



DOI: [10.29298/rmcf.v16i91.1575](https://doi.org/10.29298/rmcf.v16i91.1575)

Review article

Potential for the use of biostimulants in urban tree management

Potencial del uso de bioestimulantes en el manejo del arbolado urbano

Juan Carlos Cuevas Cruz¹, Tomás Martínez-Trinidad^{2*}

Fecha de recepción/Reception date: 19 de mayo de 2025.

Fecha de aceptación/Acceptance date: 22 de julio de 2025.

¹Universidad Autónoma Chapingo-Centro Regional Universitario del Anáhuac. México.

²Colegio de Posgraduados, Campus Montecillo, Posgrado en Ciencias Forestales. México.

*Autor por correspondencia; correo-e: tomtz@colpos.mx

*Corresponding author; email: tomtz@colpos.mx

Abstract

Biostimulants are substances that, although not classified as nutrients or pesticides, are soil improvers and promote plant growth when applied in small quantities. They are categorized into four groups: acids, microorganisms, bioactive compounds of plant origin, and others. Their application in urban trees aims to improve vitality and enhance resilience under stress conditions. Commonly used biostimulants include seaweed extracts, humic acids, non-structural carbohydrates, paclobutrazol, and beneficial microorganisms. These have shown effectiveness against drought, water, and salinity stress, and in strengthening the immune system of trees. Commercial biostimulants based on humic acids have improved survival rates, root and shoot vigor, and overall vitality, as evidenced by increased chlorophyll fluorescence. Additionally, the application of starch and glucose increases starch levels in tree trunks—an important factor, as starch depletion under severe stress is associated with tree mortality. Among biostimulants, mycorrhizal fungi are the most extensively studied in urban forestry, consistently demonstrating benefits in growth variables and stress adaptation, even at the molecular level. Finally, although most biostimulant-related knowledge comes from agricultural systems, their potential use in urban arboriculture is significant. This work presents a review of their application in field and semi-controlled environments, as well as the challenges associated with their use in urban tree management.

Keywords: Arboriculture, urban forestry, stress, mycorrhiza, paclobutrazol, vitality.

Resumen

Los bioestimulantes son sustancias que, sin ser nutrientes, pesticidas o mejoradores del suelo, promueven el crecimiento de las plantas cuando se aplican en pequeñas cantidades. Se agrupan en cuatro categorías: ácidos, microorganismos, compuestos bioactivos de origen vegetal y otros. Su aplicación en arbolado urbano busca mejorar la vitalidad y resistencia ante condiciones de estrés. Entre los bioestimulantes empleados destacan extractos de algas marinas, ácidos húmicos, carbohidratos no estructurales, paclobutrazol y microorganismos benéficos. Estos han mostrado eficacia frente al estrés por sequía, salinidad o hídrico, además de fortalecer el sistema inmunitario de los árboles. Productos comerciales a base de ácidos húmicos han mejorado la supervivencia, el vigor de raíces y brotes, y la vitalidad general, evidenciado por resultados en el aumento en la fluorescencia de clorofila. Por otro lado, la aplicación de almidón y glucosa eleva los niveles de almidón en el

tronco, lo cual es deseable ya que su reducción se asocia con la muerte en condiciones de estrés severo. Entre los bioestimulantes, los hongos micorrízicos han sido los más estudiados en el arbolado urbano, ya que proporcionan beneficios consistentes en variables de crecimiento y adaptación, incluso a nivel molecular. Finalmente, aunque gran parte del conocimiento sobre bioestimulantes proviene de la agricultura, su potencial en arboricultura es alto. Este trabajo presenta una revisión sobre su uso en condiciones de campo y ambientes semicontrolados; así como, las limitaciones que enfrenta su aplicación en el manejo del arbolado urbano.

Palabras clave: Arboricultura, dasonomía urbana, estrés, micorrizas, paclobutrazol, vitalidad.

Introduction

Trees with good vitality are valuable in cities because they more effectively provide ecosystem services such as CO₂ sequestration, noise reduction, and air purification (Derkzen et al., 2015). They also provide protection for pedestrians and infrastructure from strong winds, regulate temperature, and provide recreational value, which is linked to people's health and quality of life (Wang et al., 2022). However, tree growth and development in urban environments faces many challenges: poor and polluted soils (Rosier et al., 2021), water stress due to high temperatures caused by heat islands (Marchin et al., 2025), and saline soils (Zwiazek et al., 2019), factors that, together, weaken trees and cause morphological, physiological, and biochemical changes (Seleiman et al., 2021).

The application of biostimulants or organic compounds has been a practice that helps improve tree vitality (Percival, 2010). Biostimulants are defined as substances that, without belonging to the category of nutrients, soil improvers, or pesticides, when applied in minimal quantities promote plant growth (du Jardin, 2015). Most biostimulants used are mixtures of chemicals derived from a biological process or the extraction of biological materials (Yakhin et al., 2017).

They are classified into four groups: acids, microorganisms, bioactive substances of plant origin, and other types (Hasanuzzaman et al., 2021). Six types are distinguished within the category of plant biostimulants: chitosan, humic and fulvic acids, animal and plant protein hydrolysates, phosphites, algae extracts, and silicon (Zulfiqar et al., 2024). Additionally, they include acrylamide, amino acids, plant growth-promoting bacteria, carbohydrates, ectomycorrhizal and endomycorrhizal fungi, and vitamins (Percival, 2010).

Humic substances, protein hydrolysates, and algae extracts have been applied to urban trees (Cinantya et al., 2024). In addition to chemical compounds such as paclobutrazol (Martínez-Trinidad et al., 2013b) and non-structural carbohydrates to the soil around trees under stress conditions (Hartmann & Trumbore, 2016). However, the application of biostimulants has been mainly used in agricultural crops (Zulfiqar et al., 2024).

Biostimulants applied to trees

Seaweed extracts and humic acids

They are considered biostimulants because they contain amino acids, vitamins, growth hormones, and sometimes macro- and micronutrients (Ördög et al., 2004). Humic acids are organic compounds formed from the chemical and biological humification of plant and animal matter, which have been shown to increase plant growth and improve the assimilation of nitrogen, phosphorus, and potassium (Leite et al., 2020).

They belong to the group of humic substances that includes fulvic acid, humins, amino acids, fatty acids, and organic acids (Hasanuzzaman et al., 2021). Application methods include foliar application, root application, or a combination of these. The extracts are incorporated into the soil through fertigation, drip irrigation, or drenching (Jayaraman & Ali, 2015). The use of commercial humic acid-based biostimulants in *Betula pendula* Roth and *Sorbus aucuparia* L. improved root and shoot vigor and survival rates, with increases in chlorophyll fluorescence emissions (0.6 control vs. 0.7 best treatment Fv/Fm) and chlorophyll contents (13.5 control vs. 17.1 best treatment) observed with applications of 10 to 30 mL L⁻¹ (Barnes & Percival, 2006).

Some tree species in urban areas under drought stress conditions only improved height growth after the application of humic acid and seaweed extract (50 mL, five applications), with no positive effects related to the use of biostimulants (Cinantya et al., 2024). This trend of null response under drought stress was also detected in *Quercus ilex* L., *Ilex aquifolium* L., *Sorbus aucuparia* and *Fagus sylvatica* L., where the evaluation of the products Maxicrop Original® (United Kingdom), Bioplex® (United Kingdom) and Redicrop® (United Kingdom) with active ingredient of seaweed extract, seaweed extract+humic acids and seaweed extract with cytokinin activity, respectively, did not show beneficial effects on Fv/Fm, nor on stress-related variables (Banks & Percival, 2014). The results may be dose-related, since it has been identified that the desired effects are shown up to the application of 10 times the recommended dose (Chen et al., 2004).

Nonstructural carbohydrate applications (NSCs)

They are macromolecules that serve as substrates for the primary and secondary metabolism of plants. Glucose, fructose, and galactose are NSCs used as substrates for respiration and the synthesis of other molecules (Hartmann & Trumbore, 2016). When trees face stress conditions such as prolonged drought or salinity, they reduce the allocation of carbohydrates in their tissues and in their osmoregulatory and osmoprotection defense mechanisms, and their reserves are completely depleted (Hartmann & Trumbore, 2016; Zhang et al., 2021).

The application of carbohydrates in the form of starch and glucose to trees aims to increase the tree's energy levels in order to allocate the greatest reserves to its growth and promote its vitality (Martínez-Trinidad et al., 2013a). In *Jacaranda mimosifolia* D. Don. trees measuring 0.05 m in diameter and 2.0 meters in height, the application of 10 L of a soil solution (80 g L⁻¹ glucose with 80 g L⁻¹ sucrose) improved root dry matter ($P \leq 0.05$) after 371 days with a carbohydrate concentration of 0.034 g, while the control treatment reached 0.006 g (Morales-Gallegos et al., 2020). Higher root glucose concentrations have been associated with more efficient nutrient uptake and increased N in leaves (Shao et al., 2023). Glucose is involved in NO_3^- and NH_4^+ transport processes, so its presence in the root promotes molecular communication (Zhou et al., 2009).

Starch and glucose applications at concentrations of 120 g L⁻¹ have been made to the soil 0.5 m away from young *Quercus virginiana* Miller trees, although higher glucose concentrations were observed in shoots; $\delta^{13}\text{C}$ signatures did not provide evidence that this was due to supply (Martínez-Trinidad et al., 2009).

In contrast, another study with *J. mimosifolia*, with 80 g L⁻¹ of glucose applied to the trunk (trees 27 cm ND), increased trunk starch reserves more than twofold

(Morales-Gallegos et al., 2019). Higher starch reserves help trees withstand stress conditions, as a decrease in starch to near-zero levels has been linked to tree death (Zhang et al., 2021). Therefore, overmature trees exhibit depletion of starch, glucose, fructose, and sucrose (Hartmann & Trumbore, 2016). In woody tissues, starch degradation occurs in autumn and spring, so having reserves is crucial for tolerating low temperatures and sustaining growth in spring (Noronha et al., 2018).

Paclobutrazol (PBZ) application

This chemical compound is known to inhibit growth, promote branching, stimulate root system formation, and increase plant resistance to stress (Jiang et al., 2019). In *Populus alba* L. trees subjected to severe pruning, the near-trunk application of 0.8 g of PBZ favored a higher concentration of non-reducing sugars in the trunk and foliage. However, growth and vitality variables were not influenced (Martínez-Trinidad et al., 2013b). In *Fraxinus americana* L., *F. quadrangulata* Michx., and *F. mandshurica* Rupr. trees, PBZ application increased the root-to-total biomass ratio by 9 % and 10 %, and was positively associated with improving water and nutrient uptake under drought conditions and infertile urban soils (Tanis et al., 2015).

In the roots of fruit trees subjected to water stress, applications of 1 200 mg plant⁻¹ have been found to linearly increase the contents of total soluble sugars, starch, and reducing sugars, and inhibit tree growth and promote flowering (de Sousa-Oliveira et al., 2022). Therefore, the use of PBZ in trees presents variations in results among species, growth parameters, and concentrations.

Mycorrhizal fungi as microbial biostimulants

Microbial-based biostimulants are considered a subgroup of the heterogeneous family of biostimulants, as they stimulate biochemical and physiological processes that promote nutrient availability, strengthen the plant response system, and consequently improve their yield (Joly et al., 2021). Ectomycorrhizal fungi (EMF) and arbuscular fungi (AMF) are recognized as biostimulants (Sun & Shahrajabian, 2023), which are strongly linked to the growth and vitality of trees in urban environments (Rusterholz et al., 2020); for example, *Carya ovata* (Mill.) K. Koch with 80 % mycorrhizal colonization, it has a survival probability of 1.0, and *Quercus rubra* L. requires 100 % colonization to have a probability close to 0.8 (Tonn & Ibáñez, 2017). Inoculation of *Fraxinus uhdei* (Wenz.) Lingelsh. plants with *Pisolithus tinctorius* (Pers.) Coker & Couch (EMF) and *Glomus intraradices* N. C. Schenck & G. S. Sm. (AMF), now renamed *Rhizoglyphus intraradices* (N. C. Schenck & G. S. Sm.) Sieverd., G. A. Silva & Oehl (Sieverding et al., 2014), in severely eroded sites with low organic matter content (0.78 %), showed a survival rate of 64 % at 23 months after establishment, compared to 46 % in non-inoculated plants (Báez-Pérez et al., 2017). *P. tinctorius* inoculation has positive effects on tree root growth, increasing root dry weight 1.89 times and improving the plant's potential for nutrient absorption (Sebastiana et al., 2021). Also, inoculation of *F. uhdei* with *Lactarius deliciosus* (L.) Gray and *Laccaria laccata* (Scop.) Cooke (EMF) at concentrations of 2.5×10^5 and 1×10^6 established in a *Jal* substrate contaminated with heavy metals, showed better growth in height (47 cm) and dry weight (12 g), while uninoculated plants reached a height of 38 cm and a dry weight of 9 g (Pérez-Baltazar et al., 2020). Inoculation of tree species with AMF has positive effects during nursery

transplantation to urban sites and significantly influences plant survival, even more so than fertilizer doses applied at the nursery stage (Fini et al., 2016).

The AMF-host plant interaction can reduce flavonoid biosynthesis and affect poplar resistance, making it necessary to determine the AMF-host plant association that generates positive interactions (Jiang et al., 2022). In *Populus alba* × *P. berolinensis* seedlings inoculated with *Glomus mosseae* (T. H. Nicolson & Gerd.) Gerd. & Trappe (15 propagules g of inoculum), increased the amount of metabolites with insecticidal properties in the foliage: coumarin, stachydrin, artocarpin, norisalpinin, abietic acid, 6-formylumbelliferone and vanillic acid (Shuai et al., 2021). While the use of *Laccaria bicolor* (Maire) P. D. Orton in *Populus trichocarpa* Torr. & A. Gray seedlings to combat the poplar canker *Botryosphaeria dothidea* (Moug.) Ces. & De Not. showed that 12 of 661 genes are related to disease resistance (Dong et al., 2021).

The root-AMF symbiosis grants other abilities to the tree, improving biochemical aspects such as the regulation of metabolites with strong antioxidant capacity (Calvo-Polanco et al., 2019; Zhang et al., 2022). Also, in trees used for urban use and ornamental species, the levels of phytohormones, indole-3-acetic acid (IAA), gibberellins (GA3) and the IAA-abscisic acid (ABA) and GA3-ABA ratio increase. For example, in *Cupressus arizonica* Greene, when establishing symbiosis with *Rhizophagus irregularis* (Błaszk., Wubet, Renker & Buscot) C. Walker & A. Schüßler and *Funnelformis mosseae* (T. H. Nicolson & Gerd.) C. Walker & A. Schüßler (synonymy of *Glomus mosseae*) under drought conditions, its proline levels increased by 122 % and the content of malondialdehyde (MDA) –an antioxidant enzyme– increased by 68 % (Aalipour et al., 2020). The response of these types of biostimulants is anticipatory, as they are aimed at plant production that will be established in the urban environment. Therefore, their use in mature trees is not considered (Zwiazek et al., 2019); however, the application of organic amendments

to mature trees is recommended as they promote higher rates of colonization by mycorrhizal fungi (Ali et al., 2019).

The use of biochar-based amendments and composts in *Melia azedarach* L. and *Ficus macrocarpa* Blume trees improved the physicochemical properties of the soil, with a decrease in available organic matter, calcium, and phosphorus observed, indicating nutrient uptake by the trees (Shiu et al., 2022). Rhizospheric soil of trees in an urban environment, with pronounced nutrient deficiencies, present low mycorrhizal colonization, so organic amendments are a factor that allows symbiosis (Alam et al., 2025).

Potential and limitations in the use of biostimulants

The review focused on four alternatives from an extensive list of biostimulants that have demonstrated benefits for perennial plants. Microorganism-based biostimulants are considered to have the greatest potential for use in urban trees, given the advancement of *omics* sciences that has led to a greater understanding of their functioning (Bizjak et al., 2023). Mechanisms such as N₂ fixation, hormone biosynthesis, regulation of reactive oxygen species, and expression of genes related to different types of stress are some of the capabilities exhibited by fungi and bacteria that establish different levels of association or symbiosis with trees (Hasanuzzaman et al., 2021). However, microorganisms generate fewer positive effects under conventional production methods, so it is necessary to design protocols based on the problem to be solved (Abaurre et al., 2021).

Seaweed extracts and their combination with humic acids have not generated positive responses in urban trees (Banks & Percival, 2014). Possible reasons for this limited success include product quality (Yakhin et al., 2017). The method of

application has also been debated; it is mainly applied to the soil, which is probably the main reason why there are no positive results in urban environments (Cinantya et al., 2024). For example, in apple trees (*Malus domestica* (Suckow) Borkh.), applying 1 % (1 L 99 L⁻¹ water) of the product Fertiactyl Starter® (United Kingdom), based on seaweed and humic acids, after three years, favors thicker stems with differences of 16.3 mm and 21.9 mm compared to control trees (Kaplan et al., 2021). Applications of the microalgae product AgriAlgae® (Madrid, Spain) and Seaweed Mix® (Madrid, Spain) every 20 days to olive trees (*Olea europaea* L.) under a 50 % irrigation regime improved leaf area by 26 and 44 % and maintained stomatal conductance levels similar to those of plants under a 100 % irrigation regime (Graziani et al., 2022).

So, how is it possible that in *Quercus ilex*, *Ilex aquifolium*, *Sorbus aucuparia* and *Fagus sylvatica*, seven biostimulants products, including three algae-based ones, did not generate any benefits for tree growth and physiology? (Banks & Percival, 2014). Urban soils accentuate unfavorable characteristics for tree growth and health, such as high pH, compaction, mineral-poor soils, and pollution (Rosier et al., 2021). Therefore, under extreme conditions, biostimulants based on algae extracts are not considered a good alternative (Ricci et al., 2019).

Product diversity is a factor that can limit the use of biostimulants, each with a different active ingredient (Sun et al., 2024). Failure to follow application protocols or lacking experience in their use can result in tree physiology and morphology that differs from those expected (Sun & Shahrajabian, 2023). Epistemological contradictions are also noted in the literature, leading to discrepancies regarding what constitutes a biostimulant (Yakhin et al., 2017). This creates a state of uncertainty regarding the scope of this technology used in trees.

The use of biostimulants in urban trees based on non-structural carbohydrates, such as the application of glucose and sucrose, is limited to a few references. However, in

fruit trees, the application of sugars and amino acids is common, as their field of application is driven by the fruit market (Sun et al., 2024). Meanwhile, in urban trees, the lack of direct economic benefits has probably limited further research aimed at finding more conclusive results on tree vitality. Below, a summary of their potential use and limitations in trees in urban environments is presented (Table 1).

Table 1. Use and substances in trees.

Type of biostimulant	Species	Benefits for the tree	Reference
Seaweed extracts	<i>Quercus ilex</i> L., <i>Ilex aquifolium</i> L., <i>Sorbus aucuparia</i> L. and <i>Fagus sylvatica</i> L.	Showed no beneficial effects on Fv/Fm or on stress-related variables	Banks and Percival (2014)
	Nine species	Growth in height	Cinantya et al. (2024)
Humic acids (Ah)	<i>Betula pendula</i> Roth and <i>Sorbus aucuparia</i> L.	Better Fv/Fm: 0.7 with Ah and 0.6 without Ah; better chlorophyll content: 17.1 with Ah and 13.5 without Ah	Barnes and Percival (2006)
Non-structural carbohydrates	<i>Jacaranda mimosifolia</i> D. Don	Higher dry matter and carbohydrate concentration	Morales-Gallegos et al. (2020)
Application of paclobutrazol	<i>Populus alba</i> L.	Higher concentration of non-reducing sugars in the trunk and foliage	Martínez-Trinidad et al. (2013b)
	<i>Fraxinus americana</i> L., <i>F. quadrangulata</i> Michx. and <i>F. mandshurica</i> Rupr.	Increased root-to-total biomass ratio by 9 to 10 %	Tanis et al. (2015)
Mycorrhizal fungi	<i>Fraxinus uhdei</i> (Wenz.) Lingelsh.	64 % survival rate in inoculated plants. 46 % survival rate in non-inoculated plants	Báez-Pérez et al. (2017)
		Improved growth in height and dry weight: 47 cm and 12 g with inoculants and 38 cm and 9 g without inoculants	Pérez-Baltazar et al. (2020)
	<i>Populus berolinensis</i> <i>alba</i> × <i>P.</i>	Increased amounts of metabolites with insecticidal properties in the foliage	Jiang et al. (2022)
	<i>Populus trichocarpa</i>	Expression of 12 genes	Dong et al. (2021)

Torr. & A. Gray	related to disease resistance
<i>Cupressus arizonica</i> Greene	Proline levels increased by 122 %, and malondialdehyde (MDA) content, an antioxidant enzyme, increased by 68 %

Conclusions

In general, the results of biostimulants use have been limited, partly due to factors such as tree ontogeny and the environmental heterogeneity of urban environments, which make it difficult to observe consistent effects on growth, physiological, or carbohydrate accumulation variables. Therefore, it is proposed to consider variables at the molecular level, such as the expression of enzymes, proteins, and genes, to better understand their mechanisms of action. Among these, mycorrhizal fungi stand out for the breadth of evidence regarding their benefits on growth, root biomass, height, diameter, and nutrient uptake, in addition to their positive influence on gene expression related to systemic resistance. However, the challenge of developing efficient and species-specific inoculants for target species remains. Despite the limited literature on urban environments, all four types of biostimulants show potential for use in arboriculture, provided that key aspects such as doses, combinations, species, timing, and frequencies of application are studied in depth. Thus, the use of biostimulants represents a still open and promising line of research in urban tree management.

Acknowledgments

The authors are grateful for the graduate studies scholarship awarded to the first author by the *Secretaría de Ciencia, Humanidades, Tecnología e Innovación (Secihti)* (Secretariat of Science, Humanities, Technology, and Innovation) (*Secihti*).

Conflict of interest

The authors declare no conflict of interest.

Contribution by author

Juan Carlos Cuevas Cruz: literature review, manuscript preparation; Tomás Martínez-Trinidad: preparation, revision and restructuring of the manuscript.

References

- Aalipour, H., Nikbakht, A., Etemadi, N., Rejali, F., & Soleimani, M. (2020). Biochemical response and interactions between arbuscular mycorrhizal fungi and plant growth promoting rhizobacteria during establishment and stimulating growth of Arizona cypress (*Cupressus arizonica* G.) under drought stress. *Scientia Horticulturae*, 261, Article 108923. <https://doi.org/10.1016/j.scienta.2019.108923>
- Abaurre, G. W., Saggin Jr., O. J., & de Faria, S. M. (2021). Interaction of substrates and inoculants for *Samanea saman* (Jacq.) Merr seedling production. *Floresta e Ambiente*, 28(4), Article e20210046. <https://doi.org/10.1590/2179-8087-FLORAM-2021-0046>
- Alam, S., Azim, A., Al-Mamun, A., Ahammed, S., Ahmed, S., Zaman, S. M. S., Sultana, S., Parvez, M., Nasrin, S., & Halder, M. (2025). The mycorrhiza fungi

colonization and relationship with rhizosphere soil properties in the urban and suburban area of Southwestern Bangladesh. *Total Environment Microbiology*, 1(1), Article 100003. <https://doi.org/10.1016/j.temicr.2025.100003>

Ali, A., Ghani, M. I., Ding, H., Fan, Y., Cheng, Z., & Iqbal, M. (2019). Co-amended synergistic interactions between arbuscular mycorrhizal fungi and the organic substrate-induced cucumber yield and fruit quality associated with the regulation of the AM-fungal community structure under anthropogenic cultivated soil. *International Journal of Molecular Sciences*, 20(7), Article 1539. <https://doi.org/10.3390/ijms20071539>

Báez-Pérez, A. L., Lindig-Cisneros, R., & Villegas, J. (2017). Survival and growth of nursery inoculated *Fraxinus uhdei* in Acrisol gullies. *Madera y Bosques*, 23(3), 7-14. <https://doi.org/10.21829/myb.2017.2331418>

Banks, J. M., & Percival, G. C. (2014). Failure of foliar-applied biostimulants to enhance drought and salt tolerance in urban trees. *Arboriculture & Urban Forestry*, 40(2), 78-83. <https://doi.org/10.48044/jauf.2014.009>

Barnes, S., & Percival, G. C. (2006). Influence of biostimulants and water-retaining polymer root dips on survival and growth of newly transplanted bare-rooted silver birch and rowan. *Journal of Environmental Horticulture*, 24(3), 173-179. <https://doi.org/10.24266/0738-2898-24.3.173>

Bizjak, T., Sellstedt, A., Gratz, R., & Nordin, A. (2023). Presence and activity of nitrogen-fixing bacteria in Scots pine needles in a boreal forest: a nitrogen-addition experiment. *Tree Physiology*, 43(8), 1354-1364. <https://doi.org/10.1093/treephys/tpad048>

Calvo-Polanco, M., Armada, E., Zamarreño, A. M., García-Mina, J. M., & Aroca, R. (2019). Local root ABA/cytokinin status and aquaporins regulate poplar responses to mild drought stress independently of the ectomycorrhizal fungus *Laccaria bicolor*. *Journal of Experimental Botany*, 70(21), 6437-6446. <https://doi.org/10.1093/jxb/erz389>

- Chen, Y., De Nobili, M., & Avid, T. (2004). Stimulatory effect of humic substances on plant growth. In F. Magdoff & R. R. Weil (Eds.), *Soil Organic Matter in Sustainable Agriculture* (pp. 103-129). CRS Press. [https://hkst.cqucas.ac.cn/Files/sitefile_10/Image/files/%E7%94%9F%E6%80%81%E5%AD%A6%E7%9B%B8%E5%85%B3%E8%91%97%E4%BD%9C%20Soil%20Organic%20Matter%20in%20Sustainable%20Agriculture%20by%20Magdoff,%20Fred%20\(z-lib.org\).pdf?03115517](https://hkst.cqucas.ac.cn/Files/sitefile_10/Image/files/%E7%94%9F%E6%80%81%E5%AD%A6%E7%9B%B8%E5%85%B3%E8%91%97%E4%BD%9C%20Soil%20Organic%20Matter%20in%20Sustainable%20Agriculture%20by%20Magdoff,%20Fred%20(z-lib.org).pdf?03115517)
- Cinantya, A., Manea, A., & Leishman, M. R. (2024). Biostimulants do not affect the performance of urban plant species grown under drought stress. *Urban Ecosystems*, 27, 1251-1261. <https://doi.org/10.1007/s11252-024-01521-5>
- de Sousa-Oliveira, K. Â., Coelho-Lopes, P. R., Cavalcante, Í., Cunha-Filho, J., dos Santos-Silva, L., Valença-Pereira, E. C., & Teixeira-Lobo da Silva, J. (2022). Impact of paclobutrazol on gibberellin-like substances and soluble carbohydrates in pear trees grown in tropical semiarid. *Revista de la Facultad de Ciencias Agrarias UNCuyo*, 54(1), 46-56. <https://doi.org/10.48162/rev.39.064>
- Derkzen, M. L., van Teeffelen, A. J. A., & Verburg, P. H. (2015). Quantifying urban ecosystem services based on high-resolution data of urban green space: an assessment for Rotterdam, the Netherlands. *Journal of Applied Ecology*, 52(4), 1020-1032. <https://doi.org/10.1111/1365-2664.12469>
- Dong, F., Wang, Y., & Tang, M. (2021). Effects of *Laccaria bicolor* on gene expression of *Populus trichocarpa* root under poplar canker stress. *Journal of Fungi*, 7(12), Article 1024. <https://doi.org/10.3390/jof7121024>
- du Jardin, P. (2015). Plant biostimulants: Definition, concept, main categories and regulation. *Scientia horticulturae*, 196, 3-14. <https://doi.org/10.1016/j.scienta.2015.09.021>
- Fini, A., Ferrini, F., Seri, M., Amoroso, G., Piatti, R., Robbiani, E., & Frangi, P. (2016). Effect of fertilization and mycorrhizal inoculation in the nursery on post-transplant growth and physiology in three ornamental woody species. *Acta*

- Horticulturae*, (1108), 47-54.
https://www.actahort.org/members/showpdf?booknrarnr=1108_6
- Graziani, G., Cirillo, A., Giannini, P., Conti, S., El-Nakhel, C., Rouphael, Y., Ritieni, A., & Di Vaio, C. (2022). Biostimulants improve plant growth and bioactive compounds of young olive trees under abiotic stress conditions. *Agriculture*, 12(2), Article 227. <https://doi.org/10.3390/agriculture12020227>
- Hartmann, H., & Trumbore, S. (2016). Understanding the roles of nonstructural carbohydrates in forest trees—from what we can measure to what we want to know. *New Phytologist*, 211(2), 386-403. <https://doi.org/10.1111/nph.13955>
- Hasanuzzaman, M., Parvin, K., Bardhan, K., Nahar, K., Anee, T. I., Masud, A. A. C., & Fotopoulos, V. (2021). Biostimulants for the regulation of reactive oxygen species metabolism in plants under abiotic stress. *Cells*, 10(10), 2537. <https://doi.org/10.3390/cells10102537>
- Jayaraman, J., & Ali, N. (2015). Use of seaweed extracts for disease management of vegetable crops. In S. Ganesan, K. Vadivel & J. Jayaraman (Eds.), *Sustainable crop disease management using natural products* (pp. 160-183). CAB International. <https://doi.org/10.1079/9781780643236.0160>
- Jiang, D., Lin, R., Tan, M., Yan, J., & Yan, S. (2022). The mycorrhizal-induced growth promotion and insect resistance reduction in *Populus alba* × *P. berolinensis* seedlings: a multi-omics study. *Tree Physiology*, 42(5), 1059-1069. <https://doi.org/10.1093/treephys/tpab155>
- Jiang, X., Wang, Y., Xie, H., Li, R., Wei, J., & Liu, Y. (2019). Environmental behavior of paclobutrazol in soil and its toxicity on potato and taro plants. *Environmental Science and Pollution Research*, 26, 27385-27395. <https://doi.org/10.1007/s11356-019-05947-9>
- Joly, P., Calteau, A., Wauquier, A., Dumas, R., Beuvin, M., Vallenet, D., Crovadore, J., Cochard, B., Lefort, F., & Berthon, J.-Y. (2021). From strain characterization to field authorization: Highlights on *Bacillus velezensis* strain B25 beneficial properties

- for plants and its activities on phytopathogenic fungi. *Microorganisms*, 9(9), 1924. <https://doi.org/10.3390/microorganisms9091924>
- Kaplan, M., Lenart, A., Klimek, K., Borowy, A., Wrona, D., & Lipa, T. (2021). Assessment of the possibilities of using cross-linked polyacrylamide (Agro Hydrogel) and preparations with biostimulation in building the quality potential of newly planted apple trees. *Agronomy*, 11(1), 125. <https://doi.org/10.3390/agronomy11010125>
- Leite, J. M., Pitumpe-Arachchige, P. S., Ciampitti, I. A., Hettiarachchi, G. M., Maurmann, L., Trivelin, P. C. O., Vara-Prasad, P. V., & Sunoj, S. V. J. (2020). Co-addition of humic substances and humic acids with urea enhances foliar nitrogen use efficiency in sugarcane (*Saccharum officinarum* L.). *Heliyon*, 6(10), Article e05100. <https://doi.org/10.1016/j.heliyon.2020.e05100>
- Marchin, R. M., Esperon-Rodriguez, M., Tjoelker, M. G., & Ellsworth, D. S. (2025). Understanding urban tree heat and drought stress by tracking growth and recovery following an extreme year. *Landscape and Urban Planning*, 261, Article 105394. <https://doi.org/10.1016/j.landurbplan.2025.105394>
- Martínez-Trinidad, T., Plascencia-Escalante, F. O., e Islas-Rodríguez, L. (2013a). La relación entre los carbohidratos y la vitalidad en árboles urbanos. *Revista Chapingo Serie Ciencias Forestales y del Ambiente*, 19(3), 459-468. <https://doi.org/10.5154/r.rchscfa.2012.03.016>
- Martínez-Trinidad, T., Plascencia-Escalante, F. O., y Cetina-Alcalá, V. M. (2013b). Crecimiento y vitalidad de *Populus alba* L. con desmoche y tratado con paclobutrazol. *Revista Chapingo Serie Horticultura*, 19(3), 381-388. <https://doi.org/10.5154/r.rchsh.2013.05.016>
- Martinez-Trinidad, T., Watson, W. T., Arnold, M. A., & Lombardini, L. (2009). Investigations of exogenous applications of carbohydrates on the growth and vitality of live oaks. *Urban Forestry & Urban Greening*, 8(1), 41-48. <https://doi.org/10.1016/j.ufug.2008.11.003>

- Morales-Gallegos, L. M., Martínez-Trinidad, T., Gómez-Guerrero, A., Razo-Zarate, R., y Suárez-Espinoza, J. (2019). Inyecciones de glucosa en *Jacaranda mimosifolia* D. Don en áreas urbanas de Texcoco de Mora. *Revista Mexicana de Ciencias Forestales*, 10(52), 79-98. <https://doi.org/10.29298/rmcf.v10i52.414>
- Morales-Gallegos, L. M., Martínez-Trinidad, T., Gómez-Guerrero, A., & Suárez-Espinoza, J. (2020). Carbohydrate-based urban soil amendments to improve urban tree establishment. *Revista Chapingo Serie Ciencias Forestales y del Ambiente*, 26(3), 343-356. <https://doi.org/10.5154/r.rchscfa.2019.10.076>
- Noronha, H., Silva, A., Dai, Z., Gallusci, P., Rombolà, A. D., Delrot, S., & Gerós, H. (2018). A molecular perspective on starch metabolism in woody tissues. *Planta*, 248, 559-568. <https://doi.org/10.1007/s00425-018-2954-2>
- Ördög, V., Stirk, W. A., Van Staden, J., Novák, O., & Strnad, M. (2004). Endogenous cytokinins in three genera of microalgae from the Chlorophyta. *Journal of Phycology*, 40(1), 88-95. <https://doi.org/10.1046/j.1529-8817.2004.03046.x>
- Percival, G. C. (2010). Effect of systemic inducing resistance and biostimulant materials on apple scab using a detached leaf bioassay. *Arboriculture & Urban Forestry*, 36(1), 41-46. <https://doi.org/10.48044/jauf.2010.006>
- Pérez-Baltazar, I., Báez-Pérez, A. L., Osuna-Vallejo, V., Armendáriz-Arnez, C., y Lindig-Cisneros, R. (2020). Crecimiento de *Fraxinus uhdei* inoculado con dos cepas ectomicorrízicas en dos sustratos, uno contaminado con mercurio. *Revista Internacional de Contaminación Ambiental*, 36(2), 455-464. <https://doi.org/10.20937/RICA.53543>
- Ricci, M., Tilbury, L., Daridon, B., & Sukalac, K. (2019). General principles to justify plant biostimulant claims. *Frontiers in Plant Science*, 10, Article 494. <https://doi.org/10.3389/fpls.2019.00494>
- Rosier, C. L., Polson, S. W., D'Amico III, V., Kan, J., & Trammell, T. L. E. (2021). Urbanization pressures alter tree rhizosphere microbiomes. *Scientific Reports*, 11, Article 9447. <https://doi.org/10.1038/s41598-021-88839-8>

- Rusterholz, H.-P., Studer, M., Zwahlen, V., & Baur, B. (2020). Plant-mycorrhiza association in urban forests: Effects of the degree of urbanization and forest size on the performance of sycamore (*Acer pseudoplatanus*) saplings. *Urban Forestry & Urban Greening*, 56, Article 126872. <https://doi.org/10.1016/j.ufug.2020.126872>
- Sebastiana, M., Gargallo-Garriga, A., Sardans, J., Pérez-Trujillo, M., Monteiro, F., Figueiredo, A., Maia, M., Nascimento, R., Sousa-Silva, M., Ferreira, A. N., Cordeiro, C., Marques, A. P., Sousa, L., Malhó, R., & Peñuelas, J. (2021). Metabolomics and transcriptomics to decipher molecular mechanisms underlying ectomycorrhizal root colonization of an oak tree. *Scientific Reports*, 11, Article 8576. <https://doi.org/10.1038/s41598-021-87886-5>
- Seleiman, M. F., Al-Suhaibani, N., Ali, N., Akmal, M., Alotaibi, M., Refay, Y., Dindaroglu, T., Abdul-Wajid, H. H., & Battaglia, M. L. (2021). Drought stress impacts on plants and different approaches to alleviate its adverse effects. *Plants*, 10(2), 259. <https://doi.org/10.3390/plants10020259>
- Shao, W., Yu, H., Liu, H., Xu, G., Wang, L., Wu, W., Wu, G., & Si, P. (2023). Effects of glucose and mannose on nutrient absorption and fruit quality in peach (*Prunus persica* L.). *Journal of Soil Science and Plant Nutrition*, 23, 1326-1338. <https://doi.org/10.1007/s42729-022-00902-z>
- Shiu, J.-H., Huang, Y.-C., Lu, Z.-T., Jien, S.-H., Wu, M.-L., & Wu, Y.-T. (2022). Biochar-based compost affects bacterial community structure and induces a priming effect on soil organic carbon mineralization. *Processes*, 10(4), Article 682. <https://doi.org/10.3390/pr10040682>
- Shuai, W., Dun, J., Qinghui, M., Mingtao, T., Jiaqi, Z., Xiaoxia, L., Zhaojun, M., & Shanchun, Y. (2021). Effects of arbuscular mycorrhizal fungi on metabolism and chemical defense of *Populus alba* × *P. berolinensis* leaves. *Journal of Beijing Forestry University*, 43(5), 86-92. <http://j.bjfu.edu.cn/en/article/doi/10.12171/j.1000-1522.20200172?viewType=citedby-info>

- Sieverding, E., Alves-da Silva, G., Berndt, R., & Oehl, F. (2014, October-December). *Rhizoglosum*, a new genus of the Glomeraceae. *Mycotaxon*, 129(2), 373-386. <https://doi.org/10.5248/129.373>
- Sun, W., & Shahrajabian, M. H. (2023). The application of arbuscular mycorrhizal fungi as microbial biostimulant, sustainable approaches in modern agriculture. *Plants*, 12(17), 3101. <https://doi.org/10.3390/plants12173101>
- Sun, W., Shahrajabian, M. H., Kuang, Y., & Wang, N. (2024). Amino acids biostimulants and protein hydrolysates in agricultural sciences. *Plants*, 13(2), Article 210. <https://doi.org/10.3390/plants13020210>
- Tanis, S. R., McCullough, D. G., & Cregg, B. M. (2015). Effects of paclobutrazol and fertilizer on the physiology, growth and biomass allocation of three *Fraxinus* species. *Urban Forestry & Urban Greening*, 14(3), 590-598. <https://doi.org/10.1016/j.ufug.2015.05.011>
- Tonn, N., & Ibáñez, I. (2017). Plant-mycorrhizal fungi associations along an urbanization gradient: implications for tree seedling survival. *Urban Ecosystems*, 20, 823-837. <https://doi.org/10.1007/s11252-016-0630-5>
- Wang, Y., Chang, Q., Fan, P., & Shi, X. (2022). From urban greenspace to health behaviors: An ecosystem services-mediated perspective. *Environmental Research*, 213, Article 113664. <https://doi.org/10.1016/j.envres.2022.113664>
- Yakhin, O. I., Lubyantsev, A. A., Yakhin, I. A., & Brown, P. H. (2017). Biostimulants in plant science: a global perspective. *Frontiers in Plant Science*, 7, Article 2049. <https://doi.org/10.3389/fpls.2016.02049>
- Zhang, H., Li, L., Ren, W., Zhang, W., Tang, M., & Chen, H. (2022). Arbuscular mycorrhizal fungal colonization improves growth, photosynthesis, and ROS regulation of split-root poplar under drought stress. *Acta Physiologiae Plantarum*, 44, Article 62. <https://doi.org/10.1007/s11738-022-03393-8>
- Zhang, P., McDowell, N. G., Zhou, X., Wang, W., Leff, R. T., Pivovarov, A. L., Zhang, H., Chow, P. S., Ward, N. D., Indivero, J., Yabusaki, S. B., Waichler, S., &

Bailey, V. L. (2021). Declining carbohydrate content of Sitka-spruce trees dying from seawater exposure. *Plant physiology*, 185(4), 1682-1696. <https://doi.org/10.1093/plphys/kiab002>

Zhou, S., Gao, X., Wang, C., Yang, G., Cram, W. J., & He, G. (2009). Identification of sugar signals controlling the nitrate uptake by rice roots using a noninvasive technique. *Zeitschrift für Naturforschung*, 64c, 697-703. <https://doi.org/10.1515/znc-2009-9-1015>

Zulfiqar, F., Moosa, A., Ali, H. M., Bermejo, N. F., & Munné-Bosch, S. (2024). Biostimulants: A sufficiently effective tool for sustainable agriculture in the era of climate change? *Plant Physiology and Biochemistry*, 211, Article 108699. <https://doi.org/10.1016/j.plaphy.2024.108699>

Zwiazek, J. J., Equiza, M. A., Karst, J., Senorans, J., Wartenbe, M., & Calvo-Polanco, M. (2019). Role of urban ectomycorrhizal fungi in improving the tolerance of lodgepole pine (*Pinus contorta*) seedlings to salt stress. *Mycorrhiza*, 29, 303-312. <https://doi.org/10.1007/s00572-019-00893-3>



Todos los textos publicados por la **Revista Mexicana de Ciencias Forestales** –sin excepción– se distribuyen amparados bajo la licencia *Creative Commons 4.0 Atribución-No Comercial (CC BY-NC 4.0 Internacional)*, que permite a terceros utilizar lo publicado siempre que mencionen la autoría del trabajo y a la primera publicación en esta revista.