INVOLVEMENT OF WATER IN COORDINATION AND INTEGRATION OF PLANTS´ FUNCTIONS IN DROUGHT CONDITIONS

IMPLICAREA APEI ÎN COORDONAREA ŞI INTEGRAREA FUNCȚIILOR PLANTELOR ÎN CONDIȚII DE SECETĂ

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Abstract. *It was established that water in unfavorable conditions is one of the main factors of integration and coordination of physiological processes at the cellular, organ and organism level. The water stress caused disturbances in the functional interrelationships between organs as a result of differences in the degree of dehydration, the occurrence of reactive oxygen species and the antioxidant enzyme activities, especially in roots and inflorescences. The reason of the functional imbalance in drought conditions was the reduction of water and phytohormones transport, disturbed water homeostasis, and decreased enzymatic antioxidant protection. It was confirmed the hypothesis that water is the factor involved in regulating the functional activity of the plant, helps maintain coordinated relations between organs and performs, along with other factors, function integration at the organism level.*
Key words: *plants, drought, coordination, integration, physiological processes, water, phytohormones, reactive oxygen species, antioxidant enzyme.*

Rezumat. *S–a stabilit, că în condiții nefavorabile de umiditate apa reprezintă unul din factorii principali de integrare şi coordonare a proceselor fiziologice la nivel celular, de organ şi organism. Stresul hidric cauzează perturbări în interrelațiile funcționale dintre organe în rezultatul deosebirilor principiale ale gradului de deshidratare, apariției speciilor reactive de oxigen şi schimbării activității enzimelor antioxidante, cu precădere în rădăcini şi inflorescențe. Cauza dezechilibrului funcțional în condiții de secetă este diminuarea/inhibarea transportului apei şi fitohormonilor, dereglarea homeostazei apei, diminuarea protecției enzimatice antioxidante. S-a confirmat ipoteza conform căreia apa este factorul antrenat în reglarea activității funcționale a plantei, contribuie la menținerea relațiilor coordonate dintre organe şi îndeplineşte, de rând cu alți factori, funcția de integrare la nivel nu numai celular, dar şi de organism.*
Cuvinte cheie: *plante, secetă, coordonare, integrare, procese fiziologice, apă, fitohormoni, specii reactive de oxigen, enzime antioxidante.*

INTRODUCTION

A plant perceives environmental changes as a whole organism, and its resistance to stressogenic action of any unfavorable factor is manifested through a capacity of physiological processes coordination and by maintaining a dynamic

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balance of functions depending on oscillations of ambient conditions (Shinozaki and Yamaguchi-Shinozaki. 1999; Maurel *et al.,* 2010; Aroca *et al.,* 2012). The mechanisms of acclimation to different factors are partly identical, and non-specific primary reactions include the change of the water status and the accelerated generation of reactive oxygen species (ROS), which serve as signaling molecules of activation of protection systems (Boursiac. *et al.,* 2008; Bartolia *et al.,* 2013; Kramer and Boyer,1995). Based on the reported the objective of our study was to elucidate the role of water in the coordination and integration of crop functions in drought conditions.

MATERIAL AND METHOD

As subjects served plants of *Zea mays* L., cultivar P458, and *Phaseolus vulgaris* L., cultivar Porumbita, representing the genotypes with different resistance potential and different morphological adaptation strategies to insufficient soil water content. The experiments were conducted in the greenhouse complex under controlled hydric regime with plants grown in containers Mitcerlih with 30 kg dry soil. The hydric stress was created by the gradual decline in soil water content range 70 - 60 - 50 to 40 - 30% of total water capacity (TWC) of the soil.

The parameters of the water status have been determined by conventional methods (Vasseu and Sharkey, 1989); transpiration intensity, CO_2 assimilation, stomatal conductance - using portable gas analyzer LC*i*. The testing of lipid peroxidation (LPO) intensity was performed by determining the final product - malone dialdehyde (MDA) content using thiobarbituric acid; superoxide dismutase activity SOD – by the method (Чевари *и др.,* 1985); catalase CAT – using the method of Chance B. and Machly A. (1955); ascorbate peroxidase APX – according to Nacano and Asada (1981); glutathione reductase GR and glutathione peroxidase GPX – according to Schadle and Bassham (1977). Differences between variants were documented by ANOVA analysis ("Statistica 7").

RESULTS AND DISCUSSIONS

It was established that disturbance of internal aqueous medium and disruption of interactive relations between root – leaves - inflorescence occur under conditions of acute lack of soil water content due to different reactions of organs to hydric stress (Table 1).

Table 1

Characteristic parameters of the water status of plant Zea mays L. cultivar P458 exposed to the drought

Treatments, soil water content, % TWC	Organ	WC, g·100 g^{-1} f. m.	SD,% of full saturation	WRC, g·100 g^{-1} f. m.
Optimum, 70	leafs	80,80 ± 0,44	1,68 ± 0,11	76,63 ± 0,20
	stems	89,93 ± 0,54	2,56 ± 0,22	88,53 ± 0,12
	roots	89,00 ± 0,31	12,47 ± 0,17	70,18 ± 0,34
Drought, 30	leafs	78,35 ± 0,33	19,81 ± 0,38	76,29 ± 0,11
	stems	89,11 ± 0,31	7,29 ± 0,13	88,00 ± 0,10
	roots	73,60 ± 0,22	19,44 ± 0,14	50,17 ± 0,59

Note. WC - water content; f.m. - fresh mass; SD - saturation deficiency; WRC -water retention capacity

The drawback of soil water resulted in more prompt water content reductions in the roots, conditioning an imbalance in water supply of plant aboveground organs. Maximum quantitative differences were recorded in the net effect of the drought, also in the SD and turgidity in plant roots and inflorescences. The same profound changes were established for plants *Ph. vulgaris* L. not only in the water status of the root system, exposed to direct collisions, as well as in the leaves and, especially, in inflorescences (Fig.1).

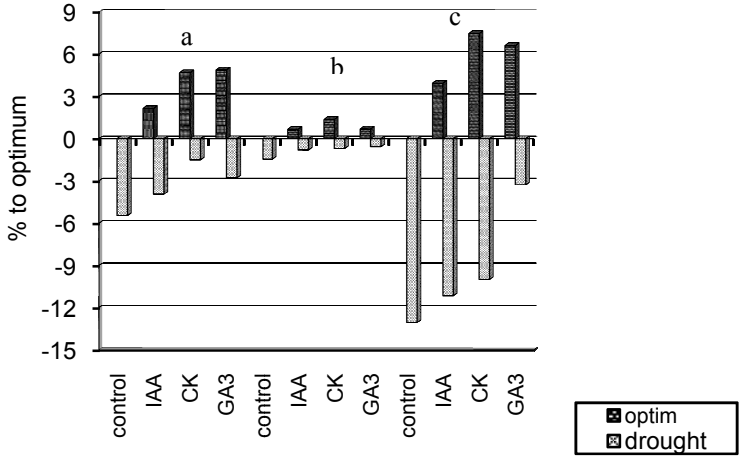

Fig.1 - Change of water content in: roots (a), leaves (b) and inflorescences (c) of plant *Ph.vulgaris* L. in drought conditions. Legend: IAA - indolyl acetic acid; CK - cytokinin; GA_3 - gibberellic acid.

It is known that the water in the organism fulfills a function of transmitting information: a decrease of water potential in root system induces a closure of stomata faster than the water content decreases in the leaves. There were significant differences in the ability to control the homeostasis of water at plants *Ph. vulgaris* L. and *Zea mays* L. under drought conditions (Table 2).

Table 2

Effect of drought on the intensity of photosynthesis, stomatal conductance and transpiration for maize and beans plants

Treatment, soil water content,% TWC	Stomatal conductance, $Mm/m^2/h$	Intensity of transpiration, $Mm/m^2/h$	Intensity of photosynthesis, $Mm/m^2/h$	WUE* Mm CO_2/ Mm water
***Ph. vulgaris,* L.**				
70	0,04±0,01	1,67±0,02	4,36±0,08	2,61±0,02
30	0,01±0,001	0,55±0,01	0,06±0,00	0,11±0,00
***Zea mays,* L.**				
70	0,10±0,002	2,64±0,07	9,86±0,16	3,73±0,05
30	0,04±0,000	0,77±0,01	1,95±0,04	2,53±0,03

* WUE - efficiency of water use

Maize plants in contrast to common bean plants under the same conditions of insufficient soil water content were able to maintain the activity of the physiological processes at a less water potential in the cells - the property

appreciated in the scientific literature as *the protoplast resistance.* Disturbance of functional interrelationships in drought conditions for plants *Ph. vulgaris* L. occured at a significantly higher water potential compared to plants of *Zea mays* L. The dehydration of tissue caused enhanced formation of ROS and organ damage by oxidative destruction of cellular components. The results of the evaluation of the intensity of lipid peroxide oxidation (LPO) in the cell membrane manifested, as shown in Table 3 and Figure 2, that already at the decrease of soil water content up to 40% TWC in the leaves of the plants took place an intensified ROS formation. Compared with the control plants for those exposed to the drought, the malone dialdehyde (MDA) content, considered the marker of oxidative stress and LPO, in leaves of bean plants was increased on average by 25.8 percent and 17.08 percent - in the leaves of maize plants. The evolution of drought in time resulted in intensifying of MDA synthesis and after 3 days of stress their contents prevailed over control plants with 58.5% and 38.6% respectively. Hence, under conditions of equal intensity and duration of drought in the leaves of plants *Ph. vulgaris* L. and *Zea mays* L. developed the oxidative stress, more pronounced in the leaves of sugar beans (Table 3).

Table 3

Dynamics of change of MDA content and protective antioxidant enzyme activities in leaves of plants *Zea mays* L and *Phaseolus vulgaris* L at soil water content fluctuation and evolution in time of drought

Soil water content, % TWC	MDA content, mkM /g f. s.	SOD, conv. un. /g f. s.	CAT, mM /g f. s.	APX, mM /g f. s.	GR, mM /g f. s.	GPX, mM /g f. s.
***Zea mays*, L.**						
70	8,7±0,2	167,4±2,1	13,7±0,3	8,0±0,1	292,5±4,1	172,7±2,0
60	8,8±0,2	177,8±3,0	13,9±0,2	8,1±0,2	301,8±3,9	182,8±2,9
50	8,9±0,2	188,2±2,8	14,2±0,3	8,2±0,1	311,0±2,7	192,8±2,1
40	10,2±0,3	222,5±3,4	16,5±0,4	10,3±0,2	341,8±3,2	271,5±3,1
30, I day	11,2±0,2	239,5±3,4	17,8±0,5	15,5±0,2	406,0±3,8	283,4±2,2
30, III days	12,1±0,4	246,4±3,8	17,8±0,5	16,0±0,3	410,2±4,1	298,7±3,0
30, V days	21,4±0,3	248,4±3,1	18,9±0,5	16,9±0,3	417,1±4,0	300,9±2,1
30, VII days	21,7±0,2	243,6±2,8	17,8±0,4	17,6±0,4	436,5±3,5	320,6±3,2
30, X days	22,0±0,5	245,1±2,3	16,6±0,5	18,5±0,3	451,7±3,9	356,9±1,0
***Ph. vulgaris*, L.**						
70	7,4±0,2	68,2±1,0	12,0±0,2	9,5±0,1	156,5±1,2	126,4±0,9
60	8,1±0,1	74,5±1,1	14,9±0,1	9,9±0,1	163,8±1,1	130,2±1,1
50	8,9±0,2	80,8±1,0	17,8±0,2	10,7±0,2	169,8±1,0	134,0±1,1
40	9,4±0,2	84,0±0,8	18,2±0,1	12,8±0,4	178,5±0,9	135,4±1,2
30, I day	10,9±0,3	94,0±0,7	18,9±0,1	14,1±0,2	189,4±1,6	137,9±1,5
30, III days	11,8±0,4	100,8±1,8	20,8±0,2	14,5±0,3	205,9±1,4	147,4±2,0
30, V days	12,4±0,2	103,6±1,6	22,0±0,4	18,2±0,2	209,9±2,1	149,7±2,1
30, VII days	16,0±0,5	129,3±1,3	22,0±0,4	22,4±0,1	244,7±3,1	176,8±1,8
30, X days	19,8±0,4	130,0±2,1	21,3±0,4	23,7±0,2	264,4±2,1	184,0±1,9

In determining the net action of drought on the change of MDA content and the activation of superoxide dismutase, the different effects were found depending

upon duration of the stress factor. If for the maize plants the SOD activation recompensed the effect of superoxide radicals, and MDA content maintained at a relatively balanced level until the 5th day of drought, for the bean plants the SOD activation was not sufficient to dismutation of ROS.

Given that, the antioxidant enzymes showed a maximum activity at different degree of hydration, the dehydration tissues at severe drought conditions could induce and a different degree of their activation. In this case there was a disruption of the degree of compliance between peroxide-producing enzyme and those of its neutralization. When the action of the unfavorable factor was directed to the roots, a result of their strong dehydration was an authentic increase of oxidative destructions more pronounced than in the leaves and, in particular, than in stems (Fig. 2).

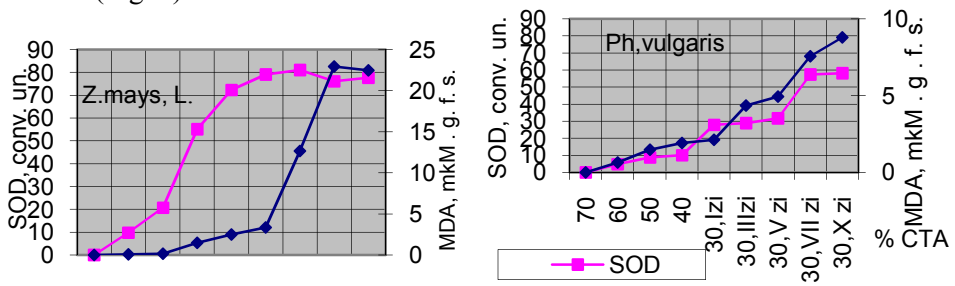

Fig. 2 - Net action of drought on MDA content and SOD activity in the leaves of plants of *Zea mays* L. and *Phaseolus vulgaris* L.

A non-significant correlation between catalase activity and parameters of the water status of the leaves for was found for weak drought-resistant plants: r = -0.26 for sensitive plants, while r = -0.84 for tolerant plants. The comparative analysis of the influence of heat accompanied drought on the degree of dehydration and SOD and CAT activity in leaves of weak resistant plants X5P515 allowed to assume that these enzymes had a different sensitivity to the degree of hydration: while SOD activity kept at a relatively high level and after 10 days of water content deficit (30% TWC), the CAT activity decreased after only 3-7 days (Table 3).

The results of the investigations carried out in this study lead to the conclusion that the genetically determined resistance to stress caused by drought was certainly correlated, primarily, with the plant property of self-regulation of the degree of tissue hydration, secondly, with the ability to quickly increase the antioxidant protective system activity.

The cause of functional imbalance in drought conditions was reducing / inhibiting water and plant hormones transportation, impaired water homeostasis, decrease of enzymatic antioxidant protection. The hypothesis has been confirmed that water was the factor involved in regulating the functional activity of the plant, helped maintain coordinated relations between organs and performed, along

with other factors, the function of integration not only at cellular, as well as, at organism level.

CONCLUSIONS

1. The water stress caused disturbances in the functional interrelationships between organs as a result of principled differences in the degree of dehydration, the occurrence of reactive oxygen species and antioxidant enzyme activities change, especially in roots and inflorescences.

2. The cause of functional imbalance in drought conditions was reducing / inhibiting water and plant hormones, impaired water homeostasis, decrease enzymatic antioxidant protection.

3. The water at unfavorable conditions of soil hydric regime was a factor involved in regulating of functional activity of the plant, which helped to maintain coordinated relations between organs, and performed, along with other factors, the function of integration not only at cellular, but also at organism level.

REFERENCES

1. **Aroca R., Porcel R., Ruiy-Loyano H., 2012 -** *Regulation of root water uptake under abiotic stress*. In: J. Exp. Bot. 63. No.1. pp.43-57.
2. **Bartolia C.G., Casalongueb C.A., Simontacchia M. et al., 2013** – *Interactions between hormone and redox signalling pathways in the control of growth and cross tolerance to stress*. In: Environ. Exp. Bot. V. 94. pp. 73–88
3. **Boursiac Y., Boudet J., Postaire O., Luu D.T. et al., 2008 -** *Stimulus-induced down-regulation of root water transport involves reactive oxygen speies-activated cell signaling and plasma membrane internalization*. In: Plant Journal. 56. P. 207 – 218.
4. **Chance B. şi Machly A. 1955 -** *Assay of catalases and peroxidases*. In: Methods in Enzymology, S. P. Colowick and N.O. Kaplan (ed). N.Y.: Acad. Press. V.2. pp. 764-775.
5. **Kramer P.J., Boyer J.S., 1995 -** *Water relations of plant and soil.* San Diego: Academic Press, 489 p.
6. **Maurel C., Simonneau T., Sutka M., 2010 -** *The significance of roots as hydraulic rheostats.* In: J. Exp. Bot. 61**.** pp. 3191 –3198.
7. **Nacano Y., Asada K. 1981 -** *Hydrogen Peroxide Is Scavenged by Ascorbate Specific Peroxidase in Spinach Chloroplasts* . In: Plant Cell Physiol. V. 22. pp. 867-880.
8. **Schadle M., Bassham J.A. 1977 -** *Chloroplast. Glutathione reductase*. In: Plant Physiology. V. 59. No. 4. pp. 1011.
9. **Shinozaki Kazuo, Kazuko Yamaguchi-Shinozaki., 1999 -** *Molecular Responses to Cold, Drought Heat and Salt Stress in Higher plants.* R. G. Landes Company. Austin. Texas. U.S.A. 170 p.
10. **Vasseu T.L., Sharkey T.D., 1989 -** *Mild water stress of Phaseolus vulgaris plants leads to reduced starch synthesis and extractable sucrose phosphate syntheses activity.* In: Plant Physiol. V. 89. pp. 1066-1070.
11. **Чевари С., Чаба И., Секей Й. 1985**. - *Роль супероксиддисмутазы в окислительных процессах клетки и метод определения её в биологических материалах*. In: Лабораторное дело. № 11. С. 578-681.