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# The effects of drought stress on the photosynthetic processes of wheat and of *Aegilops biuncialis* genotypes originating from various habitats

István Molnár[1]*, László Gáspár[2], László Stéhli[1], Sándor Dulai[3], Éva Sárvári[2], István Király[2], Gábor Galiba[1], Márta Molnár-Láng[1]

[1]Agricultural Research Institute of the Hungarian Academy of Sciences, Martonvásár, Hungary, [2]Department of Plant Physiology, Lóránd Eötvös University, Budapest, Hungary, [3]Department of Plant Physiology and Botany, Eszterházy College, Eger, Hungary

**ABSTRACT** The effects of drought stress, simulated by increasing concentrations of PEG, were examined on the photosynthetic processes of wheat and of *Aegilops biuncialis* genotypes originating from various habitats. In the course of moderate stress *Ae. biuncialis* lines originating from dry habitats fixed more $CO_2$ than the wheats due to the less intense stomatal closure. After the greater water loss caused by hard drought stress they had more rapid regeneration ability compared to the wheats. In the case of the wheat variety Sakha drought stress resulted in the induction of the generative phase, with an acceleration in flowering and ripening processes. The properties of *Ae. biuncialis* lines originating from dry habitats could be suitable for improving the drought tolerance of wheat.
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**KEY WORDS**

*Aegilops biuncialis*
drought stress
$CO_2$ fixation
stomatal conductance

It is well documented that during drought stress the relative water content (RWC) and water potential (ψ) of the cells decrease (Lawlor and Cornic 2002). Under such conditions the stomata play an important role in the optimisation of transpiration and photosynthesis. The reduction in photosynthetic activity during drought stress can be attributed in part to the reduced intercellular $CO_2$ concentration ($C_i$) due to stoma limitation and partly to metabolic factors, which may be indicated by an increase in $C_i$ (Lawlor and Cornic 2002). The reduced utilisation of $e^-$ due to the inhibition of the Calvin cycle may result in the slowing down of the electron transport. In this case the thermal dissipation of excitation energy (NPQ) may play an important role in protecting the photosynthetic apparatus from oxidative stress (Demmig et al. 1988). Since photosynthesis has a direct influence on biomass production and on the potential yield quantity, the maintenance of photosynthesis in cultivated wheat under dry conditions is an important breeding aim. *Aegilops biuncialis* Vis. (2n=4x=28) is an allotetraploid species growing chiefly in the Mediterranean, Asia Minor and the Middle East (Miller 1987), where the summers are long, dry and hot. This species could thus represent a valuable reservoir of genes for resistance to drought stress. A better understanding of the photosynthetic processes of *Ae. biuncialis* under drought stress may promote its use for wheat genetic improvement.

## Materials and Methods

The experiments were carried out on three *Aegilops biuncialis* genotypes originating from habitats with different rainfall supplies (MvGB1094 – 225 mm/year, MvGB382 – 550 mm/year, MvGB642 – 1050 mm/year; ICARDA Gene Bank, Syria) and on the breadwheat genotypes Mv9 kr1, a winter wheat carrying a crossability gene, and the drought-resistant spring genotypes Kobomugi and Sakha. The plants were grown in Hoagland solution in greenhouse with a light intensity of 200 μE $m^{-2}$ $s^{-1}$. Water deficiency stress was stimulated by increasing the PEG concentration of the solution each week (0, 12, 15, 18 and 21 m/m%). The water status of the plants was traced by determining the relative water content (RWC) and the leaf water potential ($\psi_L$). The gas exchange parameters (A, $g_s$, $C_i$) were determined between 100 and 1300 μE $m^{-2}$ $s^{-1}$ at a $CO_2$ concentration of 340 ppm using an infrared gas analyser based on the equations reported by von Caemmerer and Farquhar (1981). The chlorophyll-a fluorescence was measured in intact leaves using a PAM 101–103 fluorometer at a light intensity of 200 μE $m^{-2}$ $s^{-1}$.

## Results and Discussion

Although moderate drought stress caused similar reductions in RWC and $\psi_L$ (Table 1), *Ae. biuncialis* genotypes from drier habitats (MvGB1094 and 382) exhibited greater photosynthetic activity (A: 6.7; 9.2) than the wheat varieties Mv9 kr1 and Kobomugi (A: 5.7; 4.6). This could be due to the smaller stomatal closure of the *Aegilops* genotypes. In all the genotypes, stomatal closure proved to be the main limiting factor of $CO_2$ fixation during moderate drought stress due to the reduction in $C_i$ (Lawlor and Cornic 2002). The hard drought stress induced by 18–21% PEG led to greater water losses in the *Aegilops* genotypes, accompanied by photosynthetic activity similar to that of the other genotypes. During this phase of drought stress metabolic factors which reduce carboxylation and the efficiency of $CO_2$ diffusion into the chloroplasts of the mesophyll cells became

*Corresponding author. E-mail: imolnar@mgki.hu

**Table 1.** Effect of moderate (induced by 12 and 15%PEG) and hard (induced by 18 and 21% PEG) drought stress on the physiological processes of *Aegilops biuncialis* and *Triticum aestivum* genotypes. Parameters are given by the folowing units: $\Psi_L$: MPa, $g_s$: mmol$H_2O$m$^{-2}$s$^{-1}$, $C_i$:ppm, A: µmol$CO_2$m$^{-2}$s$^{-1}$.

| | | RWC | $\Psi_L$ | $g_s$ | $C_i$ | A | $\Delta F/F_m'$ | NPQ |
|---|---|---|---|---|---|---|---|---|
| Ae. b. 642 | Cont. | 97 ±1.6 | -0.85±0.17 | 242 ±9.9 | 201±4.5 | 11.5±0.2 | 0.63±0.04 | 0.48±0.09 |
| | Mod. s. | 82.4 ±7.2 | -1.13±0.18 | 70.7±9.2 | 164±10.3 | 6.2±0.6 | 0.60±0.01 | 0.51±0.06 |
| | Hard s. | 75.1 ±7.2 | -1.9 ±0.08 | 27.7±5.9 | 192±5.1 | 2.7±1 | 0.54±0.01 | 0.79±0.07 |
| | Recov.* | 94.5 ±2.5 | -0.91 ±0.08 | 94 ±5.5 | 220±4.7 | 5.2±0.3 | 0.61±0.02 | 0.58±0.01 |
| Ae. b. 1094 | Cont. | 96.6 ±1.9 | -0.93 ±0.16 | 303 ±31 | 225±10 | 10.5±0.8 | 0.62±0.06 | 0.46±0.04 |
| | Mod. s. | 92.5±1.2 | -1.06±0.24 | 85.7±4.1 | 175±1.6 | 6.7±0.2 | 0.60±0.01 | 0.52±0.01 |
| | Hard s. | 79±5.7 | -2.17±0.09 | 39.3±6.9 | 192±3.4 | 3.5±0.6 | 0.57±0.01 | 0.93±0.01 |
| | Recov.* | 96.3±1.3 | -0.64±0.04 | 229±24 | 216±3.1 | 9.9±0.3 | 0.63±0.01 | 0.52±0.01 |
| Ae. b. 382 | Cont. | 96.6±1.9 | -0.79±0.12 | 262±5.9 | 193±1.9 | 12.6±0.1 | 0.58±0.01 | 0.66±0.03 |
| | Mod. s. | 90.6±2.4 | -1±0.03 | 133±33 | 178±4.5 | 9.2±0.3 | 0.59±0.01 | 0.51±0.1 |
| | Hard s. | 62.8±2.1 | -1.99±0.07 | 37.4±2.9 | 188±6.4 | 3.4±0.8 | 0.41±0.04 | 1.41±0.11 |
| | Recov.* | 94.8±6.6 | -0.63±0.09 | 210±14 | 203±3.3 | 10.4±0.5 | 0.59±0.01 | 0.55±0.01 |
| Mv9 kr1 | Cont. | 96.9±1.8 | -0.66±0.05 | 256±50 | 219±5.8 | 10.2±1.5 | 0.65±0.04 | 0.39±0.12 |
| | Mod. s. | 92.3±2.5 | -0.99±0.05 | 65.8±5.1 | 169±1.7 | 5.7±0.3 | 0.63±0.08 | 0.53±0.07 |
| | Hard s. | 88.7±0.6 | -1.66±0.08 | 40.2±5.8 | 200±11 | 3.6±0.6 | 0.57±0.02 | 0.62±0.09 |
| | Recov.* | 95.3±0.6 | -0.91±0.07 | 115±9.6 | 216±2.3 | 6.3±0.2 | 0.5±0.02 | 0.96±0.07 |
| Kobo-mugi | Cont. | 95.6±0.7 | -0.56±0.04 | 316±23 | 225±13 | 10.8±1.3 | 0.62±0.01 | 0.30±0.04 |
| | Mod. s. | 94.9±1.4 | -0.83±0.17 | 74±6.2 | 213±4 | 4.6±0.8 | 0.60±0.01 | 0.50±0.03 |
| | Hard s. | 89.5±1.6 | -0.88±0.08 | 50±0.57 | 252±5.2 | 4±0.03 | 0.58±0.2 | 0.54±0.03 |
| | Recov.** | 91.2±1.6 | -0.61±0.32 | 270±7.6 | 187±2.3 | 12.4±0.4 | 0.61±0.01 | 0.39±0.12 |
| Sakha | Cont. | 96.9±0.5 | -0.65±0.13 | 246±10 | 206±6.5 | 11.1±0.5 | 0.60±0.02 | 0.59±0.12 |
| | Mod. s. | 93.8±0.6 | -1.07±0.28 | 85±22.8 | 174±4.8 | 6.8±0.8 | 0.58±0.07 | 0.45±0.04 |
| | Hard s. | 88.4±1.4 | -1.12±0.09 | 60±4.4 | 155±4.2 | 5.5±0.3 | 0.64±0.03 | 0.32±0.02 |
| | Recov.** | 81.9±2.7 | -1.22±0.2 | 19±1.56 | 196±8 | 1.6±0.2 | 0.61±0.06 | 0.48±0.17 |

* Recovery without PEG after 4 days.
** Recovery without PEG after 7 days.

decisive in the inhibition of $CO_2$ fixation. This means that while stomatal conductance ($g_s$) continued to decline, there was an increase in $C_i$ (Lawlor and Cornic 2002). It was probably these processes which resulted in the retarded regeneration of $CO_2$ fixation in Mv9 kr1 and in the *Ae. biuncialis* genotype adapted to plentiful rainfall (MvGB642) compared with the other two *Ae. biuncialis* genotypes (1094 and 382). In contrast with $CO_2$ assimilation, the primary processes in photosynthesis were not affected by drought stress ($F_v/F_m$ did not change; data not shown). Nevertheless, despite the largely unchanged activity of the electron transport chain ($\Delta F/F_m$') the *Ae. biuncialis* genotypes (especially 1094 and 382) were characterised by an increase in non-radiative energy dissipation (NPQ) during hard stress, suggesting a disturbance in ATP synthesis (Lawlor and Cornic 2002). The same was observed for Mv9 kr1 on the 4$^{th}$ day of regeneration. By contrast, in the wheat variety Sakha drought stress caused an acceleration of the biological programme and the plants entered the generative phase. The relatively high level of $CO_2$ fixation may be due to the early spike formation, while the lack of regeneration could be the result of further water losses associated with the ripening and aging processes. The properties of the *Ae. biuncialis* genotypes 1094 and 382, which originate from drier habitats, could be suitable, after successful crossing, for the improvement of wheat yield stability under dry conditions, since their photosynthesis is less sensitive to water loss and they regenerate more rapidly after severe water loss.

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