Magnetite Nanoparticles as Biostimulant Agents in Grapevines Lead to Differential Physiological and Structural Responses to Foliar and Root Applications

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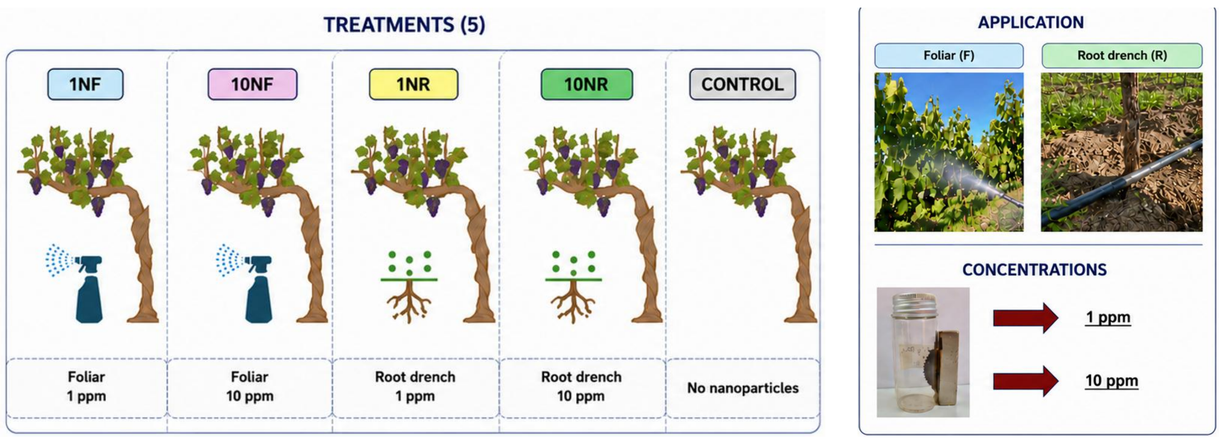
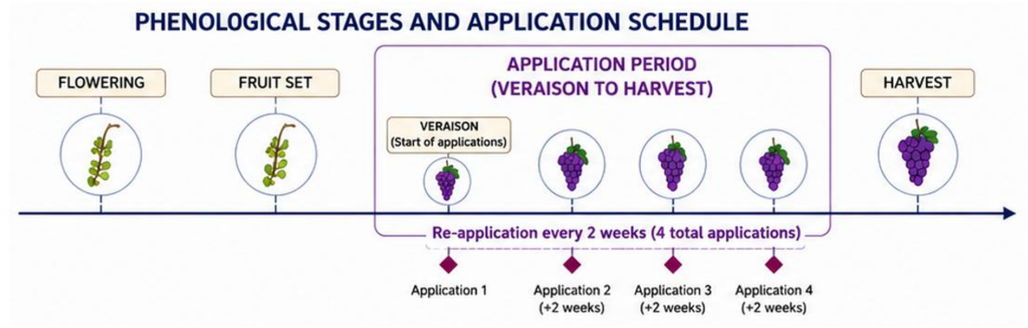
Introduction

Nanomaterials are emerging as tools to improve crop performance under adverse environments. Magnetite (Fe_3O_4) nanoparticles (NPs) combine a high surface area and superparamagnetism with iron bioavailability, and may act either as biostimulants or as stress elicitors depending on dose and delivery route.

Grapevines in the Atacama Desert face intense radiation, hyper-aridity and saline soils, which challenge berry metabolism. Here, we evaluated how application route (foliar vs. root) and concentration (1 vs. 10 ppm) of Fe_3O_4 NPs modulate leaf chlorophyll, yield components and the berry phenolic profile of *Vitis vinifera* cv. Gros Colman under field conditions.

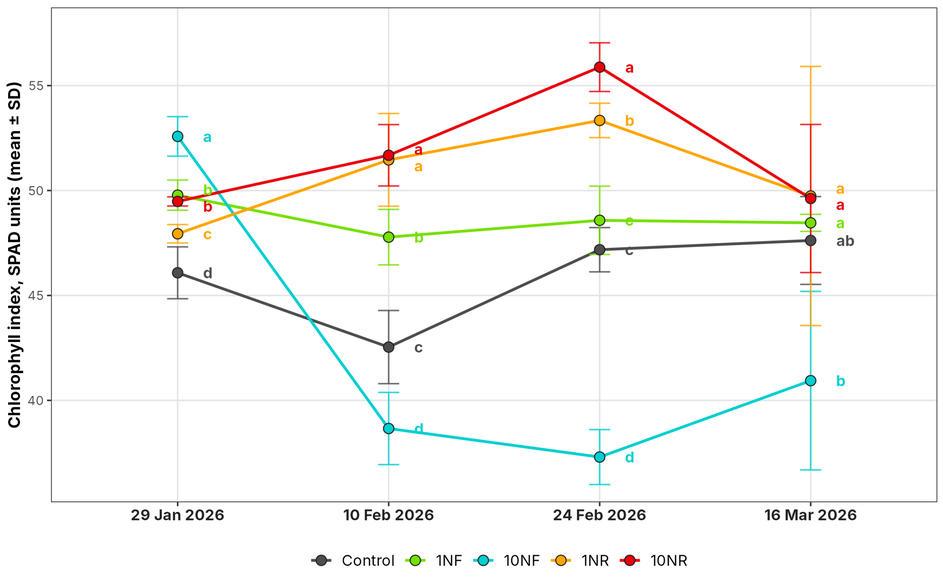
Methodology





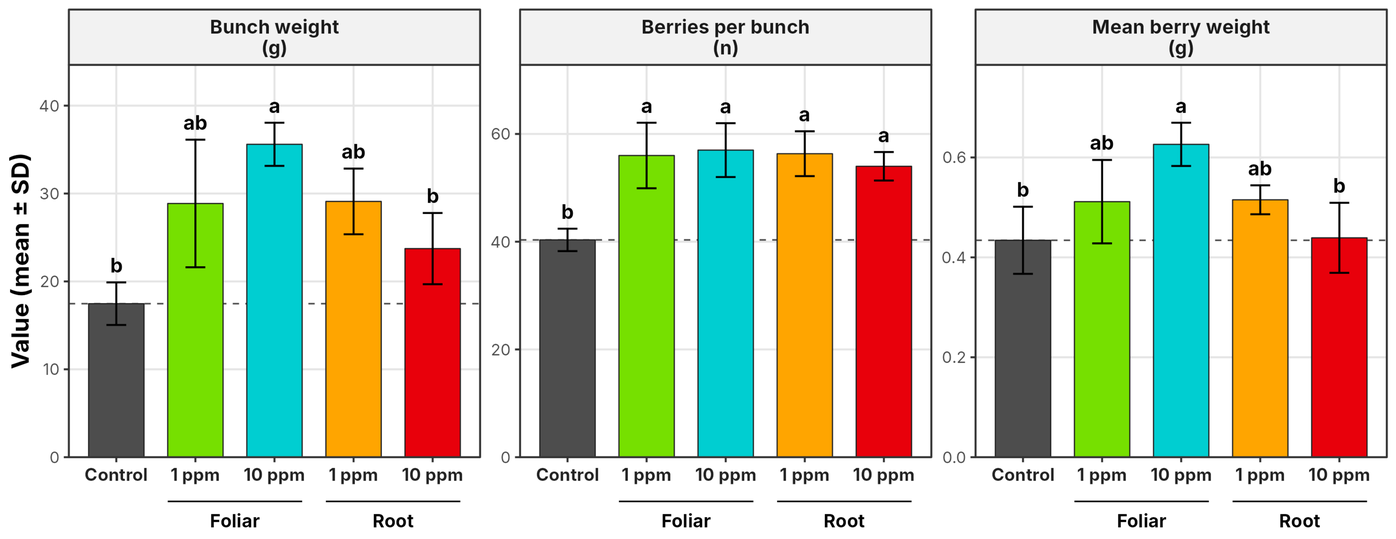
Study site: Canchones Experimental Station (UNAP), Atacama Desert; cv. Gros Colman.
Measured: SPAD (n = 5), yield components (n = 3) and berry phenolics by HPLC (n = 3).
Statistics: one-way ANOVA + Tukey HSD; Dose × Route two-way ANOVA; Dunnett vs. control.

Results



Letters: one-way ANOVA + Tukey HSD within each date (P < 0.05); same letter = not different. n = 5 plants per treatment.

Fig. 1. Leaf chlorophyll (SPAD) over time. Root applications (1NR, 10NR) sustained the highest SPAD values, whereas foliar 10 ppm (10NF) fell ~20% below control from the second application onward, coinciding with visible leaf stress.



Letters: one-way ANOVA + Tukey HSD across the five groups, Control included (P < 0.05). Dashed line = Control mean.
Dose × Route factorial ANOVA (NP treatments only, Control excluded) is given in the accompanying table.

Fig. 2. Yield components at harvest. All NP treatments increased berries per bunch (+34–41%). 10NF doubled bunch weight (35.6 vs. 17.5 g) and showed the highest berry weight.

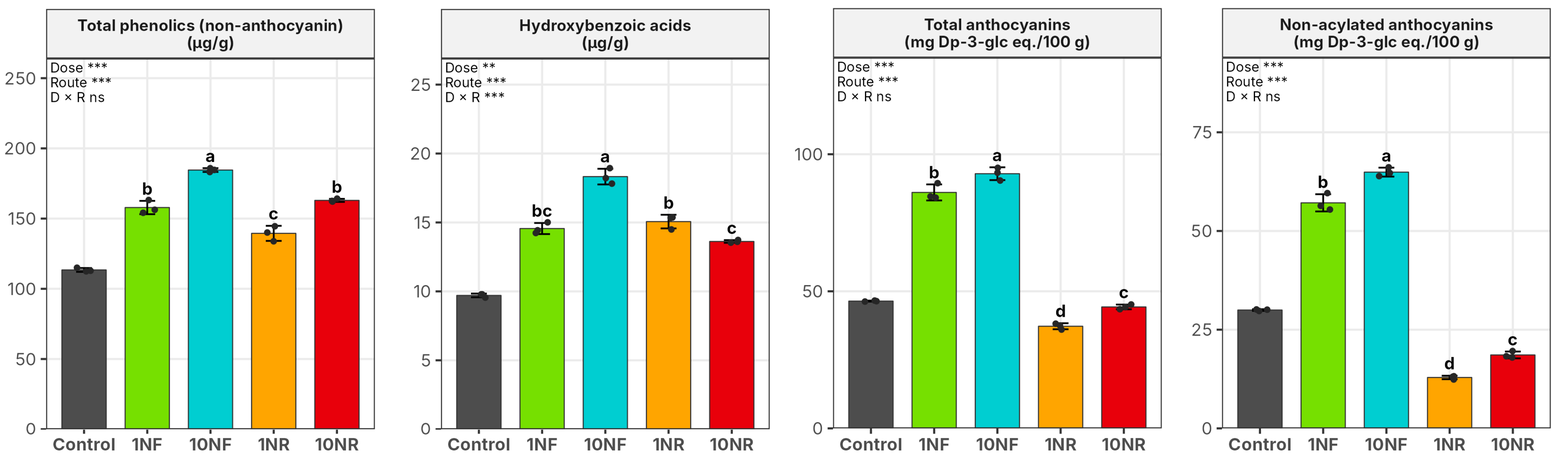
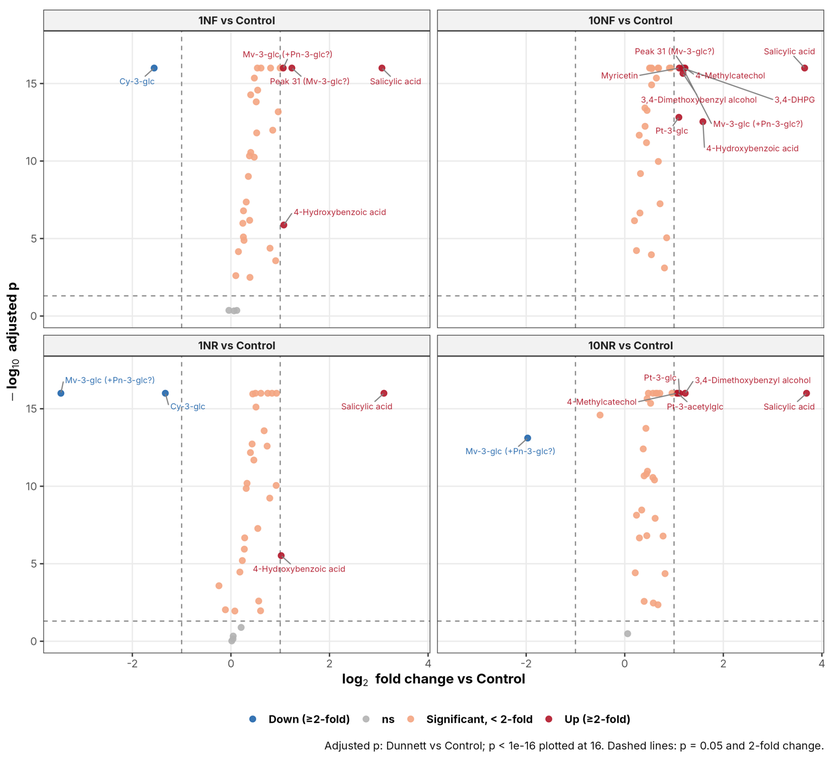


Fig. 3. Berry phenolics and anthocyanins (HPLC). Fe_3O_4 NPs increased non-anthocyanin phenolics, with 10NF reaching the highest totals (+63% vs. control) and hydroxybenzoic acids. Anthocyanins were route-dependent: foliar application doubled them, whereas root drench reduced them, mainly through non-acylated forms (Route ***).



Adjusted p: Dunnett vs Control; p < 1e-16 plotted at 16. Dashed lines: p = 0.05 and 2-fold change.

Fig. 4. Key compounds vs. control. Salicylic acid was the most induced compound in every treatment (8–12-fold); malvidin-3-glucoside decreased strongly under root application.

Conclusions

- Fe_3O_4 NP effects were strongly route-dependent: root drench enhanced leaf chlorophyll without visible stress, whereas foliar 10 ppm induced leaf stress and lowered SPAD.
- Despite leaf stress, foliar 10 ppm gave the highest bunch weight and phenolic accumulation, and doubled berry anthocyanins.
- Strong induction of salicylic acid in all treatments points to activation of stress signalling and defence-related secondary metabolism.
- Magnetite NPs act as biostimulants or stress elicitors depending on application strategy, opening options for precision viticulture in arid regions.

Acknowledgments

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