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# NORDIHDROGUAIARETIC ACID AS BIOPESTICIDE EXTRACTED OF LEAVES AND STEMS OF *Larrea tridentata* IN TWO LOCALITIES.

By

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## Abstract

*Nordihydroguaiaretic acid (NDGA) is a natural phenolic lignin of Larrea tridentata with antifungal activity; this compound also delays the senescence of the fruits to provide further quality and postharvest duration. The NDGA concentration depends on the part of the plant where it is extracted. This study aimed to determine the concentration of NDGA in leaves and seeds of Larrea tridentata from two localities using three solvents for its extraction. The localities were: Mapimí Valley, Durango and La Saucedá, Ramos Arizpe, Coahuila; the extraction solvents used were: 10% vinegar, 10% methanol, and 10% ethanol in water. NDGA extraction was performed following a 2×2×3 factorial arrangement with four completely randomized repeats. HPLC performed NDGA quantification. No significant difference was found in the extraction solvent and vegetative parts; however, in the localities, the highest value was for Saucedá, with 224.85 mg kg<sup>-1</sup>, compared to Mapimí, with 123.83 mg kg<sup>-1</sup> of NDGA. In the interaction of extraction methods and vegetative part, no significant difference was found; the interaction of extraction methods and localities was found a significant difference with ethanol in Saucedá with 233.57 mg kg<sup>-1</sup> as the best, the interaction of vegetative part and localities with significance in leaf in the Saucedá with 231.70 mg kg<sup>-1</sup>, the interaction of extraction methods, vegetative part and localities was significant in leaf with vinegar in La Saucedá with 245.83 mg kg<sup>-1</sup>, these being the best responses. Vinegar and the leaves of Larrea tridentata from La Saucedá were the best options for elaborating a biorational product.*

**Keywords:** concentration, antifungal, biorational

## INTRODUCTION

*Larrea tridentata* is a species endemic to the Chihuahuan Desert, commonly known as Gobernadora, for its dominance in the large areas of the arid zone of northern Mexico. Gobernadora is located in the Sonoran Desert, including the states of Baja California Norte, Baja California Sur, and Sonora, and in the Chihuahuan Desert, including the states of Chihuahua, Coahuila, Nuevo León, Zacatecas, San Luis Potosí, and Durango (López, 2017).

The leaves of *L. tridentata* have a thick layer of resin produced by glandular trichomes during their development and can form more than 20% of the dry weight of the plant (Lira, 2003). From 16 to 21% of the dry weight of the resin contains phenolic lignans, such as heminorisoguaiacin, nordihydroguaiacin, dihydroguaiaretic acid, and nordihydroguaiaretic acid (NDGA), this represents almost 50% of the concentration of phenolic lignans (Rahman *et al.*, 2011, Aguirre *et al.*, 2019). The resin is also found in new

stems without complete lignification, making it easy to obtain from the plant.

The effects of NDGA are known as antioxidant, anti-carcinogenic, and anti-viral, which are most noticeable in medicine (Mala *et al.*, 2020). NDGA inhibits glyoxalase which is an enzyme that contributes to the pathogenicity of several diseases (Watanabe *et al.*, 2022); it also has beneficial effects in alleviating and inhibiting the formation of malignant tumors due to its antioxidant capacity (Manciu *et al.*, 2022).

The active principles of Gobernadora resin and its phytochemical compounds are considered a biodegradable product, which does not produce an imbalance in ecosystems in the control of pest insects and diseases (Zelaya *et al.*, 2022). Biological products, including NDGA, represent an attractive plant disease control alternative (Cervantes *et al.*, 2020). NADG inhibits the effect of abscisic acid on fruit cracking because it reduces the osmotic pressure, water absorption capacity, and turgor pressure of the fruit cuticle

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(Yu *et al.*, 2020). The NDGA sprayed on jojoba reduces the incidence of grasshoppers that feed on it and is considered part of a plant defense mechanism (Nakano *et al.*, 2022). Ge *et al.* (2019) found that NDGA inhibits anthocyanin accumulation, inhibits antioxidant activity, and inhibits the content of other phenols at doses of 100  $\mu\text{mol/L}$  (30.24 mg/ka) of NDGA in the strawberry crop when it comes to disease. NADG is a natural Larrea lignin, which inhibits the activity of the enzyme 9-cis-epoxycarotenoid dioxygenase (NCED) and has an antagonistic effect with abscisic acid (ABA), and NDGA can delay senescence, postharvest losses and maintain fruit quality (Li *et al.*, 2023).

## Research Elaborations

To have three extraction methods, two localities from where the sample was obtained and two vegetative parts, which are leaves and stems with four repetitions for a factorial design  $2 \times 2 \times 3$  completely random with three factors. Three factors were worked on: A) Extraction solvent, B) Locality, and C) vegetative part. The extraction solvents were 1) 10% vinegar in water, 2) 10% methanol in water, and 3) 10% ethanol in water. The localities were a) Valle de Mapimí, State of Durango, b) La Sauceda, Ramos Arizpe, Coahuila. The vegetative parts were a) leaves and b) stems.

The extraction was carried out by weighing 20 g of each vegetative part with its repetitions and was placed in an Erlenmeyer flask of 250 mL, where the extraction solutions of 100 mL were applied; stirred for 24 hours in an INO orbital incubator – 650 M at 36 °C and milled in a blender, the ground mixture was placed in a Büchner funnel with a filter No. 615 CMSLLC 3856 of 8  $\mu\text{m}$  and with a Chemker 300 vacuum pump towards a 500 mL Kitasato flask, where about 50 mL were collected, in this solution (Brown *et al.*, 2015), in each sample was diluted in 1:10 in a volumetric flask of 10 mL, and the dilution is passed to a beaker of 10 mL, and 2 mL are taken, with a syringe of 5 mL then the water is changed. A 0.45  $\mu\text{m}$  Agilent filter is placed in the syringe, and the sample is passed to a 9 mm, 2 mL Verex vial for analysis.

The analysis was performed with an HPLC brand Agilent 1200 with diode array detector at 280 nm. A SupelcoSil C18 column 150 $\times$ 4.6 mm; 5  $\mu\text{m}$  was used for analyte separation. As mobile phase, a mixture of methanol and acetic acid at 5% in relation to 70% methanol and 30% acetic acid was used, with a flow of 0.6 mL min<sup>-1</sup> and a maximum pressure of 400 bar; the injection was 10  $\mu\text{L}$  and the analysis time was 20 minutes (Martins *et al.*, 2011).

The calibration curve was performed with 50, 100, 200, 300, and 400 ppm using a Nordihydroguaiaretic acid standard ( $\geq 97\%$ , Sigma Aldrich).

Statistical analysis of treatments was performed with an error  $p \leq 0.05$  and the difference between treatments with Tukey (SAS 9.4, 2022).

## Results and Discussion

### Calibration

An NDGA calibration curve with a 0.8626 correlation coefficient was obtained (Figure 1).

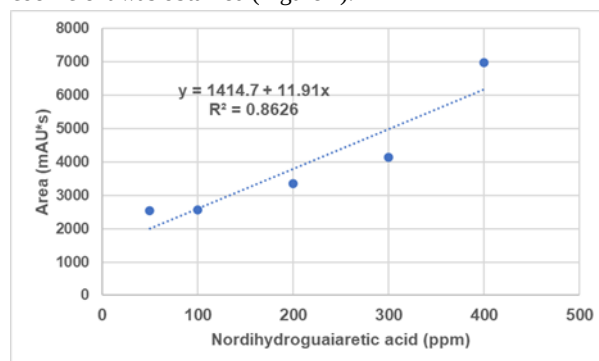


Figure 1. Calibration curve of nordihydroguaiaretic acid.

From this calibration curve, the NDGA concentration, in ppm, can be calculated by the following equation:

$$[\text{NDGA}], \text{ppm} = \frac{\text{peak area} - 1414.7}{11.91}$$

### Individual effects

The analysis of the individual factors in the effect of the extraction solvents did not find a significant difference between the vegetative parts because the stem presented a value of 169.21 mg kg<sup>-1</sup> and the leaves with 179.48 mg kg<sup>-1</sup> of NDGA, nor was a significant difference found in the extraction solvent since vinegar had 191.65 mg kg<sup>-1</sup>, ethanol presented a value of 170.30 mg kg<sup>-1</sup> and methanol with 161.09 mg kg<sup>-1</sup> of NDGA. This sequence with extractants disagrees with the reported by Pérez *et al.* (2020), where ethanol and methanol are the extractants used for *L. tridentata*.

For the locality, a significant difference was found ( $p \leq 0.05$ ), where the highest value was for Sauceda, with 224.85 mg kg<sup>-1</sup>, compared to Mapimí, with 123.83 mg kg<sup>-1</sup> of NDGA.

### Interactions

The individual effect does not express the relationship between the factors evaluated; the interaction extraction method and locality are shown in Table 1, where the Sauceda with ethanol presented a value of 233.57 mg kg<sup>-1</sup>; it is already observed that ethanol and methanol do have the effect indicated by Pérez *et al.*, (2020) for extraction and since they are alcohols, once the extraction process is carried out, a part is volatilized because they are volatile organic compounds (Wade, 2016), but this volatilization should not be total, because NDGA has low solubility in an aqueous medium that is reduced by increasing ethanol concentration (Wikeley *et al.*, 2022).

**Table 1.** Interaction of extraction methods and localities of *Larrea tridentata* in the concentration of nordihydroguaiaretic acid.

|               |               | 2. Nordihydroguaiaretic acid (mg kg <sup>-1</sup> ) |              |  | 5. $\bar{x}$ |
|---------------|---------------|-----------------------------------------------------|--------------|--|--------------|
| 1. Solvent    | 3. Saucedá    | 4. Mapimi                                           |              |  |              |
| 6. Ethanol    | 7. 233.57 ax  | 8. 107.02 by                                        | 9. 170.30 a  |  |              |
| 10. Methanol  | 11. 226.16 ax | 12. 96.01 by                                        | 13. 161.09 a |  |              |
| 14. Vinegar   | 15. 214.82 ax | 16. 168.47 ax                                       | 17. 191.65 a |  |              |
| 18. $\bar{x}$ | 19. 224.85 ax | 20. 12.83 y                                         | 21.          |  |              |

a, b, c = Values with different literals in a column, are different Tukey ( $p \leq 0.05$ ).

x, y, z = Values with different literals in a row, are different Tukey ( $p \leq 0.05$ ).

No significant difference was found for the extractant interaction and vegetative part (Table 2). The similarity of the

values in both rows and columns indicates that using the leaves or stems with any extractant evaluated in this study is indistinct. The highest concentration of NDGA corresponds to the interaction stem and vinegar with 194.33 mg kg<sup>-1</sup> but is lower by 39.24 mg kg<sup>-1</sup> to the concentration of the interaction Saucedá and ethanol; therefore, there is no significant difference and a lower concentration.

**Table 2.** Interaction of extraction methods and vegetative part of *L. tridentata* in NDGA concentration.

|               |               | 2. Nordihydroguaiaretic acid (mg kg <sup>-1</sup> ) |              |  |  |  |
|---------------|---------------|-----------------------------------------------------|--------------|--|--|--|
| 1. Solvent    | 3. Leaf       | 4. Stem                                             | 5. $\bar{x}$ |  |  |  |
| 6. Ethanol    | 7. 175.27 ax  | 8. 165.32 ax                                        | 9. 170.30 a  |  |  |  |
| 10. Methanol  | 11. 174.20 ax | 12. 147.97 ax                                       | 13. 161.09 a |  |  |  |
| 14. Vinegar   | 15. 188.97 ax | 16. 194.33 ax                                       | 17. 191.65 a |  |  |  |
| 18. $\bar{x}$ | 19. 179.48 x  | 20. 169.21 x                                        | 21.          |  |  |  |

a, b, c = Values with different literals in a column, are different Tukey ( $p \leq 0.05$ ).

x, y, z = Values with different literals in a row, are different Tukey ( $p \leq 0.05$ ).

In the interaction vegetative part and locality, there is a significant difference between columns. For the locality La Saucedá and the vegetative part, the leaf presented the highest

concentration of NADG with 231.7 mg kg<sup>-1</sup> (Table 3). NDGA has an effect on *Aspergillus flavus*, *Aspergillus niger*, *Penicillium chrysogenum*, *Penicillium expansum*, and *Fusarium moniliforme* under controlled conditions with the low effect of prolonged toxicity (Herrera *et al.*, 2021), a dose of 231. mg kg<sup>-1</sup> can control these bacteria, but its effect in the field was not determined.

**Table 3.** Interaction of vegetative part and localities of *L. tridentata* in the NDGA concentration.

|               |               | 2. Nordihydroguaiaretic acid (mg kg <sup>-1</sup> ) |              |  |  |
|---------------|---------------|-----------------------------------------------------|--------------|--|--|
| 1. Locality   | 3. Leaf       | 4. Stem                                             | 5. $\bar{x}$ |  |  |
| 6. Saucedá    | 7. 231.70 ax  | 8. 218.00 ax                                        | 9. 224.85 a  |  |  |
| 10. Mapimi    | 11. 127.20 bx | 12. 120.41 bx                                       | 13. 123.83 b |  |  |
| 14. $\bar{x}$ | 15. 179.48 x  | 16. 169.20 x                                        | 17.          |  |  |

a, b, c = Values with different literals in a column, are different Tukey ( $p \leq 0.05$ ).

x, y, z = Values with different literals in a row, are different Tukey Tukey ( $p \leq 0.05$ ).

1. In the interaction vegetative part, extraction solvent and locality, which is the triple interaction and which

was analyzed as treatments (Table 4) and the results were different and significant ( $p \leq 0.05$ ), the highest value observed was 245.83 mg kg<sup>-1</sup> that corresponds to the locality of Saucedá, in the leaf with the extraction of vinegar, similar to the locality Saucedá in stem and with the extraction of ethanol (239.64 mg kg<sup>-1</sup>) and methanol (230.55 mg kg<sup>-1</sup>), as the highest values in the concentration of NDGA in the study.

**Table 4.** Interaction of extraction methods, vegetative part, and localities of *Larrea tridentata* in the concentration of nordihydroguaiaretic acid.

|     |          | 2. Nordihydroguaiaretic acid (mg kg <sup>-1</sup> ) |               |     |            |           |           |  |  |
|-----|----------|-----------------------------------------------------|---------------|-----|------------|-----------|-----------|--|--|
| 1.  | Solvent  | 3. Saucedá                                          |               |     |            | 4. Mapimi |           |  |  |
|     |          | 5. Leaf                                             | 6. Stem       |     |            | 7. Leaf   | 8. Stem   |  |  |
| 9.  | Methanol | 10. 221.78 a                                        | 11. 230.55 a  | 12. | 126.63 abc | 13.       | 65.39 c   |  |  |
| 14. | Ethanol  | 15. 227.50 a                                        | 16. 239.64 a  | 17. | 123.04 abc | 18.       | 91.00 bc  |  |  |
| 19. | Vinegar  | 20. 245.83 a                                        | 21. 18.82 abc | 22. | 132.11 abc | 23.       | 204.84 ab |  |  |

a, b, c = Values with different literals in a column, are different Tukey ( $p \leq 0.05$ ).

Doses of 0.78 mg mL<sup>-1</sup> (780 mg kg<sup>-1</sup>) of NDGA, inhibit the concentration to the minimum of *Clavibacter michiganensis* sbsp. *michiganensis*, *Pseudomonas syringae*, and *Xanthomonas campestris* (Morales *et al.*, 2021). The highest dose found in the study was 245.83 mg kg<sup>-1</sup>, which does not meet the indicated dose because it is lower by 534.17 mg kg<sup>-1</sup>.

NDGA alters the morphology and physiological state of plants subjected to salt stress, because they become less sensitive to salt stress (Ye *et al.*, 2022). One of the advantages of NDGA is to inhibit the effect of ABA, which is the response of plants to frost through the modulation of the antioxidative system, which improves cold tolerance (Li *et al.*, 2021). Lipoxigenases catalyze the hydro peroxidation of polyunsaturated fatty acids, which is the first step in the synthesis of fatty acid metabolites in plants due to stress, and NDGA inhibits lipoxigenase activity (Hajdinák and Szarka, 2022).

A plant under drought water stress produces hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>), ABA, and jasmonic acid (JA) in its leaves. NDGA reduces water content through the antioxidant enzymatic capacity of plant biomass accumulation and the MYC2 gene that reactivates the disease-resistance protein RPM1 (Li *et al.*, 2019, Wang *et al.*, 2021, Liu *et al.*, 2022).

In the ripening of jujube or red date (*Ziziphus jujuba*), NADG at doses of 50 mg kg<sup>-1</sup>, regulates secondary photosynthesis, lipid metabolic processes, cell wall arrangement, and concentration of starch and sugar because NADG is an inhibitor of the effect of ABA because it reduces the respiration activity of the fruit and the concentration of ethylene that induce fruit ripening (Zhang *et al.*, 2019).

In the problem of abscission, transport and postharvest storage of grapes (*Vitis vinifera* L.), NADG at doses of 100 µmol L<sup>-1</sup> (30.24 mg kg<sup>-1</sup>), reduces the activity of ABA and ethylene by decreasing the expression of VvNCED1 and VvACO1 genes that reduce their synthesis, also reduces the activity of pectinesterase, polygalacturonase, and cellulase, the content of malondialdehyde and relative conductivity in the cell wall, additionally decreases the content of total soluble solids, titratable acids, vitamin C and weight loss (Zhu *et al.*, 2022).

NDGA is an inhibitor of ABA synthesis in peach ripening (*Prunus armeniaca* L.); peach ripening is related to the

PaPYL9 gene by inhibiting its expression reduces the color index for grapes, the content of total soluble solids, titratable acids, and firmness and delays the ripening process (Jia *et al.*, 2022). For Japanese peach (*Prunus mume* Sieb. et Zucc.) the same effect is had with NDGA with 100 µM L<sup>-1</sup> (Tomiya *et al.*, 2021).

For the Japanese cherry tree (*Prunus serrulata* Lindl), when it has full foliage coverage, 10 mg L<sup>-1</sup> of NDGA was applied by sprinkling and decreases the color intensity and increases the fruit size in late ripening varieties; this effect is inverse in early ripening varieties (Time *et al.*, 2021).

Blueberry (*Vaccinium corymbosum*), applying 300 mg L<sup>-1</sup> of NDGA decreased the concentration of ABA, but did not affect the harvest time or the evolution of ethylene; hence it follows that for this fruit, ethylene is the promoter of maturity (Watanabe *et al.*, 2021).

In flower buds of LilyDay (*Hemerocallis citrina*) the enzyme β-1,3-glucanase acts during the fungal pathogenic and plant process; when the fungus infects the plant, the enzyme is completely inhibited by NDGA at concentrations of 25 µM (7.6 mg kg<sup>-1</sup>), so it is considered as an antifungal agent in crop protection (Vargas *et al.* 2009). NDGA has been evaluated for the control of *Alternaria alternata*, *Fusarium oxysporum*, *Colletotrichum gloeosporioides* and *Botrytis cinerea* having a positive effect on control. However, its most significant effect was on *Fusarium oxysporum* (Aguirre *et al.*, 2018).

The use of heterodimers such as quercetin/NDGA 5'– 5', have greater antimicrobial activity against *L. monocytogenes*, *S. aureus*, *Escherichia coli* and *Enterobacter cloacae* (Ngubane *et al.*, 2022). Fatty hydroxy acids have the function of maintaining the stability of the membranes and cell walls of fungi and bacteria, the enzyme that catalyzes the reactions of linoleate with fatty acids and oxygen to form hydroxy acids is 12-lipoxygenase (12LOXcd), NDGA, at doses of 2.5 µM (0.7 mg kg<sup>-1</sup>) inhibits the catalytic domain of the enzyme 12LOXcd (Xu *et al.*, 2022), with which, in microorganisms such as fungi and pathogenic bacteria, their cell membranes are denatured causing lysis and death of these pathogens.

The effect of climate change and the increase in direct radiation (Stamatis *et al.*, 2024), produces a stomatal closure causing temporary wilting in the crops, photosynthesis is modified, CO<sub>2</sub> ingress is reduced, and O<sub>2</sub> concentration in cells is increased, this increase the reactive oxygen species (ROS) such hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>), superoxide (O<sub>2</sub><sup>-</sup>), and singlet oxygen (O<sub>2</sub>) are produced to initiate signaling

pathways (Martin *et al.*, 2022). The stomatal closure with increase the ABA concentration in cells guards in the stomata. The NDGA reduce the concentration of H<sub>2</sub>O<sub>2</sub>, in cells, excess H<sub>2</sub>O<sub>2</sub>, at 10 nM can damage the membrane cell in the leaves and kill the cells of leaves (Ruiz-Sáenz *et al.*, 2025), NDGA regulate the concentration of ROS molecules and use them to control pathogenic viruses and fungi.

Pathogens such as the fungus *Fusarium oxysporum* f. sp. *Vasinfestum* also utilize H<sub>2</sub>O<sub>2</sub> during the infection process; through the rapid production of ROS via membrane-bound NADPH oxidases, successful fungal pathogens employ strategies to increase cellular damage to healthy crop tissue during infection (Wang *et al.*, 2021). This raises the question of whether a biopesticide containing NDGA exerts a greater effect on the pathogen than the pathogen does on the crop; consequently, organic and sustainable biopesticides demonstrate effectiveness rates ranging from 62% to 75%, the NDGA concentration in one organic product, It must be greater than that of the pathogen, and its effect must be faster, in order to control the pathogen, this is an alternative to protect plants from diseases and drought stress damage (Covarrubias *et al.*, 2025).

## Conclusions

The best extractant for NDGA is 10% vinegar, the vegetative part with the highest concentration was the leaves and the best locality was Saucedá, demonstrating that these would be the best conditions for obtaining NDGA.

The higher concentration of NDGA (245.83 mg kg<sup>-1</sup>) is useful to delay senescence and postharvest losses and maintain fruit quality. It also has beneficial effects by avoiding the water stress of plants and demonstrating frost tolerance.

The NDGA showed that it is a good controller of pathogens such as fungi and bacteria, inhibiting the enzymatic activity of protection, and is a sustainable product with application in agriculture, although it is also used in medical situations.

## Declarations

### Consent for publication

The authors consent published in this journal

### Competing interests

The authors declare no competing interests.

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## References

1. Abdullahi, H. U., Usman, A.G., Abba, S.I. 2020. Modelling the Absorbance of a Bioactive Compound in HPLC Method using Artificial Neural Network and Multilinear Regression Methods. DUJOPAS 6 (2): 362-371.
2. Aguirre J., J. A., L. Pastrana C., D. Nieto O., J. Ventura S., R. Rojas M., and C. N. Aguilar. 2018. The physicochemical, antifungal and antioxidant

properties of a mixed polyphenol based bioactive film. Heliyon 4:e00942.

3. Aguirre J., J. A., Cerqueira, M. A., Ventura S., J., Aguilar G., M. A., Carbó A., E., Pastrana C., L., Aguilar, C. N. 2019. Candelilla Wax-Based Coatings and Films: Functional and Physicochemical Characterization. Food and Bioprocess Technology 12:1787–1797. <https://doi.org/10.1007/s11947-019-02339-2>.
4. Brown T. L.; LeMay Jr H. E.; Bursten B. E.; Murphy C. J.; Woodward P. M. and Stoltzfus. 2015. <https://doi.org/10.1007/978-1-4939-9730-7>. Chemistry. The Central Science. 13th Edition, AP® Edition. Pearson. USA. 1195 p.
5. Cervantes J., M. M., Olalde P., V., Martínez F., M. B., Notario Z., M I., Valdés R., S. E. 2020. La cistatina de amaranto previene y controla el tizón temprano en tomate. Revista Mexicana de Ciencias Agrícolas 11(3):567-580.
6. Covarrubias R., J. M.; Díaz J., L. y Carlos H., S. 2025. Calentamiento global y mecanismos de los cultivos para resistir la sequía. En: III Congreso Internacional de Riego, Drenaje y Biosistemas. Jiutepec, Morelos, México. COMEII-2025: 1-9.
7. Ge, C., Luo, Y., Mo F., Ling Y., Mo Q., Shu Luo, S., and Tangl, H. 2019. Nordihydroguaiaretic acid treatment on the antioxidant properties of strawberry fruit. AIP Conference Proceedings 2079, 020013. <https://doi.org/10.1063/1.5092391>.
8. Hajdinák, P. and Szarka, A. 2022. Cell death in plant protection: improving the security of food supply by the means of molecular biology. Journal of Food Investigation 68 (4): 4240-4244. <https://doi.org/10.52091/EVIK-2022/4-7-ENG>.
9. Herrera M., R. E., Álvarez F., G. Contreras S., C and García L., J. C. 2021. Creosote Bush (*Larrea tridentata*) Phytochemical Traits and its Different uses: A Review. Journal of Applied Life Sciences International. 24(2): 34-45.
10. Jia M., J. Feng, L. Zhang, S. Zhang, W. Xi. 2022. PaPYL9 is involved in the regulation of apricot fruit ripening through ABA signaling pathway. Horticultural Plant Journal 8(4):461-473. <https://doi.org/10.1016/j.hpj.2021.11.012>.
11. Li, P., H. Wang, L. Wang, H. Liu, H. Hou, C. Zhang, A. Li, A. Zhu, J. Hu, Y. Lin, L. Liu. 2019. Physiological and transcriptome analyses reveal short-term response and formation of memory under drought stress in rice. Frontier Genetic 10:55.
12. Li, M., Wang, C., Shi, J., Zhang Y., Liu, T., Qi, H. 2021. Absciscic acid and putrescine synergistically regulate the cold tolerance of melon seedlings. Plant Physiology and Biochemistry 166:1054-1064.
13. Li, K., Xu, R., Cao, J., Jiang, W. 2023. Nordihydroguaiaretic acid (NDGA) maintains the postharvest quality of fresh daylily flower buds (*Emerocallis citrina*) by enhancing antioxidant metabolism and regulating phytohormone equilibrium. Postharvest Biology and Technology

- 200 (2023) 112326.  
<https://doi.org/10.1016/j.postharybio.2023.112326>.
14. Liu, L., X. Cao, Z. Zhai, S. Ma, Y. Tian, J. Cheng. 2022. Direct evidence of drought stress memory in mulberry from a physiological perspective: Antioxidative, osmotic and phytohormonal regulations. *Plant Physiology and Biochemistry* 186: 76–87.
15. Lira S., R. H. 2003. Estado actual del conocimiento sobre las propiedades biocidas de la gobernadora [*Larrea tridentata* (D.C.) Coville]. *Rev. Mex. Fitopatol.* 21(2):214-222.
16. López A., S. 2017. Extracción, cuantificación y valoración biológica del extracto de hoja de *Larrea tridentata* (sessé & moc. ex dc.) coville para su uso como agente biocida. Tesis Doctor en Ciencias. UASLP. San Luis Potosí, S.L.P. 82 p.
17. Mala J., G. S., Kumari V., V., Takeuchi, S., Shankar P., R., Venkatraman. G., Kumar R., S. 2020. Facile synthesis and nanoscale features of a nanostructured nordihydroguaiaretic acid analog for therapeutic applications. *Journal of Nanobiotechnology* 18:74.  
<https://doi.org/10.1186/s12951-020-00628-z>.
18. Manciu, F. S., Jose Guerrero, J., Bennet, K. E., Chang, S. Y., Rahman, M., Martinez L., L. V., Chantigian, S., Castellanos, M., Manciu, M. 2022. Assessing nordihydroguaiaretic acid therapeutic effect for *glioblastoma multiforme*. *Sensors* 22-2643. <https://doi.org/10.3390/s22072643>.
19. Martins, S., S. I. Mussatto, G. Martínez-Avila, J. Montañez-Saenz, C. N. Aguilar, J. A. Teixeira. 2011. Bioactive phenolic compounds: Production and extraction by solid-state fermentation. A review. *Biotechnology Advances* 29:365–373.
20. Martin, R. M.; Postiglione, A. E. and Muday, G. K. 2022. Reactive oxygen species function as signaling molecules in controlling plant development and hormonal responses. *Current Opinion in Plant Biology* 69:102293.  
[www.sciencedirect.com/science/journal/13695266](https://www.sciencedirect.com/science/journal/13695266).
21. Morales U., A. L., Rivero P., N., Ávila R., F., Aquino T., E., Prieto M., Hetta, H. F., El-Saber B., G. and Zaragoza B., A. 2021. Bactericidal Activity of *Larrea tridentata* Hydroalcoholic Extract against Phytopathogenic Bacteria. *Agronomy* 11(5),957. <https://doi.org/10.3390/agronomy11050957>.
22. Nakano, M., Morgan-Richards, M., Trewick, S. A., Clavijo-McCormick, A. 2022. Chemical Ecology and Olfaction in Short-Horned Grasshoppers (Orthoptera: Acrididae) *Journal of Chemical Ecology* 48:121–140.  
<https://doi.org/10.1007/s10886-021-01333-3>.
23. Ngubane, S., Permaul, K., Kudanga, T. 2022. Characterisation of inhibition and thermodynamic properties of *Trametes pubescens* laccase and application in the synthesis of hybrid antioxidants. *Process Biochemistry* 122 (2022) 181–193. <https://doi.org/10.1016/j.procbio.2022.10.012>.
24. Pérez L., R., Torres R., M., Flores C., M. A., González F., A. C., Hernández R., A., Soto P., J. M., Robles H., L. Phytotoxic and dissuasive activity of Chihuahua desert plant. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 48(1):426-435. DOI:10.15835/nbha48111505.
25. Rahman, S., Ansari, R. A., Rehman, H., Parvez, S., Raisuddin, S. Hindawi. 2011. Evidence-Based Complementary and Alternative Medicine. Publishing Corporation, Volume 2011, Article ID 734785, 10 pages. doi:10.1093/ecam/nep076.
26. Ruiz-Sáenz, D. R., López-Delgado, H. A., Diana Daniela Ayala Hernández, D. D., Mora-Herrera, M. E., Trejo, C., Uscanga Mortera, E., Flores López, R. 2025. Induction of Tolerance to Cryogenic Stress in *Solanum tuberosum* by Hydrogen Peroxide Mediated by Enzymatic Antioxidant Activity. *American Journal of Potato Research*. <https://doi.org/10.1007/s12230-025-10031-9>
27. Stamatis, M.; Hatzianastassiou, N.; Korras-Carraca, M. B.; Matsoukas, Ch.; Wild, M. and Vardavas, I. 2024. How strong are the links between global warming and surface solar radiation changes? *Climatic Change* 177:156. <https://doi.org/10.1007/s10584-024-03810-6>.
28. Statical Analysis System (SAS). 2022. Software 9.4 (TS1M7). SAS Institute Inc. Cary, N.C. USA.
29. Time A., C. Ponce, N. Kuhn, M. Arellano, B. Sagredo, J. M. Donoso, L. A. Meisel. 2021. Canopy Spraying of Absciscic Acid to Improve Fruit Quality of Different Sweet Cherry Cultivars. *Agronomy* 11-1947. <https://doi.org/10.3390/agronomy11101947>.
30. Tomiyama, H., Y. Goto, P. Opio, T. Saito, K. Ohkawa, H. Ohara, S. Kondo. 2021. A combination of hot water and absciscic acid (ABA) biosynthesis inhibitor regulates ripening of Japanese apricot (*Prunus mume*) fruit. *Eur. J. Hortic. Sci.* 86(5):461–468. <https://doi.org/10.17660/eJHS.2021/86.5.2>.
31. Vargas A., I., A. Contreras V., M. Á. Martínez T. 2009. Lignans from *Larrea tridentata* (Creosote bush) as fungal  $\beta$ -1,3-glucanase inhibitors. *Pesticide Biochemistry and Physiology*. 94 (2–3): 60-63. <https://doi.org/10.1016/j.pestbp.2009.04.002>.
32. Wade, L. G. 2016. *Química orgánica*. 9 ed. Pearson. Madrid, Esp. 744 p.
33. Wang, X., Q. Li, J. Xie, M. Huang, J. Cai, Q. Zhou, T. Dai, D. Jiang. 2021. Absciscic acid and jasmonic acid are involved in drought priming-induced tolerance to drought in wheat. *The crop journal* 9:120-132.
34. Watanabe M., R. Goto, M. Murakami, S. Komori, A. Suzuki. 2021. Interaction Between Ethylene and Absciscic Acid and Maturation in Highbush Blueberry. *The Horticulture Journal* 90 (1): 14–22. <https://doi.org/10.2503/hortj.UTD-210>.
35. Watanabe, M., Toyomura, T., Ikegami, R., Suwaki, Y., Sada, M., Wake, H., Takashi Nishinaka, T., Hatipoglu, O. F., Takahashi, H., Nishibori, M.,

- Mori, S. 2022. Nordihydroguaiaretic acid inhibits glyoxalase I and causes the accumulation of methylglyoxal followed by cell-growth inhibition. *Molecular Biology Reports* 49:10499–10507. <https://doi.org/10.1007/s11033-022-07929-6>.
36. Wikeley, A. S., Przybylowski, J., Lozano-S., P., Caffio, M., James, T. D., Bull, S. D., a Fletcher P. F. and Frank Marken F. 2022. Polymer indicator displacement assay: electrochemical glucose monitoring based on boronic acid receptors and graphene foam competitively binding with poly-nordihydroguaiaretic acid. *The Royal Society of Chemistry. Analyst* 147:661–670.
37. Xu, J.; Liu, Y.; Ma, J.; Li, P.; Geng, Z.; Wang, D.; Zhang, M.; Xu, W. 2022. Recombinant Porcine 12-Lipoxygenase Catalytic Domain: Effect of Inhibitors, Selectivity of Substrates and Specificity of Oxidation Products of Linoleic Acid. *Foods* 11, 980. <https://doi.org/10.3390/foods11070980>.
38. Ye, Y., Jia, X., Xue, M., Gao, Y., Yue, H., Ma, F., Gong, X. 2022. MpSnRK2.10 confers salt stress tolerance in apple via the ABA signaling pathway. *Scientia Horticulturae* 298- 110998. <https://doi.org/10.1016/j.scienta.2022.110998>.
39. Yu, J., Zhu, M., Wang, M., Tang, W., Wu, S., Zhang, K., Yang, G. 2020. Effect of nordihydroguaiaretic acid on grape berry cracking. *Scientia Horticulturae* 261-108979. <https://doi.org/10.1016/j.scienta.2019.108979>.
40. Zelaya M., L. X., Chávez D., I, F., De los Santos V., S., Cruz C., C. I., Ruíz R., S. y Rojas A., E. 2022. Control biológico de plagas en la agricultura mexicana. *Revista Mexicana de Ciencias Agrícolas, Pub. Esp.* 27:69-79.
41. Zhang, Z., C. Kang, S. Zhang, X. Li. 2019. Transcript analyses reveal a comprehensive role of abscisic acid in modulating fruit ripening in Chinese jujube. *BMC Plant Biology* 19:189. <https://doi.org/10.1186/s12870-019-1802-2>.
42. Zhu M., Z. Liu, Y. Zeng, J. Yu. 2022. Nordihydroguaiaretic acid reduces postharvest berry abscission in grapes. *Postharvest Biology and Technology* 183-111748. <https://doi.org/10.1016/j.postharvbio.2021.111748>.