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RESPONSE TO DROUGHT STRESS OF THREE STRAWBERRY CULTIVARS GROWN UNDER GREENHOUSE CONDITIONS

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A B S T A R C T

The reaction of three strawberry cultivars ('Elsanta', 'Elkat', 'Salut') to drought stress was examined by evaluating the yield and morphological (leaf area, root development) and physiological (leaf gas exchange, leaf water potential) parameters. Plants were subjected to two different water regimes: optimal irrigation (control), and reduced irrigation (drought stress treatment). Genotypes differed in their response to water deficiency. Cultivar 'Elsanta' had high rate of net photosynthesis with high water use efficiency (a ratio of photosynthesis rate to transpiration rate) under water shortage conditions. Drought stress reduced leaf area in all cultivars, but root development was retarded in 'Elkat' only. Under water deficiency conditions 'Elsanta' gave the highest yield whereas 'Elkat' the lowest. Among examined cultivars, 'Elsanta' appeared to be the most drought tolerant, which was reflected by both growth and yield parameters.

Key words: *Fragaria ananassa*, photosynthesis, transpiration, growth, water stress

INTRODUCTION

Drought is one of the most common environmental factors affecting plant growth and productivity. Reduced water availability induces numerous physiological and biochemical changes in all plant organs. Gas exchange in leaves is limited, which in turn reduces carbon assimilation. Changes in the distribution of photoassimilates can reduce vegetative growth and severely retard the development of plant reproductive organs (Boyer, 1970; Gehrmann, 1985; Singer et al., 2003).

Genotypic differences in drought tolerance have been observed for various crop species (Bota et al., 2001, Herralde et al., 2001). However, there is still a lack of information about morpho-physiological behaviour of different strawberry cultivars under limited water availability. Therefore, the main objective of this study was to examine the response of three strawberry cultivars to drought stress by evaluating their productivity and selected morphological and physiological parameters.

MATERIAL AND METHODS

The experiment was carried out in 2006 in a greenhouse of the Research Institute of Pomology and Floriculture in Skierniewice, Poland on three strawberry cultivars: ‘Elsanta’, ‘Elkat’ and ‘Salut’. “Frigo” plants were planted in plastic containers (18 dm^3) filled with a peat substrate. The plants were fertigated with nutrient solution according to Treder (2002) by CNL emitters (2 $dm^3\ h^{-1}$) (Netafim, Israel). Nutrient solution application was controlled by Akbar irrigation computer (AMGi, Spain) according to growing medium moisture measurements. The moisture content of the substrate was monitored with ECH_2O capacitance probes (Decagon Devices, USA). Plants were subjected to two water regimes: (i) optimal regime (control) – plants were watered to maintain 90 – 100% of substrate water capacity (SWC); (ii) reduced regime (stress treatment) – moisture was maintained at a level of about 50% of SWC. Substrate water capacity was determined according to water retention curves prepared for the growing medium used in the experiment (Fonteno, 1996). Both water regimes were applied to the plants at the beginning of the experiment and lasted for its whole period (3 months). The experiment was prepared in four replicates, each consisted of one container with six plants.

Measurements of leaf water potential and leaf gas exchange (net photosynthesis and transpiration) were performed twice during the experimental period (two sampling times: thirty and sixty days after the commencement of the experiment). The gas exchange rate was measured on two young, fully expanded leaves from each plant using an LI-6400 portable photosynthesis system (LI-COR, USA). Temperature, CO_2 concentration and irradiance in the leaf chamber during analysis were set to approximate ambient conditions. Measurements of the midday leaf water potential were made using the SKMP-1400/40 pressure chamber (Skye Instruments, UK).

Plant morphometry involved measurement of total leaf area and root length. Measurements were performed at the end of the experiment. The leaf surface area was measured using WinDIAS image analysis system (Delta-T Devices, UK). Root samples from each plant were collected and cleaned. The total root length was measured using a Scan image analysis system (Delta-T Devices, UK).

All data were statistically elaborated using analysis of variance (ANOVA), followed by means separation using Duncan's multiple-range t-test at $p < 0.05$. All calculations were performed with the help of the Statistica 6.0 software package (StatSoft, USA).

RESULTS AND DISCUSSION

The physiological status of the strawberry plants was assessed by measuring water potential and gas exchange rate in the leaves. Water deficiency significantly decreased leaf water potential of all the cultivars examined (Tab. 1). In the situation when the water content in a growing medium is insufficient to provide the adequate plant supply, the water loss through transpiration reduces the water potential in tissues. Such reaction was observed in many plant species both under field and protected conditions (Valancogne et al., 1997; Blanke and Cooke, 2004). The cultivars studied showed different capacities in maintaining the leaf water potential under water deficiency conditions (Tab. 1). Cultivar 'Elsanta' was able to maintain a higher potential in comparison to the two others. This was especially visible 60 days after the beginning of the experiment.

Generally, plants grown in soilless culture under greenhouse conditions are exposed to sudden and severe stress when irrigation fails. This is because the volume of the substrate in which the plants are growing, and thus water holding capacity, is limited. Water reserves are therefore quickly exhausted and the plants suffer from drought. In our study the plants received reduced irrigation during the whole experimental period. However, no wilting of the plants was observed even at the lowest recorded values of water potential (-1.87 MPa for 'Salut'). It is in general accordance with observations of Sruamsiri and Lenz (1986) who suggested -1.7 MPa as the threshold for wilting and -2.5 MPa as the threshold for irreversible drought damage in strawberry plants.

Water availability is a limiting factor for a wide range of physiological processes in plants. One of the first responses of plants to drought is stomatal closure, which restricts gas exchange between the inside of the leaf and the atmosphere. Therefore, this is the main mean of regulating water relations and carbon assimilation in plants (Hetherington and Woodward, 2003). Stomatal closure protects plants against excessive water loss, but also restricts the diffusion of CO_2 into the photosynthetic parenchyma (Chaves et al., 2003).

The leaf gas exchange parameters in the control plants showed significant differences among the cultivars examined (Fig. 1, 2). As drought developed, the rate of gas exchange decreased in all cultivars, although not to the same extend. The strongest decrease in net photosynthesis and transpiration rates was observed 60 days after the beginning of the experiment for 'Elsanta' (75 and 82%, respectively), followed by 'Elkat' (72 and 72%, respectively) and

Table 1. Leaf water potential of control and drought stressed strawberry plants

Cultivar	Leaf water potential [MPa]			
	first sampling time		second sampling time	
	control	stressed	control	stressed
Elsanta	-0.74c*	-1.61b	-0.72c	-1.45b
Elkat	-0.74c	-1.75ab	-0.85c	-1.68a
Salut	-0.62c	-1.81a	-0.75c	-1.87a

*Means in the columns followed by the same letter are not significantly different according to Duncan's multiple-range t-test at $p < 0.05$. Analysis performed separately for each sampling date

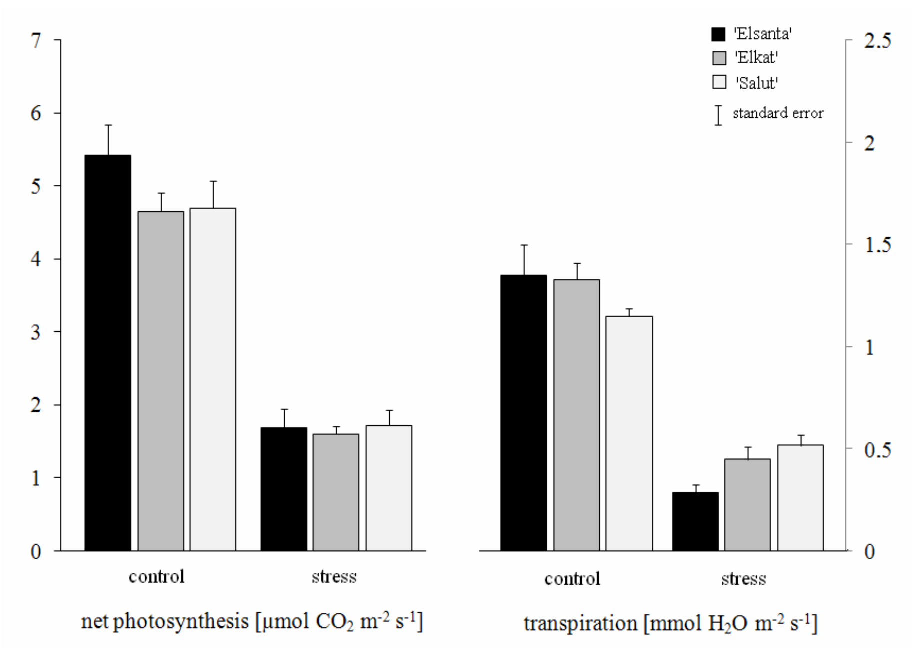

Figure 1. Gas exchange of control and drought stressed strawberry plants (first sampling time)

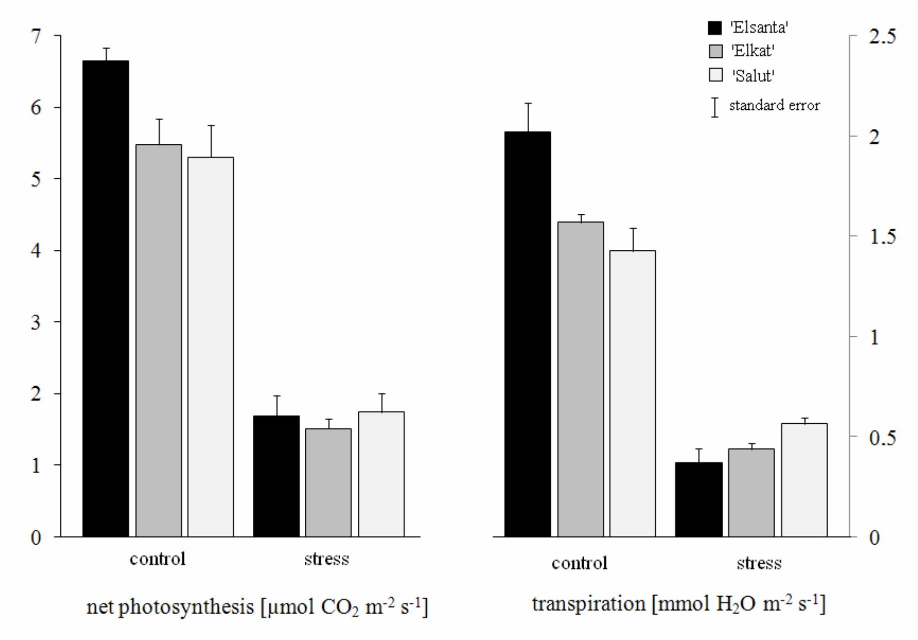

Figure 2. Gas exchange of control and drought stressed strawberry plants (second sampling time)

'Salut' (67 and 60%, respectively). Reduction in gas exchange has been observed in many fruit crops grown under drought conditions (Jorba et al., 1985; Chandler and Ferree, 1990; Klamkowski and Treder, 2002).

The decrease in photosynthesis in drought-stressed plants can be attributed both to stomatal (stomatal closure) and non-stomatal (impairments of metabolic processes) factors. At present most researchers agree that the stomatal closure and resulting CO_2 deficit is the main cause of decreased photosynthesis under mild and moderate stresses (Flexas and Medrano, 2002) while changes in photosynthetic reactions are considered as a prevailing factor which leds to photosynthesis restriction under severe drought (Yordanov et al., 2003). In our previous study (Klamkowski and Treder, 2006) we have demonstrated that in strawberry plants grown under moderate water stress stomatal closure was the dominant factor limiting photosynthesis. This is in agreement with results obtained in this study – for the 'Elsanta' plants stomatal conductance (and transpiration) was more affected by drought than photosynthesis (Fig. 1, 2) (results for stomatal conductance are not presented).

The water use efficiency (WUE) was calculated in order to integrate the results on changes in gas exchange rates. At the leaf level, WUE can be determined as a ratio of photosynthesis rate to transpiration rate or to leaf conductance for water vapour (Sinclair et al., 1984; Pietkiewicz et al., 2005). According to Boyer (1982), the ratio of carbon fixation to water loss (i.e. water use efficiency) is critical to plant survival, crop yield and vegetation dynamics. WUE has been used in many experiments on water relations and drought resistance in various crop species (Flore et al., 1985; Escalona et al., 1999).

In the present study, WUE varied significantly depending on the examined cultivar and water availability (Tab. 2). In case of cultivar 'Elsanta', WUE of the stressed plants was higher compared to the well-irrigated ones. High WUE observed for this cultivar was a consequence of a high value of net photosynthesis rate at low transpiration (Fig. 1, 2). Such results indicate increased capacity for water saving by 'Elsanta' in comparison to the two other cultivars. Chaves et al. (2003) concluded that most plants tend to show an increase in water use efficiency under conditions of mild and moderate water deficiency. This increase results from the non-linear relationship between stomatal conductance and carbon assimilation. It means that water loss is restricted earlier and more intensely than the inhibition of photosynthesis. According to Escalona et al. (1999), high WUE reflects an ability to maintain photosynthetic capacity under water deficiency conditions and a higher resistance to drought (Bota et al., 2001).

The linkage between water availability and plant growth is well documented in a wide range of species including strawberry (Gehrmann, 1985; Chandler and Ferree, 1990; Gehrmann and Lenz, 1991). Alterations in biomass distribution patterns resulting in growth modifycations are generally considered as important acclimation mechanisms to drought conditions (Buwalda and Lenz, 1992; Starck, 1995). Growth inhibition is one of the earliest responses of plants to water deficiency (Boyer, 1970; Hsiao, 1973). In our study, significant changes in morphological parameters were observed in the plants subjected to drought (Tab. 3). The leaf area of the stressed plants was considerably reduced as compared to that of the control ones. The sharpest reduction in the leaf area was recorded in 'Elkat' (approx. 34% compared to control) and 'Salut' (approx. 19%) cultivars. No significant differences in the root length were observed between well-irrigated and drought stressed 'Elsanta' and 'Salut' plants, while the root development in 'Elkat' cultivar was retarded (Tab. 3). Generally, growth inhibition in response to reduced water availability was higher in the above-ground portions of the plants than in the root systems. A deeper, more extensive root system enables the plants to increase water uptake and survive during drought.

Photosynthesis is an important factor that determines plant productivity. In the present study, limited irrigation resulted in a significant decrease of berry yield (Tab. 3). The highest yield (both

Table 2. Water use efficiency of control and drought stressed strawberry plants

Cultivar	Water use efficiency [μmol CO_2 m^{-2} s^{-1}/mmol H_2O m^{-2} s^{-1}]			
	first sampling time		second sampling time	
	control	stressed	control	stressed
Elsanta	4.09ab*	5.86c	3.36a	4.80b
Elkat	3.58a	3.65a	3.48a	3.46a
Salut	4.45b	3.61a	3.74a	3.08a

*Explanation, see Table 1

Table 3. Fruit yield and growth related parameters of control and drought stressed strawberry plants

Cultivar	Root length [cm $plant^{-1}$]		Total leaf area [cm^2 $plant^{-1}$]		Yield [g $plant^{-1}$]	
	control	stressed	control	stressed	control	stressed
Elsanta	3771.41ab*	3547.35a	2309.50d	1985.38bc	169.77d	126.44bc
Elkat	4249.31b	3689.90a	2001.06bc	1311.62a	136.31bc	85.15a
Salut	4269.75b	3809.10ab	2154.90cd	1737.62b	150.36cd	106.38ab

*Means in the columns followed by the same letter are not significantly different according to Duncan's multiple-range t-test at $p < 0.05$

under optimal and reduced water availability) was obtained from the cultivar 'Elsanta'. The losses in yield in response to drought treatment were: 38% for 'Elkat', 29% for 'Salut', and 26% for 'Elsanta' cultivar.

According to Bota et al. (2001), cultivars which are more resistant to drought (having high WUE values at reduced water availability) are usually less productive under favourable conditions. Similar observations were made by Chandler and Ferree (1990) on two strawberry cultivars. In their experiment, the cultivar 'Surecrop' was more resistant to drought than the cultivar 'Raritan', having higher gas exchange rates and minimal losses in yield when subjected to water deficiency. However, under favourable conditions 'Raritan' (less resistant to drought) produced much higher fruit yield than 'Surecrop'. In our study cultivar 'Elsanta' outyielded the two other cultivars both under conditions of optimal and limited irrigation (Tab. 3).

CONCLUSIONS

The study presented revealed significant morphological and physiological differences between three examined strawberry genotypes. Cultivar 'Elsanta' was evaluated as the most adaptable to water shortage. It was superior in reducing water consumption under drought conditions. This cultivar had high rates of net photosynthesis and a high value of water use efficiency both under favourable and water deficiency conditions. Morphological and physiological adaptations allowed 'Elsanta' plants to maintain growth and productivity when water availability was decreased.

The plants of cultivar 'Elkat' showed the lowest tolerance to water shortage. Drastic reduction in growth and losses in yield in response to drought treatment confirms low usefulness of this genotype to cultivation in drought-prone environments.

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REAKCJA NA STRES SUSZY TRZECH ODMIAN TRUSKAWKI UPRAWIANEJ POD OSŁONAMI

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STRESZCZENIE

Truskawka jest zaliczana do roślin o dużym zapotrzebowaniu na wodę i dużej wrażliwości na jej deficyt. W badaniach nad nawadnianiem coraz większy nacisk kładzie się na poznanie reakcji na niekorzystne czynniki środowiska poszczególnych odmian roślin uprawnych. Odmiany o mniejszych wymaganiach wodnych i/lub wyższej tolerancji na suszę mogą być przydatne na obszarach, gdzie istnieje ograniczony dostęp do źródeł wody lub w sytuacjach, gdzie oszczędności wynikłe z ograniczonego nawadniania będą równoważyć straty związane z obniżeniem plonu. Ma to szczególne znaczenie w technologiach uprawowych stosowanych pod osłonami, gdzie jedynym źródłem wody jest tylko ta podawana przez system nawodnieniowy, a więc dąży się do jak najbardziej oszczędnego zużycia wody i nawozów.

W doświadczeniu określono reakcję na suszę trzech odmian truskawki – ‘Elsanta’, ‘Elkat’, ‘Salut’. Rośliny były uprawiane w szklarni w pojemnikach (18 dm^3) wypełnionych substratem torfowym. Zastosowano dwie kombinacje nawodnieniowe: (i) optymalne nawadnianie – wilgotność podłoża utrzymywana na poziomie 90-100% pojemnikowej pojemności wodnej (PPW) (kontrola), (ii) deficyt wody – wilgotność podłoża utrzymywana na poziomie 50% PPW. Rośliny stresowane otrzymywały obniżone dawki wody w ciągu całego cyklu uprawowego. Wilgotność podłoża w skrzynkach była kontrolowana za pomocą sond pojemnościowych. Wykonywano pomiary intensywności wymiany gazowej oraz potencjału wody liści. Ponadto oceniano wzrost roślin (pomiary powierzchni liści i długości korzeni) oraz ich plonowanie.

Wyniki badań wskazały, iż deficyt wody w podłożu znacznie ograniczył natężenie wymiany gazowej oraz potencjał wody w liściach roślin. Pomiędzy badanymi odmianami stwierdzono istotne różnice w tolerancji na suszę. Najbardziej odporne na suszę były rośliny odmiany ‘Elsanta’, u których stwierdzono najmniejsze zahamowanie rozwoju systemu korzeniowego, powierzchni liści oraz plonowania. Na podstawie pomiarów parametrów fizjologicznych (natężenia fotosyntezy i transpiracji, których stosunek wyraża efektywność wykorzystania wody) wykazano, że rośliny odmiany ‘Elsanta’ charakteryzują się sprawniejszą regulacją stosunków wodnych, co znalazło swoje potwierdzenie w większym plonowaniu tych roślin w warunkach suszy.

Słowa kluczowe: *Fragaria ananassa*, wzrost, fotosynteza, transpiracja, stres wodny