PHOTOSYNTHETICA 28 (2): 289-295, 1993

1

Changes in some photosynthetic parameters in pea plants after treatment with cobalt

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Abstract

CO_2 (40, 200, 400 μM) was added to the root system of 10-d-old pea plants (*Pisum sativum* L. cv. Ran). The Co^{2+}-excess caused a reduction in the plant fresh and dry masses and water and chlorophyll contents. The rates of photosynthesis and transpiration decreased, while proline content and stomata resistance increased. The dramatic effect of Co^{2+}-toxicity was expressed both in an inhibition of ribulose 1,5-bisphosphate (RuBP) carboxylase activity and a stimulation of RuBP-oxygenase and phosphoenolpyruvate carboxylase activities on the 4th day of cultivation of plants in a solution of 400 μM Co^{2+}.

PHOTOSYNTHETICA 28 (3): 341-350, 1993

2

Cu^{2+} effect upon photosynthesis, chloroplast structure, RNA and protein synthesis of pea plants

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Abstract

Ten day old pea plants (*Pisum sativum* L., cv. Ran) were used to analyze the effects of Cu^{2+} ions on the dry mass, chlorophyll, carotenoid and proline contents, rates of photosynthesis (P_N) and transpiration (E), stomatal resistance (r_s), carboxylation enzymes activities (RuBPC, PEPC), RNA and protein syntheses and changes in chloroplast structure. Cu^{2+} treated plants showed lower chlorophyll *a* and carotenoids contents, and higher r_s than controls. P_N, E and protein synthesis were significantly reduced. Four days after metal treatment P_N was 5-7 % at 500 and 1000 μM Cu^{2+} from the controls, r_s was reduced and E was increased by all used metal concentrations. The lower RuBPC activity after the 4 d treatment by 1000 μM Cu^{2+} could be due to the inhibition of *de novo* protein synthesis. The higher proline content was probably due to the same reason. Cu^{2+} ions did not change RNA synthesis in pea leaves. We found complete disintegration of chloroplast lamellar system 4 d after 1000 μM Cu^{2+} treatment, which confirmed the observed functional changes.

PHOTOSYNTHETICA 29 (3): 625-630, 1993

BRIEF COMMUNICATION

4

Leaf area measurement using hand scanner

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Abstract

A versatile and inexpensive system with a hand scanner was developed and evaluated for measuring leaf area. A *BASIC* programme was created for processing the image files and calculating the area of scanned objects. The accuracy was better than 1 % of the reference area and it fell only when the area/perimeter ratio was less than 0.3 or when the measured object size was smaller than 0.1 cm^2.

PHOTOSYNTHETICA 29 (4): 521-527, 1993

5

The effect of pre-treatment with proline on the responses of *Pisum sativum* to salt stress

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Abstract

10-d-old pea plants (*Pisum sativum* L. cv. Ran 1) were treated for 24 h with proline (10^{-6} M or 10^{-5} M) before salinization with 50 mM NaCl for 2 d. Salt stress resulted in an increase of endogenous free proline content, CO_2 compensation concentration, photorespiration and glycollate oxidase activity; net photosynthetic rate (P_N) was inhibited, but dark respiration rate (R_D) was not affected. $^{14}CO_2$ fixation by protoplasts isolated from salt stressed plants was inhibited by 60 %, however, the $^{14}CO_2$ fixation by protoplasts, isolated from plants treated with proline before salinization, was only slightly reduced by NaCl. Proline alleviated the inhibitory effect of NaCl in a concentration-depending manner. Pre-treatment with proline decreased Na^+ and Cl^- accumulation in the shoot; the root content of these ions was increased.

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Доклади на Българската академия на науките
Comptes rendus de l'Académie bulgare des Sciences
Tome 46, N° 8, 1993

VARIATION ON THE RUBISCO PROPERTIES AND THE INTENSITY OF THE LEAF GAS EXCHANGE AMONG THE SEEDLINGS OF DIFFERENT BARLEY VARIETIES*

M. Metodiev, Ts. Tsonev

These in vivo and in vitro experiments demonstrated variability in leaf photosynthesis among barley varieties, which correlated with the observed differences in Rubisco amounts and kinetics. The results suggest that Rubisco quantity should not be used as a parameter in the assessment of leaf photosynthesis and modelling without reliable determination of its kinetics because of variability among varieties of a given species.

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J. Plant Physiol. Vol. 143. pp. 245–249 (1994)

ABA as a Modulator of the Response of *Pisum sativum* to Salt Stress

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Summary

Ten-day-old pea plants (*Pisum sativum* L., cultivar Ran 1) were treated for 24 h with 10^{-5} M or 10^{-6} M ABA before a salinity treatment with 50 mM NaCl lasting 48 h. The sodium chloride treatment alone resulted in an increase of endogenous proline content, CO_2 compensation point, photorespiration and glycolate oxidase activity. Photosynthesis was significantly inhibited. ABA eliminated the inhibitory effect of NaCl and the values of the observed parameters were similar to those of the control. $^{14}CO_2$ fixation of protoplasts isolated from salt stressed plants was inhibited about 60 %; $^{14}CO_2$ fixation by protoplasts isolated from plants treated with ABA before salinization was almost equal to that of the control. 10^{-5} M or 10^{-6} M ABA added exogenously to the protoplast reaction medium did not affect $^{14}CO_2$ fixation. The reduced CO_2 fixation of protoplasts isolated from NaCl stressed plants indicated a direct effect of NaCl on the photosynthetic process, which was not dependent upon stomatal closure.

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PHOTOSYNTHETICA 30 (1): 107-116, 1994

Stomatal and nonstomatal limitations to photosynthesis in two wheat cultivars subjected to water stress

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Abstract

Two wheat (*Triticum aestivum* L.) cultivars, Trakia (drought-sensitive, DS) and Slavianka 196 (drought-tolerant, DT), were subjected to water stress induced by polyethyleneglycol (PEG) 6000: 15 % PEG for 6 h (mild stress); 25 % PEG for 6 h and 15 % PEG for 24 h (severe stress). Exposure of plants to water stress led to a noticeable decrease in both the initial slope of net photosynthetic rate to intercellular CO_2 concentration (P_N/c_i) curves and the maximum P_N. Ribulose 1,5-bisphosphate carboxylase (RuBPC) activity was almost unchanged under mild stress while under severe stress it was reduced by about 26-27 %. The ratio of variable to maximal chlorophyll fluorescence did not change which implied that there was little effect of examined stress conditions on the photosystem 2 electron transport. The relative magnitude of stomatal and nonstomatal factors in limitation of photosynthesis depended on stress severity.

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J Plant Growth Regul (1994) 13:203–211

Protective Effect of Exogenous Polyamines against Atrazine in Pea Plants

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Abstract. The effect of exogenously applied polyamines in reversing the effect of atrazine stress on pea seedlings (*Pisum sativum* L., cv. Koray) was investigated. The plants treated with combinations of atrazine (14 mM) + spermidine (1 mM) and atrazine (14 mM) + spermine (1 mM) possessed improved growth (30–35% increase of leaf area and 10–20% increase of fresh weight 10 days after treatment) and chlorophyll content (50–60% increase) in comparison with atrazine- (14 mM) treated plants. Spermine and spermidine also diminished the inhibitory effect of atrazine on gas exchange and photosystem II function. This fact supports the hypothesis of Yordanov and Goltsev (1990, Plant Physiol 4:42–51) that the interaction of polyamines with the thylakoid membrane surface led to their stacking, to separation of the photosystems, and to the association of light-harvesting complex II with the photosystem II core complex.

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J. Plant Physiol. Vol. 144. pp. 100–108 (1994)

Physiological Changes in Higher Poikilohydric Plants — *Haberlea Rhodopensis Friv.* and *Ramonda Serbica Panč.* during Drought and Rewatering at Different Light Regimes

Yuliana K. Markovska*, Tsonko D. Tsonev**, Georgi P. Kimenov*, and Anka As. Tutekova*

Summary

A comparative physiological characterization of the transitions biosis-anabiosis-biosis in the poikilohydrous higher polants *Haberlea rhodopensis Friv.* and *Ramonda serbica Panc.* (Gesneriaceae) is made, analyzing the changes in the rates of net photosynthesis, transpiration and stomatal resistance under light conditions, close to the natural (65 $\mu mol \cdot m^{-2} \cdot s^{-1}$), and in the dark. The role of light in the physiological processes during these transitions is discussed.

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PHOTOSYNTHETICA 30 (4): 629-643, 1994

Evaluation of relative contribution of initial and variable chlorophyll fluorescence measured at different temperatures

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Abstract

The temperature dependence of the induction kinetics parameters of chlorophyll (Chl) fluorescence in leaves and isolated chloroplasts of young plants of *Phaseolus vulgaris* L. was studied. Theoretical prerequisites for the influence of fluorescence measuring temperature as well as 3 min pretreatment of leaf discs on both the photophysical and dark processes in the photosynthetic apparatus were evaluated. The registration manner of fluorescence kinetics determined the pattern of temperature dependence curve. The characteristic temperature of sharp changes of induction kinetics parameters, maximal and initial fluorescence F_m and F_0, were in ranges of 45-47 and 55-60 °C, respectively. The fitting of experimental data from thermograms registered at weak exciting irradiance in thermoinactivated leaf discs allowed to estimate the activation energy (E_a) of the internal energy conversion process in excited Chl molecule as 51.2±0.15 kJ mol^{-1}. The theoretical analysis of F_0 measured by a PAM fluorometer showed that F_0 registered even at low irradiances markedly exceeded its ideal dark value. The F_0 measured at 25 °C was increased by 125±5.3 % by the herbicide DCMU and diminished by -23.8±1.6 % by the electron acceptor DCBQ. At the experimental conditions used there were about 25 % of F_v from closed Q_B non-reducing reaction centres in the measured F_0 value. Thus the thermoinduced increase in F_0 observed within the temperature interval of 45-50 °C might be done by a transition of PS2 reaction centres from a state capable of reducing Q_B to a Q_B-non-reducing state.

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Bulg. J. Plant Physiol., 1995, 21(1), 12–28

THERMAL ACCLIMATION OF THE PHOTOSYNTHETIC APPARATUS DEPENDING ON TEMPERATURE AND DURATION OF TREATMENT

Ivan Yordanov[*1], Vassilii Goltsev[2], Tsonko Tsonev[1], Lidia Kruleva[1]*

Summary. The ability of young bean plants to increase the thermal tolerance of their photosynthetic apparatus after treatment with different high temperatures or at fixed temperature with different duration was studied. Parameters of chlorophyll fluorescence induction kinetics were used as a criterion to evaluate the photosynthetic activity of primary leaves. The thermosensitivity of photosynthesis was estimated immediately after the acclimation procedure, as well as after additional stress treatment at 55 °C for 5 hours. Exposure of the plants for 5 hours to high temperatures (38, 43, 45 or 47.5 °C) led to a marked increase (2–3 °C) in thermal tolerance of the photosynthetic apparatus. This effect was most obvious in plants exposed at 45 °C for 5 hours. Additional stress caused further development of plant resistance. It was shown that under the experimental conditions used, maximal stability was achieved at sublethal temperatures. The dynamics of temperature acclimation was followed by changes in thermosensitivity of fluorescence parameters after 0.5, 1, 2, 4, and 8 hour's exposure of the plants at 45 °C. It was found that even a very short treatment (30 min) led to well-expressed acclimation allowing the plants to endure additional stress. Thermal stability (T_{50}) of variable fluorescence (F_v/F_m) was unchanged at short-term acclimation (0.5–1 h), but it rose from 45 °C up to 48 °C after 8 h hardening. It was assumed that acclimation effect is realized primarily not on the level of primary photosynthetic reactions, but on the cellular level.

PHOTOSYNTHETICA 32 (2): 171-180, 1996

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Effect of thermal stress combined with different irradiance on some photosynthetic characteristics of barley (*Hordeum vulgare* L.) plants

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Abstract

The treatment of plants for 4 h with high temperature, HT (42 °C) at 100 μmol m^{-2} s^{-1} (LI) photon flux density (PFD) led to about 27 % decrease in CO_2 uptake in comparison to the controls (LI and 25 °C = LT). Similar lowering in the photosynthetic rate (about 20 % in comparison to the combination LT plus 1000 μmol m^{-2} s^{-1} = HI) was observed after subjecting the plants for 4 h at HT, HI. The rate of electron transport, including photosystem (PS) 2 + PS1, was greatly reduced at HT. HI did not enhance the inhibition due to HT. The electron transport of PS1 measured under the same conditions was almost resistant to the effect of thermal stress. Under HI the formation of zeaxanthin was observed both under LT and HT.

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PHYSIOLOGIA PLANTARUM 96: 623–629. 1996

Drought- and ABA-induced changes in photosynthesis of barley plants

Losanka P. Popova, Tsonko D. Tsonev, Galia N. Lazova and Zhivka G. Stoinova

The changes caused by drought stress and abscisic acid (ABA) on photosynthesis of barley plants (*Hordeum vulgare* L. cv. Alfa) have been studied. Drought stress was induced by allowing the leaves to lose 12% of their fresh weight. Cycloheximide (CHI), an inhibitor of stress-induced ABA accumulation, was used to distinguish alterations in photosynthetic reactions that are induced after drought stress in response to elevated ABA levels from those that are caused directly by altered water relations. Four hours after imposition of drought stress or 2 h after application of ABA, the bulk of the leaf's ABA content measured by enzyme-amplified ELISA, increased 14- and 16-fold, respectively. CHI fully blocked the stress-induced ABA accumulation. Gas exchange measurements and analysis of enzyme activities were used to study the reactions of photosynthesis to drought stress and ABA. Leaf dehydration or ABA treatment led to a noticeable decrease in both the initial slope of the curves representing net photosynthetic rate versus intercellular CO_2 concentration and the maximal rate of photosynthesis; dehydration of CHI-treated plants showed much slower inhibition of the latter. The calculated values of the intercellular CO_2 concentration, CO_2 compensation point and maximal carboxylating efficiency of ribulose 1,5-bisphosphate (RuBP) carboxylase support the suggestion that biochemical factors are involved in the response of photosynthesis to ABA and drought stress. RuBP carboxylase activity was almost unaffected in ABA- and CHI-treated, non-stressed plants. A drop in enzyme activity was observed after leaf dehydration of the control and ABA-treated plants. When barley plants were supplied with ABA, the activity of carbonic anhydrase (CA, EC 4.2.2.1) increased more than 2-fold. Subsequent dehydration caused an over 1.5-fold increase in CA activity of the control plants and a more than 2.5-fold increase in ABA-treated plants. Dehydration of CHI-treated plants caused no change in enzyme activity. It is suggested that increased activity of CA is a photosynthetic response to elevated ABA concentration.

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J Plant Growth Regul (1996) 15:75–80

Effect of Jasmonic Acid on the Stomatal and Nonstomatal Limitation of Leaf Photosynthesis in Barley Leaves

M. V. Metodiev, T. D. Tsonev, and L. P. Popova*

Abstract. The effect of long-term (7 days) and short-term (up to 2 h) treatment of barley plants with jasmonic acid (JA) on the components contributing to stomatal and nonstomatal limitation of photosynthesis was studied. Net CO_2 assimilation rate (A) responses to intercellular CO_2 concentration (C_i), i.e., A/C_i curves, were used to assess the photosynthetic ability. Long-term treatment of barley plants with JA led to a noticeable decrease in both the initial slope of the A/C_i curves and the maximum A at saturating C_i. The proportion of stomatal and nonstomatal factors in limitation of photosynthesis depended on the applied JA concentration. Short-term treatment with JA affected neither the stomatal conductivity for CO_2 nor the rate of photosynthetic CO_2 assimilation. We suggest that JA may affect photosynthesis indirectly, either as a stress-modulating substance, or through the alterations in gene expression.

Bulg. J. Plant Physiol., 1996, 22(1–2), 13–21

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EFFECT OF COLD HARDENING ON SOME PHOTOSYNTHETIC CHARACTERISTICS OF PEA (*Pisum sativum* L., CV. RAN 1) PLANTS

Ivan Yordanov, Katya Georgieva, Tsonko Tsonev, Violeta Velikova*

Summary. The effect of 96 h cold acclimation of pea (*Pisum sativum* L., cv. Ran 1) plants on their photosynthetic capacity was investigated. It was found that pea plants were able to modulate their photosynthetic rate during growth at low temperature and adjust it to needs for survival. The advantages of hardening to low temperature were very clearly expressed when the effects on O_2 evolution and on the relative part of Q_B non-reducing centres were analysed. Analysis of photosynthetic rates and fluorescence parameters showed that these processes were more resistant to freezing in cold hardened than in non-hardened pea plants. It was proposed that for pea plants the maintenance of active photosynthesis at low overzero temperatures is also very important for survival, because in early spring such unfavourable conditions are not rare.

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Bot. Acta. 110 (1997) 18 – 24

Regulation of CAM and Respiratory Recycling by Water Supply in Higher Poikilohydric Plants – *Haberlea rhodopensis* Friv. and *Ramonda serbica* Panč. at Transition from Biosis to Anabiosis and *Vice Versa*

Y. Markovska [1], T. Tsonev [2], and G. Kimenov [1]

Abstract: In this paper the expression of C_3 and CAM in the resurrection plants *Haberlea rhodopensis* Friv. and *Ramonda serbica* Panč. during the transition from biosis to anabiosis and *vice versa* is reported for the first time. The transition from predominantly C_3 metabolism to net dark fixation of CO_2 occurred in leaves of *R. serbica* during desiccation. Desiccated plants of *H. rhodopensis* react by reducing light assimilation of CO_2. When watering was resumed night time fixation of CO_2 by *R. serbica* was observed within 24 hours. The recovery of CO_2 fixation by *H. rhodopensis* was not seen until the 8 th day. Desiccated and rehydrated plants of *H. rhodopensis* recapture a higher proportion of respiratory CO_2 than well-watered plants. Since both species have little capacity for water conservation in their tissues, the early onset of high recycling of CO_2 following drought could be an important mechanism for potentially saving water.

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PHOTOSYNTHETICA 33 (3-4): 391-402, 1997

Interactive effect of water deficit and high temperature on photosynthesis of sunflower and maize plants 1. Changes in parameters of chlorophyll fluorescence induction kinetics and fluorescence quenching

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Abstract

Effects of high temperature (HT, 42 °C) and water stress (WD) applied separately and in combination, on the chlorophyll fluorescence kinetics and photochemical (q_P) and non-photochemical (q_N) quenching in 21-d-old sunflower and maize plants were studied. The WD was created by addition of polyethylene glycol (M_r 6000) to the nutrient solution. When the fluorescence was measured at 47 °C, the F_v/F_0 ratio in sunflower considerably increased in plants under combined stress, whereas in maize plants it remained practically unchanged. The combined action of HT+WD led also to a noticeable (in sunflower) or a weaker (in maize) increase of F_0(25 °C)/F_0(47 °C) ratio (a criterion for stability of the light-harvesting complex LHC2 at HT) and a decrease of the F_v(25 °C)/F_v(47 °C) ratio (tolerance of the photochemical activity and O_2-evolving system). The q_P and q_N values measured at 47 °C in maize were different from those of sunflower. The q_P values were high, but practically not influenced by HT and WD. In both plant species most of the effects induced by stress treatments disappeared after a 72 h recovery.

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PHOTOSYNTHETICA 33 (3-4): 423-431, 1997

Gas exchange and chlorophyll fluorescence during water and high temperature stresses and recovery. Probable protective effect of carbamide cytokinin 4-PU30

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Abstract

Two-weeks-old *Phaseolus vulgaris* plants were subjected to increasing water deficit (WD) and to combination of WD + high temperature (HT). The possible protective or reparatory effect of carbamide cytokinin 4-PU30 [N-(2-chloro-4-pyridyl)-N-phenylurea] applied before and after the stress was studied. The photosynthetic gas exchange and chlorophyll fluorescence induction kinetics excited by low (60 μmol m^{-2} s^{-1}) and saturating (3000 μmol m^{-2} s^{-1}) photon flux densities at 25 and 45 °C were measured on the primary leaves. The WD (17-20 % after 3 d) caused significant decrease in rates of CO_2 uptake and O_2 evolution, and its combination with HT (40-44 % WD and leaf temperature of 45 °C) led to an almost complete inhibition of them. The effects in the parameters characterizing the state of photosystem 2 reaction centres were less expressed. The dynamics of recovery of CO_2 uptake and O_2 evolution were different in plants under WS or WS + HT. The carbamide cytokinin 4-PU30 in 10^{-6} M concentration favourably affected the recovery and not so noticeably actioned during the stress.

PHOTOSYNTHETICA 34 (2): 293-302, 1997

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Effects of Cd^{2+} on the physiological state and photosynthetic activity of young barley plants

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Abstract

Barley plants (*Hordeum vulgare* L. cv. Obzor) were grown as a water culture in a climatic room. One part of them was subjected to a long-term Cd^{2+} stress - 12 d with 5.4×10^{-5} M Cd. The Cd^{2+} stress inhibited formation of the photosynthetic apparatus and its capacity for ^{14}C photoassimilation, decreased the content of soluble proteins, increased the dark respiration rate and the free amino acids content, disturbed plant water relations, as well as the distribution of ^{14}C within primary photoproducts of the treated barley plants.

PHOTOSYNTHETICA 34 (4): 563-567, 1997

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Effect of cytokinins on the photosynthetic apparatus in water-stressed and rehydrated bean plants

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Abstract

Effects of the cytokinins 6-benzylaminopurine (BAP) and N-2-chloro-4 pyridyl-N'-phenylurea (4-PU-30) on the photochemical activity, oxygen flash yields, and thermoluminescence in bean plants under a water stress were studied. The cytokinins increased the photochemical (Hill reaction) activity and thermoluminescence "B"-band in control as well as in stressed and rehydrated plants, while the oxygen flash yields were affected only in the stressed and rehydrated plants.

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EFFECT OF SOME CYTOKININS ON THE PHOTOSYNTHETIC APPARATUS OF BEAN PLANTS

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It is well known that the cytokinins of purine type, e. g. BAP (6-benzylaminopurine), and of phenylurea type, e. g. 4-PU-30 (2- (N-chloro-4 pyridy1)-N'-phenylurea), stimulate the cell division and differentiation, RNA-polymerase activity, protein synthesis, etc. Positive effects of the phenylurea cytokinins on the plant productivity [1] and on the photysynthetic activity [2,3] were demonstrated for several plant species. On the other hand, many problems concerning the site and the mechanisms of the action of these substances remain unclear. The purpose of this study was to investigate the effect of some cytokinins on photosynthetic apparatus of bean plants and especially on the photochemical activity and oxygen evolving mechanisms.

It was shown that the so-called PSIIa centres, situated in grana regions, operate by non-cooperative Kok's mechanism for 0, production and are especially sensitive to different kinds of stress factors. Obviously, after the application of both cytokinins a significant increase in the number of stroma situated PSIIP centres is observed, which are functioning by the cooperative 0, evolving mechanism. This explains the two-fold increase in the rate of Hill reaction activity (reflecting the full oxygen evolving capacity of the photosynthesizing system, i. e. cooperative and non-cooperative mechanisms) (Table 1) and the abscence of the pronounced effect on the 0, flash yield amplitudes (or on the kinetic parameters of the PSIla centres, working in the grana partitions (Fig. 1, Table 2). As the samples are with equal chlorophyll concentrations it should be assumed that the number of oxygen evolving centres in the treated with both cytokinins plants contain less antennae cldorophyll molecules in their photosynthetic units or are functioning with higher rate (shorter turnover time). Undoubtedly, this statement needs further investigations.

PHOTOSYNTHETICA 34 (4): 523-535, 1997

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Effects of simulated acid rain on the photosynthetic characteristics of *Phaseolus vulgaris* L.

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Abstract

A single treatment with a low pH solution of bean plants led to serious changes in the net photosynthetic rate (P_N) as well as in various parameters of photosystem 2 (PS2) activity. A considerable suppression of P_N was established already in the first hours (3 and 5) following the acid treatment (pH 2.4-1.8). The period of strong inhibition of CO_2 uptake and photochemical activity was followed by the period of recovery (24-72 h). At a single spraying, pH values exceeding 2.0 did not lead to irreversible damages of the photosynthetic apparatus. The damages resulting from treatments with pH 2.0 and 1.8 were on the threshold of irreversible ones and were the cause of faster ageing.

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Effect of Pretreatment with Methyl Jasmonate on the Response of *Pisum sativum* to Salt Stress

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Summary

10-day-old pea seedlings (*Pisum sativum* L. cv. Ran 1) were supplied with 10^{-5} M methyl jasmonate for 3 days before salinization with 30 mmol/L NaCl for 3 and 6 days. Salt stress resulted in an increase of free proline content, CO_2 compensation concentration (Γ), photorespiration (R_P), stomatal resistance (r_s), and activity of glycolate oxidase (GO) and phosphoglycolate phosphatase (PGP). Net photosynthetic rate (P_N), transpiration (E), protein content and relative water content (RWC) were decreased. Pretreatment with methyl jasmonate helps the plants to counteract the salt stress or for adaptation to it. P_N, RWC and protein content of these seedlings were higher in comparison to NaCl-treated seedlings. Exogenously supplied jasmonate itself plays the role of a stressor that causes typical stress responses – accumulation of free proline, high R_P and Γ. Pretreatment with methyl jasmonate leads to a decrease of Na^+ and Cl^- accumulation in the shoot. This protection is discussed with respect to involvement of methyl jasmonate in osmoregulation or osmoprotection based on increased proline accumulation and decreased ion accumulation.

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INFLUENCE OF CARBAMIDE CYTOKININ 4-PU30 ON PHOTOSYNTHESIS OF BEAN PLANTS ENDURED MILD HIGH TEMPERATURE STRESS

I. Yordanov, T. Tsonev, K. Georgieva, M. Merakchiiska-Nikolova, V. Velikova, L. Kruleva

One of the ways to maintain photosynthetic apparatus in active state is *the* use of chemicals which can protect its integrity. Cytokinins of purine and phenylcarbamide type (4-PU30) favour protein synthesis, inhibit ageing of detached leaves, increase the yield of wheat [5-8]. In this paper we report the influence of 4-PU30 on photosynthesis of bean plants grown at mild high temperature stress (HTS).

These results are an indication for acclimation of plants to mild HTS. It is interesting to mention that this acclimation effect is rather short-term and under experimental conditions we used practically disappeared after 24 h recovery. Our results also showed that under these conditions 4-PU30 applied after 3 times heating of bean plants does not influence the processes investigated. Therefore, in bean plants experienced mild HTS proceeds an acclimation process which increased the thermotolerance of the photosynthetic apparatus. Under experimental conditions we used the carbamide cytokinin 4-PU30 protects, in some extent, the photosynthesis only when is applied before enduring of mild HTS by plants.

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Regulation

J Plant Growth Regul (1998) 17:153–159

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A Possible Role for Jasmonic Acid in Adaptation of Barley Seedlings to Salinity Stress

T. D. Tsonev, G. N. Lazova, Z. G. Stoinova, and L. P. Popova*

Abstract. The changes caused by NaCl salinity and jasmonic acid (JA) treatment (8 days) on growth and photosynthesis of barley plants (*Hordeum vulgare* L., var. Alfa) have been studied. Gas exchange measurements and analysis of enzyme activities were used to study the reactions of photosynthesis to salinity and JA. Both 100 mM NaCl and 25 μM JA treatment led to a noticeable decrease in both the initial slope of the curves representing net photosynthetic rate vs intercellular CO_2 concentration and the maximal rate of photosynthesis. The calculated values of the intercellular CO_2 concentration, CO_2 compensation point, and maximal carboxylating efficiency of ribulose-1,5-bisphosphate carboxylase support the suggestion that biochemical factors are involved in the response of photosynthesis to JA and salinity stress. The activities of phosphoenolpyruvate carboxylase and carbonic anhydrase increased more than twofold. Pretreatment with JA for 4 days before salinization diminished the inhibitory effect of high salt concentration on the growth and photosynthesis. The results are discussed in terms of a possible role of JA in increasing salinity tolerance of the barley plants.

Environmental Pollution 103 (1998) 287–293

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Physiological response of barley plants (*Hordeum vulgare*) to cadmium contamination in soil during ontogenesis

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Abstract

A study was made on the physiological response of two winter barley cultivars (Obzor and Hemus), grown as pot-soil cultures, to cadmium treatment. It was established that a soil Cd concentration of 45 mg/kg inhibited dry mass accumulation and suppressed development of barley plants. The unfavourable Cd effect was better expressed in the plants of cv. Hemus and more significant at the early phenological stages of vegetation. Visual symptoms of phytotoxicity were observed in roots, where the Cd concentration was about 10 times higher than in the above-ground organs. In the overground parts of plants, the highest concentration was found in the lower leaves, increasing during ontogenesis. In the other parts, the Cd concentration decreased during ontogenesis towards stems, leaves of the upper floor, ears and grains. A slight tendency to decrease in the photosynthetic rate was observed in the Cd-treated plants of both cultivars. The rate of transpiration as well as the plastid pigment concentration did not change significantly.

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Effects of Exogenous Polyamines Applied Separately and in Combination with Simulated Acid Rain on Functional Activity of Photosynthetic Apparatus

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Summary

Ten-day-old bean seedlings (*Phaseolus vulgaris* L.) were grown in a greenhouse and sprayed with spermidine or spermine. After 24 h they were treated with a cocktail of simulated acid rain (pH 5.6 and 1.8). Polyamines were applied separately or in combination with acid rain. Their protective effect on the functional activity of the photosynthetic apparatus in the acid rain-treated plants was investigated. It was found that acid rain with pH 1.8 applied separately decreased strongly the photosynthetic rate, the oxygen evolution, as well as the PS2 activity. Polyamines (spermidine and spermine) applied 24 h the before the acid rain treatment partially diminished the inhibitory effect of acid rain on the photosynthetic apparatus. The results showed also that the favourable effect of spermine was higher than that of spermidine. The protective action of polyamines could be explained by their polycationic nature, their ability to bind with photosynthetic membranes, resulting in conformational changes and stabilization, of the membrane and by their ability to act as free radical scavengers.

G. Garab (ed.), Photosynthesis: Mechanisms and Effects, Vol. IV, 2497–2500.

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PHOTOSYNTHETIC ACTIVITY OF BEAN PLANTS UNDER CONDITIONS OF HIGH- AND LOW-TEMPERATURE INDUCED PHOTOINHIBITION

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Here we compare the changes in the photosynthetic apparatus evaluated by chlorophyll fluorescence characteristics and oxygen evolution rate after photoinhibitory treatment at different temperatures.

In conclusion, our experiments showed that at the background of high temperature the characteristics of PI differ from these at low temperature. Obviously, various types of regulation prevails at different stress conditions.

G. Garab (ed.), Photosynthesis: Mechanisms and Effects, Vol. IV, 2577–2580.

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EFFECT OF CARBAMIDE CYTOKININ 4PU-30 ON THE PHOTOSYNTHESIS OF BEAN PLANTS ENDURED DROUGHT AND HIGH TEMPERATURE STRESSES

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Conclusion: The results obtained showed that: the mild WS (17-20%) applied separately influenced photosynthesis and light curves of O_2 evolution relatively weaker and after rewatering of plants both parameters recovered in 24 hours. The combined stress (WD 40-44%) on the third day drought plus high temperature - 2 days 42°C, 5h and on the 3-rd day 45°C, 2h) strongly influenced both the rate of photosynthesis and O_2-evolution. When the components of this stress have their maximal values both processes were practically totally inhibited, but they were even capable to recover although for a longer time. It was also shown that carbamide cytokinin 4PU-30 protected the parameters investigated (during stress) and enhanced the recovery processes.

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HIGH- AND LOW-TEMPERATURE INDUCED PHOTOINHIBITION IN BEAN PLANTS CHARACTERIZED BY PHOTOACOUSTIC AND FLUORESCENCE MEASUREMENTS

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Photoacoustic spectroscopy and prompt fluorescence were used for *in vivo* characterization of changes in photosynthetic reactions in bean plants at combined stress conditions, including four-hour treatments with moderately high light intensity - 1100 μmol m^{-2} s^{-1} photon flux density, and high (42°C) or low (13°C) temperature. The decline of the photothermal signal after switching off the background light (RS-drop) is proposed as a good indicator of the change in the proton gradient.

PHOTOSYNTHETICA 37 (3): 447-457, 1999

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Influence of drought, high temperature, and carbamide cytokinin 4-PU-30 on photosynthetic activity of bean plants. 1. Changes in chlorophyll fluorescence quenching

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Abstract

Fifteen-day-old bean plants (*Phaseolus vulgaris* L.) grown in a climatic chamber were exposed to water deficit (WD) and high temperature (HT) stresses applied separately or in combination. Changes in chlorophyll fluorescence quenching were investigated. Bean plants that endured mild (42 °C, 5 h for 2 d) WD separately or in combination with HT did not change their q_P and q_N quenching (measured at 25 °C) compared with those of the control. After 5 min testing at 45 °C, q_P in control and droughted plants strongly decreased, while q_P of plants that experienced combined WD+HT stress was insignificantly influenced, suggesting the acclimation effect of HT treatments. At more severe stresses (after 3 d-treatment), q_P measured at 25 °C was the lowest in WD+HT plants and q_N values were the highest. But when measured at 45 °C, q_P of WD+HT plants had practically the same values as at 25 °C. Under these conditions q_P of WD plants also showed an adaptation to HT. Twenty-four hours after recovery, the unfavourable effects of the stresses were strongly reduced when measured at 25 °C, but they were still present when measured at 45 °C. Positive effect of the carbamide cytokinin 4-PU-30 was well expressed only in droughted plants.

PHYSIOLOGIA PLANTARUM 107: 77–83. 1999

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Light and CO_2 responses of photosynthesis and chlorophyll fluorescence characteristics in bean plants after simulated acid rain

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The effects of simulated acid rain on some chlorophyll fluorescence characteristics and photosynthetic gas exchange at different light intensities and CO_2 concentrations of bean plants were investigated. Measurements were carried out 3, 5 and 24 h after spraying. The results showed that a single acid rain (pH 1.8) treatment of bean plants reduced gas exchange, the maximal carboxylating efficiency and photochemical quenching. This treatment led also to increased CO_2 compensation point and non-photochemical quenching and changed the shape of CO_2 and light curves of photosynthesis. Both stomatal and non-stomatal factors contributed to the decreased photosynthetic rate, but their proportion changed with time of recovery of the photosynthetic apparatus. Three hours after the treatment, the stomatal factors predominated in photosynthesis reduction, while during the next experimental period (5–24 h), mainly non-stomatal factors determined the decreased photosynthetic rate. It is suggested that the effects observed in consequence of acid rain treatment could be due to an increased intracellular accumulation of H^+ and harmful ions contained in the cocktail. This probably led to impaired membrane permeability, enhancement of stroma acidity, uncoupled electron transport and insufficient accumulation of ATP and NADPH, which affected carbon metabolism.

Bulg. J. Plant Physiol., 1999, 25(3–4), 45–53

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RECOVERY OF THE PHOTOSYNTHETIC APPARATUS IN BEAN PLANTS AFTER HIGH- AND LOW-TEMPERATURE INDUCED PHOTOINHIBITION *

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Summary. The recovery after photoinhibition in 20-day-old bean plants (*Phaseolus vulgaris* L.) induced by 4 h treatment with low (12 °C), normal (24 °C) and high (42 °C) temperatures under high (1000 μmol.m^{-2}.s^{-1}) and low (100 μmol.m^{-2}.s^{-1}) photon flux density (PFD) was studied. The changes in the photosynthetic apparatus were analysed using chlorophyll fluorescence measurements. The ratios F_v/F_m measured by PAM fluorimeter were used as characteristics of quantum efficiency of photosystem II. Data showed that both high and low temperatures enhance the photoinhibition manifested as F_v/F_m decrease. At all temperatures investigated this decrease was due in greater extent to F_m decrease while the increases in F_o were insignificant. Different pattern of photosynthetic apparatus recovery after photoinhibition at various temperatures was observed, suggesting that different mechanisms of photoinhibitory injury predominate in these cases.

PHOTOSYNTHETICA 38 (3): 361-366, 2000

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Abstract

Effects of high-temperature stress (HTS) and PEG-induced water stress (WS), applied separately or in combination, on the functional activity and ultrastructure of the photosynthetic apparatus (PSA) of maize (*Zea mays* L.) and sunflower (*Helianthus annuus* L.) plants were investigated. In maize plant tissues WS provoked the decrease in RWC by 10.9 %, HTS by 7.0 %, and after simultaneous application of the both treatments the decrease was 32.7 % in comparison with control plants. Similar but more expressed changes were observed in sunflower plants. Sunflower was more sensitive to these stresses. Net photosynthetic rate decreased significantly after all treatments, more in sunflower. In mesophyll chloroplasts after separately applied WS and HTS the number of grana and thylakoids was reduced and electron-transparent spaces appeared. At combined stress (WS+HTS) granal and stromal thylakoids were considerably affected and chloroplast envelope in many of them was partially disrupted.

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Biochemistry **2000,** *39,* 15250−15257

Thermooptic Effect in Chloroplast Thylakoid Membranes. Thermal and Light Stability of Pigment Arrays with Different Levels of Structural Complexity†

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ABSTRACT: In chloroplast thylakoid membranes, chiral macrodomains, i.e., large arrays of pigment molecules with long-range chiral order, have earlier been shown to undergo light-induced reversible and irreversible structural changes; such reorganizations did not affect the short-range, excitonic pigment−pigment interactions. These structural changes and similar changes in lamellar aggregates of the main chlorophyll *a*/*b* light-harvesting complexes exhibited a linear dependence on the intensity of light that was not utilized in photosynthesis. It has been hypothesized that the light-induced rearrangements are driven by a thermooptic effect, i.e., thermal fluctuations due to the dissipation of excess excitation energies [Barzda, V., et al. (1996) *Biochemistry 35*, 8981−8985]. To test this hypothesis, we have utilized circular dichroism (CD) spectroscopy to investigate the structural stability of the chiral macrodomains and the constituent bulk pigment−protein complexes of granal thylakoid membranes against heat and prolonged, intense illumination. (i) In intact thylakoid membranes, the chiral macrodomains displayed high stability below 40 °C, but they were gradually disassembled between 50 and 60 °C; the thermal stability of the chiral macrodomains could be decreased substantially by suspending the membranes in reaction media that were hypotonic or had low ionic strength. (ii) The chiral macrodomains were also susceptible to high light: prolonged illumination with intense white light (25 min, 2500 μE m^{-2} s^{-1}, 25 °C) induced similar, irreversible disassembly to that observed at high temperatures; in different preparations, lower thermal stability was coupled to lower light stability. (iii) The light stability depended significantly on the temperature: between about 5 and 15 °C, the macrodomains in the intact thylakoids were virtually not susceptible to high light; in contrast, the same preillumination at 35−40 °C almost completely destroyed the chiral macrodomains. (iv) As testified by the excitonic CD bands, the molecular organization of the pigment−protein complexes in all samples exhibited very high thermal stability between about 15 and 65 °C, and virtually total immunity against intense illumination. These data are fully consistent with the hypothesis of a thermooptic effect, and are interpreted within the frame of a simple model.

J. Plant Physiol. 157. 169–176 (2000)

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JOURNAL OF PLANT PHYSIOLOGY

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Photosynthetic activity during high temperature treatment of pea plants

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Summary

The functional activity of the photosynthetic apparatus of pea plants (*Pisum sativum*, L.) under high temperature conditions was investigated. The rates of CO_2 uptake and O_2 evolution declined after 1 h exposure to 45 °C and their activity did not change significantly up to the 8th h of treatment, which could be due to some acclimation to the unfavourable temperature. Photosynthetic activity sharply decreased after 24 h at 45 °C.

Information about the functional activity of PSII was derived from analyses of *in vivo* chlorophyll fluorescence. It was recorded at 25 °C and also at 45 °C, immediately after the respective time of 45 °C treatment of pea plants.

Our results showed that when whole plants were exposed to 45 °C up to 24 h the CO_2 assimilation and O_2 evolution rate were more inhibited than the yield of primary photochemistry (estimated by the ratio F_v/F_m). These values started to decrease after 5 h of high temperature exposure and was reduced to a greater extent after 24 h of treatment.

The higher PSII thermostability *in vivo* could be due to the protective effect of low light intensity and the low air humidity during the heat treatment.

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HEAT-INDUCED CHANGES IN THE CHLOROPHYLL FLUORESCENCE OF PEA CHLOROPLASTS

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(*Submitted by Corresponding Member E. Karanov on May 13, 1999*)

The aim of this study was to compare the temperature responses of chlorophyll fluorescence induction kinetics of different thylakoid preparations in which the macroorganization of complexes varied by changing the cation content and the osmotic strength of the medium. This allows us to establish correlation between the heat-induced decrease in photosynthetic activity and changes in the macroorganization of the pigment system in thylakoids.

It is proposed that the macroorganization of the pigment system, which can be disassembled by high temperatures or depletion of membranes from cations, significantly influences the operational conditions of the photosyntnetic apparatus. This can be understood by taking unto account that the complexes which participate in the macrodomains constitute the vast majority of structure proteins of grana and thus can determine the bulk protolytic and electric properties of the membranes.

PHOTOSYNTHETICA 38 (1): 171-186, 2000

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REVIEW

Plant responses to drought, acclimation, and stress tolerance

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Abstract

At the whole plant level, the effect of stress is usually perceived as a decrease in photosynthesis and growth. That is why this review is focused mainly on the effect of drought on photosynthesis, its injury, and mechanisms of adaptation. The analysed literature shows that plants have evolved a number of adaptive mechanisms that allow the photochemical and biochemical systems to cope with negative changes in environment, including increased water deficit. In addition, the acquisition of tolerance to drought includes both phenotypic and genotypic changes. The approaches were made to identify those metabolic steps that are most sensitive to drought. Some studies also examined the mechanisms controlling gene expression and putative regulatory pathways.

Bulg. J. Plant Physiol., 2001, 27(3–4), 20–33

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CHANGES IN CO_2 ASSIMILATION, TRANSPIRATION AND STOMATAL RESISTANCE OF DIFFERENT WHEAT CULTIVARS EXPERIENCING DROUGHT UNDER FIELD CONDITIONS

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Summary. The response of the photosynthetic apparatus of different wheat cultivars (cvs) of *Triticum aestivum* L. to drought was investigated. The cvs. were sowed in a special "desiccation greenhouse", i.e. field area covered by polyethylene in order to prevent plant watering by rain. Photosynthetic CO_2 uptake, stomatal resistance and transpiration were measured on the flag leaf with a portable photosynthetic system LI 6000 (Li-Cor, USA). It was found that mild water deficit (WD) decreased the rate of photosynthesis to a different extent depending on drought tolerance of the cvs. With the further increase of drought, the reduction of photosynthetic rate increased and the wheat cvs. demonstrated rather different drought tolerance compared to mild WD. In most cases no direct correlation between the extent of reduction in photosynthetic rate, transpiration and stomatal resistance was found. On the basis of the data obtained it was suggested that even under mild WD the stomatal resistance was not always the main factor limiting photosynthesis in drought-ed plants. Especially under severe WD the photosynthetic CO_2 uptake depended not only on transpiration rate and stomatal resistance. Obviously, under such conditions non-stomatal factors, e.g. chloroplast capacity to fix CO_2 limited to a greater extent the rate of photosynthesis. The differences in drought tolerance of wheat cvs. in dependrnce of the severity of WD, reported here may be related to the extent of "physiological window" (Burke, 1990).

On the basis of the data characterizing net photosynthetic rate and WUE the cultivars were divided in three groups.

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RESPONSE OF THE PHOTOSYNTHETIC APPARATUS OF DIFFERENT WHEAT GENOTYPES TO DROUGHT: I. LABORATORY EXPERIMENTS UNDER CONTROLLED LIGHT AND TEMPERATURE CONDITIONS

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Abstract

The response of the photosynthetic apparatus of 5 wheat (*Triticum aestivum* L.) cultivars—Flamura, Pliska, Sadovo, Slavianka and Spartanka to increased water deficit was investigated. Plants were cultivated as a sand culture on Knop's nutrient solution in a climatic chamber at 14 h photoperiod, 120 μmol $m^{-2}s^{-1}$ photon flux density and temperature 23–25 °C.

The drought tolerance of plants was evaluated by parameters of functional activity of the photosynthetic apparatus—gas exchange and prompt chlorophyll fluorescence. It was found that under these experimental conditions the most tolerant were plants of cv. Spartanka followed by cv. Flamura, used as a standard in the selection of wheat forms resistant to drought. The other three cultivars were more sensitive to drought. Among the fluorescence parameters the most sensitive was its variable component (Fv).

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Responses of photosynthetic apparatus of different wheat (*Triticum aestivum* L.) genotypes to drought under field conditions. II. Changes in O_2 evolution and chlorophyll fluorescence parameters – a possible basis for screening of drought tolerance

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ABSTRACT. The drought tolerance of different wheat genotypes of *Triticun aestivum* L. grown in field was investigated using two different methods – O_2 evolution and prompt Chl *a* fluorescence. It was found that under mild water deficit (10-15%) the PS2 efficiency was slightly affected. However, under severe water deficit (25-30%) PS2 is strongly inhibited and even injured. It was also established that the advantages of wheat cultivars were better expressed under strong drought stress, near to the threshold of water deficit. Our data showed that the percentage of inhibition of O_2 evolution was stronger than that of PS2 photochemical activity (F_v/F_m ratio). This indicates that the primary photochemical reactions were more stable than integral photosynthetic process under strong water deficit. Therefore, in order to precisely determine such a complex trait as drought tolerance more functional parameters must be taken into account as gas exchange, fluorescence, photosynthetic metabolism etc. For this reason a preliminary arrangement of wheat cultivars is proposed. According to F_v/F_m ratio in the group of drought tolerant cultivars could be included Spartanka, Svilena, Charodejka,Flamura, Kristal, Prelom, Laska, Elitsa, while according to O_2 evolution in the same group can be included the cultivars Zora, Preslav, Albena, Enola, Pobeda, Sadovo, Vratsa, Todora, Svilena.

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Int. Agrophysics, 2002, 16, 203–208

Multichannel measuring system for profile monitoring of CO_2 concentration in cultivation equipment

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A b s t r a c t. A multichannel measuring system MMS-05 for continuous and synchronized profile monitoring of the CO_2 concentration in cultivation installations is described. The system guarantees the performance of vertical and horizontal gradient measurements and registration of CO_2 concentration in a greenhouse. Experimental studies with 6 cultivars of greenhouse tomato plants performed for testing the system show that the fluctuations in CO_2-profiles, and respectively the CO_2 concentration in the greenhouse, follow a time dependant pattern with a pronounced decrease during the midday hours 10 a.m. ÷ 6 p.m. when CO_2 concentration reaches 160 ÷ 180 μmol mol^{-1}. During the night, as a result of plant and soil respiration, the CO_2 concentration rises to 450 ÷ 500 μmol CO_2 mol^{-1}.

PHOTOSYNTHETICA 40 (3): 449-452, 2002

BRIEF COMMUNICATION

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Effects of reddening of cotton (*Gossypium hirsutum* L.) leaves on functional activity of photosynthetic apparatus

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Abstract

Strong inhibition of rates of CO_2 assimilation and transpiration, stomatal conductance, and water use efficiency as well as photosystem 2 (PS2) photochemical activity were related to the severity of reddening. The inhibition of photosynthesis in red cotton leaves was due to both decreased photochemical activity and stomatal limitation. Lowered photosynthetic capacity could be one of the main factors of reduced yield in reddening cotton.

Annals of Botany **91**: 1–10, 2003

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Low Temperature Enhances Photosynthetic Down-regulation in French Bean (*Phaseolus vulgaris* L.) Plants

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The mechanisms of photosynthetic adaptation to different combinations of temperature and irradiance during growth, and especially the consequences of exposure to high light (2000 µmol m^{-2} s^{-1} PPFD) for 5 min, simulating natural sunflecks, was studied in bean plants (*Phaseolus vulgaris* L.). A protocol using only short (3 min) dark pre-treatment was introduced to maximize the amount of replication possible in studies of chlorophyll fluorescence. High light at low temperature (10 °C) significantly down-regulated photosynthetic electron transport capacity [as measured by the efficiency of photosystem II (PSII)], with the protective acclimation allowing the simulated sunflecks to be used more effectively for photosynthesis by plants grown in low light. The greater energy dissipation by thermal processes (lower F_v'/F_m' ratio) at low temperature was related to increased xanthophyll de-epoxidation and to the fact that photosynthetic carbon fixation was more limiting at low than at high temperatures. A key objective was to investigate the role of photorespiration in acclimation to irradiance and temperature by comparing the effect of normal (21 kPa) and low (1·5 kPa) O_2 concentrations. Low [O_2] decreased F_v/F_m and the efficiency of PSII (Φ_{PSII}), related to greater PSII down-regulation in cold pre-treated plants, but minimized further inhibition by the mild 'sunfleck' treatment used. Results support the hypothesis that photorespiration provides a 'safety-valve' for excess energy.

Bulg. J. Plant Physiol., Special Issue 2003, 187–206

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PLANT RESPONSES TO DROUGHT AND STRESS TOLERANCE

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Summary. In the natural environment plants are well adapted to minimize damages which only occurs under extreme conditions. In the frame of "physiological window" mild drought induces in plants regulation of water loss and uptake allowing maintenance of their leaf relative water content within the limits where the photosynthetic capacity shows no or little changes. But severe drought induces in plants unfavourable changes leading to inhibition of photosynthesis and growth. The most severe drought stress is desiccation. On the basis of presence or absence of bulk water, the mechanisms of protection are different. While the mechanisms conferring drought tolerance are mainly based on structural stabilization by preferential hydration, desiccation tolerance mechanisms are based on the replacement of water by molecules that form hydrogen bonds. The roles of stomatal and non-stomatal limitation, the behaviour of PS2, specific proteins and Rubisco, lipids and sugars, as well as mechanisms of acclimation and stress tolerance in droughted plants are discussed.

Plant Cell Physiol. 44(8): 828–835 (2003)

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Contribution of Photosynthetic Electron Transport, Heat Dissipation, and Recovery of Photoinactivated Photosystem II to Photoprotection at Different Temperatures in *Chenopodium album* Leaves

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Temperature dependence of photoinhibition and photoprotective mechanisms (10–35°C) was investigated for *Chenopodium album* leaves grown at 25°C under 500 µmol quanta m^{-2} s^{-1}. The fraction of active photosystem II (PSII) was determined after photoinhibitory treatment at different temperatures in the presence and absence of lincomycin, an inhibitor of chloroplast-encoded protein synthesis. In the absence of lincomycin, leaves were more tolerant to photoinhibition at high (25–35°C) than at low (11–15°C) temperatures. In the presence of lincomycin, the variation in the tolerance to photoinactivation became relatively small. The rate constant of photoinactivation (k_{pi}) was stable at 25–35°C and increased by 50% with temperature decrease from 25 to 11°C. The rate constant of recovery of inactivated PSII (k_{rec}) was more sensitive to temperature; it was very low at 11°C and increased by an order of magnitude at 35°C. We conclude that the recovery of photoinactivated PSII plays an essential role in photoprotection at 11–35°C. Partitioning of light energy to various photoprotective mechanisms was further analyzed to reveal the factor responsible for k_{pi}. The fraction of energy utilized in photochemistry was lower at lower temperatures. Although the fraction of heat dissipation increased with decreasing temperatures, the excess energy that is neither utilized by photochemistry nor dissipated by heat dissipation was found to be greater at lower temperatures. The k_{pi} value was strongly correlated with the excess energy, suggesting that the excess energy determines the rate of photoinactivation.

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CHANGES IN CHL A FLUORESCENCE AND ABSORBANCE AT 820nm IN BEAN PLANTS, SUBJECTED TO DIFFERENT REGIMES OF TEMPERATURE, LIGHT INTENSITY AND CO_2 CONCENTRATION

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Summary

The effect of high CO_2 concentration (1.300µmol.mol^{-1}) on the PSII and PSI activity in 19 days-old bean plants (Phaseolus vulgaris L.), exposed for four days (8h per day) to combinations of low (100µmol.m^{-2}.s^{-1} PPFD) and high (1.000µmol.m^{-2}.s^{-1} PPFD) irradiation and temperatures (10, 23 and 39°C), was studied by means of Chl a fluorescence transients, oxygen evolution and absorbance changes at 820nm.

Bean plants exposed to high irradition (HL) had a lower maximal quantum yield of primary photochemistry and electron transport efficiency. The HL effects deepened at low temperature (10°C) and lessened at high temperature (39°C).

It was concluded that the intensity of 1.000µmol.m^{-2}.s^{-1} was photoinhibitory at low-temperature conditions but increased the photosynthetic capacity under high temperature.

Four-days growth of plants in atmosphere with 1.300µmol.mol^{-1} CO_2 concentration at 39°C and HL decreased the rate of O_2 evolution.

This was associated with increased variable fluorescence in the 0,3ms range and led to the assumption that the temperature stability of PSII was impaired by elevated [CO_2]. High CO_2 concentration intensified the low-temperature-HL-induced pho-toinhibition of PSII and reduction of the PSI activity.

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Early acclimation changes in the photosynthetic apparatus of bean plants during short-term exposure to elevated CO_2 concentration under high temperature and light intensity

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Abstract

To follow the early response of the photosynthetic apparatus to elevated [CO_2] applied in combination with other stress factors we exposed 19-day-old bean plants (*Phaseolus vulgaris* L. cv. Cheren Starozagorski) for relatively short period (4 days, 8 h per day) to different temperature, light and [CO_2] regimes: 23 or 39 °C air temperature, low (100 μmol m^{-2} s^{-1} – LL) or high (1000 μmol m^{-2} s^{-1} – HL) photosynthetic photon flux density (PPFD) and ambient (350 μmol mol^{-1}) or elevated (1300 μmol mol^{-1}) CO_2 concentration. Chlorophyll fluorescence kinetics and the response of assimilation rate to intercellular CO_2 concentration were registered during the 4-day period. At growth temperature (23 °C), we observed some stimulation of photosynthesis by elevated [CO_2], expressed by higher maximal net photosynthetic rate, carboxylation capacity and electron transport capacity, while at high temperature (39 °C) the effect of elevated [CO_2] on photosynthesis was negative, i.e. HT induced downward acclimation. The negative effect of the CO_2 enrichment at HT, expressed as diminished Rubisco activity and limitations in RuBP and P regeneration, may be due to starch accumulation as it was seen from the electron micrographs. Our results show that the ratio of intercellular to ambient [CO_2], which reflects the coupling between stomata and photosynthetic CO_2 assimilation, was unaffected by elevated [CO_2] as well as by changes in light and temperature. In the 4-day period, the PSII efficiency was not affected by the elevated [CO_2]. The fluorescence parameters were noticeably reduced at HL already on the first day and decreased further with time. We concluded that 4-day growth of plants in atmosphere with CO_2 concentration more than three times above the natural modifies the response of plants to light and temperature, which was connected with functional and structural changes.

Tree Physiology 25, 1523–1532

Localized ozone fumigation system for studying ozone effects on photosynthesis, respiration, electron transport rate and isoprene emission in field-grown Mediterranean oak species

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Summary We used a localized ozone (O_3) fumigation (LOF) system to study acute and short-term O_3 effects on physiological leaf traits. The LOF system enabled investigation of primary and secondary metabolic responses of similarly and differently aged leaves on the same plant to three different O_3 concentrations ($[O_3]$), unconfounded by other influences on O_3 sensitivity, such as genetic, meteorological and soil factors. To simulate the diurnal cycle of O_3 formation, current-year and 1-year-old *Quercus ilex* (L.) and *Quercus pubescens* (L.) leaves were fumigated with O_3 at different positions (and hence, different leaf ages) on the same branch over three consecutive days. The LOF system supplied a high $[O_3]$ (300 ± 50 ppb) on leaves appressed to the vents, and an intermediate, super-ambient $[O_3]$ (varying between 120 and 280 ppb) on leaves less than 30 cm from the vent. Leaves more than 60 cm from the O_3 vent were exposed to an $[O_3]$ comparable with the ambient concentration, with a 100 ppb peak during the hottest hours of the day. Only leaves exposed to the high $[O_3]$ were affected by the 3-day treatment, confirming that Mediterranean oak are tolerant to ambient and super-ambient $[O_3]$, but may be damaged by acute exposure to high $[O_3]$. Stomatal and mesophyll conductance and photosynthesis were all reduced immediately after fumigation with high $[O_3]$, but recovered to control values within 72 h. Both the intercellular and chloroplast CO_2 concentrations ($[CO_2]$) remained constant throughout the experiment. Thus, although treatment with a high $[O_3]$ may have induced stomatal closure and consequent down-regulation of photosynthesis, we found no evidence that photosynthesis was limited by low $[CO_2]$ at the site of fixation. One-year-old leaves of *Q. ilex* were much less sensitive to O_3 than current-year leaves, suggesting that the low stomatal conductance observed in aging leaves limited O_3 uptake. No similar effect of leaf age was found in *Q. pubescens*. Dark respiration decreased during the treatment period, but a similar decrease was observed in leaves exposed to low $[O_3]$, and therefore may not be an effect of O_3 treatment. Light respiration, on the other hand, was mostly constant in ozone-treated leaves and increased only in leaves in which photosynthesis was temporarily inhibited by high $[O_3]$, preventing them from acting as strong sinks that recycle respiratory CO_2 in the leaves. There was no evidence of photochemical damage in *Q. ilex* leaves, whereas *Q. pubescens* leaves exposed to a high $[O_3]$ showed limited photochemical damage, but recovered rapidly. Biochemical markers were affected by the high $[O_3]$, indicating accumulation of reactive oxygen species (ROS) and increased denaturation of lipid membranes, followed by activation of isoprene biosynthesis in *Q. pubescens* leaves. We speculate that the high isoprene emissions helped quench ROS and normalize membrane stability in leaves recovering from O_3 stress.

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Effect of Zn pollution on plant growth and photosynthesis

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Our survey shows that owing to development and applications of many new methods of biophysics, biochemistry and molecular biology and genetics, there is essential progress in understanding of the mechanisms underlying Zn toxicity in different levels of organization of the plants. The extent of plant injury by elevated Zn concentrations is species specific and strongly depends on the environmental conditions and the availability of other heavy metals. We did not discuss here the protective mechanisms that plants have developed to resist Zn toxicity, including avoidance, chelation and sequestration inside the cells, or efflux from the cytosol to the apoplast. Topic of other survey could be also plants that have the ability to survive and reproduce on soils containing high concentrations of Zn in forms that are toxic to other plants - the so called hyperaccumulators. About 400 different species belonging to a wide range of taxa have been described as hyperaccumulators (Baker and Brooks 1989) of which about 18 species are identified as Zn-hyperaccumulators (Reeves and Baker 2000). Further clarifying of the mechanisms of Zn toxicity and Zn tolerance and identifying new Zn- hyperaccumulators will be beneficial for reducing the unusable Zn-polluted fields by the method of phytoremediation.

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Short-term effect of elevated CO_2 concentration and high irradiance on the antioxidant enzymes in bean plants

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Abstract

The effect of short-term exposure to elevated CO_2 concentration and high irradiance on the activity of superoxide dismutase (SOD), ascorbate peroxidase (APX), guaiacol peroxidases (GPX) and catalase (CAT), and on the extent of the lipid peroxidation was studied in bean (*Phaseolus vulgaris* L.) plants. Plants were exposed for 4 d (8 h a day) to irradiance of 100 (LI) or 1000 (HI) μmol m^{-2} s^{-1} at ambient (CA, 350 μmol mol^{-1}) or elevated (CE, 1300 μmol mol^{-1}) CO_2 concentration. Four-day exposure to CE increased the leaf dry mass in HI plants and RuBPC activity and chlorophyll content in LI plants. Total soluble protein content, leaf dry matter and RuBPC activity were higher in HI than in LI plants, although the HI and CE increased the contents of malonyldialdehyde and H_2O_2. Under CA, exposure to HI increased the activity of APX and decreased the total SOD activity. Under CE, HI treatment also activated APX and led to reduction of both, SOD and GPX, enzymes activities. CE considerably reduced the CAT activity at both irradiances, possibly due to suppressed rate of photorespiration under CE conditions.

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Isoprene prevents the negative consequences of high temperature stress in *Platanus orientalis* leaves

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Abstract. The phenomenon of enhanced plant thermotolerance by isoprene was studied in leaves of the same age of 1- or 2-year-old *Platanus orientalis* plants. Our goals were to determine whether the isoprene emission depends on the age of the plant, and whether different emission rates can influence heat resistance in plants of different age. Two-year-old plants emit greater amounts of isoprene and possess better capacity to cope with heat stress than 1-year-old plants. After a high temperature treatment (38°C for 4 h), photosynthetic activity, hydrogen peroxide content, lipid peroxidation and antiradical activity were preserved in isoprene emitting leaves of 1- and 2-year-old plants. However, heat inhibited photosynthesis and PSII efficiency, caused accumulation of H_2O_2, and increased all indices of membrane damage and antioxidant capacity in leaves of plants of both ages in which isoprene was inhibited by fosmidomycin. In isoprene-inhibited leaves fumigated with exogenous isoprene during the heat treatment, the negative effects on photosynthetic capacity were reduced. These results further support the notion that isoprene plays an important role in protecting photosynthesis against damage at high temperature. It is suggested that isoprene is an important compound of the non-enzymatic defence of plants against thermal stress, possibly contributing to scavenging of reactive oxygen species (ROS) and membrane stabilising capacity, especially in developed plants.

Photosynth Res (2007) 94:321–332

Trapping of the quenched conformation associated with non-photochemical quenching of chlorophyll fluorescence at low temperature

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Abstract The kinetics of non-photochemical quenching (NPQ) of chlorophyll fluorescence was studied in pea leaves at different temperatures between 5 and 25°C and during rapid jumps of the leaf temperature. At 5°C, NPQ relaxed very slowly in the dark and was sustained for up to 30 min. This was independent of the temperature at which quenching was induced. Upon raising the temperature to 25°C, the quenched state relaxed within 1 min, characteristic for qE, the energy-dependent component of NPQ. Measurements of the membrane permeability (ΔA_{515}) in dark-adapted and preilluminated leaves and NPQ in the presence of dithiothreitol strongly suggest that the effect of low temperature on NPQ was not because of limitation by the lumenal pH or the de-epoxidation state of the xanthophylls. These data are consistent with the notion that the transition from the quenched to the unquenched state and vice versa involves a structural reorganization in the photosynthetic apparatus. An eight-state reaction scheme for NPQ is proposed, extending the model of Horton and coworkers (FEBS Lett 579:4201–4206, 2005), and a hypothesis is put forward concerning the nature of conformational changes associated with qE.

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Isoprene emission and primary metabolism in *Phragmites australis* grown under different phosphorus levels

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ABSTRACT

Aquatic plants are generally used for wastewater purification and phytoremediation, but some of them also emit large amounts of isoprene, the most abundant biogenic volatile organic compound. Since isoprenoid biosynthesis requires high amounts of phosphorylated intermediates, the emission may also be controlled by inorganic phosphorus concentration (Pi) in leaves. We carried out experiments to determine the emission of isoprene from *Phragmites australis* plants used in reconstructed wetlands to phytoremediate elevated levels of phosphorus contributed by urban wastes. Four groups of plants were grown hydroponically in water containing different levels of KH_2PO_4. High levels of phosphorus in the water resulted in high Pi in the leaves. High Pi stimulated photosynthesis at intercellular CO_2 concentrations lower and higher than ambient, implying higher ribulose 1,5-bisphosphate carboxylase (Rubisco) activity and higher ribulose 1,5-bisphosphate regeneration rates, respectively. However, isoprene emission was substantially lower at high Pi than at low Pi, and was not associated to photosynthesis rates at high Pi. This surprising result suggests that isoprene is limited by processes other than photosynthetic intermediate availability or by energetic (ATP) requirements under high Pi levels. Irrespective of the mechanism responsible for the observed reduction of isoprene emission, our results show that *Phragmites* plants may effectively remove phosphorus from water without concurrently increase isoprene emission, at least on a leaf area basis. Thus, *Phragmites* used in reconstructed wetlands for phytoremediation of urban wastes rich of phosphates will not contribute high loads of hydrocarbons which may influence air quality over urban and peri-urban areas.

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BVOC emissions, photosynthetic characteristics and changes in chloroplast ultrastructure of *Platanus orientalis* L. exposed to elevated CO_2 and high temperature

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A B S T R A C T

To investigate the interactive effects of increasing [CO_2] and heat wave occurrence on isoprene (IE) and methanol (ME) emissions, *Platanus orientalis* was grown for one month in ambient (380 μmol mol^{-1}) or elevated (800 μmol mol^{-1}) [CO_2] and exposed to high temperature (HT) (38 °C/4 h). In pre-existing leaves, IE emissions were always higher but ME emissions lower as compared to newly-emerged leaves. They were both stimulated by HT. Elevated [CO_2] significantly reduced IE in both leaf types, whereas it increased ME in newly-emerged leaves only. In newly-emerged leaves, elevated [CO_2] decreased photosynthesis and altered the chloroplast ultrastructure and membrane integrity. These harmful effects were amplified by HT. HT did not cause any unfavorable effects in pre-existing leaves, which were characterized by inherently higher IE rates. We conclude that: (1) these results further prove the isoprene's putative thermo-protective role of membranes; (2) HT may likely outweigh the inhibitory effects of elevated [CO_2] on IE in the future.

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Journal of Experimental Botany

The impact of blue light on leaf mesophyll conductance

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Abstract

Blue light has many direct and indirect effects on photosynthesis. The impact of blue light on mesophyll conductance (g_m), one of the main diffusive limitation to photosynthesis, was investigated in leaves of *Nicotiana tabacum* and *Platanus orientalis*, characterized by high and low g_m, respectively. Leaves were exposed to blue light fractions between 0% and 80% of incident light intensity (300 μmol photons m^{-2} s^{-1}), the other fraction being supplied as red light. Leaves exposed to blue light showed reduced photosynthesis and unaltered stomatal conductance. The g_m, measured using the chlorophyll fluorescence-based method, was strongly reduced in both plant species. Such a reduction of g_m may not be real, as several assumptions used for the calculation of g_m by fluorescence may not hold under blue light. To assess possible artefacts, the electron transport rate measured by fluorescence (J_f) and by gas-exchange (J_c) were compared in leaves exposed to different fractions of blue light under non-photorespiratory conditions. The two values were only equal, a prerequisite for correct g_m measurements, when the illumination was totally provided as red light. Under increasing blue light levels an increasing discrepancy was observed, which suggests that J_f was not correctly calculated, and that such an error could also upset g_m measurements. Blue light was not found to change the absorbance of light by leaves, whereas it slightly decreased the distribution of light to PSII. To equate J_f and J_c under blue light, a further factor must be added to the J_f equation, which possibly accounted for the reduced efficiency of energy transfer between the pigments predominantly absorbing blue light (the carotenoids) and the chlorophylls. This correction reduced by about 50% the effect of blue light on g_m. However, the residual reduction of g_m under blue light was real and significant, although it did not appear to limit the chloroplast CO_2 concentration and, consequently, photosynthesis. Reduction of g_m might be caused by chloroplast movement to avoid photodamage, in turn affecting the chloroplast surface exposed to intercellular spaces. However, g_m reduction occurred immediately after exposure to blue light and was complete after less than 3 min, whereas chloroplast relocation was expected to occur more slowly. In addition, fast g_m reduction was also observed after inhibiting chloroplast movement by cytochalasin. It is therefore concluded that g_m reduction under blue light is unlikely to be caused by chloroplast movement only, and must be elicited by other, as yet unknown, factors.

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Changes in photosynthesis, mesophyll conductance to CO_2, and isoprenoid emissions in *Populus nigra* plants exposed to excess nickel

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A B S T R A C T

Poplar (*Populus nigra*) plants were grown hydroponically with 30 and 200 μM Ni (Ni_{30} and Ni_{200}). Photosynthesis limitations and isoprenoid emissions were investigated in two leaf types (mature and developing). Ni stress significantly decreased photosynthesis, and this effect depended on the leaf Ni content, which was lower in mature than in developing leaves. The main limitations to photosynthesis were attributed to mesophyll conductance and metabolism impairment. In Ni-stressed developing leaves, isoprene emission was significantly stimulated. We attribute such stimulation to the lower chloroplastic [CO_2] than in control leaves. However chloroplastic [CO_2] did not control isoprene emission in mature leaves. Ni stress induced the emission of cis-β-ocimene in mature leaves, and of linalool in both leaf types. Induced biosynthesis and emission of isoprenoids reveal the onset of antioxidant processes that may also contribute to reduce Ni stress, especially in mature poplar leaves.

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Effect of water deficit and potassium fertilization on photosynthetic activity in cotton plants

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Abstract

Physiological mechanisms that can contribute to drought tolerance and the role of potassium fertilization in cotton were studied by evaluation of parameters describing photosynthetic performance. Gas-exchange and chlorophyll fluorescence characteristics were measured on leaves of two cotton genotypes, one drought sensitive (Nazilli 84-S) and the other drought tolerant (Sahin 2000), grown in field conditions in the Aegean region of Turkey under different regimes of water and potassium supply. It was shown that under drought conditions without potassium fertilization Sahin 2000 had a higher photosynthetic rate and stomatal conductance than Nazilli 84-S. Potassium fertilization to a great extent compensated for the inhibitory effect of drought on photosynthesis. Application of the JIP test by using chlorophyll fluorescence data revealed that the drought sensitive Nazilli 84-S was more responsive to potassium fertilization than Sahin 2000, as judged by a number of parameters representing quantum efficiency of the processes and energy fluxes in photosystem (PS) II. The observed decrease in photosynthetic CO_2 assimilation in both cotton cultivars under drought conditions was not accompanied by any significant decrease in the electron transport flux in PSII and maximum quantum yield of primary photochemistry.

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EFFECTS OF ENHANCED BRASSINOSTEROID PERCEPTION ON PHOTOSYNTHESIS IN *ARABIDOPSIS THALIANA* LINE *BRIOE*

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Abstract

The relation between brassinosteroid signalling and photosynthesis in *Arabidopsis thaliana* is studied by comparing the photosynthetic performance of wild-type plants and *BRIOE* line with increased level of the brassinosteroid receptor BRI1. The data reveal that enhanced brassinosteroid perception does not influence the net photosynthetic rate but leads to lower stomatal conductance and transpiration rate. Furthermore, the results presented demonstrate that *BRIOE* plants are characterized by lower oxygen evolution yield and alterations of the energy coupling of photosystem II core complex. While the photochemistry of photosystem II in *BRIOE* is not modified, the photochemical efficiency of photosystem I is reduced.