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INFLUENCE OF LIGHT AND HEAVY LANTHANIDES ON THE PHYSIOLOGICAL PROCESSES OF *Taraxacum hybernum*

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KEYWORDS

Taraxacum hybernum

NMR-Spectroscopy

Poly (Cis-1,4-Isoprene)

Lanthanides

CO₂-Assimilation Intensity

ABSTRACT

The current study was carried out to study the influence of light and heavy lanthanides on the physiological process of Crimean-Saghyz/ Krim-saghyz (dandelion - *Taraxacum hybernum*). Lanthanide belongs to the group of light or heavy; infiltration of dandelion (Crimean saghyz) seeds with light and heavy lanthanides solutions increased the germination energy by 26%. The differences in the influence of light (cerium) and heavy (lutetium) were manifested in the quantum efficiency change of the photosystem 2 (PS II). Treatment of leaves with high concentrations (100 µM) led to a decrease of Y (II), moreover, under the influence of light lanthanide, the decrease was greater by 21%. It is assumed that the effect of the used lanthanides on the dandelion photosynthetic apparatus is multidirectional. Cerium influenced the PS II antenna complex, and lutetium influenced the reaction centers. A 10-fold decrease in the concentration did not change the nature of cerium action, except that Y (II) was restored already on the second day after treatment. The effect of lutetium became noticeable only by the 8th day after treatment when Y (II) became higher than that of untreated plants. Thus, the results of the study suggested that in dandelion leaves, lanthanides with a concentration of 10 µM increased the quantum efficiency of PS II in contrast to cerium.

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1 Introduction

More than a hundred years have been passed since the discovery of the stimulating effect of lanthanides (Ln^{+3}), but until now there is no generally accepted understanding of the lanthanide mode of action (Chien & Ostenhout, 1917; Hu et al., 2004; Migaszewski & Galuszka, 2015). According to Goecke et al. (2015) under the magnesium deficiency, the lanthanides lead to the stimulation of growth and rate of photosynthesis in the microalga *Desmodesmus quadricauda*. Under similar conditions, higher photosynthetic and antioxidant activity was reported in the spinach plants (Chao et al., 2009; Yin et al., 2009; Ze et al., 2009), while chlorophyll biosynthesis, carbon, and nitrogen metabolism were restored in corn (Zhou et al., 2011; Zhao et al., 2012). These effects, obtained at low concentrations of light lanthanides (La, Ce, Pr, Nd), can be explained by the authors from the standpoint of magnesium and calcium replacement by Ln^{+3} in organometallic compounds with the retention of functions (or even with some activation) of the later. More toxic heavy Ln^{+3} (Tb, Dy, Ho, Er, Tm, Yb, Lu) are not used in agricultural practice (Gonzalez et al., 2014) because these substances reducing the possibility of obtaining hormesis effects while in the case of light Ln^{+3} substance application, various physiological processes activate.

The available data on the effect of lanthanides on seed germination of various crops are not unambiguous. Both inhibitory and stimulating effects were found, and this depends on the plant species, lanthanide types, its concentration, and dose (Genty et al., 1996; Hu et al., 2004).

It was assumed that the elements (cerium and lutetium), which are far apart from each other in the lanthanide series, will show differences in their influence on sufficiently studied physiological processes, such as seed germination and the quantum efficiency of the photosystem II (Ramírez-Olvera et al., 2018). The current study aimed to evaluate the effect of light and heavy lanthanides on the physiological process including seed germination of Crimean-Saghyz.

2 Materials and Methods

The seeds of the Crimean sagyz dandelion (*Taraxacum hybernum* Steven) were collected in December 2017 in the vicinity of Sevastopol (Crimean Peninsula). The collected seeds were stored in paper bags at room temperature in a dry place. The seeds of the Crimea-sagyz were germinated in four replicates (50 seeds each) in Petri dishes on settled tap water in the following variants: before stratification; after stratification for 30 days at the temperature of -20°C ; after stratification and infiltration. Infiltration was carried out at the pressure of 10 Pa for 60 minutes in distilled water and in 100 μM solutions of $\text{Ce}(\text{NO}_3)_3 \times 6\text{H}_2\text{O}$ and $\text{Lu}(\text{NO}_3)_3 \times 6\text{H}_2\text{O}$. Germination energy was determined on the 4th day of germination.

The germinated seedlings were planted in 0.5 liter container with "Terra vita" commercial soil. The cultivation of plants was carried out in a climatic chamber at the temperature of 22°C with the photoperiod of 16/8 and a luminous flux intensity of 150 $\mu\text{mol photons m}^{-2}\text{s}^{-1}$ for estimating the effect of lanthanides on the efficiency of photosystem II. After one month of planting, the leaves of each plant were treated with 3 ml solutions of the two selected concentration (100 μM and 10 μM) of lanthanides.

Variable chlorophyll fluorescence was measured with the help of PAM 2500 fluorometer (Heinz Walz GmbH, Germany) at 22°C . Fluorescence was recorded in response to the saturation light pulse ($\lambda = 625 \text{ nm}$, 12000 $\mu\text{mol of photon m}^{-2}\text{s}^{-1}$, the duration made 500 ms). The effective light intensity was 194 $\mu\text{mol of photon m}^{-2}\text{s}^{-1}$. Effective PSII quantum efficiency ($Y(\text{II})$), and the quantum yield of light-induced non-photochemical quenching ($Y(\text{NPQ})$), and the quantum yield of unregulated heat and fluorescence emission ($Y(\text{NO})$) were measured in light-adapted samples according to the PAM 2500 manual (Heinz Walz GmbH, Germany) and calculated by the equations: $Y(\text{II}) = (F'_m - F_s)/F'_m$; $Y(\text{NPQ}) = F_s/F'_m - F/F'_m$; $Y(\text{NO}) = F/F'_m$, where F_s - the stationary level, and F'_m - the light-induced maximum level of chlorophyll fluorescence in light-adapted leaves (Wang et al., 2014).

All experiments were performed in six biological agilities. The results were statistically analyzed using the OriginPro 9.0 software. The statistical significance of differences between the variants was assessed by the Mann-Whitney U test at $p < 0.05$.

3 Results and Discussion

The available data on the effect of lanthanides on seed germination of various crops are not unambiguous. Previous studies suggested both inhibitory and stimulating and it depends on the plant species, types of lanthanide, and its concentration (Genty et al., 1996; Hu et al., 2004). Despite the differences in the toxicity of light and heavy lanthanides (Gonzalez et al., 2014), one-hour infiltration of Crimea-sagyz seeds with 100 μM solutions of $\text{Ce}(\text{NO}_3)_3$ and $\text{Lu}(\text{NO}_3)_3$ increased the germination energy (Table 1). Infiltration of stratified seeds in water did not affect the germination energy, in contrast to the infiltration in solutions of cerium and lutetium nitrates, which led to the germination energy increase by 26%.

Table 1 The seed germination energy of the Crimean-sagyz dandelion (in%) after stratification and infiltration with 100 μM $\text{Ce}(\text{NO}_3)_3$ and $\text{Lu}(\text{NO}_3)_3$ at a pressure of 10 Pa for 60 minutes

After stratification	After stratification and infiltration in H_2O	After stratification and infiltration in 100 μM $\text{Ce}(\text{NO}_3)_3$	after stratification and infiltration in 100 μM $\text{Lu}(\text{NO}_3)_3$
39±9 ^b	40±1.7 ^b	66±1.2 ^a	66±1.3 ^a

Shown mean ± SD, n = 6. The same letters denote the absence of statistically significant differences between the Mann Whitney U tests at $p < 0.05$

Differences between cerium and lutetium germination energy are nonsignificant and this might be because of the less incubation time which is not sufficient for the inhibitory effect or both lanthanides can replace calcium in bioorganic compounds and thereby trigger biochemical reactions responsible for the exit of seeds from dormancy.

The differences in the effect of lanthanum and cerium have manifested the efficiency of photosystem II when dandelion leaves were treated with these salts solutions. It is known that when leaves were treated with lanthanide ions solutions, lanthanoid enters into the cell by endocytosis processes (Hendrickson et al., 2004). Lanthanum and cerium penetrated in the cell did not have a similar effect on Y(II). Figure 1 shows the slow kinetics of the photochemical conversion quantum yield of absorbed light energy Y(II). The greatest decrease in Y(II) by 21% was caused by cerium 24 hours after the treatment of the Crimea-sagyz dandelion leaves while this inhibition was 8.6% in Lutetium treatment.

The decrease in the effective quantum yield of chlorophyll Y(II) fluorescence under the influence of 100 μM $\text{Ce}(\text{NO}_3)_3$ was due to the increase of the quantum yield fraction of the energy part controlled dissipation Y(NPQ) (Figure 2), which corresponds to the fraction of energy dissipated in the form of heat by adjustable photoprotective mechanism (Ikeuchi et al., 2014). Non-photochemical quenching also includes Y(NO), a constitutive energy loss that is passively dissipated in the form of heat and fluorescence, mainly due to closed PS II reaction centers (Samson et al., 2019). Under the influence of 100 μM $\text{Lu}(\text{NO}_3)_3$, the increase of Y(NO) causes a decrease in the Y(II) (Figure 3).

A 10-fold decrease in concentration did not change the nature of cerium action, except that Y(II) was restored on the second day after treatment (Figure 1b). The effect of lutetium became noticeable only on the 8th day after treatment when Y(II) became higher than in untreated plants (Figure 4).

Conclusions

Lanthanide belongs to the light or heavy group, infiltration of the Crimean sagyz dandelion seeds in the lanthanide solutions increased the germination energy. Differences in the influence of light (cerium) and heavy (lutetium) were manifested in the quantum efficiency which changes the photosystem 2 (PS II). Treatment of leaves with high concentrations (100 μM) led to a decrease in Y(II), moreover, under the influence of light lanthanide, it shows higher reduction. Further, results of the study suggested that cerium influenced the PS II antenna complex while lutetium influenced its reaction centers. A 10-fold decrease in concentration did not change the nature of cerium action, except that Y(II) was restored on the second day after treatment. The

Figure 1 Slow kinetics of the quantum yield of the photochemical conversion of absorbed light energy 24 hours after leaf treatment with salt solutions (a – H_2O , b – 100 μM $\text{Lu}(\text{NO}_3)_3$, c – 100 μM $\text{Ce}(\text{NO}_3)_3$)

Figure 2 Separation of absorbed light energy under the influence of 100 μM $\text{Ce}(\text{NO}_3)_3$; * - a statistically significant difference from the zero point is indicated at $p = 0.05$.

Figure 3 Separation of absorbed light energy under the influence of 100 μM $\text{Lu}(\text{NO}_3)_3$; * - a statistically significant difference from the zero point at $p = 0.05$ is indicated.

Figure 4 Dynamics of the quantum efficiency of photosystem 2 under the influence of 10 μM solutions: a - $\text{Ce}(\text{NO}_3)_3$; b - $\text{Lu}(\text{NO}_3)_3$; * - a statistically significant difference from the zero point at $p = 0.05$ is indicated.

effect of lutetium became noticeable only on the 8th day after treatment when $Y(II)$ became higher than that of untreated plants. From the results of the study, it can be concluded that lanthanide treatment increased the quantum efficiency of PS II in dandelion leaves of Krym-sagyz and it was higher than the cerium treatment at the concentration of 10 μM .

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Conflict Of Interest

Authors would hereby like to declare that there is no conflict of interests that could possibly arise.

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