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Effect of Water Stress on Photosynthetic Characteristics of Two Sorghum Cultivars

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ABSTRACT

The effects of water stress on the photosynthetic characteristics of two locally-cultivated sorghum cultivars ('Segaolane' and 'Town') were investigated over a period of weeks. Water stress was imposed on 1-week-old plants by withholding water. Measurements of chlorophyll fluorescence were used to determine changes in the efficiency of light utilization for electron transport, the occurrence of photoinhibition of photosystem II photochemistry on the sorghum cultivars. Drought treatment significantly decreased leaf area in all species, an important factor in drought-induced decreases in photosynthetic productivity. Water-stressed 'Town' exhibited a decrease in maximum photochemical efficiency of PSII (estimated from dark-adapted F_v/F_m ratio) with increasing period of withholding water. Light-adapted F_v'/F_m' estimated the efficiency of excitation energy transfer to *open* PSII centres. Water-stressed 'Town' displayed a decrease in the efficiency of excitation energy transfer to open PSII reaction centres throughout the entire study period. The quantum yield of PSII electron transport (ΦPSII), which represents electron flow beyond PSII, decreased markedly in water-stressed 'Town' compared with that of water-stressed 'Segaolane'. These initial findings indicate that 'Town' is more prone to photoinhibition than 'Segaolane'.

Keywords: chlorophyll fluorescence, dark-adapted F_v/F_m, photoinhibition, 'Segaolane', 'Town'

INTRODUCTION

The aim of the study was to assess the effect of water stress on photosynthetic characteristics of two locally-cultivated sorghum varieties, *viz.*, 'Segaolane' and 'Town'.

Sorghum is one of the five major cereal crops in the world (Krieg 1983). It is generally considered to be more tolerant to drought than maize (Ackerson *et al*. 1977; Rai *et al*. 1999). In spite of its relatively high tolerance to drought, sorghum yields can increase by as much as four-fold if produced under irrigation (Osmanzai 1994; Rai *et al*. 1999). Previous studies have shown that total leaf area, specific leaf weight, specific leaf area and grain yield all decreased with water stress while root/shoot ratio increased (Munamava *et al*. 2001). Reduction in leaf area in response to water can occur either through hastened leaf senescence or a decline in leaf expansion and the extent of reduction appears to be dependent on relative tolerance of sorghum varieties (Stout *et al*. 1980; Krieg 1994; Asraf and Ahmad 1998). Munamava *et al*. (2001) observed that although varietal differences in yield were not significant, based on overall performance the older 'Segaolane' appeared superior to the more recently developed 'Phofu' and 'Mahube' varieties, in conditions of hydrological unpredictability and intermittent water stress.

Under severe water stress, electron transport to O_2 and increased quenching of excitation energy in the photosystem II (PSII) antennae may be unable to dissipate the excess excitation energy in the PSII antennae and photodamage to PSII will result, with a possible net loss of D_1 protein of PSII reaction centres (Baker 1993; Cornic 1994). As Long *et al*. (1994) pointed out, such effects can have significant consequences for the photosynthetic productivity of plants.

A decrease in the ratio of variable to maximal chlorophyll fluorescence (i.e., dark-adapted F_v/F_m) has been employed as an indicator of the degree of photoinhibition (Gravett 1992; Groom *et al*. 1992; Moseki 1997; Kreslavski *et al*. 2008). Dark-adapted F_v/F_m estimates the efficiency of excitation energy capture by *open* PSII reaction centres (Butler and Kitajima 1975) and provides a rapid method for determining changes in maximum quantum efficiency of PSII photochemistry. Decreases in F_v/F_m can result from both light-dependent increases in nonphotochemical processes, which dissipate excitation energy in the PSII antennae as heat and/or damage to the D_1 protein of PSII reaction centres (Ortiz-Lopez *et al*. 1990). Light-adapted F_v'/F_m' estimated the efficiency of excitation energy transfer to *open* PSII centres (Genty *et al*. 1989).

MATERIALS AND METHODS

Leaf surface area

Seeds of 'Segaolane' and 'Town' sorghum cultivars were germinated in Petri dishes at 25°C. After emergence the seedlings were transferred to pots filled with vermiculate. Each pot contained one plant. The plants were raised in a greenhouse at 25°C and relative humidity of 65-70%. When the plants were one week old, they were separated into two groups. One group was irrigated with Hoagland culture solution every other day, whilst the other group was water stressed by withholding water. All measurements were carried out on the third fully expanded leaf. The leaf area was determined at two-day interval using a leaf area meter (MK2, Delta- T Devices, Cambridge, UK).

Chlorophyll fluorescence

Plants were raised as previously described in leaf area section. The efficiency of excitation energy capture by *open* PSII reaction centres was estimated from the ratio of variable to maximal chlorophyll fluorescence (i.e., dark-adapted F_v/F_m). Fully expanded leaves of four different plants from each treatment were dark-adapted for 15 min by placing the plants in a dark room and the dark-adapted F_v/F_m was then determined using Hansatech fluoro-

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Research Note

meter (FMS2, Hitchin, UK. The light-adapted F_v'/F_m' ratios and the maximum quantum yield of PSII electron (ΦPSII) transport and were also determined using the Hansatech fluorometer (FMS2, Hitchin, UK).

RESULTS AND DISCUSSION

The results of the effect of water stress on the leaf surface area of the two sorghum cultivars, 'Segaolane' and 'Town' are presented in **Table 1**. Overall the leaf surface area of 'Town' is higher than that of 'Segaolane'. There was significant reduced growth of the leaf surface with increase in the period of withholding water for both cultivars with 'Town' exhibiting the highest reduction in leaf surface area ($F_{1,72}$ = 436.918, P < 0.0001). Furthermore, the water stressed leaf areas were observed to be significantly smaller than that of the controls in both cultivars ($F_{1,72}$ = 29.273, P < 0.0001).

The maintenance of a small leaf area by 'Town' and 'Segaolane' when experienced water stress could serve to minimize water loss and light absorption (**Table 1**) consistent with results obtained by Nogues *et al.* (2001).

There was a general decrease in the dark-adapted F_v/F_m ratio of the two sorghum cultivars with increase in duration of withholding water in water stressed plants (**Table 2**) ($F_{1,72}$ = 389.607, P < 0.001). There was a significant decrease in the maximum photochemical efficiency (estimated from dark-adapted F_v/F_m ratio) of the two cultivars, with 'Segaolane' exhibiting a less decrease in the ratio ($F_{1,72}$ = 63.331, P < 0.001). The decrease in dark-adapted F_v/F_m ratio exhibited by 'Town' variety could be attributed to damage to PSII reaction centres (Ortiz-Lopez *et al.* 1990). Previous studies have also shown that, on re-watering 'Town', it took longer to recover with respect to dark-adapted F_v/F_m ratio than 'Segaolane' (Moseki 2000). Sousa *et al.* (2004) also observed that an advance phase of water stress, a down regulation of PSII activity occurred as revealed by decreases in the maximum quantum yield of PSII (F_v/F_m) and complete recovery of F_v/F_m occurred 3 days after re-watering. It is therefore logical to suggest that decreases in F_v/F_m ratio exhibited by 'Segaolane' (**Table 2**) can be ascribed mainly to down-regulation of PSII by the xanthophyll cycle rather than damage to PSII reaction centres (Cornic 1994).

Light-adapted F_v'/F_m' estimated the efficiency of excitation energy transfer to *open* PSII centres. There was a general decrease in the light-adapted F_v'/F_m' ratio with increase in the period of withholding water (**Table 3**). Although 'Town' appeared to exhibit more reduction in the F_v'/F_m' ratio than 'Segaolane', the difference was not statistically significant ($F_{5,72}$ = 1.099, P = 0.368). The observed small differences in the efficiency of excitation energy transfer to open PSII reaction centres between the two cultivars might contribute to the decrease in the quantum yield of PSII electron transport of 'Town' (**Table 4**).

The quantum yield of PSII electron transport (ΦPSII), which represents electron flow beyond PSII (Bhagooli and Hidaka 2006), decreased significantly in both cultivars when subjected to water stress ($F_{1,72}$ = 80.017, P < 0.001) (**Table 4**). Of the two cultivars, 'Town' exhibited a significantly more reduced quantum yield of PSII electron transport than 'Segaolane' ($F_{5,72}$ = 2.896, P = 0.019. These results suggest that the primary step of water stress-induced damage in 'Town' sorghum cultivar's photosynthetic apparatus appeared to involve a component beyond the PSII, probably at the level of the dark reaction as indicated by reduced quantum yield of PSII electron transport (**Table 4**) and the PSII damage appeared to be secondary (Bhagooli and Hidaka 2006).

Table 1 The effect of water stress on leaf surface area of two sorghum cultivars.

Period of withholding water (days)	Segaolane		Town	
	Control	Stressed	Control	Stressed
6	864 ± 32	674 ± 85	878 ± 34	643 ± 15
9	1134 ± 120	767 ± 198	2538 ± 149	999 ± 20
12	2144 ± 295	799 ± 198	2788 ± 511	1157 ± 31
16	3039 ± 143	855 ± 22	3618 ± 109	1573 ± 29
20	3933 ± 53	1051 ± 188	4469 ± 72	1098 ± 18
24	4600 ± 441	989 ± 61	6650 ± 69	1013 ± 19

Table 2 The effect of water stress on the maximum photochemical efficiency of PSII (estimated from dark-adapted F_v/F_m ratio of two sorghum cultivars.

Period of withholding water (days)	Segaolane		Town	
	Control	Stressed	Control	Stressed
6	0.78 ± 0.04	0.77 ± 0.01	0.77 ± 0.01	0.73 ± 0.03
9	0.77 ± 0.01	0.69 ± 0.03	0.75 ± 0.02	0.62 ± 0.03
12	0.76 ± 0.01	0.69 ± 0.02	0.75 ± 0.02	0.62 ± 0.04
16	0.75 ± 0.01	0.65 ± 0.03	0.73 ± 0.02	0.62 ± 0.02
20	0.75 ± 0.01	0.71 ± 0.01	0.75 ± 0.01	0.64 ± 0.01
24	0.75 ± 0.01	0.69 ± 0.02	0.76 ± 0.01	0.62 ± 0.02

Table 3 The effect of water stress on the light-adapted F_v'/F_m' ratio (± SEM) of two sorghum cultivars.

Period of withholding water (days)	Segaolane		Town	
	Control	Stressed	Control	Stressed
6	0.72 ± 0.03	0.73 ± 0.03	0.73 ± 0.03	0.70 ± 0.02
9	0.73 ± 0.01	0.68 ± 0.04	0.73 ± 0.01	0.64 ± 0.03
12	0.72 ± 0.02	0.67 ± 0.03	0.71 ± 0.02	0.59 ± 0.07
16	0.69 ± 0.02	0.68 ± 0.02	0.70 ± 0.02	0.62 ± 0.01
20	0.70 ± 0.01	0.69 ± 0.01	0.68 ± 0.01	0.64 ± 0.02
24	0.74 ± 0.01	0.69 ± 0.03	0.72 ± 0.01	0.62 ± 0.04

Table 4 The effect of water stress on the quantum yield of PSII electron transport of two sorghum cultivars.

Period of withholding water (days)	Segaolane		Town	
	Control	Stressed	Control	Stressed
6	0.74 ± 0.01	0.70 ± 0.02	0.72 ± 0.02	0.67 ± 0.03
9	0.74 ± 0.01	0.69 ± 0.02	0.72 ± 0.04	0.64 ± 0.01
12	0.72 ± 0.01	0.69 ± 0.02	0.73 ± 0.02	0.61 ± 0.04
16	0.70 ± 0.02	0.68 ± 0.01	0.71 ± 0.02	0.64 ± 0.07
20	0.70 ± 0.01	0.68 ± 0.02	0.68 ± 0.01	0.62 ± 0.01
24	0.73 ± 0.01	0.70 ± 0.02	0.71 ± 0.02	0.62 ± 0.03

CONCLUSIONS

The results indicate that it is the differences in the maximum photochemical efficiency of PSII and the quantum yield of PSII which are the dominant factors in distinguishing between these cultivars when they experience water stress. These two parameters appeared to be more prone to water stress in 'Town' than 'Segaolane'.

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