological yield over the fruits and the vegetative organs was most favorable and gave grounds to claim the characteristics of the balance between the photosynthetic apparatus and the fruits to be approaching the optimum to the greatest extent. A natural expression of the high biological and physiological potential of the indicated variant is the biomass efficiency coefficient, representing the average daily increase of the fruit dry matter for 1 da. Its value was considerably higher compared with the other variants, thus making its evaluation even more objective physiologically. The photosynthetic potential is an important index and the total photosynthetic productivity depends on it. It characterizes the photosynthetic power of the crops during the vegetative period or for a given interval. Higher values for that index were reported in the 20-25-day old seedlings group, the 66-cell variant, providing 28 cm^2 planting area, standing out. When comparing the variants according to the dry mass quantity synthesized by a leaf surface unit, it was observed that the absolute value of that index was the highest in variant 3, followed by variant 8, where the net photosynthetic productivity was 11.7 and 11.6 g/m^2 respectively for a 24h period. A more accurate and objective characterization of the plant as a photosynthesizing system is offered by the index, introduced by Vasev (1977). It represents the grams of dry matter of the economic yield, obtained from a unit of the photosynthetic potential. The results indicated variant 8 to be with the highest values for that particular index, followed by variant 3 and variant 7. The results of the leaf gas exchange measurements are in conformity with the increased productivity of the photosynthetic apparatus (Table 2).

The measurements for the three defining indexes at the stage of first fruit formation the outlining trends for the two experimental years were unidirectional. It was observed that the younger the transplants, the more intensive the leaf gas exchange was during the vegetative period. The photosynthetic rate was lowest in the 40-45-day old seedlings variants, which did not differ significantly from the control. The values for that index in the other two age groups were very close, with not statistic significance differences. High transpiration intensity was measured in the variants of 20-25-day old seedlings. That was a proof for a better water status and a greater physiological potential, especially if in combination with a greater stomatal conductance, which was reported for the same age group. An advantage of the 20-25-day group as to the leaf gas exchange performance was also detected during the measurement at the stage of first fruit reddening. Over the two years, the highest photosynthetic rate was measured when using 66- and 40-cell containers, with very small differences, without statistical significance. In all variants of that age group (including the control) high values for the transpiration intensity

Table 2
Leaf gas exchange per plant

Variant №	Number of cells plant area, cm^2	First fruit formation stage						First fruit bearing stage					
		A		E		G_s		A		E		G_s	
		2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
40-45 day seedlings													
1	40 (44)	16.67 c	21.81 b	2.01 c	1.76 c	0.070 g	0.027 e	16.38 cd	18.27 c	2.53 b	20.2 b	0.062 cd	0.046 bc
2	66 (28)	19.88 ab	22.63 b	2.07 c	1.71 c	0.075 g	0.026 ef	14.59 e	18.63 bc	2.57 b	2.05 b	0.071 bc	0.046 bc
3	104 (17)	18.61 b	22.16 b	2.03 b	2.03 b	0.080 ef	0.030 d	15.51 de	18.75 bc	2.47 b	1.98 b	0.060 cd	0.040 c
30-35 day seedlings													
4	40 (44)	21.45 a	24,49 a	2.05 b	2.00 b	0.081 ef	0.031 d	17.81 bc	19.00 b	2.50 b	1.99 b	0.060 cd	0.046 bc
5	66 (28)	21.78 a	26.05 a	2.18 b	2.20 a	0.088 cd	0.035 c	15.41 de	18.27 c	2.29 b	2.04 b	0.050 d	0.040 c
6	104 (17)	19.82 ab	24.70 a	2.14 b	2.09 b	0.080 ef	0.030 d	17.51 bc	18.38 c	2.62 b	1.95 b	0.060 cd	0.041 c
20-25 day seedlings													
7	40 (44)	21.05 a	25.42 a	2.59 a	2.19 a	0.090 bc	0.036 c	22.63 a	20.06 a	3.27 a	2.25 a	0.080 ab	0.056 ab
8	66 (28)	21.71 a	26.39 a	2.63 a	2.33 a	0.099 a	0.040 a	22.72 a	21.78 a	3.38 a	2.62 a	0.092 a	0.062 a
9	104 (17)	19.12 b	26.00 a	2.48 a	2.25 a	0.095 ab	0,038 b	18.66 b	20.54 a	3.03 a	2.44 a	0.070 bc	0.059 a
10	Control	17.30 bc	22.46 b	2.04 b	1.85 c	0.083 de	0.025 f	18.21 b	18.90 bc	3.24 a	2.39 a	0.072 bc	0.056 ab

Legend: a,b,c.. Duncan's multiple range test ($P<0.05$)

and stomatal conductance indexes were reported and they considerably surpassed the ones obtained for the variants of the other two age groups. The results for the photosynthetic pigment content complement the physiological characterization of the plants during the vegetative growth period (Table 3). At the first fruit formation stage, the green pigment content *(a+b)* increased as the age of the seedlings decreased. Within each age group, their quantity was bigger in the variants with a larger planting area for the container-grown transplants. That factor had its impact on the chlorophyll *a*/chlorophyll *b* correlation. Its values were bigger for the variants with a larger planting area, which indicated a more strongly marked effect on the chlorophyll *a* content. The values of the green pigment content and the overall photosynthetic pigment content were almost equal in the 20-25-day old seedlings grown in 40- and 66-cell containers. They surpassed all the others, the increase over the control being by 6.2-7.4% for the first feature and by 6.7-7.7% for the second. No significant changes in the levels of the specific pigments were reported during the second measuring at the first fruit reddening stage, but the direction of the correlation green pigments *(a+b)* /planting area size of the transplants was changed. For the three age groups that correlation was at its least in the 40-cell variants.

The quantity of green pigments and the total content of photosynthetic pigments were the highest in the 20-25-day old seedlings grown in 66-cell containers. The relative increase against the control was by 14.6% and 14.0% respectively. Only in the 40-45-day old seedlings grown in 40-cell containers, the values of the same two indexes were lower compared with the control. No trends in the pigment correlations, which had comparatively close values, were observed.

Table 3
Plastid pigment content

Variant №	Number of cells, plant area, cm²	Plastid pigment, mg/g fresh mass																	
		First fruit formation stage									First fruit bearing stage								
		Chl. *a*	Chl. *b*	carotenoids *c*	*a+b*		*a+b+c*		*a/b*	*(a+b)/c*	Chl. *a*	Chl. *b*	carotenoides *c*	*a+b*		*a+b+c*		*a/b*	*(a+b)/c*
					mg	%	mg	%						mg	%	mg	%		
40-45 day seedlings																			
1	40(44)	1.19	0.39	0.44	1.58	97.50	2.02	97.10	3.05	3.59	1.04	0.38	0.38	1.42	90.40	1.80	90.00	2.74	3.74
2	66(28)	1.11	0.38	0.42	1.49	92.00	1.91	91.80	2.92	3.55	1.16	0.43	0.46	1.59	101.30	2.05	102.50	2.70	3.46
3	104(17)	1.08	0.38	0.42	1.46	90.10	1.88	90.40	2.84	3.48	1.19	0.44	0.46	1.63	103.80	2.09	104.50	2.70	3.54
30-35 day seedlings																			
4	40(44)	1.22	0.41	0.48	1.63	100.60	2.11	101.40	2.98	3.40	1.17	0.43	0.44	1.60	101.90	2.04	102.00	2.72	3.64
5	66(28)	1.15	0.40	0.44	1.55	95.70	1.99	95.70	2.88	3.52	1.24	0.45	0.46	1.69	107.60	2.15	107.50	2.76	3.67
6	104(17)	1.09	0.38	0.43	1.47	90.70	1.90	91.30	2.87	3.42	1.24	0.43	0.46	1.67	106.40	2.13	106.50	2.88	3.63
20-25 day seedlings																			
7	40(44)	1.31	0.43	0.50	1.74	107.4	2.24	107.7	3.05	3.48	1.22	0.42	0.45	1.64	104.5	2.09	104.5	2.90	3.64
8	66(28)	1.29	0.43	0.50	1.72	106.2	2.22	106.7	3.00	3.44	1.32	0.48	0.48	1.80	114.6	2.28	114.0	2.75	3.75
9	104(17)	1.14	0.39	0.44	1.53	94.4	1.97	94.7	2.92	3.48	1.25	0.44	0.45	1.69	107.6	2.14	107.0	2.84	3.76
10	control	1.20	0.42	0.46	1.62	100.0	2.08	100.0	2.86	3.52	1.14	0.43	0.43	1.57	100.0	2.00	100.0	2.65	3.65
Gd 5%		0.03	0.03	0.02							0.02	0.03	0.03						
Gd 1%		0.04	0.04	0.03							0.03	0.04	0.04						
Gd 0.01%		0.06	0.05	0.05							0.05	0.05	0.05						

Conclusions

In the late tomato field production the age and the size of the planting area of the container grown seedlings influence the plant physiological potential and productivity of the photosynthetic apparatus during the vegetative growth period. The factor seedlings' age exerts a stronger influence on the physiological features related to the quantity of the synthesized photosynthetic product. In younger seedlings, the photosynthetic potential and biological yield grow in the vegetative period, the photosynthetic pigment content and leaf gas exchange increase. The plant physiological potential during the vegetative period is highest when using 20-25-day old seedlings, grown in 66-cell containers and providing a planting area of 28 cm^2 per plant. In that case the economic photosynthetic productivity is the highest and the distribution of synthesized dry phytomass over the photosynthetic apparatus and the food-storing parts of the plant is the most favorable.

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