

BRIEF COMMUNICATION

Chlorophyll fluorescence as a tool for evaluation of drought stress in strawberry

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Abstract

The effect of water deficit on chlorophyll fluorescence, sugar content, and growth parameters of strawberry (*Fragaria×ananassa* Duch. cv. Elsanta) was studied. Drought stress caused significant reductions in leaf water potential, fresh and dry masses, leaf area, and leaf number. A gradual reduction of photochemical quenching (q_p) and quantum efficiency (Φ_{PS2}) was observed under drought stress while non-photochemical quenching (q_N) increased. Maximum efficiency of photosystem 2 (F_v/F_m) was not affected by drought stress.

Additional key words: *Fragaria×ananassa*; maximum efficiency of photosystem 2; photochemical and non-photochemical quenching; photosynthesis; water deficit.

Water deficiency is a limiting factor for plant growth and development as well as for a wide range of physiological processes such as photosynthesis. Chlorophyll (Chl) fluorescence provides useful information about leaf photosynthetic performance of many plants under drought stress (Baker and Rosenqvist 2004). However, studies on strawberry under drought stress are still limited and focus mainly to research on irrigation scheduling (Kruger *et al.* 1999). In order to better understand the response of strawberry to the onset and progress of drought stress we studied Chl fluorescence parameters in parallel with plant growth performance.

A greenhouse experiment was conducted from October 2006 till February 2007 with the short day cultivar *Fragaria×ananassa* Duch. cv. Elsanta. Plants were grown in 3 000 cm³ pots in 80 : 20 % peat and perlite mixture at 18/14 °C day/night temperature, a daily average vapour pressure deficit (VPD) of 0.5–0.9 kPa, and a 16-h photoperiod. Natural day length was extended with metal halide lamps giving 30–40 $\mu\text{mol(PAR)} \text{ m}^{-2} \text{ s}^{-1}$ at canopy level and daily average value of PAR ranged from 20 till 150 $\mu\text{mol m}^{-2} \text{ s}^{-1}$. Plants were weekly supplied with 100 cm³ of a standard nutrient solution for strawberry (Lieten 1995) and with rain water on the other

days maintaining the pots close to field capacity. After nine weeks pots were assigned to a control and a drought stress (irrigation stop) treatment in a completely randomized block design with three replicates and 25 plants for each experimental plot. Volumetric substrate moisture content θ_v (*Theta probe, ML2X, Delta T Devices, Cambridge, UK*) was recorded at hourly intervals. During the experiment, measurements were performed at days 1, 16, 27, 40, 44, and 51. The leaf water potential (Ψ_w) of the upper leaflet of the youngest fully developed leaf ($n = 6$ per experimental plot) was measured with a thermocouple psychrometer operating in the psychrometric mode between 08:00 and 09:00. Chl fluorescence was measured on the youngest fully expanded triplet leaf ($n = 4$ per experimental plot) using a portable fluorometer (*PAM-2000, Walz, Effeltrich, Germany*). Leaves were allowed to dark adapt for 20 min (Genty *et al.* 1998). Sugars of fully expanded leaves ($n = 6$ per experimental plot) were extracted with 80 % ethanol and analyzed by HPLC with pulsed amperometric detection (*Dionex, column CarboPac PA10 with companion guard column*). Morphological traits were determined at the start and end of the drought stress experiment. Measurements included number of leaves, leaf area, and fresh and dry masses

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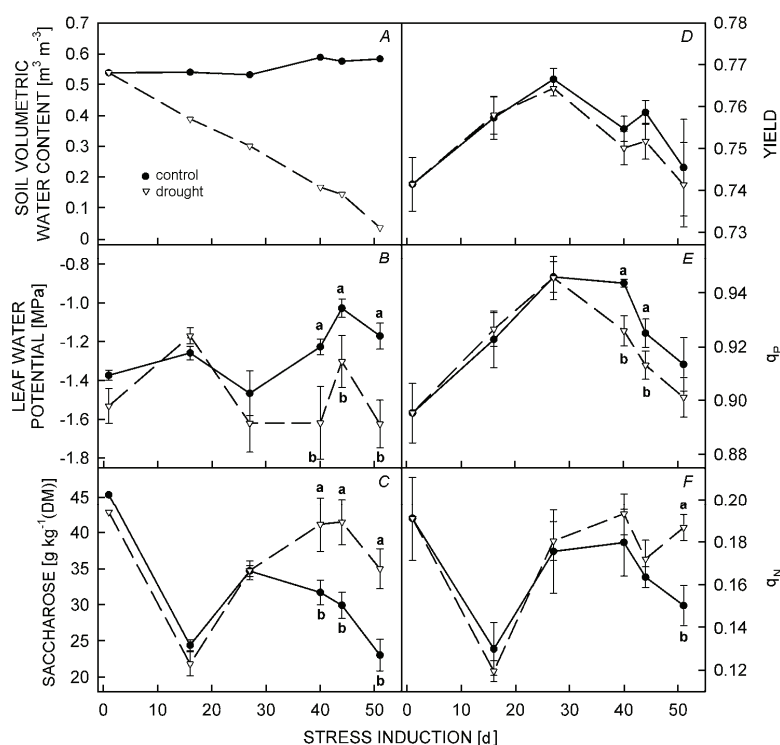


Fig. 1. Effect of increasing drought stress on (A) substrate volumetric water content, (B) leaf water potential, (C) saccharose content of leaves, (D) the quantum yield of PS2 electron transport (Φ_{PS2}), (E) photochemical quenching (q_P), and (F) non-photochemical quenching (q_N) of *Fragaria* \times *ananassa* Duch. cv. Elsanta. Means \pm SE, $n = 3$, significant differences were calculated by student F-test and indicated by a, b ($p \leq 0.05$).

of the aerial biomass. Data were subjected to one-way ANOVA using *SPSS 15.0.1* (SPSS, Chicago, USA).

The continuing decrease of θ_v (Fig. 1A) and of Ψ_w (Fig. 1B) during the experiment demonstrated an increasing drought stress imposed on the strawberry plants. From day 40 on ($\theta_v < 0.20 \text{ m}^3 \text{ m}^{-3}$), Ψ_w of the stressed plants was significantly lower than in control plants. In control plants Ψ_w showed unexpectedly important fluctuations that might be caused by short-term weather conditions and might therefore be a more sensitive measure of water status (Jones 1990). Sircelj *et al.* (2005) demonstrated that pre-dawn and midday Ψ_w of apple leaves under progressing drought stress showed comparable responses. In our experiment, the differences in Ψ_w between control and stressed plants were not higher than 0.5 MPa which would suggest a mild drought stress according to Hsiao (1973). The visible wilting of strawberry leaves at noon after withholding water for 51 d suggests, however, that this classification can not be applied to all plants. In strawberry leaves, the distribution of absorbed photons between photochemical and non-photochemical quenching changed with increasing drought, especially from day 40 on as indicated by a significant decline and rise of q_P and q_N , respectively (Fig. 1E,F). Due to the low irradiances during our experiment in winter, q_N increased rather moderate under severe stress, but thermal dissipation of absorbed photon energy is well established in studies with higher irradiances (Flexas and Medrano 2002). Haupt-Herting and Fock (2000) demonstrated in tomato that under

$90 \mu\text{mol m}^{-2} \text{ s}^{-1}$, q_N increased but to a lower extent compared to the same stress at $400 \mu\text{mol m}^{-2} \text{ s}^{-1}$. The effects on q_N and q_P for both irradiances were also moderate in tomato for Ψ_w of -1.2 MPa, but were very pronounced for Ψ_w of -2.0 MPa. Therefore, a further decrease of Ψ_w in the strawberry leaves might further enhance the increase in q_N . A slight decrease of Φ_{PS2} was noted when θ_v decreased below $0.30 \text{ m}^3 \text{ m}^{-3}$ (day 27, Fig. 1D), while F_v/F_m was not significantly affected by the applied drought stress (data not shown) which corresponds with previous reports (Baker and Rosenqvist 2004). The reduction of Φ_{PS2} might therefore be attributed to the decline of q_P . The slow development of drought stress in this experiment might enable the activation of different acclimation mechanisms such as osmotic adjustment, leading to the maintenance of photosynthetic capacity (Flexas *et al.* 1999). Indeed, from day 40 on we found a significant increase of saccharose content (Fig. 1C) which is a well-known osmolyte (Ingram and Bartels 1996); this is consistent with previous observations on *Fragaria chiloensis* (Zhang and Archbold 1993). Drought stress significantly reduced both fresh and dry biomass, leaf area, and leaf number in strawberry cv. Elsanta (Table 1). A decrease in leaf area reduced transpiration and was observed in many crops under drought stress (Hsiao 1973) as well as in strawberry cultivars (Klamkowski and Treder 2006).

In conclusion, our results demonstrate that under low irradiances drought stress in strawberry induces changes in leaf water potential, photosynthetic parameters, and sugar content as well as morphological adaptations. The

Table 1. Effect of drought stress on plant growth parameters and the water content of the aerial biomass of *Fragaria* × *ananassa*. Means ± SE, $n = 3$, significant differences were calculated by student F-test and indicated by a, b ($p \leq 0.05$).

	Start of experiment	End of experiment Control	Drought
Number of leaves	6.83 ± 0.33	9.55 ± 0.62 a	7.88 ± 0.77 b
Youngest fully opened leaf area [cm ²]	47.00 ± 3.80	81.40 ± 9.10 a	54.20 ± 3.60 b
Fresh mass [g per plant]	12.47 ± 0.39	22.13 ± 2.10 a	14.71 ± 1.90 b
Dry mass [g per plant]	3.41 ± 0.13	5.38 ± 0.46 a	3.66 ± 0.40 b
Shoot water content [%]	72.00 ± 0.80	75.00 ± 1.40 a	74.00 ± 0.60 a

Chl fluorescence parameters q_p and q_N reflect the photosynthetic responses to drought stress better than Φ_{PS2} and F_v/F_m . However, it cannot be excluded that these

parameters might also be a useful indicator for rapid screening of tolerance to drought stress if irradiances were high enough.

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