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Biostimulant effects of lanthanum (La) on crop growth, yield, and quality

Contreras-Martínez, Guadalupe[1]; Gómez-Merino, Fernando C.[2]; Peralta-Sánchez, María G.[1]; Alcántar-González, Gabriel[1]; Trejo-Téllez, Libia I.[1*]

[1] Colegio de Postgraduados Campus Montecillo. Montecillo, Texcoco, Estado de México, México. C. P. 56230.

[2] Colegio de Postgraduados Campus Córdoba. Manuel León, Amatlán de los Reyes, Veracruz, México. C. P. 94953.

* Correspondence: tlibia@colpos.mx

ABSTRACT

Objective: To analyze the various effects that the use of La as an inorganic biostimulant has on growth, yield, and quality of different crops.

Design/Methodology/Approach: We explored and analysed recent literature concerning the effects of lanthanum on various economically important crops. Subsequently, the most relevant information was selected, analyzed, and grouped by type of effect.

Results: The addition of low doses of lanthanum has been tested in different crops. La has been proven to increase growth, development, and quality in various species. Likewise, positive effects have been reported in germination, in the absorption of nutrients, and in the mitigation of the deficiencies of some essential elements, as well as in the promotion of physiological and biochemical responses.

Study Limitations/Implications: The analyzed results have been generated in a great diversity of plant species, under different production systems, and with dissimilar doses, as well as with different sources and application methods. This situation presents a challenge, since it hinders the possibility to issue general recommendations.

Findings/Conclusions: Lanthanum improves yield and quality, as well as some physiological, biochemical, and nutritional responses in different crops of economic importance.

Keywords: rare earth elements, hormesis, biostimulation.

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INTRODUCTION

Plant biostimulation consists of the application of some substances or microorganisms (Figure 1) to plants to promote an efficient nutrient use, increase stress tolerance, and improve plant quality, regardless of their nutritional content (Du Jardin, 2015).

Biostimulants can be of natural or synthetic origin and have an organic or inorganic composition. Natural biostimulants may include plant and seaweed extracts, while synthetic ones may be represented by beneficial elements and phosphite salts.

Among the inorganic compounds, the positive effects of phosphite and various elements of the so-called "beneficial" group —including mainly alkaline-

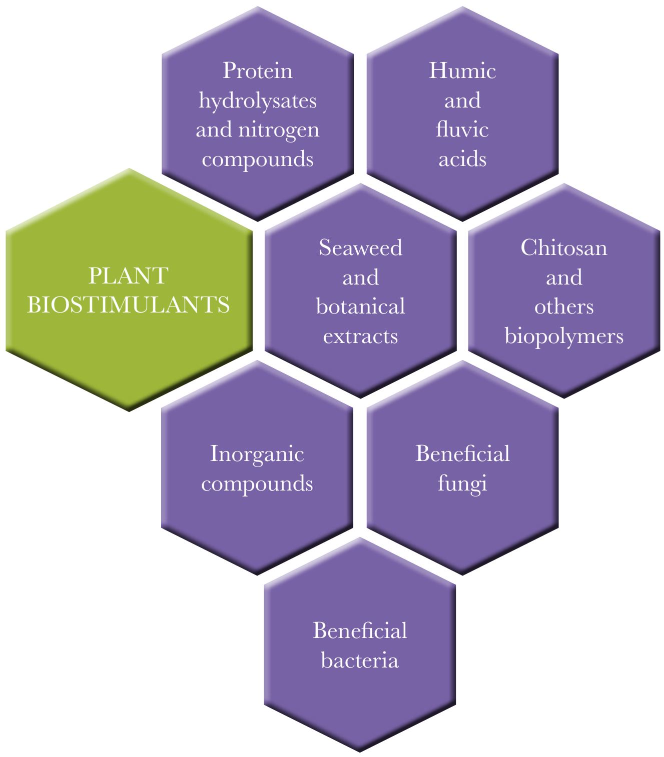

Figure 1. The current seven categories of biostimulants used in crop production.

earth elements, transition metals, and metalloids— have been recorded (Gómez-Merino and Trejo-Téllez, 2015). These elements are called beneficial because, provided in small amounts, they promote growth, quality, and yield in various crops (Ramírez-Martínez *et al*., 2012). Consequently, they represent an alternative for the current agronomic problems, such as loss of fertile soils due to erosion, nutrient depletion, organic carbon loss, soil sealing, industrialization, and climate change (FAO, 2015). The beneficial transition metals include the rare earth elements (REE), a group to which lanthanum (La) belongs.

Rare earth elements in agriculture

Plants require at least 17 mineral elements (C, H, O, N, P, K, Ca, Mg, S, Cl, Fe, B, Mn, Zn, Cu, Mo, and Ni) to complete their life cycle; they are mainly acquired from the soil or are included in a nutrient solution. However, plants also accumulate small quantities of non-essential elements (Watanabe *et al.*, 2007). These elements include the REEs that, in low concentrations, can stimulate physiological and biochemical processes, growth, development, and yield in plants, improve the stress tolerance of the plant and the absorption of elements, and stimulate the resistance mechanisms of biotic and abiotic factors (Kastori *et al.*, 2010; Liu *et al.*, 2013; Gómez-Merino and Trejo-Téllez, 2018). REEs have certain effects on the activity of some enzymes, the content of phytohormones, the productivity and intensity of photosynthesis, the development of chloroplasts, chlorophyll content, resistance to water stress, the symbiotic fixation of atmospheric nitrogen, seed germination, and the growth and productivity of many crops (*e.g.*, rice, sugarcane, sugar beets, soybeans, and sunflowers). Interestingly, the Casparian strip of the root may lead to differences in the mobility of REEs —as the group of lanthanides that contains the element lanthanum (La)— limiting its transport in the root. Therefore, the absorption is much faster through the leaves than through the root (Hu *et al.*, 2004; Kastori *et al.*, 2010).

Lanthanum as an inorganic biostimulant in plants

Lanthanum (La) was isolated as an oxide: a cerium nitrate impurity contained in cerite minerals. It was discovered by the Swedish chemist Carl Gustaf Mosander in 1839, who gave it the name lanthanum. Its name derives from the Greek "lanthanein" (*i.e.*, "the hidden one"), a name given because its identification was a difficult process (González, 2019).

Small amounts of lanthanum have been applied to promote the growth and development of higher plants, taking advantage of hormesis, a phenomenon characterized by stimulation, when applied at low doses, and inhibition, when applied at high doses (Kobayashi *et al.*, 2007; Brioschi *et al.*, 2013; Calabrese and Blain, 2009; Agathokleous *et al.*, 2018). Table 1 shows some examples of studies carried out with different lanthanum sources in various plant species and the concentrations evaluated. In all cases, the doses are low (50-250 μM La) aiming at the zone of positive effects.

Table 1. Examples of lanthanum (La) doses evaluated in different species of model and cultivated plants.

Crop species	Source	Dosis		References
		Minimum	Maximum	
Barley (*Hordeum vulgare* cv. Clipper)	La^{+3}	10^{-2} M	10^{-4} M	Van Steveninck *et al.* (1976).
Rice (*Oryza sativa*)	$La(NO_3)_3$	100 μg g^{-1}	700 μg g^{-1}	Fashui *et al.* (2000).
Arabidopsis (*Arabidopsis thaliana*)	$La(NO_3)_3$ $6H_2O$	0.5 mM	50 mM	He and Loh (2000).
Tobacco (*Nicotiana tabacum* L.)	$LaCl_3$	5.0 mg L^{-1}	100 mg L^{-1}	Chen *et al.* (2001).
Wheat (*Triticum durum*)	$LaPO_4$	0.5 mg L^{-1}	25 mg L^{-1}	Hu *et al.* (2002).
Barley (*Hordeum vulgare* L. cv. YC 01301)	$La(NO_3)_3$ $6H_2O$	2 μM	100 μM	Han *et al.* (2005).
Lettuce (*Lactuca sativa* L.)	$La(NO_3)_3$	0.04 mg L^{-1}		He *et al.* (2005).
Arabidopsis (*Arabidopsis thaliana*)	$LaCl_3$	1.0 μM	1.5 μM	Kobayashi *et al.* (2007).
Wheat (*Triticum durum*)	$La(NO_3)_3$	0.01 mM	10 mM	D´Aquino (2009).
Tulip (*Tulipa gesneriana* L.)	$LaCl_3$ y $La(NO_3)_3$ $6H_2O$	0.5 μM	40 μM	Ramírez-Martínez *et al.* (2012).
Rice (*Oryza sativa*)	$La(NO_3)_3$	0.05 mM	1.5 mM	Liu *et al.* (2013).
Cucumber (*Cucumis sativus* L.)	La_2O_3	0.2 mg L^{-1}	2000 mg L^{-1}	Ma *et al.* (2015).
Soybean (*Glycine max* L. Merrill).	$La(NO_3)_3$ $6H_2O$	5 μM	160 μM	De Oliveira *et al.* (2015).
Pepper (*Capsicum annuum* L. cv. Sven, Sympathy, Yolo Wonder and Zidenka)	$LaCl_3$	10 μM		García-Jiménez *et al.* (2017).
Lisianthus (cv. Mariachi Blue and Echo Lavanda).	$La(NO_3)_3$ $6H_2O$ $LaCl_3$	10 μM	30 μM	Torres-Flores *et al.* (2018).
Pak choi (*Brassica chinensis* L.) and sunflower (*Helianthus annuus* L.)	La_2O_3	20 mg kg^{-1}	300 mg kg^{-1}	Rezaee *et al.* (2018).

The term hormesis means "to set in motion" or "to drive something forward". This natural phenomenon is a response to stress, which leads to an adaptive compensatory process against potentially toxic substances or compounds that affect organisms (Poschenrieder *et al.*, 2013).

The REEs effects have been researched in the various biological processes mediated by calcium in plants. As a Ca analog, La has been called "supercalcium" (Brown *et al.*, 1990). Therefore, Kastori *et al.* (2010) have proposed that the application of La^{+3} can mitigate Ca deficiency symptoms and can stimulate plant growth, as well as the stability, permeability, and functioning of cell membranes. Nevertheless, La inhibits many enzymes and other functional proteins. When it displaces Ca at extracellular binding sites, the extracellular and intracellular Ca efflux can be inhibited, which has negative consequences for the plant (Thomas *et al.*, 2014).

La has a positive influence on nutrient absorption, which may be due to the fact that it is the most electropositive of the REEs and its chemical properties are similar to alkaline-earth elements, including Ca and Mg. La has positive effects on K uptake in cotton (*Gossypium hirsutum* L.), wheat (*Triticum aestivum* L.), and rice (*Oryza sativa* L.). Furthermore, the application of lanthanum chloride increases the K^{+} and Mg^{+2}-ATPases activity of the cell membrane under Ca deficiency conditions (Ramírez-Martínez *et al.*, 2012).

The application of 5 and 20 μM of La to tulips increases the bioaccumulation of potassium, calcium, and lanthanum (Ramírez-Martínez *et al.*, 2012). In rice, low concentrations of La^{+3} improved root growth and increased the accumulation of K, Mg, Ca, Na, Fe, Mn, Zn, Cu, and Mo (Liu *et al.*, 2013). In sunflower (*Helianthus annuus* L.), treatment with low doses of La and Nd ($<$100 mg kg^{-1}) had positive effects (Rezaee *et al.*, 2018). However, high concentrations of La can affect the absorption of Ca, Fe, Cu, Zn, Mg, Mn, P, and K in faba bean (*Vicia faba* L.) seedlings (Liu *et al.*, 2012).

The positive effects on nutrient uptake can be reflected in plant growth. Such is the case of pepper (*Capsicum annuum* L.) seedlings: the treatment with La increased their height, stem diameter, number of flower buds, and leaves (García-Jiménez *et al.*, 2017).

La has also positive effects on the germination of old rice seeds (Fashui *et al.*, 2000), by promoting respiration and the activities of the superoxide dismutase, catalase, and peroxidase enzymes (Olivares *et al.*, 2011; Liu *et al.*, 2012). Therefore, it is suggested that La can reduce oxidative stress.

La favors chlorophyll content, improving growth, development, yield, and quality in crops (Turra *et al.*, 2015; Luo *et al.*, 2021). Its application has improved the quality of potted and postharvest flowers. In two varieties of lisianthus (*Eustoma grandiflorum* L.), doses of 10 μM of La increased the life of the potted flower (Torres-Flores *et al.*, 2018). During the vase life of the tulip, the application of La enlarged the length and diameter of the buds and the length of the stem, improving water absorption, which was reflected in a fresh weight increase of the flower stem (Gómez- Merino *et al.*, 2020a). During the final stage of the tulips' vase life, an increase in the concentration of chlorophyll was recorded (Gómez-Merino *et al.*, 2020b). Figure 2 shows a summary of the biostimulant effects of lanthanum on crop production.

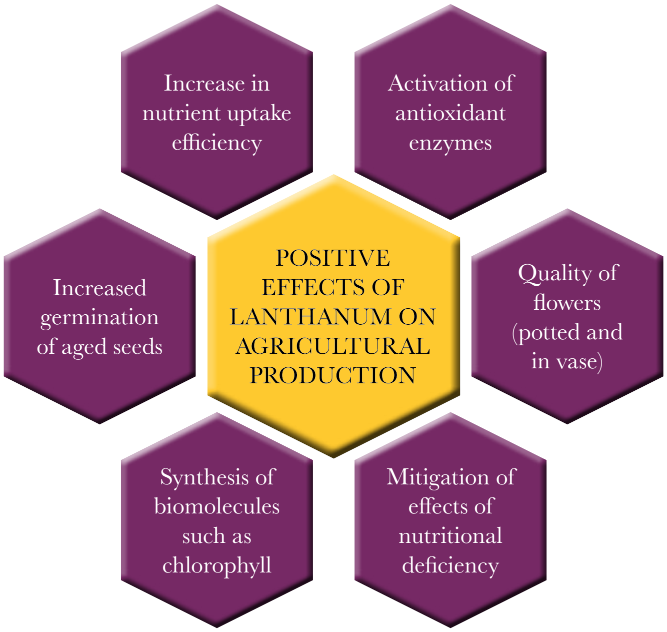

Figure 2. Some of the biostimulant effects of lanthanum (La) on crop production.

CONCLUSIONS

Lanthanum is a beneficial element that stimulates plant metabolism in a hormetic manner. Applied in adequate concentrations and considering hormetic limits, La can improve various processes such as nutrient absorption, activation of antioxidant enzymes, and improvement of photosynthetic indicators. This leads to the improvement of the growth, yield, and quality indicators of the crops, as well as to a greater capacity to face abiotic environmental stress.

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