EFFECTS OF SALINATION ON OSMOTIC POTENTIAL, PHOTOSYNTHESIS AND GROWTH OF YOUNG SPRING BARLEY GENOTYPES*

J. Jedličková, B. Zámečníková

Czech University of Life Sciences, Faculty of Agrobiology, Food and Natural Resources, Department of Botany and Plant Physiology, Prague, Czech Republic

The experiments studying the effects of salination on changes of osmotic potential of leaves, photosynthesis and transpiration and growth of spring barley leaves were established under controlled conditions of air-conditioned box in hydroponic culture. The varieties Jersey (the Dutch modern variety), Malz (the Czech modern variety) and Norimberk (the historical variety) were cultivated; the first in Knop's nutrient solution, later with addition of NaCl in concentrations 0.06M, 0.15M and 0.25M. The stress was induced in the phase of the third leaf formation (12.DC) and lasted for 5 days. Statistically significant differences were found in the varieties and in the treatments. The lowest values of osmotic potential were found in the variety Norimberk with increasing salination. The effects of rising salt concentrations were manifested by decrease in rate of photosynthesis and transpiration, while the varieties Jersey and Malz were different at low concentration of salination (0.06M of NaCl), but they keep relatively higher values compared to the variety Norimberk. At the concentration 0.15M of NaCl, on the contrary, the variety Norimberk exceeds the varieties Jersey and Malz by its values of photosynthesis and transpiration rate. The rate of leaf growth fell the most in the variety Malz. The varieties show different physiological responses on stress induced by salination.

transpiration; historical and modern varieties; water stress; psychrometric determinations; controlled condition

INTRODUCTION

Soil salinity is a serious world problem mainly in arid and semiarid regions. El-Hendawy et al. (2007) reported that the issue of salinity is solving by 35–50% of world population of approximately 80 countries. High concentration of Na^+ and Cl^- ions in soil solution disturbs the equilibrium in nutrient uptake and thus decreases also the production of biomass and stable yields. Decrease of osmotic potential induces water uptake and closure of stomata, followed by reduction of CO_2 uptake for photosynthesis, what is one of the reasons of reduction of productivity under stress conditions (Balogh et al., 2007; Hasegawa et al., 2000; Abdelkader et al., 2007; Kim et al., 2005). Salinity has also a negative impact on longivity growth of plants by reducing the uptake of water into the plant (Munns, 2002). It was found out that genotypes tolerant to salination have a capacity to exclusion undesirable ions. Garthwaite et al. (2005) found this ability in wild growing barley varieties that have a high tolerance against salination compared to cultural species. Similar ability of discharge of ions was found also in rice. Fricke and Peters (2002) studied reduction of prolonging growth, reduction of water and osmotic potential in hydroponic cultures of spring barley in the stage of the third leaf. Growth and production processes of plants are given by genetic properties and environmental effects as well that are mutually affected (Hejnák, 2003; Hniličkа et al., 2005).

It follows from the given facts that for screening of genotypes tolerant to salination it is necessary to assess more physiological parameters simultaneously. The aim of breeders generally (Muramoto et al., 1999) is to culture tolerant genotypes against environmental stresses, because just suitable genotypes are at least expensive solution of the whole problem. Main mechanisms of adaptation of crops to osmotic stress and stress caused by accumulation of harmful ions include osmotic adjustment.

As reported Babu (1999), Sinclair et al. (1985), Siddigue et al. (1999), a lack of water or osmotic potential of leaves are a suitable parameter for quantification of response of plants where a possible intensity of adjustment of plants to stress conditions can be assumed according to their values. Induction of stress by salination in definited growth stages of plants is a suitable way of limitation of genotype differences in view of water use efficiency. Their application will allow to study changes in reactions that are comparable with reactions to gradual dehydration and may be further used for testing of water stress tolerance. The method of fast dehydration of leaves is one of the possibilities how to monitoring variety differences in physiological properties of leaves.

This study was aimed at testing of the effect of induced osmotic stress by salination as affected young plants of selected spring barley varieties with emphasis on changes of values of osmotic potential, photosynthesis and transpiration rate and on the rate of leaf growth.

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MATERIAL AND METHODS

Three spring barley varieties were chosen as an experimental material – two present malting varieties Jersey (the Dutch modern variety) and Malz (the Czech modern variety) and Norimberk (the historical variety of 1832). The seed used was obtained from the Research Institute Kroměříž.

The grains were placed in air-conditions box for germination at the temperature 20 °C. After three days germinating plants were replanted into pots containing Knop's nutrient solution. In the time of cultivation in air-conditioned box stable lighting of 300 μmol.m^{-2}.s^{-1} was set up, the length of day was 14 hours; the temperature 22 °C day, 18 °C night and air humidity 40–60%.

In the stage of the third leaf formation (12.DC) stress conditions were induced by adding of NaCl into the nutrient solution in three concentrations and water potential of solution reached the following values: 0.06M NaCl = –0.27 MPa; 0.15M NaCl = –0.7 MPa and 0.25M NaCl = –1.14 MPa. Water potential of solutions was measured by psychrometer determination. Plants were stressed for five days, and then the samples of leaves from each treatment were taken. The leave samples were frozen and after unfreezing they served for psychrometric determination of osmotic potential from cell sap of experimental plants. To the measurement osmotic potential, a special thermocouple psychrometer Psypro (Wescor, USA) was used. The principle of measurement is the determination of dew point by chilling of thermocouple in the measuring chamber (C-52) after equilibration of water vapour above the sample. The photosynthesis and transpiration rate was measured in the phase of fully developed third leaf (13. C), i.e. on the fourth day of stress using gasometrical system LC PRO^{+}, based on the principle of infrared gases analyser. During measurement in open gasometrical system the leaves were closed in flow assimilation chamber with the temperature of 25 °C, intensity of irradiation 400 μmol. m^{-2}.s^{-1} and relative air humidity 30–50%. The rate of growth of the third leaf was measured during five days and the rate of growth of the third leaf was evaluated in mm in all treatments. The relationship GR (growth rate) = dL/dt = $(L_2 – L_1/(t_2 – t_1)$ (mm/day) was used for interpretation of results, where $L_{1,2}$ = length of leaves and $t_{1,2}$ = days. The whole experiment of induction of short-term stress was carried out in three replications and the values obtained from each replication were averaged out of the total number of 15 plants.

The measured values were statistically assessed using the program StatSoft, Inc. (2007) STATISTICA Cz (Software system for data analysis); version 7.1. The evaluation of data was done by analyses of variance classification on the level of significance $\alpha = 0.05$. The significance of differences between the means was assesed using Tukey-test.

RESULTS AND DISCUSSION

Salination caused a reduction of important physiological functions in all varieties and the differences in sensitivity of selected varieties on the presence of Na^{+} and Cl^{-} ions in medium were found. The values of osmotic potential prove that the ability of osmotic adjustment of all varieties and the differences are manifested on the level of varieties and on the level of treatments. The historic variety Norimberk reduced highly the osmotic potential against the control, i.e. by –1.9 MPa. Norimberk can also manifest the best capacity of osmotic adjustment because it is based on prerequisite (B a b u , 1999) that the lower osmotic potential, better adaptation of the given varieties can be reached, i.e. to accumulation of osmotically active substances, and hence to reduce their osmotic potential and to maintain the turgor potential.

On the contrary, the Czech modern variety Malz has the lowest ability of osmotic adjustment according to this prerequisite, which reduced the osmotic potential against the control only by –1.35 MPa. The results are in agreement with the results published by R e g g i a n i et al. (1995) who proved the significant differences of osmolarity in different wheat cultivars within increasing external concentration of the salt. The variety differences in response to plants against salination were found in further varieties of spring barley as reported by J e d l i č k o v á and Z á m e č n í k o v á (2007).

The varieties with a very low osmotic adjustment have almost fully closed stomata (Ž i v č á k et al., 2006). Dif-

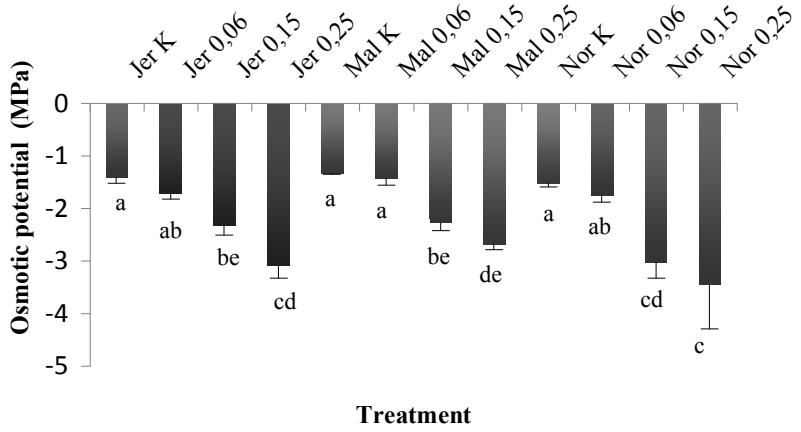


Fig. 1. Mean values of osmotic potential in control and salt-stressed plants showing differences among barley varieties and treatments in dependence on increasing concentration of NaCl (control treatment K – Knop's nutrient solution, experimental treatment – NaCl addition in three concentrations: 0.06M, 0.15M, 0.25M). The abbreviations of varieties: Jer – Jersey, Mal – Malz, Nor – Norimberk

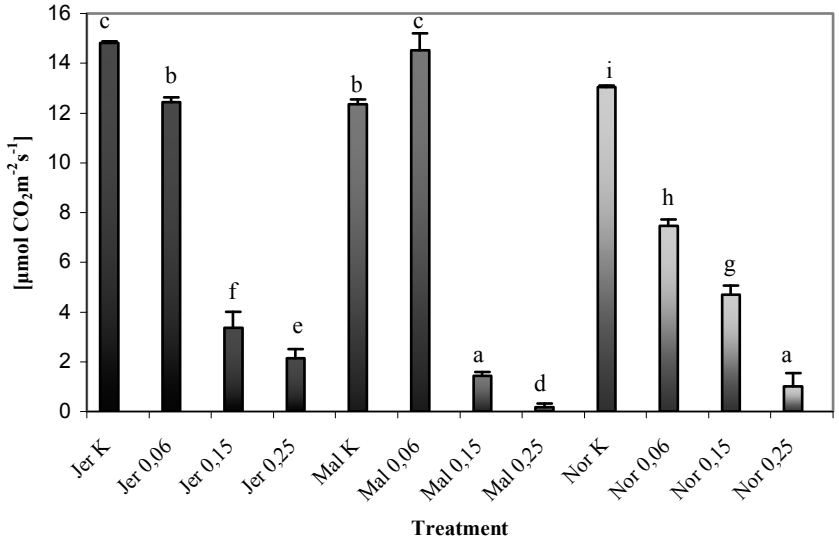


Fig. 2. Mean values of the rate of photosynthesis denoting different sensitivity of varieties within response to conditions of salination (control treatment K – Knop's nutrient solution, experimental treatment – NaCl addition in three concentrations: 0.06M, 0.15M, 0.25M). The abbreviations of varieties: Jer – Jersey, Mal – Malz, Nor – Norimberk

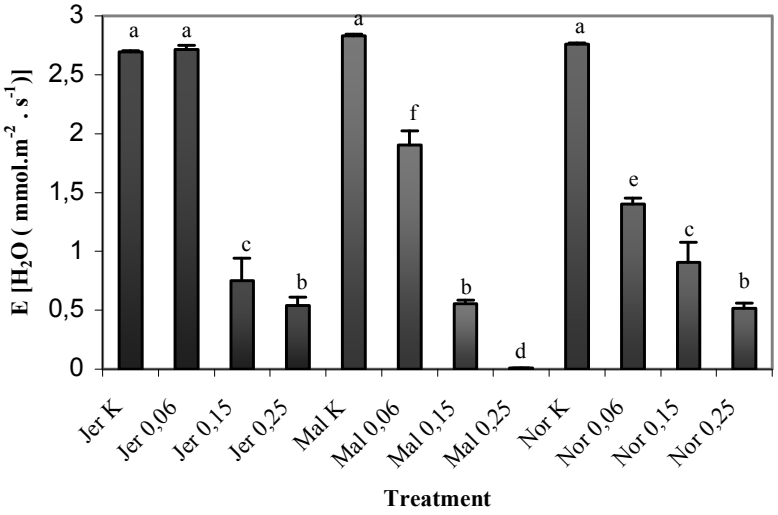
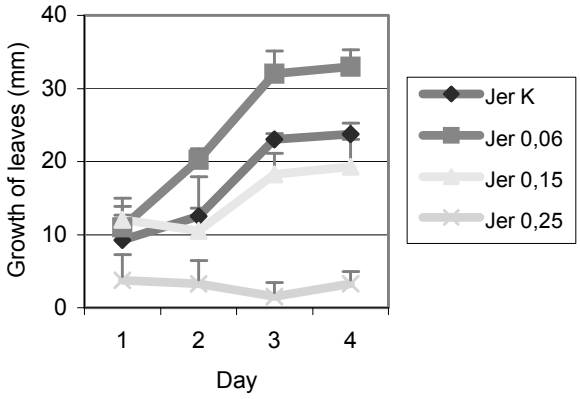


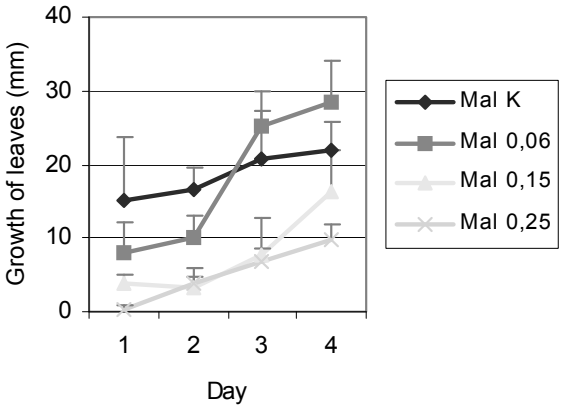
Fig. 3. Mean values of transpiration in selected varieties that again prove difference not only among different varieties as well as among different treatments of salination (control treatment K – Knop's nutrient solution, experimental treatment – NaCl addition in three concentrations: 0.06M, 0.15M, 0.25M). The abbreviations of varieties: Jer – Jersey, Mal – Malz, Nor – Norimberk

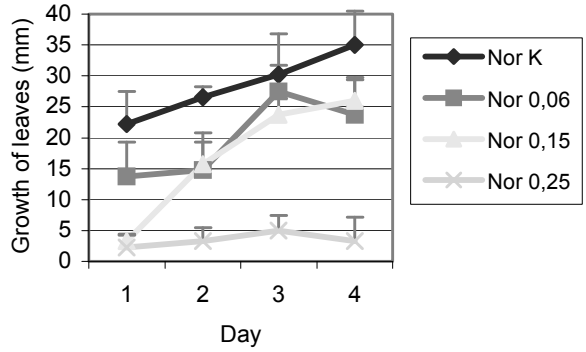
ferent functions are ascribed to osmotic adjustment, when keeping turgor during water deficit belongs to the most important functions, what plays a significant role in opening of stomata, and hence also CO_2 assimilation connected with it. As presented in Fig. 1 in conditions of stronger stress in concentrations i.e. 0.15M and 0.25M, closure of stomata occurred and final rate of photosynthesis and transpiration as well was much reduced (Figs 2, 3). The variety Jersey, even in strong salination, kept relatively high rate of photosynthesis compared to the variety Malz with lower ability of photosynthesis rate. It can be presupposed that at slower starting and longer acting stress in field conditions, keeping of higher rate of net photosynthesis can be an important mechanism for reaching of higher yields.

The variety Jersey responds to slight values of salination by increase of the growth of leaves compared to the control treatment. Decrease of the growth was recorded with concentration 0.15M, later followed by adjustment and faster growth. This corresponds to the course of stress reaction after S e l y e (1956). NaCl concentration 0.25M caused full stop of the growth of leaves. The growth under stress was reduced in the variety Malz in the first two days and action of stress induces probably adjustment to increase of growth in remaining days. In the concentrations 0.15M and 0.25M of NaCl were followed by a great growth depression in compared with the control treatment, but leaves were continuously growing for the whole period of time and the growth does not stop like in the previous variety Jersey. The lowest sensitivity in the rate of growth in salination was recorded in the historical variety Norimberk where the control treatment showed greatest growth. Treatments with NaCl 0.06M and 0.15M in the first two days caused growth depression due to adjustment in further days the growth is rising even in the treatment 0.15M. High concentration of salt 0.25M stops the growth of plants, this was confirmed by M u n n s (2002).

Toxicity is prevailingly manifested in decrease of growth, though addition of Na^+ ions of low concentration to growth medium with deficit of K^+ cations may support the growth of some plants (F l o w e r s et al. 1983). Published data give the suitability of the use of Knop's nutrient solution for cultivation of cereals with respect to its representation of all elements as well as pH of solution.







Figs 4, 5, 6. The rate of growth of the third leaf measured during five days in the varieties in the control treatment (K) and in salination with concentrations of NaCl (0.06M, 0.15M and 0.25M)

There is a question that arise from monitoring of the growth of leaves whether Knop' s solution is sufficiently suitable, when added salt in low concentrations can induce rise of growth compared to the control.

Statistically significant differences were found for leaf osmotic potential of Norimberk and in variants for osmotic potential statistically significant differences were found in concentration 0.15M and 0.25M. Within photosynthesis statistically significant differences were found among varieties and among treatments as well, and for the factor of transpiration the variety Jersey showed statistically significant difference compared to the other varieties. Statistically significant differences for transpiration were found among different treatments.

Great differences in the tested varieties were not recorded during measuring of the growth of leaves in the control treatment and in comparison of the treatment with concentration 0.06M. On the contrary, the varieties Jersey and Malz showed in slightly salted solution higher rate of photosynthesis than in the control treatments. The variety Jersey manifested the lowest difference between control and stressed treatment, i.e. by 14.6 mm on average, what indicates the variety less sensitive to salination regarding the growth of leaves. In the variety Jersey in NaCl 0.06M the difference was 77 mm compared to the concentration 0.25M. The lowest values of the rate of growth of leaves were found in the variety Malz that had under the same conditions the control treatment longer by 60.6 mm compared to the treatment 0.25M, but interesting differences were found with concentration 0.06M, where the difference was 75.8 mm compared to the concentration NaCl 0.25M.

CONCLUSION

Differences in sensitivity of different varieties of barley to conditions of salination are evident from the results obtained. Differences were found not only among of genotypes but also on the level of different treatments of salination. It was confirmed that the presence of Na^+ and Cl^- ions in nutrient medium much reduces physiological parameters – photosynthesis and transpiration rate, osmotic potential of leaf cell sap and growth – of experimental plants, and can probably to reduce of the yield stability. Therefore, the future research of the effects of harmful ions of salts on adaptation of plants in arid and semiarid regions has its meaning and prospects.

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JEDLIČKOVÁ, J. – ZÁMEČNÍKOVÁ, B. (Česká zemědělská univerzita, Fakulta agrobiologie, potravinových a přírodních zdrojů, katedra botaniky a fyziologie rostlin, Praha, Česká republika):

Efekt zasolení na osmotický potenciál, fotosyntézu a růst u mladých genotypů jarního ječmene.

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Pro sledování vlivu zasolení na fyziologické parametry v rostlinách byl v řízených podmínkách klimatizovaného boxu založen krátkodobý nádobový pokus se třemi odrůdami jarního ječmene s odlišnými genotypy: Jersey (holandská moderní odrůda), Malz (česká moderní odrůda) a Norimberk (historická odrůda). Všechny odrůdy byly kultivovány v Knopově živném roztoku (kontrolní varianta) a v zasolení (0,06M, 0,15M a 0,25M NaCl), přičemž stres byl navozen ve fázi tvorby třetího listu (12.DC) aplikací NaCl. Cílem předložené práce bylo sledovat fyziologické odezvy mladých rostlin jarního ječmene na podmínky zasolení, a to v rámci osmotického potenciálu, fotosyntézy a transpirace a rychlosti růstu listů. Na základě naměřených hodnot osmotického potenciálu v listech byly nalezeny statisticky významné rozdíly v citlivosti jednotlivých odrůd k zasolení. Jako nejméně citlivá odrůda vůči zasolení se projevila odrůda Norimberk, která oproti kontrole snížila svůj osmotický potenciál o –1,9 MPa, což bylo ve srovnání s českou odrůdou Malz o 69,8 % více. V rámci účinků různé koncentrace soli na rychlost fotosyntézy a transpirace má zahraniční odrůda Jersey při koncentraci NaCl 0,25M vyšší hodnoty fotosyntézy ve srovnání s ostatními odrůdami. Odrůda Jersey dosahovala rychlosti fotosyntézy v koncentraci 0,25M o 8,38 % vyšší než odrůda Malz za stejných podmínek. Při stanovení rychlosti růstu délky listů vykazovala největší nárůst ve stresu odrůda Jersey, naopak odrůda Malz při zasolení nárůst listů silně redukovala, což se také projevilo ve snížené fotosyntéze a transpiraci.

transpirace; historické a moderní odrůdy; vodní stres; psychrometrické stanovení; regulované podmínky

Contact Address:

Ing. Brigita Z á m e č n í k o v á , Česká zemědělská univerzita v Praze, Fakulta agrobiologie, potravinových a přírodních zdrojů, katedra botaniky a fyziologie rostlin, Kamýcká 957, 165 21 Praha 6-Suchdol, Česká republika, tel.: +420 224 382 521, e-mail: zamecnikova@af.czu.cz