EFFECT OF CARBOXYLIC ACID HYDRAZID DERIVATIVES ON THE ADVENTITIOUS ROOTS FORMATION AND PHOTOSYNTHETIC ELECTRON TRANSPORT IN PHASEOLUS VULGARIS

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The influence of carboxylic acid hydrazid derivatives (CAHD) on bean (Phaseolus vulgaris L.) adventitious root formation and photosynthetic electron transport was investigated. These plant growth regulators were applied on bean hypocotyls cuttings and the dynamics of adventitious root formation was observed. CAHD influence on photosynthetic apparatus was examined by measuring changes of chlorophyll fluorescence yield. Results of experiment revealed that chlorophyll fluorescence parameters qP (photochemical quenching) and ETR (photosynthetic electron transport rate) at 310 μmol·m⁻²·s⁻¹ PAR (photosynthetic active radiation) correlated with adventitious root number (r = 0.77) and was significantly increased after application of 0.05 mg·l⁻¹ and 0.075 mg·l⁻¹ of st-120 as well as st-119 at 0.10 mg·l⁻¹ and 0.25 mg·l⁻¹ concentrations. Bean cuttings, treated with 0.05 mg·l⁻¹ st-120 showed the biggest number of adventitious root followed by highest root mass. Growth regulator st-119 in 0.10 mg·l⁻¹ and 0.25 mg·l⁻¹ concentrations demonstrated lower effect than 0.05 mg·l⁻¹ of st-120 but also significantly induced adventitious root formation. Both CAHD significantly raised qP which represents the actual fraction of open PSII (II photosystem) reaction centers and ETR that reflects efficiency of photosynthetic energy conversion and it is closely related with quantum yield of CO₂ fixation. Investigative growth regulators did not markedly increase chlorophyll concentration in bean leaves.

Key words: growth regulators, chlorophyll fluorescence, common bean, adventitious roots.

Introduction. Plant growth regulators as well as endogenously synthesized phytohormones are responsible for many physiological and developmental processes in plant. Carboxylic acid hydrazid derivatives (CAHD) are synthetic growth regulators, which are synthesized from b-alanine and hypothetically have a similar mode of operation as auxins. Results from experiments with Caladium (accomplis-
hed in Lithuanian University of Agriculture, Department of Botany) demonstrate that CAHD had physiological effect like NAA (naphthalene acetic acid) and stimulated tubercle formation in vitro.

During the recent decade the modes of operation of growth regulating substances are of the big interest. Accordingly, there were made number of experiments proving the importance of phytohormones on root formation. At present, it is well known that lateral and adventitious root initiation is mostly promoted by auxin group phytohormones as NAA or IAA (Indole-3-acetic acid) (Weigel et al., 1984; Moncousin et al., 1989). For example, the induction of soybean adventitious roots could be stimulated by exogenously applied auxins and polyamines (Zin-Huang et al., 1998; Sagee et al., 1992; Hausman, 1993). There were published also some interesting studies suggesting that other phytohormones can play an important role in altering root growth and development (Weathers et al., 2005). As it has been proposed by Ohkawa et al. (1989), gibberellins can promote growth of hairy roots in some species, including Datura innoxia and Artemisia annua (Weathers et al., 2005). Some authors demonstrated that brassinosteroids participate in the initiation of Arabidopsis lateral roots and synergistically interact with auxins by affecting its polar transport and in this hormonal cross-talk mechanism promotes initiation of lateral root primordial (Fang et al., 2004).

There are numerous reports describing the promoting effect of different phytohormones on photosynthetic process. Pandey et al. (2000) proposed that in cotton exogenously applied IAA enhanced RuBPCO (Ribulose-1,5-bisphosphate carboxylase/oxygenase) activity. BAP (Benzy1 amino purine) increased RuBPCO activity under water logging and draught stresses. Cytokinins together with light promote de-etiolation and play the most important role in plastid development (Parthier, 1979). Exogenously applied BA (benzyl adenine) or kinetin promotes grana formation and stacking, chloroplast differentiation and plastid multiplication (Chory et al., 1994; Synkova et al., 2003). All these changes in photosynthetic apparatus regulated by phytohormones should be sensitively reflected by measuring chlorophyll fluorescence. Hence, the fluorometry might be a useful tool in the assessment of the physiological plant response to different conditions, including exogenously applied plant growth regulators. For instance, chlorophyll fluorescence parameter as actual efficiency of PSII photochemistry (ΔF/Fm’) can give a measure of the linear electron transport rate (ETR) and thus the indication of overall photosynthesis (Maxwell and Johnson, 2000; Juneau et al., 2005). In addition, this parameter correlates with the quantum yield of carbon fixation (ΦCO2). Thus, the chlorophyll fluorescence technique potentially has many applications in plant production and development programs as well as assessment of environmental stresses. The current understanding of how changes in chlorophyll fluorescence characteristics pertain to plant physiological performance have led to a widespread use of chlorophyll measurements in plant physiological studies (Baker and Rosenqvist, 2004).

The aim of the present study is to investigate the effect of CAHD on Phaseolus vulgaris adventitious root formation and the leaf photosynthetic performance by means of the chlorophyll fluorescence technique. Furthermore, we are attempting to determine if the CAHD have a similar effect as auxin group phytohormones.

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Materials and methods. Plants. Common beans cv. ‘Vytautas’ (*Phaseolus vulgaris*) were grown in soil-vermiculite substratum for two weeks. Before the treatments with growth regulators (CAHD – st-120 and st-119), 14 days bean hypocotyls were cut at the upper side of root neck. Prepared cuttings consisted of 8 cm hypocotyl, cotyledons, epicotyl and two primary leaves. After removing roots, cuttings were immediately immersed to glasses with solution, containing distilled water and particular concentration of CAHD. Each variant contained 8 cuttings, experiment was repeated three times. After 24 hours, cuttings were transferred to distilled water and kept there till the end of experiment. Water in glass was changed every 24 hours.

Treatments. To discover the most effective concentration of CAHD, there were made two experimental sets. During the first experiment, the widest range of concentrations was chosen – $5 \times 10^{-5}$, $5 \times 10^{-4}$, $5 \times 10^{-3}$, 0.05, 0.1, 1.0 and 5.0 mg/l of each CAHD (data not shown). Second experiment was made with the reference to first one by selecting the most effective concentrations, which were split up in smaller gradient. St-120 were tested in 0.01, 0.02, 0.03, 0.04, 0.05 and 0.075 mg/l, whereas st-119 in 0.05 mg/l, 0.075 mg/l, 0.1 mg/l, 0.25 mg/l, 0.5 mg/l and 1.0 mg/l concentrations.

Fluorescence measurements. Chlorophyll fluorescence was recorded with portable fluorometer (*PAM-210*, Walz, Germany). Chlorophyll fluorescence measurements were performed on the light adapted beans. For each plant of a variant repetition, two fluorescence measurements on both leaves in different four places were done. Actinic PAR was 310 $\mu$mol$_{\text{photos}}$m$^{-2}$s$^{-1}$, irradiance of day light lamps was 200 $\mu$mol$_{\text{photos}}$m$^{-2}$s$^{-1}$. Saturation pulse – red light emitting diode with 3 500 $\mu$mol$_{\text{photos}}$m$^{-2}$s$^{-1}$PAR density was applied after 3 min. of actinic illumination.

In this article, we evaluated the photochemical quenching (qP) and relative electron transport rate (ETR). Parameter qP represents capacity of PSII RCs to execute charge separation and it is indirectly proportional to a redox state of primary electron acceptor $Q_h$ (Rohiček, 2002). ETR indicates the efficiency of photosynthetic energy conversion and/or photosynthetic carbon fixation at given PAR. According to Genty et al. (1989) ETR can be correlated with quantum yield of CO$_2$ assimilation.

The definitions of both parameters are as follows:

\[ qP = \frac{(Fm' - Ft)}{(Fm' - Fo')} \]  \hspace{1cm} (1)

\[ ETR = \frac{(Fm' - Ft)}{Fm' \times PAR \times 0.5 \times 0.84} \]  \hspace{1cm} (2)

In Eq. 2, $(Fm' - Ft) / Fm' = \Delta F / Fm'$ means the actual efficiency of PSII photochemistry, PAR – photosynthetically active radiation, 0.5 is a multiplication factor indicating that according to light-driven electron flow, transport of a single electron needs the absorption of 2 quanta. Coefficient 0.84 indicates the specific fraction of incident quanta absorbed by the leaf. (White and Critchley, 1999). In both equations, Fm’ is the maximum chlorophyll fluorescence yield measured on a light adapted sample with closed PSII RCs and all active non-photochemical processes in a thylakoid membrane optimized. Fo’ is the minimum chlorophyll fluorescence yield measured on a light adapted sample with open PSII RC, measured after turning off actinic light and application of short flash of infrared light. Ft – actual
chlorophyll fluorescence yield at any time of induction by an actinic light (Roháček and Barták, 1999).

**Concentration of chlorophylls.** Chlorophylls \((a + b)\) content in fresh bean leaves was determined by spectrophotometer (Beckman DU-40, UK), using solvent 90% acetone. According to Wetsstein methodic, the equations (3) and (4) were employed to determine concentration of chlorophyll \(a (C_a)\) and chlorophyll \(b (C_b)\) (Čkaščěákží, 1975).

\[
C_a = 9.78D_{662} - 0.99D_{644} \quad (3)
\]

\[
C_b = 21.43D_{645} - 4.65D_{662} \quad (4)
\]

Absorbance of chlorophyll extraction was measured at wavelength of 643 and 660 nm.

**Statistical analysis.** Statistical significance among the means of particular values was estimated by one-way ANOVA (Tukey test) using program “Statistica 6” (StatSoft 2001). Reciprocity among fluorescence parameters and adventitious root formation was demonstrated using correlation coefficient and regression equations.

**Results and discussion.** Experimental growth regulators – st-119 and st-120 – affected adventitious root formation on bean hypocotyls cuttings at relatively small concentrations. In both experimental sets, the most effective was 0.05 mg·l\(^{-1}\) st-120 solution which significantly \((p = 0.00014)\) induced initiation of adventitious roots (Fig.1). In comparison with control plants, st-120 at 0.04 mg·l\(^{-1}\) \((p = 0.04)\) and 0.075 mg·l\(^{-1}\) \((p = 0.002)\) concentrations had significantly higher number of roots per plant, but less than 0.05 mg·l\(^{-1}\) of the same growth regulator. Application of st-119 at 0.1 mg·l\(^{-1}\) \((p = 0.044)\) and 0.25 mg·l\(^{-1}\) \((p = 0.00015)\) concentration also considerably promoted adventitious root initiation (Fig.1) and root growth (Fig. 6), but was less effective than st-120. The pronounced effect was seen on fifth day after treatment with abovementioned effective concentrations of growth regulators. The rest experimental concentrations had no significant effect on root formation and showed no difference from control plants, which were treated with distilled water.

![Fig. 1. Adventitious root number per bean hypocotyl cutting treated with CAHD – st-120 (mg·l\(^{-1}\)) and st-119 (mg·l\(^{-1}\)). Measurements were done after 6, 10 and 14 days respectively after treatment. (Significance level \(p = 0.05\)](image)

1 pav. Augimo reguliatoriais st-120 (mg·l\(^{-1}\)) ir st-119 (mg·l\(^{-1}\)) apipūrškų nupjautų pudelių hipokotilių pridėtinį šakų skaicius. Matavimai atlikti praėjus 6, 10 ir 14 dienų po purškimo (patikimumo lygis \(p = 0.05\))
Effect like induction of adventitious root formation is typical for auxin group phytosterones as it was found in experiments of Jun Chen et al. (1995) with soybeans cuttings, treated with NAA. Adventitious root formation was induced by NAA between 10 and 500 µM showed the optimum root number at 500 µM followed by inhibition at 1 000 µM and higher concentrations of NAA. Similar results were also reported by Zin-Huang et al. (1998), when adventitious root formation was particularly enhanced by exogenously applied auxins and polyamines. IBA promoted the soybean hypocotyls rooting in vitro more than NAA did. It could be explained as the exogenously applied auxin (IBA or NAA) acts on polyamine synthase and IAA oxidase at the gene level or through enzyme regulation (Zin-Huang et al., 1998).

Chlorophyll fluorescence, emitted from PSII responds to large number of different environmental factors and reflects the physiological state of higher plants and algae. Fluorescence measurements are based on the principle by which light quantum, captured by chlorophyll of light-harvesting complex is transferred to chlorophyll P680 in PSII RC and via electron transport chain between both photosystems produces photochemical work. Otherwise it can be dissipated non-photochemically as heat or fluorescence. As described by Kitajima and Butler (1975) these processes can be considered as competing first order reactions with rate constants for fluorescence, thermal dissipation and photochemistry. Increased flow of the excitation energy into a photochemical pathway leads to a decrease (quenching) of the chlorophyll fluorescence yield. In this way chlorophyll fluorescence reflects changes in the efficiency of photosynthetic processes (Schreiber et al., 1995; Weis and Lechtenberg, 1989; Govindjee, 1995). Exploring the influence of phytohormones on photosynthesis the most reported effect is stomata regulation, also protective mechanism in the stress conditions. However, the scientific literature contains more evidence that phytohormones can regulate other processes of photosynthesis. For instance, Pandey et al. (2000) reported in the experiment of hormonal regulation of photosynthetic enzymes in cotton under water stress reported that all investigative hormones (IAA, GA3, BAP, ABA and ETH) enhanced RuBPCO activity and IAA was most stimulatory. Various experiments show that phytohormones positively affect photosynthetic processes under stress conditions. Soybeans exogenously treated with different plant growth regulators under water stress had a noticeable effect on the chlorophyll content, photosynthetic rate and PSII photochemical efficiency whereas under normal conditions no significant difference between control and plants affected with growth regulators was found (Mingcai et al., 2004). Analyzing the effect of ABA and cytokinins on bean stomatal conductance, rates of transpiration and photosynthesis, Pospisilova J. (2003) reported that both growth regulators decreased net photosynthetic rate, transpiration rate and stomatal conductance in sufficiently watered plants when they were immersed to the solution with phytohormones (Pospisilova, 2003).

Results of the present study demonstrated that particular CAHD concentrations, which stimulated adventitious root formation, also increase bean photosynthetic activity. As it is seen in Fig. 4, st-120 (0.05 mg·l⁻¹) enhanced photochemical quenching and was by 11% higher than in control plants. This parameter shows the actual fraction of PSII reaction centers that are in open state (with re-oxidised
and indicates the photochemical capacity of PSII in light adapted state (Ročiček, 2002; Oxborough and Baker, 1997). Increased values of qP maintain a higher proportion of oxidized \( Q_A \) and indicate effective electron transport between both photosystems as well as efficient energy utilization by Calvin cycle activity. Reduction rate of the PSII primary electron acceptor \( Q_A \) is predominantly controlled by the rate of reduction of intersystem electron carrier pool (PQ pool) and the distribution of excitation energy within both photosystems (PSII and PSI) (Yordanov et al., 1995).

In all bean plants, affected with CAHD, qP mean was about 0.8 which characterizes that almost all PSII are functionally almost intact. But as seen from Fig. 4, 0.05 mg·l\(^{-1}\) and 0.075 mg·l\(^{-1}\) of st-120 (\( p = 0.00013 \) and \( p = 0.003 \)) as well as 0.10 mg·l\(^{-1}\) and 0.25 mg·l\(^{-1}\) of st-119 (\( p = 0.027 \) and \( p = 0.00014 \)) showed much higher qP values than in control plants. In addition, qP and number of adventitious root per bean hypocotyl cutting had a strong correlation (Fig. 5). We suppose that abovementioned experimental growth regulators by significantly increasing qP, performed potentially higher reoxidation rate of \( Q_A \) and also improved activity of Calvin cycle, which is partially represented by relatively higher ETR values (Fig. 2).

![Photo of graph](image)

**Fig. 2.** Photosynthetic electron transport rate (ETR) at 310 µmol·m\(^{-2}\)·s\(^{-1}\) PFD in bean leaves treated with different CAHD (st-120 and st-119) concentrations (Significance level 0.05)

2 pav. Pupelių hipokotilių lapų fotosintetinio elektronų transporto greitis (ETR) panaudojus augimo regulatorius st-120 ir st-119. Apšviestumas – 310 µmol·m\(^{-2}\)·s\(^{-1}\) (patikimumo lygis \( p = 0.05 \))

![Photo of graph](image)

**Fig. 3.** Reciprocity between photosynthetic electron transport rate (ETR) at 310 µmol·m\(^{-2}\)·s\(^{-1}\) PFD and root number per bean hypocotyl cutting. (\( R-regresion coefficient \))

3 pav. Pupelių hipokotilių pridėtinių šaknų skaičius priklauso nuo fotosintetinio elektronų transporto greičio (esant 310 µmol·m\(^{-2}\)·s\(^{-1}\) apšviestumui) (\( R-regresijos koeficientas \))
Fig. 4. Photochemical fluorescence quenching (qP) in bean leaves treated with different CAHD (st-120 and st-119) concentrations. (Significance level 0.05)

Fig. 5. Reciprocity between photochemical fluorescence quenching (qP) and root number per bean hypocotyl cutting (R-regression coefficient)

Considering the finding that adventitious root initiation could be regulated by the level of endogenous phytohormone levels (Zin-Huang et al., 1998) or exogenously applied growth regulators, its growth is either dependant on carbon allocation in roots and CO₂ assimilation rate (Katrina et al., 1999). Under sufficient light intensity CO₂ assimilation rate is usually evaluated by the quantum yield of photosynthesis and might be linearly related to ETR. According to Michito et al. (2003), gross photosynthesis rate and ETR has a linear relationship under PFD of 400 μmol photons\textsuperscript{-1}·m\textsuperscript{-2}·s\textsuperscript{-1}. Nevertheless, relationship between ETR and rate of electron transport depending on CO₂ assimilation (J\textsubscript{CO₂}) varies in different plant species with particular leaf anatomy. Results by Michito et al. (2003) indicate that symmetric leaves of *Acacia* with high chlorophyll content had a high correlation between J\textsubscript{CO₂} and ΔF/Fm’ at all PFDs. Asymmetric *Cucumis* leaves with low chlorophyll concentration showed the same result, whereas *Ternstroemia* asymmetric leaves with high content of chlorophyll pigments had the linear relationship between mentioned parameters only at low PFDs.

In the present study we found that 0.05 mg·l\textsuperscript{-1} st-120 at 310 μmol/m\textsuperscript{2}·s\textsuperscript{-1} PFD intensity raised ETR to 76.7 μmol·m\textsuperscript{-2}·s\textsuperscript{-1} and compared to control, it was by 25% higher (p = 0.00014) (Fig. 2). In addition, ETR was also significantly increased in beans treated with 0.075 mg·l\textsuperscript{-1} of st-120 (p = 0.001) likewise as 0.1 mg·l\textsuperscript{-1} and 0.25 mg·l\textsuperscript{-1} of st-119 (p = 0.006 and p = 0.00016). In the rest of experimental variants, photosynthetic electron transport rate was slightly reduced by smaller
ΔF/Fm’, which could be associated with partially blocked photosynthetic energy conversion and electron transport. (Lichtenthaler and Burkart, 2003). Moreover, high ETR values of beans treated with 0.05 mg-l⁻¹, 0.075 mg-l⁻¹ of st-120, 0.1 mg-l⁻¹ and 0.25 mg-l⁻¹ of st-119 showed a high correlation (r = 0.77) with adventitious root biomass as well as root number per plant (Fig. 3). As follows from our results, the experimental growth regulators increased the efficiency of PSII photochemistry as well as ETR and on this basis raised efficiency of photosynthetic energy conversion, Jₐ CO₂ and gross photosynthetic rate by supplying more assimilates to adventitious roots.

Auxin group phytohormones activity on photosynthetic efficiency of *Brassica juncea* was reported by Ahmad et al. (2001). In the experiments with *Brassica juncea* plants, chlorosubstituted auxins were tested on photosynthesis and some related processes. Monochloroindole acetic acids as 4-Cl-IAA either 7-Cl-IAA and dichloroindole acetic acid 4.7-C12-IAA stimulated the activity of photosynthetic carboxylases, which are the most abundant soluble proteins in chloroplasts of C3 plants after RuBPCO. Chlorosubstituted auxins enhanced the net photosynthetic rate, which has a linear relationship with ETR (Ahmed et al., 2001).

![Graph showing adventitious root weight (mg per plant) of beans cuttings affected with growth regulators (CAHD) st-120 and st-119](image1)

**Fig. 6. Adventitious root weight (mg per plant) of beans cuttings affected with growth regulators (CAHD) st-120 and st-119**

6 pav. Augimo regiulatorių paveiktų pupelių hipokotilių pridėtinių šaknų masė, mg augale

![Graph showing chlorophyll (a+b) concentration (mg-g⁻¹) in bean fresh leaves after 14 days when CAHD were applied on bean cuttings](image2)

**Fig. 7. Chlorophyll (a+b) concentration (mg-g⁻¹) in bean fresh leaves after 14 days when CAHD were applied on bean cuttings**

7 pav. Chlorofilo (a+b) koncentracija (mg-g⁻¹) augimo regiutorių pavektuose pupelių hipokotilių lapuose

Chlorophyll content in bean leaves after application of different concentrations of CAHD had a similar dynamic trend as changes in chlorophyll fluorescence (Fig. 7).
Correlation coefficient (r) between total chlorophyll content in bean leaves and ETR was about 0.6. The content of chlorophyll was not markedly increased by examined growth regulators

**Conclusions.** Experimental growth regulators, Carboxylic acid hydrazid derivatives (CAHD) – st-120 and st-119, applied on bean hypocotyl cuttings had the auxin like effect. The CAHD st-120 at 0.05 mg·l⁻¹ and 0.075 mg·l⁻¹ as well as st-119 at 0.1 mg·l⁻¹ and 0.25 mg·l⁻¹ concentrations significantly induced been adventitious root initiation. Abovementioned experimental growth regulators also positively affected bean photosynthetic performance by increasing ETR, which represents photosynthetic energy conversion and can be correlated with quantum yield of CO₂ assimilation. Photochemical quenching of chlorophyll fluorescence (qP) was also increased in beans, treated with physiologically effective CAHD concentrations. Raised value of qP was associated with higher proportion of oxidized Qₐ (fraction of open PS II reaction centers) and improved activity of Calvin cycle.

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**References**


34. Гавриленко В. Ф., Ладыгина М. Е., Хандобина Л. М. Большой практикум по физиологиі ростений. Москва, 1975.

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**KARBOKSIIRŪGŠČIŲ HIDRAZIDŲ DARINIŲ ĖTAKA PUPELIŲ PRIDĖTINIŲ ŠAŅŲ FORMAVIMUISI IR FOTOSINTETINIAM ELEKTRONŲ JUDĖJIMUI**

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**Santrauka**

Tyrimų tikslas – nustatyti, kokį poveikį turi augimo reguliatoriai – karboksirūgščių hidrazidų dariniai st-120 ir st-119 – pupelių hipokotilių pridėtinių šaknų formavimuosi ir fotosintetinio elektronų judėjimo greičiui (ETR). Panaudojus augimo reguliatorius, buvo stebima pupelių hipokotilių pridėtinių šaknų augimo dinamika. Fotosintetinio elektronų judėjimo greičiui (esant 301 μmol m⁻²s⁻¹ aktininės šviesos intensyvumui) ir fotocheminio fluorescencijos slopinimui (qP) nustatyti buvo pritaikytas fluorometrijos metodas, matuojant chlorofilu fluorescenciją šviesoje adaptuotose pupelėse. Šiais tyrimais nustatyta, kad st-120 augimo reguliatoriaus 0,05 mg·l⁻¹ ir 0,075 mg·l⁻¹ koncentracijos bei st-119 augimo reguliatoriaus 0,1 mg·l⁻¹ ir 0,25 mg·l⁻¹ koncentracijos darė esminę Ėtaką pupelių hipokotilių pridėtinių šaknų formavimuosi, šviesos energijos virsmo į fotosintetinę energiją našumui (ETR) ir II fotosistemos reakcinių centrų okreso būklei (qP). Tarp pupelių pridėtinių šaknų skaiciaus ir chlorofilu fluorescencijos rodiklių ETR bei qP nustatytas stiprus korelacinis ryšys. Didžiausią efektą analizuojamiems rodikliai turėjo st-120 augimo reguliatoriaus 0,05 mg·l⁻¹ koncentracija. Nuo tiriamų augimo reguliatorių gerokai padidėjo chlorofilu (a + b) koncentracija.

**Reiškminiai žodžiai:** augimo reguliatoriai, chlorofilu fluorescencija, fotosintetinis elektronų judėjimo greitis, pupelės, pridėtinės šaknys.