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PHOTOSYNTHESIS AND WATER USE EFFICIENCY RELATIONS TO YIELD OF TEN PEPPER VARIETIES (*CAPSICUM ANNUUM* L.)

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Abstract

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Search for new pepper variety with high yields, along with tools for prediction of pepper yield is constantly on the way. The link between net photosynthesis measured at specific phase of pepper development and crop yield is not well defined. There are still arguments whether increasing leaf photosynthesis during fruit ripening increases plant yields in optimal growth conditions. Ten pepper varieties were grown in a plastic greenhouse and at outdoor field area, in order to determine if there are positive correlations of photosynthetic performance, leaf concentration of chlorophyll a, b and carotenoids, transpiration rates and water use efficiency with pepper fruit yield. Almost all pepper varieties grown in the greenhouse had higher fruit weight per hectare. Although some variability has been determined among pepper varieties, crop yield was not significantly correlated with photosynthetic performance, or water usage in pepper plants, during ripening.

Key words: paprika yield, CO_2 assimilation, pigment content
Abbreviations: WUE – water use efficiency

Introduction

A great number of diverse pepper varieties are commercially available in Europe with a range of different morphological and organoleptic properties. Pepper fruits are accounted for their high nutritional and biological values. Constant search for new improved varieties with potential for higher yield production is continuously on the way. Most studies that deal with *Capsicum annuum* are mainly focused on pepper quality as a nutrient resource, for food production (Guil-Guerrero et al., 2006). It is known that nutritional and visual quality of fruit depends both on pepper variety and growth conditions (Pivovarov et al., 2009). Since photosynthesis is the foundation of organic production and potentially, higher crop yield in pepper, ten pepper varieties were selected in order to establish a link between photosynthesis, transpiration and pepper yield. Photosynthetic intensity is affected by many factors such as leaf position, growth stage, and light intensity, number of environmental factors and agricultural methods of growth. It is suspected that net photosynthesis is related to fruit characters at the late phase of flowering and fruit setting (Zou et al., 2007). When pepper plants are exposed to additional stress, strong reduction of net photosynthesis is always followed by lower pepper yields (Takemoto et al., 1988). However, it is still controversial whether higher leaf photosynthesis in optimal growth conditions increases plant yields (Sinclair et al., 2004). Some studies showed that this relation depends on phase of plant development (Oshumi et al., 2007; Peng et al., 2008). The aim of this paper was to determine if there is any significant and direct connection of net photosynthetic intensities, transpiration rates and water use efficiency measured at mid day time during ripening of fruits in relation with the fruit

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yield of specific commercially available pepper varieties grown in optimal conditions. Possible correlations between these parameters were analyzed at field trial and at plastic greenhouse.

Materials and Methods

This study was conducted using ten commercial varieties of pepper (*Capsicum anuum* L.): Amfora 1, Anita, Vranjska, Novosadjanka, Amfora, Una, Plamena, S.M., Krušnica and Ljuta 127. These varieties of pepper were developed at the Institute of Field and Vegetable Crops in Novi Sad, Serbia. Two experimental trials were set, one in semicontroled conditions of a plastic greenhouse and other at outdoor field area, both with additional irrigation applied. Both experimental trials were set at the same locality, with identical soil types. Seeds were sawn at the end of March and the beginning of April. Mature fruits were harvested and measured at the end of July and beginning of August. All analyses were conducted during ripening, just before fruit harvest. Some parameters of fruit production on field are not available, do to the heavy atmospheric icefall that occurred during the last phase of ripening.

Photosynthesis and transpiration rates were measured on mature, fully developed leaves (5th, 6th or 7th leaf from the top of the shoot), using the LCpro+ portable photosynthesis system manufactured by ADC BioScientific Ltd. Light conditions were set using the LCpro+ light unit, which emitted saturated photo synthetically active radiation (PAR) with photon flux density at 1000 μmol m^{-2} s^{-1}. The air supply unit provided a flow of ambient air to the leaf chamber at a constant rate of 100 μmol s^{-1}. Temperature, CO_2 concentration and humidity were at ambient levels. Water use efficiency (WUE) was calculated as the ratio of photosynthesis to transpiration rate (μmol of CO_2 m^{-2} s^{-1}/mmol of H_2O m^{-2} s^{-1}). All parameters were measured between 10-13h, during a clear sunny day.

Concentration of photosynthetic pigments was determined by employing spectrophotometry of 100% acetone leaf pigment extracts by method of Wettstei (1957).

Measurements were conducted in 9 replicates per each pepper variety randomly selected at each crop. Bioproduction parameters were analyzed using t test for independent samples. All other data were analyzed with Duncan's multiple range test. Values shown are arithmetic means of 9 replicates and error bars indicate standard error. Significance level used was $p<0.05$. The average values shown in figures followed by the same letter did not differ significantly.

Results

Analyses of fruit development showed significant variations between ten pepper varieties (Table 1). Total fruit yield per one hectare was higher in greenhouse that in field with exception of variety Krušnica (9). The highest yield was determined for Vranjska (3), Anita

Table 1
Parameters of fruit production (arithmetic means ± standard error)

Pepper varieties	Fruits number per plant		Fruits weight per plant, kg		Fruits weight per hectare, t/ha	
	Greenhouse	Field	Greenhouse	Field	Greenhouse	Field
1. Amfora 1	4.3 ±1.2	NA	0.62 ±0.2	NA	1.38	NA
2. Anita	62.0 ±1.0	85.0 ±14.6	5.75 ±0.5	*8.07 ±1.2	16.87	16.13
3. Vranjska	91.3 ±6.4	73.0 ±14.5	*8.26 ±0.7	6.11 ±1.2	18.36	12.24
4. Novosadjanka	99.0 ±7.1	117.7 ±3.3	5.38 ±0.4	5.80 ±0.2	11.96	11.61
5. Amfora	10.7 ±3.2	6.0 ±3.1	1.23 ±0.4	0.59 ±0.3	2.73	1.18
6. Una	67.7 ±1.2	62.7 ±11.7	4.50 ±0.12	3.60 ±0.8	9.99	7.21
7. Plamena	115.0 ±4.9	*155.0 ±11.8	5.69 ±0.3	4.86 ±0.6	12.65	9.71
8. S.M.	99.0 ±13.6	NA	3.25 ±0.5	NA	7.22	NA
9. Krušnica	43.7 ±2.8	*79.0 ±9.5	1.69 ±0.1	2.00 ±0.1	3.75	4.01
10. Ljuta 127	145.0 ±31.0	NA	1.00 ±0.3	NA	2.23	NA

* t test significant difference between greenhouse and field mean values ($p<0.05$)

(2), Plamena (7) and Novosadjanka (4) at both greenhouse and field.

Correlation of fruits weight per hectare (crop yield) with fruits number per plant was low for both greenhouse and field (0.34 and 0.55), whilst correlation of crop yield with fruits weight per plant is high (0.99 for both greenhouse and field).

Photosynhetic intensity showed statistical specificity for pepper varieties (Figure 1). The variations of CO_2 assimilation values between different varieties were more diverse in field conditions, which is in correlation with greater variability of transpiration rates of field-grown plants. Although in 6 of ten pepper varieties, photosynthesis and water use efficiency was higher in the greenhouse than in field conditions, there are no clear correlations between higher yields of pepper grown in the greenhouse and measured photosynthetic intensities or WUE.

All leaves of pepper used for analyses were green colored, homogenous without any foliar variegation. Concentration of photosynthetic pigments was significantly different between investigated pepper varieties

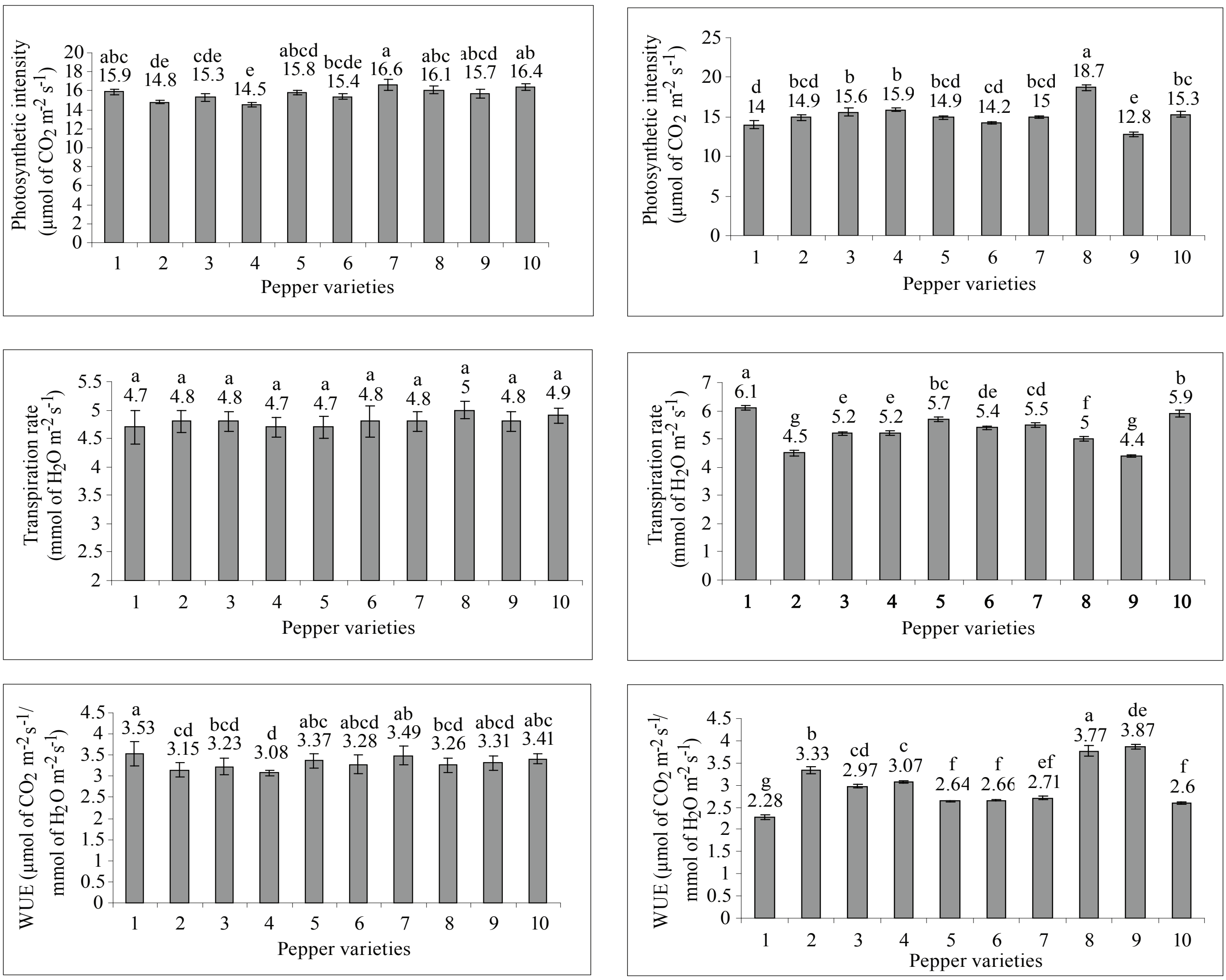

Fig. 1. Parameters of photosynthetic CO_2 assimilation, transpiration rate and water use efficiency of 10 pepper varieties grown in a plastic greenhouse and on field

(Figure 2). However, the variability of pigments content was not the same in field conditions as for plants grown in the plastic greenhouse. As with photosynthetic and transpiration intensities, significant correlations could not be determined between pigments content and pepper yield. The correlation between photosynthetic activity and pigment concentrations was also not significant (-0.42). Concentrations of chlorophyll a, b and carotenoids was significantly higher in the leaves of plants grown in the greenhouse, which was expected since the light intensities of the greenhouse are lower that in the open field area. However, lower pigment concentration did not cause disturbances in photosynthetic activity or pepper yield production.

Discussion

Significant differences between investigated pepper varieties were previously determined for anatomical parameters, germination dynamics, potassium and calcium content and oil quantity in seed (Krstic et al., 2001; 2010). Except Krusnica (9) all varieties have showed

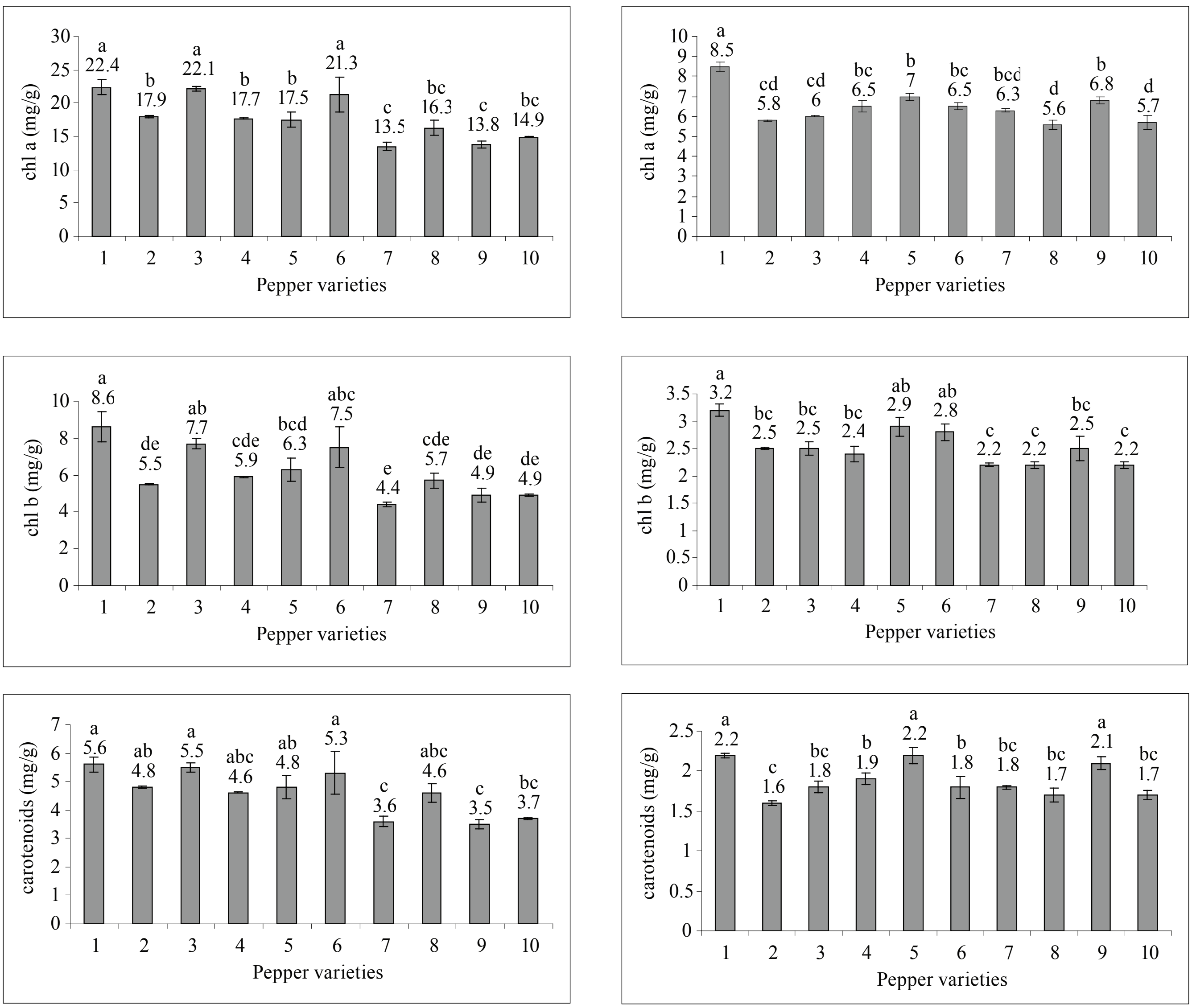

Fig. 2. Pigment content in leaves of 10 pepper varieties grown in a plastic greenhouse and on field

greater potential for production in a plastic greenhouse due to determined higher fruit yields. Slightly greater variability of measured photosynthetic and transpiration parameters between pepper varieties in the field conditions indicate to more stabile environment in the plastic greenhouse, when applied standard growth methods are used. Established diversity between pepper varieties is expected since peppers are know for their morphological and physiological diversity (Guil-Guerrero et al., 2006; Stummel and Bosland, 2007; Todorova, 2007). Todorova (2007) has confirmed the variability of pepper varieties in fruit characterization, and its correlations with genotypic and environmental factors. Fruit weight per plant has shown high correlation with total pepper yield per hectare, for all ten investigated varieties. Although each variety had, its specific values of net photosynthesis, transpiration, water use efficiency and pigment content, measured values are not directly correlated with high pepper yield. However, photosynthetic intensity was measured only at one point, during ripening, in the mid day, between 10-13h when the CO_2 assimilation should be at its highest rate. The dynamic of total photosynthetic activity throughout the vegetation season could nevertheless display specific relations to the crop yield of each variety. It is very important to define at what time of plant development the net photosynthesis has been measured, since the relation between photosynthesis and crop yield depends on phase of plant development (Sinclair et al., 2004; Takai et al., 2006; Peng et al., 2008; Wyzgolik et al., 2008).

Higher pigment content in pepper determined for all varieties grown on a field is probably related to lower light intensities of a plastic greenhouse. Polyethylene foil used for this greenhouse is known to slightly reduce solar irradiation, therefore reducing available light intensity on the leaf surface (Czarnowski and Cebula, 1994), but without disturbances to crop yield (Wyzgolik et al., 2008). It is already confirmed that photosynthetic performance and pigment content in leaves depends on light intensity (Fu et al., 2010). Lower light intensities usually cause upraise in the concentration of photosynthetically active leaf pigments. Wyzgolik et al. (2008) confirmed that sweet pepper plants grown under lower light intensities also had higher concentration of chlorophyll and carotenoids, which correlated with lower photosynthetic intensity. Results indicate that lower concentrations of chlorophyll a, b and carotenoids did not reflect to photosynthetic activity or water use efficiency of investigated pepper varieties. Clearly, higher pepper yield of each variety is a function of more complex range of parameter sets and not a simple reflection of peak mid day values of photosynthetic CO_2 assimilation, phtosynthetically active pigments in the leaves, transpiration rate and water use efficiency. Furthermore, one point measuring of these photosynthetic and water usage parameters, during fruit ripening are not a reliable indicators and predictors of pepper yield bioproduction, when peppers are not exposed to any additional stress.

Conclusions

Ten investigated pepper varieties showed specific variations in fruit number, fruit weight per plant and total yield per hectare. Variability of each pepper variety was also specifically expressed in relations to photosynthetic intensity, concentration of photosynthetic pigments, transpiration rates and water use efficiency. Low, insignificant correlation was determined between one point mid day-measured values of photosynthetic CO_2 assimilation, transpiration rates and water use efficiency in relation to pepper fruit yield. These results indicate to more complex links between pepper yields and photosynthetic and transpiration activities, which require additional analyses of seasonal and circadian dynamics of these metabolic parameters.

Acknowledgements

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