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Cerium (Ce) Affects the Phenological Cycle and the Quality of Tulip (*Tulipa gesneriana* L.)

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ABSTRACT

Objective: To study the effect of cerium (Ce) applied in a nutrient solution during the productive cycle, on the duration of the phases of the phenological cycle of tulip (*Tulipa gesneriana* L.) cv. Jan van Nes.

Design/Methodology/Approach: Commercial bulbs (caliber 12+) were planted under shade cloth conditions during the autumn-winter period. The levels of Ce used were 5, 15 and 15 μ M from $\text{CeCl}_3 \cdot 7\text{H}_2\text{O}$; Ce was applied in the nutrient solution from the first day of the sowing, apart from the control without its application.

Results: The different concentrations of Ce stimulated bulb sprouting. The low concentration of Ce (5 μ M) promoted the early formation of floral buds and their coloration. Hence, the application of 5 μ M Ce induces flowering of the tulip without exhibiting changes in the period of time to reach senescence. When 25 μ M Ce were applied, the opposite effects were observed. The duration of the flower was not significantly affected by the treatments.

Study Limitations/Implications: This study was made only in one cultivar of tulip.

Findings/Conclusions: The application of 5 μ M of Ce had a positive effect in the tulip cycle, by stimulating bulb sprouting, the formation of the floral bud, the coloration, and the induction of the flowering cycle.

Keywords: biostimulation, rare earth elements, hormesis, ornamentals.

INTRODUCTION

Rare earth elements (REE) are a family of 17 chemical elements formed by group III of the periodic table (scandium and yttrium) and the series of lanthanides (from lanthanum and lutetium) which exhibit chemical similarities as a group, while they express individually distinctive and varied electronic properties (Voncken, 2016; Cheisson and Schelter, 2019).



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For this study, cerium (Ce) is of particular importance, for which both positive and negative effects are reported in plants, with these being dependent on the dose, time of exposure, method of application, plant species, growth conditions, pH, as well as nutrient interaction, development stage, among other factors (Zhang *et al.*, 2013; Ramos *et al.*, 2016, Xu *et al.*, 2016; García-Jiménez *et al.*, 2017).

On the other hand, tulip is the main ornamental bulb plant produced worldwide. The Netherlands has 60% of global production. In recent years, the studies performed in tulip have centered on increasing stem elongation, bulb quality, and stimulating early flowering (Kurtar and Ayan, 2005). In this study we aimed to evaluate the effect of Ce supplied during the productive cycle in nutrient solution, on the duration of the phenological cycle stages of tulip cv. Jan van Nes.

MATERIALS AND METHODS

Plant Material and Experiment Conditions

The experiment was developed in a greenhouse under 50% black monofilament shadecloth. The average temperature that was found during the cultivation cycle was 14 °C, 52% of relative humidity, and light intensity of 125 lumen m⁻².

Commercial cultivar Jan van Nes (caliber 12+) tulip bulbs were used. This cultivar produces intense yellow flowers. Planting was done in 7-inch pots, and a mixture of red *tezontle*, perlite (Agrolita^{MR}) and peat (Promix[®] FLX) in a proportion of 70:20:10 (v:v:v) was used as substrate. Before planting, the bulbs were previously disinfected.

Steiner's nutrient solution (Steiner, 1984) at 50% was used for the fertilization, which contained in g L⁻¹: 0.5313 Ca(NO₃)₂ 4H₂O, 0.2464 MgSO₄ 7H₂O, 0.0680 KH₂PO₄, 0.1516 KNO₃ and 0.1306 K₂SO₄; it was complemented with a commercial mixture of micronutrients, TradeCorp[®] AZ, added at 0.0665 g L⁻¹ of the nutrient solution. The pH of the nutrient solution was adjusted to 5.3, using concentrated H₂SO₄. The nutrient solution was supplied in the localized drip irrigation system using 1/2 HP pumps.

Treatment and Experiment Design

Different concentrations of Ce added to the nutrient solution were evaluated. The levels of Ce used were 5, 15 and 25 μ M from CeCl₃ 7H₂O; in addition to a control, without application of Ce.

The experiment was established in a completely randomized design (CRD), and the experimental unit consisted of one plant per pot and each treatment had eight repetitions. The application of the treatments started from the first day of planting the bulbs.

Evaluated Variables

The influence of Ce on bulb emergence, formation of flower bud, coloration of buds, anthesis and senescence; these variables were evaluated at different days after planting (dap).

Emergence of bulbs was characterized with the appearance of the apical meristem. The coloration was defined when the flower bud presented changes in its coloration (green tepals with green border). Anthesis was defined as the days in full flowering, the flower was completely open, and the gynoecium showed the three lobes of the stigma and all the completely formed stamens. The plant was considered senescent when the flower presented withering and tepal fall.

The duration of the flower was estimated by counting the days from anthesis until senescence.

Statistical Analysis

With the data obtained, an analysis of variance was performed and the means were compared using Tukey's test with a significance of $\alpha=0.05$. The statistical analysis system version 9.4 (SAS Institute, 2013) was used.

RESULTS AND DISCUSSION

The cultivation cycle of the tulip plants was prolonged on average 4.28 days with the addition of 25 μ M Ce in the nutrition solution, compared with the control plants that completed their cycle in 57.14 days, whereas the other concentrations had a similar duration to the control (data not shown).

Bulb emergence was stimulated with the addition of different concentrations of Ce in the nutrition solution, which happened on average at 6 dap, while the emergence of the apical meristem took place 2 days later (8 dap) in control plants without addition of Ce (Figure 1).

In a similar way as in bulb emergence, the formation of the flower bud was ahead in 1.85 and 3.25 days in treated plants with 5 and 15 μ M Ce, respectively, compared to the control where this event happened at

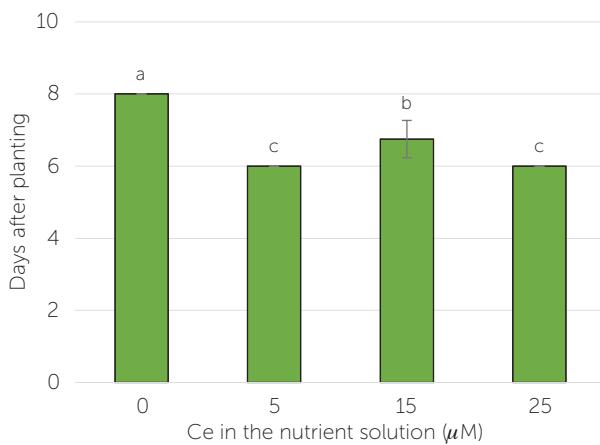


Figure 1. Sprouting of tulip bulbs treated with different concentrations of Ce in the nutrient solution during the productive cycle. Means \pm SD with different letters indicate significant differences (Tukey, $p \leq 0.05$). $n=8$.

38.62 dap. In contrast, the dose of 25 μ M Ce delayed the formation of the flower bud by 0.5 days, also compared to the control (Figure 2a). Plants treated with 5 μ M Ce presented coloring of the bud in a shorter time (44.75 dap) compared to the control (46.25 dap) as observed in Figure 2b; as consequence, the period of anthesis was 1.14 days before than in the control plants (50.71 dap; Figure 2c). Meanwhile, in the plants that were exposed to 25 μ M Ce, coloring of the flower bud (2.75 days; Figure 2b) and anthesis (3.29 days; Figure 2c) were delayed compared to the control plants.

In plants treated with Ce, the period of time to reach senescence was not different from the control, except in the plants treated with 25 μ M Ce, where the period to reach senescence was prolonged on average in 4.28 days compared to control plants (57.14 dap) (Figure 3).

The duration of the flower was estimated by counting the days from the period of anthesis until senescence of the flower, that is, when the withering and fall of tepals happened. The doses of Ce of 5 and 25 μ M prolonged the life of the flower in 1.15 and 1.05 days, respectively, compared to the control where the life of the flower was 6.42 days, although these increases were not significant (Figure 4).

DISCUSSION

In this study, the application of the different doses of Ce in the nutrition solution stimulated the emergence of the bulbs, advancing this process 2 days compared with the control (8 dap); however, only the low dose of Ce (5 μ M) affected positively the formation of the flower

bud, and therefore promoted the early coloration and flowering in tulip, although the period of time to reach senescence was equal to the that of the control plants. Contrasting results were obtained in plants treated with 25 μ M of Ce, where all the phases evaluated were delayed compared to the control and the period to reach senescence was longer. The reason why the low dose of Ce stimulates the emergence of the bulbs and advances the flowering period is probably that Ce

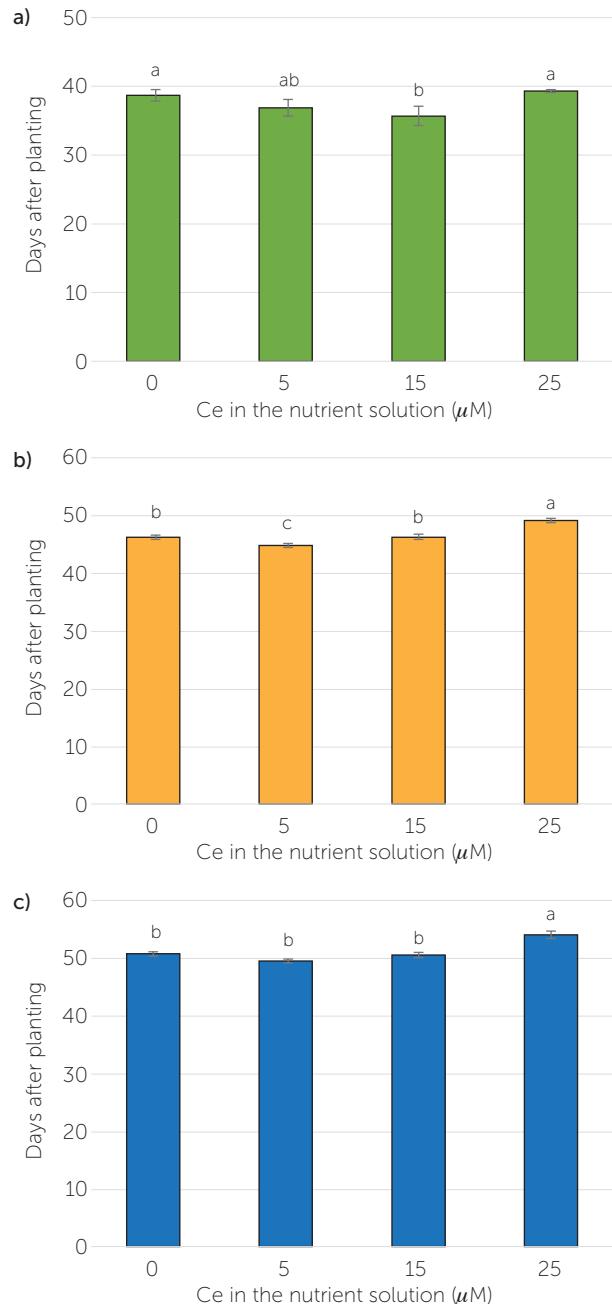


Figure 2. Flower bud formation (a), bud coloration (b) and anthesis (c) in tulip plants treated with different concentrations of Ce in the nutrient solution during the productive cycle. Means \pm SD with different letters in each subfigure indicate significant differences (Tukey, $p \leq 0.05$). $n=8$.

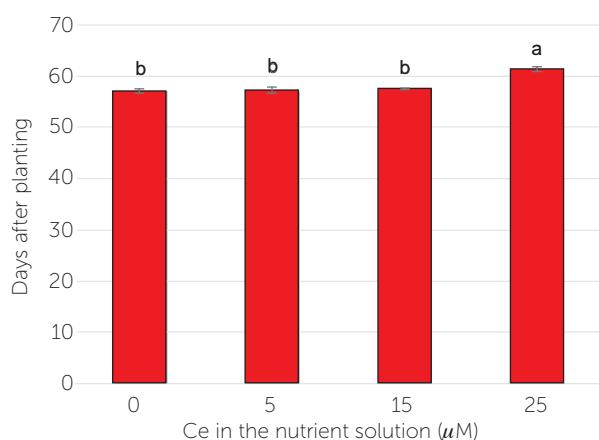


Figure 3. Senescence of tulip plants treated with different concentrations of Ce in the nutrient solution during the productive cycle. Means \pm SD with different letters indicate significant differences (Tukey, $p \leq 0.05$). $n=8$.

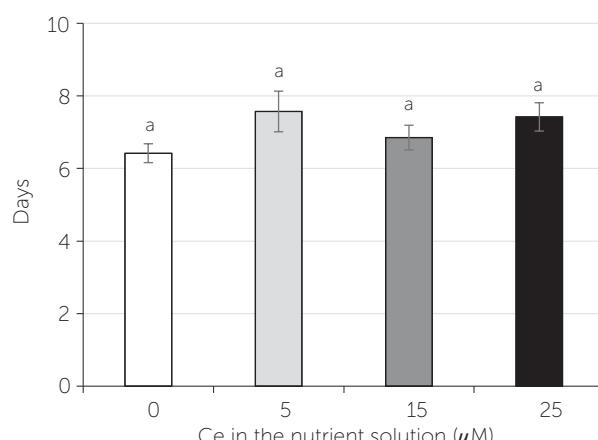


Figure 4. Duration of the flower in tulip plants treated with different concentrations of Ce in the nutrient solution during the productive cycle. Means \pm SD with different letters indicate significant differences (Tukey, $p \leq 0.05$). $n=8$.

is related to some plant hormone that favors these processes.

The moment of transition of plant growth to flowering is important in agriculture. Flowering is regulated by a complex network of genes that integrate multiple environmental signs and endogenous signs for flowering to take place in the adequate moment; hormonal regulation, signaling and homeostasis are very important in this process (Galvão and Schmid, 2014; Campos-Rivero *et al.*, 2017). In tulip, endogenous plant hormones that are related directly with bulb emergence and flowering are gibberellins (Cocozza-Talia and Stellacci, 1979). In various studies it has been found that the production of plant hormones can be affected by the presence of REE; in some cases, REE can act synergically with some plant hormones that can stimulate germination and flowering (He and Loh, 2002; Wang *et al.*, 2014; Wang *et al.*, 2015; Ramos *et al.*, 2016). Despite this, it is not completely clear whether REE are directly involved with the signaling of plant hormones; likewise, the responses of stimulus or inhibition of plant hormones are variable between species and different REE (Wang *et al.*, 2015). In *Arabidopsis* plants, La interacts with the signal from abscisic acid (ABA) on root growth, in addition to a concentration of $10 \mu\text{mol La}^{+3} \text{ L}^{-1}$ which increases the rate of seed germination when these are inhibited by ABA (Wang *et al.*, 2014). In *Dendrobium densiflorum* plant, the application of $5 \mu\text{mol Nd}^{+3} \text{ L}^{-1}$ significantly increased the level of endogenous indole-3-acetic acid (IAA) and the rate of IAA and cytokinins during the formation process of the root primordium, which favored the rooting

of cuttings (Luo *et al.*, 2008). In *Arabidopsis thaliana*, low concentrations of Ce ($0.5\text{-}10.0 \mu\text{M}$) significantly stimulated flowering and the number of flowers per plant, which is why it was considered that Ce and other rare earth elements can have a potential to develop as non-hormonal flowering promoting agents for certain kinds of crops (He and Loh, 2000). He and Loh (2002) pointed out that these responses were related with a higher production of endogenous cytokinins in the plant, which is why they suggested that REE have a synergic effect with this plant hormone.

On the other hand, the duration of the potted flower was prolonged 1.15 and 1.05 days with a dose of Ce of 5 and $25 \mu\text{M}$, respectively, in comparison to the control (6.42 days), although these increases were not statistically significant.

CONCLUSION

It is concluded that the application of $5 \mu\text{M}$ Ce has a positive effect on the growth, development and reproductive parameters of tulip, when stimulating the emergence of the bulb, formation of the flower bud, coloration, and advancing the flowering period.

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