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Transpiration Intensity in Cereal Crops under the Conditions of Osmotic Stress

Vladimir N. Vorob'ev[1,2]*, Evgeniy A. Alexandrov[2], Alexander L. Mikhailov[1]

[1] Institute of Fundamental Medicine and Biology, Kazan Federal University, Kazan, Russia
[2]Kazan Institute of Biochemistry and Biophysics, FRC Kazan Scientific Center, Russian Academy of Sciences, Kazan, Russia

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Abstract

The study of leaf gas exchange among medium and highly drought tolerant spring varieties of Tríticum aestívum during moderate osmotic stress modeling showed a significant difference in the dynamics of transpiration intensity (E) at the initial stage of the experiment. The monotonic dynamics of E decrease correlated with the change in stomatal conductance of water (gw) and CO2 assimilation rate decrease (A) in a highly drought tolerant variety, which is explained by stomata closure. The dynamics of E among the varieties resistant to drought had the form of a complex curve with an extremum during the first 12 minutes of the experiment, which is explained by the gas embolism of xylem vessels. Embolization of a part of xylem vessels has led to the imbalance in gas exchange rates. 75% decrease of E during the experiment did not coincide with the change of gw, which decreased only by 50%. In addition, under conditions of E decrease, a significant decrease of A was not observed. Transpiration decrease during osmotic stress due to stomata closure led to 28% drop of A, and comparable decrease in transpiration due to xylem vascular embolism reduced A by 6%. It has been shown that the tendency to xylem vascular embolization in the medium-drought-tolerant variety of spring wheat Tríticum aestívum under the conditions of moderate water deficiency makes it possible to maintain a high level of CO_2 assimilation rate, which is comparable with a highly resistant variety that can ultimately lead to a higher yield.

Keywords: Gas embolism, transpiration rate, stomatal water conductivity, CO_2 assimilation rate

1 Introduction

Loss of water during transpiration should be equivalently supported by the rate of water uptake by the root. The imbalance between absorption and transpiration leads to water potential decrease in xylem vessels. Low potentials of water induce the formation of air bubbles within the xylem vessels (the so-called embolism or cavitation) (1, 2). In general, the phenomenon of gas embolism leads to water transport disruption in a plant, which negatively affects its vital activity. The ability of plants to restore the hydraulic conductivity of xylem (to eliminate gas embolism) depends on metabolic activity (3, 4), dormin level (5) and root pressure (for monocotyledons) (6).

It is assumed that the likelihood of gas embolism in cereals depends on the hydraulic architecture of the roots. The presence of a "safety zone" at the root-shoot transition points is a characteristic of spring barley (7), wheat and rye (8). The central roots of winter wheat, winter barley and spring rye show a high degree of vascular segmentation in the root-shoot transition zone. About 80% of these roots are connected to the shoot system via tracheids. In spring varieties of these plants, 60% of the root vessels are directly connected to the shoot. Existing differences are characteristic not only for different species, but also for individual varieties of the same species (8, 25, 26). Despite the obvious negative effect of embolism, most plant species live with a certain share of non-functional xylem vessels due to gas embolism [9]. Besides, embolism can also have a positive value, since it protects the root system from water loss during drought (10, 22-24). Based on the foregoing, it can be assumed that the resistance to water deficiency among different drought tolerant varieties is associated, among other things, with a different predisposition to xylem vessels gas embolism. At the same time, embolism of a part of vessels can reduce transpiration loss of water without significant damage to photosynthesis. To confirm this hypothesis, we analyzed the dynamics of transpiration intensities (E) and CO_2 assimilation rates (A) in medium and highly drought resistant varieties of spring wheat Tríticum aestívum during osmotic stress modeling.

2 Materials and Methods

For research, we used 7-10-day old seedlings of winter wheat variety highly resistant to drought (Kazan 560),

***Corresponding author:** Vladimir N. Vorob'ev, (a) Kazan Federal University and (b) Kazan Institute of Biochemistry and Biophysics, FRC Kazan Scientific Center, Russian Academy of Sciences. E-mail: almihailov@bk.ru. Tel.: 89274455173.

spring wheat variety medium resistant to drought (Simbirtsit) and spring highly resistant to drought wheat variety (Omskaya-36) provided by the Tatar Agricultural Research Institute (TatARI). Plants were germinated with tap water at illumination of 150 µmol/m2 with a photoperiod of 16/8 at the temperature of 22 °C.

The transpiration intensity (E) and the assimilation rate of CO_2 (A) were determined by WALZ GFS 3000 gas analyzer (Germany) with built-in software for the following parameters: relative humidity in the measuring cell - 70% (at lower humidity, the transpiration intensity is not stable); air flow rate through the cell - 750 µmol/s; photoactive radiation (PAR) - 1000 µmol/m2; the temperature in the cell is 22 °C; the concentration of CO_2 in the cell makes 400 ppm.

The sample placed in the gas analyzer cell was kept at these measurement parameters for 30 minutes (the time was determined empirically and is sufficient to stabilize transpiration under new conditions). A fixed transpiration level (5-6 values with an interval of 2 minutes) was the initial for subsequent measurements. Then a pause was provided in the measurement program, during which the growing solution quickly changed to the solution of polyethylene glycol (PEG) 6000 of the corresponding osmotic potential. Immediately after the solution replacement, the measurement program was started with the record of the main indicators of gas exchange (E, A, stomatal conductivity of water - gw) for 60 minutes within the interval of 2 minutes. To simulate osmotic stress, they used 18% PEG solution with theoretically calculated osmotic potential of -0.4 MPa. The experiments were repeated 4-6 times. The graphs show the characteristic dependences of transpiration intensity dynamics. The text presents mean ± SD.

3 Results and Discussion

The possibility of gas embolism formation in spring and winter cereals during water deficiency is determined by the differences in the architecture of the hydraulic system of water transport from leaves to roots (7, 8). The central roots of winter wheat are highly segmented in the root-shoot transition zone, which can significantly reduce the risk of gas embolism. The increase of the osmotic gradient due to the placement of roots in the PEG solution leads to the expected decrease of winter wheat leaf transpiration rate of the variety Kazan 560 (Fig. 1, b), which is observed from the 8th minute after the solution replacement. The variety Simbirtsit, related to spring varieties, that is, without tracheids in root-shoot transition zone, demonstrated the complex dynamics of transpiration intensity. The increase in transpiration intensity (E) was observed already during the fourth minute after root placement in PEG solution (-0.4 MPa) and lasts 8 minutes. After reaching an extremum, E was sharply decreased going to a plateau after 30-40 minutes of root exposure in hypertonic PEG solution (Fig. 1, a).

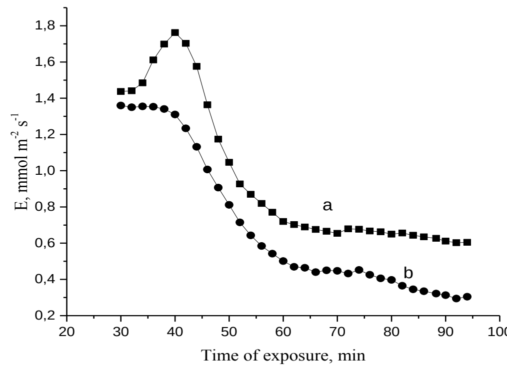

Figure 1: Dynamics of transpiration under the conditions of osmotic stress of spring and winter wheat Tríticum aestívum: a - spring wheat cultivar Simbirtsit, b - winter wheat cultivar Kazan 560

It is known that vascular embolization is accompanied by a short-term increase of transpiration (11, 12). It is likely that a sharp increase by 0.4 MPa of the gradient between the air medium in the measuring cell of the gas analyzer and the aqueous medium in the tube where the roots are located leads to the formation of large cavitation bubbles in the vascular system of seedlings of the spring medium-drought-resistant wheat variety (Simbirtsit). For a winter cultivar highly resistant to drought (Kazan 560), such a pressure gradient is not enough for xylem vessel embolization. Regardless of the differences in the dynamics of transpiration intensity, stabilization of E is observed by the 30-40th minute of the experiment. However, the achieved level of spring variety transpiration intensity was 0.53 mmol m-2s-1, whereas it made 0.24 mmol m-2s-1 for the winter variety.

The existing differences in the architecture of the root-shoot transition zone are characteristic not only between spring and winter crops, but also among spring varieties (8). Given this circumstance, they suggested that the dynamics of highly drought-resistant spring variety Omskaya 36 transpiration will be similar to the dynamics of the winter highly resistant variety Kazan 560 transpiration during replacement the solution of the root habitat with a PEG solution. Figure 2 shows the dynamics of plant transpiration of Omskaya 36 varieties highly resistant to drought (Fig. 2, b), which differs little from the dynamics of the winter varieties highly resistant to drought (Kazan 560) (Fig. 2, a).

It can be assumed that the change in the transpiration of both varieties is based on the similarity of the stomatal apparatus regulation rate and the similar structure of the root-shoot transition zone, which determines the dynamics of E. The decrease of transpiration during osmotic stress may be due to water permeability decrease of the roots and/or the closure of stomata. In general, stomatal conductivity in both varieties decreases by 85 ± 5%. Comparing the stomatal conductivity of medium and drought resistant spring varieties, it should be noted that with the same osmotic stress, the stomatal conductivity of the Simbirtsit variety decreases only by 50 ± 4%. Under the conditions of the proposed model of osmotic stress of the drought-resistant spring variety Omskaya 36, the dynamics of transpiration intensity is practically repeated by the dynamics of CO2 assimilation (Fig. 3). When E decreases by 80 ± 6%, A decreases by 28 ± 3%.

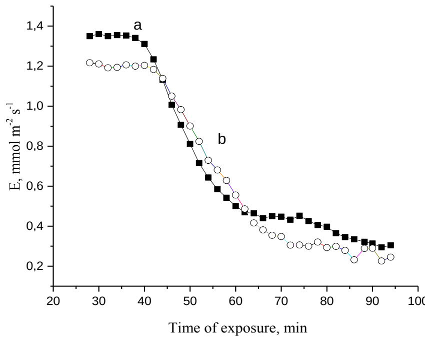

Figure 2: Dynamics of transpiration under the conditions of osmotic stress of spring and winter wheat Tríticum aestívum: a - winter wheat cultivar Kazan 560; b - spring wheat of Omskaya 36

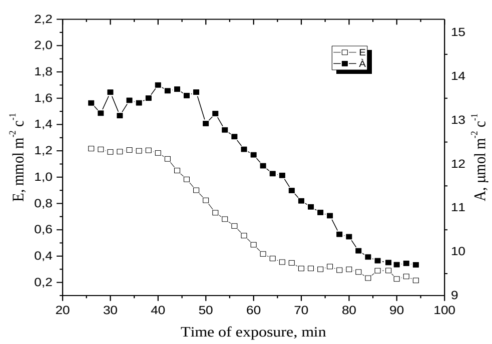

Figure 3: Comparison of the dynamics of transpiration intensity - E (empty squares) and the assimilation rate of CO2 - A (filled squares) in the drought-resistant spring wheat variety Omskaya 36

It is likely that during the breeding of a variety highly resistant to drought, selection was aimed at the manifestation of isohydric properties, which are expressed in a stable maintaining of water potential of cells due to the closure of stomata. This thesis is confirmed by comparison of gw and E. Among the varieties highly resistant to drought under osmotic stress, gw decreases by 85 ± 5%. E is also decreased by the same level approximately. Under the same conditions, the drought-tolerant variety Simbirtsit (Fig. 4) demonstrates an alternative change of the observed processes.

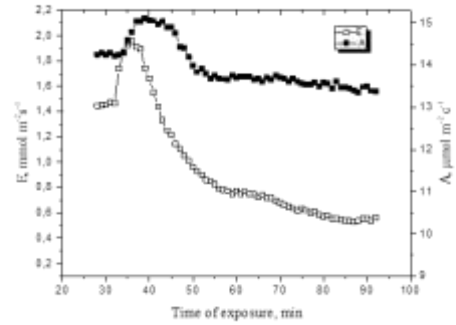

Figure 4: Comparison of the dynamics of transpiration intensity - E (empty squares) and the assimilation rate of CO2 - A (filled squares) in the drought-resistant variety of spring wheat cultivar Simbirtsit

If at the beginning of the experiment the dynamics of A with some lag repeats the dynamics of E, then from about the twentieth minute there is a significant difference in the recorded indicators. Thus, E decreases by 75 ± 5%, and A by 6 ± 2% only. If we compare the variation of gw and E for a given variety, then their imbalance becomes apparent. With the decrease of E by 75 ± 5%, gw decreased only by 50 ± 4%. Such a mismatch may be due to embolism of some vessels. Then the decrease of E is caused not so much by the closure of the stomata as by the decrease of xylem vessel number through which water is transported and this is probably the reason for a slight decrease. It is known that when moderate water deficiency occurs, anisohydric plants lose water during transpiration in exchange for CO2 intake. Such a strategy proves to be advantageous, and anisohydric plants can outperform isohydric ones in growth and yield (13-16). Comparison of the maximum yield of the used spring varieties shows the advantage of medium drought tolerant variety, the yield of which can reach 6.58 t/ha, while the yield of the drought tolerant variety does not exceed 4.86 t/ha (17-21).

4 Summary

We have shown that the tendency to xylem vascular embolization in a medium-resistant variety of spring wheat Tríticum aestívum under the conditions of moderate water deficiency allows to maintain a high level of CO2 assimilation rate with a comparable decrease of transpiration intensity, which ultimately leads to higher productivity as compared to a highly resistant variety.

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