biology and life sciences forum

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Proceeding Paper

Mineral Interaction in Biofortified Tomatoes (*Lycopersicum esculentum* L.) with Magnesium †

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† Presented at the 1st International Electronic Conference on Horticulturae, 16–30 Apr 2022; Available online: https://iecho2022.sciforum.net/.

Citation: Coelho, A.R.F.; Luís, I.C.; Marques, A.C.; Pessoa, C.C.; Daccak, D.; Silva, M.M.; Simões, M.; Reboredo, F.H.; Pessoa, M.F.; Legoinha, P.; et al. Mineral Interaction in Biofortified Tomatoes (*Lycopersicum esculentum* L.) with Magnesium. *Biol. Life Sci. Forum* **2022**, *2*, x. https://doi.org/10.3390/xxxxx

Academic Editor(s):

Published: 12 April 2022

Abstract: Magnesium is considered an essential nutrient for humans, where about 60 % of Mg plays an important role in skeletal development. However, its deficiency can trigger several health pathologies (namely, asthma, Alzheimer's disease, hypertension, type-2 diabetes). In plants, Mg is especially important, being involved in protein synthesis and correlated with chlorophyll pigments. Its deficiency can compromise photosynthesis and can also lead to shorter roots and necrotic zones in leaves. Mineral deficiency (namely, Mg) in plants can lead to a global problem considering the increase of human population and the needs to produce more food and that nutritionally meet human needs, being necessary adopt new technology and approaches. In this context, this study aimed to understand the mineral interactions with Mg biofortification in *Lycopersicum esculentum* (H1534 variety). Biofortification was promoted during the life cycle of the culture throughout six leaf applications with four concentrations (4%, 8%, 12%, and 16%) of MgSO4, equivalent to 702, 1404, 2106 and, 2808 g ha^{-1}. At harvest, 4% $MgSO_4$ treatment showed the highest content of Mg and P, and the lowest content of Fe and Zn. Additionally, the highest treatment showed the lowest content of Mg and on the other hand, the highest content of Fe. In conclusion, despite the synergistic and antagonistic relationships between minerals in the different concentrations of Mg applied, there were no significant changes in total soluble solids content in the fruits.

Keywords: biofortification; H1534 variety; *Lycopersicum esculentum* L.; mineral interaction; natural enrichment with magnesium.

1. Introduction

Magnesium is considered an essential nutrient for humans and the fourth most abundant in the body [1] and thus an adequate supply of Mg is important to maintain health

[2]. About 60% of Mg is in humans bones and plays an important role in skeletal development [3]. Nevertheless, Mg deficiency can trigger several health pathologies namely, asthma, Alzheimer's disease, hypertension, cardiovascular disease, osteoporosis, and type-2 diabetes mellitus [1,4]. In plants, Mg also plays important roles, namely in structural and regulatory functions [5]. In fact, Mg has diverse functions and is especially important, being involved in protein synthesis, correlated with chlorophyll pigments [3], is a key element in photosynthesis and is deeply involved in the phloem loading of sucrose [5]. Its deficiency can compromise plant growth, photosynthesis, crop productivity, can also lead to shorter roots, and to necrotic zones in leaves [3,5]. Additionally, Mg deficiency in fields can be due to is ionic antagonism with competing cations (H^+, Al^{3+}, Ca^{2+}, K^+ and Na^+) that strongly inhibit Mg^{2+} root uptake [5]. Magnesium is considered a phloem mobile element and is rapidly translocated within the plant to the growing parts, that's why the first symptoms start to appear on older leaves [6]. Mineral deficiency in plants begins to be a global problem considering the increase of human population and the urge to meet the future worldwide food and nutrient needs [7]. Additionally, with the growth and development of food industry and agriculture, the ability to produce safe and nutritious food in the future is largely dependent on new technologies and approaches [7]. As such, considering that nutrients are mainly obtained through plants in human diet [8], agronomic biofortification can be a viable strategy to be implemented with the aim of increasing different mineral content in the edible part of plants, in particular through foliar fertilization/applications [9]. In this context, being tomato (*Lycopersicum esculentum*) one of the most popular and consumed horticultural crop globally and the need to improve mineral content in edible crops, this study aimed to understand the mineral interactions (synergistic and antagonistic relationships) in tomatoes of an industrial variety (H1534) biofortified with Mg.

2. Materials and Methods

2.1. Biofortification Intinearary

The experimental tomato-growing field, located in Beja (Alentejo region)—South of Portugal (GPS coordinates: 38°01′40″ N; 7°52′20″W) -, was used to growth H1534 variety (*Lycopersicum esculentum* L.). During the agricultural period, from 8 May 2019 (planting date) to 10 September 2019 (harvest date), air temperatures reached an average daily of 20.4 and 13.8 °C (with maximum and minimum values varying between 38.9 and 5.7 °C, respectively. Biofortification was promoted during the life cycle of the culture throughout six leaf applications with four concentrations (4%, 8%, 12%, and 16%) of $MgSO_4$, equivalent to 702, 1404, 2106 and, 2808 g ha^{-1}. The first foliar application was carried out on 12 July 2019 and the remaining five foliar applications were performed within 7 to 11 days interval. Four replicates per concentration were planted and control plants were not sprayed at any time with $MgSO_4$.

2.2. Mineral Content in Tomatoes

Mineral content was carried out after tomatoes (with similar size) being washed, dried at 60 °C until constant weight and grounded in an agate mortar. After that, the homogenate was divided into four samples (n = 4) and an acid digestion procedure was performed with a mixture of HNO3- HClO4 (4:1) according to [10,11]. After filtration, mineral content of Mg, Ca, Fe, Zn, P, K and Cu was measured by atomic absorption spectrophotometry, using a model Perkin Elmer AAnalyst 200, and the absorbency was determined with a coupled AA WinLab software.

2.3. Total Soluble Solids

Total soluble solids content was measured in tomatoes juice, according to [12].

2.4. Statistical Analysis

Data were statistically analyzed using a One-Way ANOVA to assess differences among treatments in H1534 variety, followed by a Tukey's for mean comparison. A 95% confidence level was adopted for all tests.

3. Results

Mineral content of tomatoes at harvest was assessed in H1534 variety (Table 1). Magnesium, Ca, Zn and Cu did not vary significantly, unlike Fe, P and K which varied significantly. The treatment 4% $MgSO_4$ showed the highest content in Mg and P, and the lowest content of Fe and Zn. Control showed a higher content of Ca, Zn, K and Cu compared to the biofortified treatments. Calcium, P, K and Cu showed a lower content in 12% $MgSO_4$ treatment and 8% $MgSO_4$ treatment always presented intermediate values considering the mineral elements analyzed. Additionally, the highest treatment (16% $MgSO_4$) showed the lowest content of Mg and on the other hand, the highest content of Fe. Relatively to control, biofortified tomatoes with 4% and 8% $MgSO_4$ treatments showed an increase in Mg content of 3.5 and 2.6 fold, respectively. In addition, biofortified tomatoes with the 12% $MgSO_4$ treatment showed an increase of Mg content of 2.1%.

Table 1. Mean values ± S.E. (n = 4) of Mg, Ca, Fe and Zn in tomatoes of *Lycopersicum esculentum* (H1534 variety), at harvest. Letters a,b, and c indicate significant differences, between treatments (statistical analysis using the single factor ANOVA test, $p \leq 0.05$). Foliar spray was carried out with four concentrations (4%, 8%, 12%, and 16% of $MgSO_4$). Control was not sprayed at any time.

Treatments	**Mg**	**Ca**	**Fe**	**Zn**	**P**	**K**	**Cu**
	mg/100 g						
Control	53.97a ± 1.08	31.48a ± 0.16	6.36b ± 0.13	1.86a ± 0.47	283abc ± 9	4616a ± 44	1.68a ± 0.24
4% $MgSO_4$	190a ± 91	30.93a ± 6.39	5.13b ± 0.30	0.73a ± 0.16	315a ± 10	3509b ± 89	1.13a ± 0.02
8% $MgSO_4$	143a ± 35	31.20a ± 0.29	6.12b ± 0.86	1.75a ± 0.41	270bc ± 12	3735b ± 67	1.54a ± 0.23
12% $MgSO_4$	55.11a ± 7.43	18.78a ± 0.91	6.41b ± 1.05	1.05a ± 0.41	254c ± 1	3410b ± 116	1.08a ± 0.21
16% $MgSO_4$	49.48a ± 2.50	19.16a ± 2.36	10.25a ± 0.91	1.37a ± 0.20	297ab ± 8	3558b ± 155	1.42a ± 0.04

Total soluble solids did not vary significantly (Figure 1), yet control showed the lowest content and 8% $MgSO_4$ treatment showed the highest content compared to the remaining treatments.

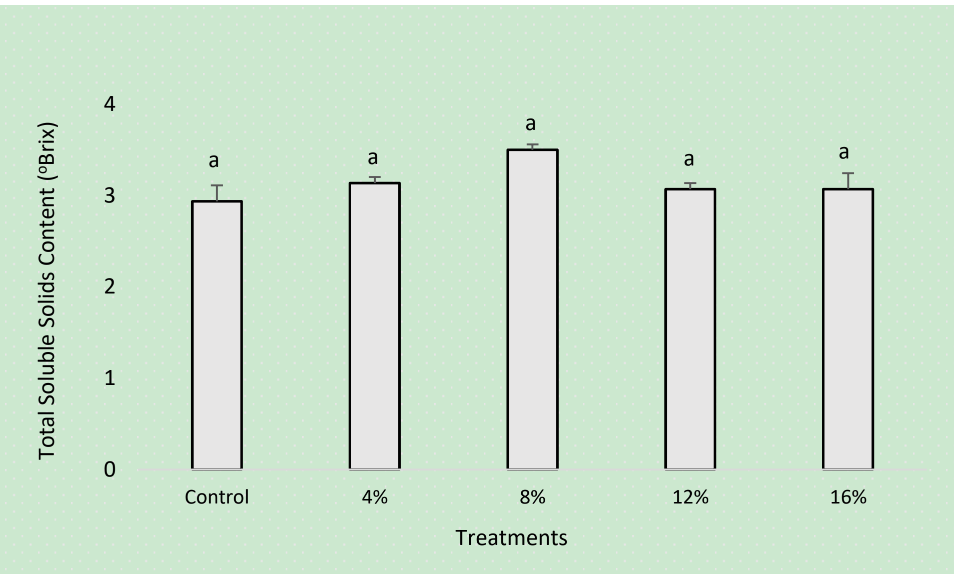

Figure 1. Mean values ± S.E. (n = 4) of total soluble solids (ºBrix) in tomatoes of *Lycopersicum esculentum* (H1534 variety), at harvest. Letter a indicate no significant differences between treatments

(statistical analysis using the single factor ANOVA test, $p \leq 0.05$). Foliar spray was carried out with four concentrations (4%, 8%, 12%, and 16% of $MgSO_4$). Control was not sprayed at any time.

4. Discussion

Mineral interactions have been proven to be important, mainly regarding indicating deficiencies and toxicity in plants [13]. As such, mineral content of Mg, Ca, Fe, Zn, P, K, and Cu was assessed in tomatoes at harvest (Table 1). These mineral elements analyzed are considered essential elements for plant growth and development, being supplied by soil or fertilizers [14]. Tomatoes biofortified with $MgSO_4$ showed higher content of Mg (except in 6% $MgSO_4$ treatment) regarding control, indicating that biofortification occurred and had a better index with the lower concentration applied (4% of $MgSO_4$). Preciously, in another study carried out with the same variety showed also with 4% of $MgSO_4$ treatment the highest Mg content [15]. Nevertheless, the higher content of Mg in 4% $MgSO_4$ treatment showed a lower Fe content, presenting a tendency of antagonism in the biofortified tomatoes considering that as the Mg content increased, Fe content decreased. In fact, this antagonistic relationship between Fe and Mg was already verified in growth and metabolism of another horticultural crop [16]. This type of interaction between ions whose have similar chemical properties (in this case—similar size and charge) can lead to competition in the site of absorption, transport and even function within plant tissues [17]. Additionally, 16% $MgSO_4$ treatment showed less content of Mg probably because plants submitted to that concentration started to show signs of toxicity in leaves after six foliar applications. Nevertheless, 4% $MgSO_4$ treatment that showed the higher Mg content, also showed the highest P content regarding the remain treatments. A previously study carried out by [18] showed evidence of a synergistic mechanism of Mg and P, however in our study there isn't a clear tendency of that mechanism. Yet, regarding Mg, Ca, and K, there is no tendency of antagonistic interactions, previously reported by [19] and by [20] (regarding the antagonistic effect of K on Mg content). However, considering a study carried out by [21], states that the relationship between Mg and K in plant tissues can be antagonistic or synergistic depending, namely, on plant species. Also reported that antagonistic relationship of K on Mg is much stronger than Mg on K in both root absorption and in transport within plants, and probably because of that, there is no tendency of antagonistic effect of Mg on K in our study. In addition, K and Cu showed at the same treatments the highest (in control) and lowest content (12% $MgSO_4$ treatment), also showing lower contents in biofortified treatments. This effect was previously reported by [20], higher K content have resulted in the increased of Cu. Additionally, K and Zn also have a synergetic effect [20], however our data did not show a clear tendency of that relationship between both mineral elements.

Regarding total soluble solids is considered one of the most relevant parameters in tomatoes [22], being flavors influenced by this content [23]. As such, our data showed values higher values in the biofortified treatment and lower values considering the catalog of the variety [24]. Yet, differences in total soluble solids can be due to environmental factors [25].

5. Conclusions

At harvest tomato (*Lycopersicum esculentum*) of H1534 variety submitted to a biofortification itinerary with Mg trough foliar spraying, showed a higher content in 4% of $MgSO_4$ treatment. Additionally, was possible to identify an antagonistic effect with Mg and Fe and a tendency of a synergetic relationship with K and Cu. In conclusion, despite the synergistic, antagonistic and no clear tendency of relationships between the minerals analyzed, there were no significant changes in the total soluble solids content in tomatoes, showing in fact, a no significant increase in biofortified tomatoes with $MgSO_4$.

Supplementary Materials: Not applicable.

Author Contributions: Conceptualization, A.R.F.C. and F.C.L.; methodology, F.C.L.; software, A.R.F.C.; formal analysis, A.R.F.C., I.C.L., A.C.M., C.C.P, D.D. and C.G.; investigation, A.R.F.C., D.D., I.C.L., A.C.M. and C.C.P.; resources, M.M.S., M.S., F.H.R., M.F.P., P.L., C.G., M.R., J.R., J.D., N.B., I.G., J.C.R., P.S.C., I.P.P. and J.N.S.; writing—original draft preparation, A.R.F.C.; writing—review and editing, F.C.L.; supervision, F.C.L.; project administration, F.C.L.; funding acquisition, F.C.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by PDR2020, grant number 101-030701.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors thanks to Mariana Regato, José Regato, João Dias, Nuno Beja and Idália Guerreiro for technical assistance in the agricultural parcel as well as to the project PDR2020-101-030701 for financial support. We also thanks to the research centers (GeoBioTec) UIDB/04035/2020, and (CEF) UIDB/00239/2020.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. Gröber, U.; Schmidt, J.; Kisters, K. Magnesium in Prevention and Therapy. *Nutrients* **2015**, *7*, 8199–8226. https://doi.org/10.3390/nu7095388.
2. Schonewille, J.T. Magnesium in dairy cow nutrition: An overview. *Plant Soil.* **2013**, *368*, 167–178. https://doi.org/10.1007/s11104-013-1665-5.
3. Guo, W.; Nazim, H.; Liang, Z.; Yang, D. Magnesium deficiency in plants: An urgent problem. *Crop. J.* **2016**, *4*, 83–91. https://doi.org/10.1016/j.cj.2015.11.00.
4. Song, Y.; Ridker, P.M.; Manson, J.E.; Cook, N.R.; Buring, J.E.; Liu, S. Magnesium intake, C-reactive protein, and the prevalence of metabolic syndrome in middle-aged and older U.S. Women. *Diabetes Care* **2005**, *28*, 1438–1444. https://doi.org/10.2337/diacare.28.6.1438.
5. Ceylan, Y.; Kutman, U.B.; Mengutay, M.; Cakmack, I. Magnesium applications to growth medium and foliage the starch distribution, increase the grain size and improve the seed germination in wheat. *Plant Soil* **2016**, *406*, 145–156. https://doi.org/10.1007/s11104-016-2871-8.
6. Gransee, A.; Führs, H. Magnesium mobility in soils as a challenge for soil and plant analysis, magnesium fertilization and root uptake under adverse growth conditions. *Plant Soil* **2013**, *368*, 5–21. https://doi.org/10.1007/s11104-012-1567-y.
7. Clugston, G.A.; Smith, T.E. Global nutrition problems and novel foods. *Asia Pac. J. Clin. Nutr.* **2002**, *11*, S100–S111. https://doi.org/10.1046/j.1440-6047.11.s6.1.x.
8. Díaz-Gómez, J.; Twyman, R.M.; Zhu, C.; Farré, G.; Serrano, J.C.; Portero-Otin, M.; Muñoz, P.; Sandmann, G.; Capell, T.; Christou, P. Biofortification of crops with nutrients: Factors affecting utilization and storage. *COBIOT* **2017**, *44*, 115–123. https://doi.org/10.1016/j.copbio.2016.12.002.
9. Alshaal, T.; El-Ramady, H. Foliar application: From plant nutrition to biofortification. *EBSS* **2017**, *1*, 71–83. https://doi.org/10.21608/JENVBS.2017.1089.1006.
10. Carrondo, M.; Reboredo, F.; Ganho, R.; Santos Oliveira, J.F. Heavy metal analysis of sediments in Tejo estuary, Portugal, using a rapid flameless atomic absorption procedure. *Talanta* **1984**, *31*, 561–564.
11. Reboredo, F.H.S.; Ribeiro, C.A.G. Vertical distribution of Al, Cu, Fe and Zn in soil salt marshes of the Sado estuary, Portugal. *Int. J. Environ. Stud.* **1984**, *23*, 249–253.
12. Coelho, A.R.F.; Lidon, F.C.; Pessoa, C.C.; Marques, A.C.; Luís, I.C.; Caleiro, J.; Simões, M.; Kullberg, J.; Legoinha, P.; Brito, M.; et al. Can Foliar Pulverization with $CaCl_2$ and $Ca(NO_3)_2$ Trigger Ca Enrichment in *Solanum tuberosum* L. Tubers? *Plants* **2021**, *10*, 245. https://doi.org/10.3390/plants10020245.
13. Hermans, C.; Chen, J.; Coppens, F.; Inzé, D.; Verbruggen, N. Low magnesium status in plants enhances tolerance to cadmium exposure. *New Phytol.* **2011**, *192*, 428–436. https://doi.org/10.1111/j.1469-8137.2011.03814.x.
14. Uchida, R. Essential nutrients for plant growth: Nutrient functions and deficiency symptoms. *Plant Nutr. Manag. Hawaii's Soils* **2000**, *4*, 31–55.
15. Coelho, A.; Pessoa, C.; Marques, A.; Luís, I.; Daccak, D.; Silva, M.M.; Simões, M.; Reboredo, F.; Pessoa, M.; Legoinha, P.; et al. Nutrient Interactions in Natural Fortification of Tomato with Mg: An Analytical Perspective. In Proceedings of the 1st International Electronic Conference on Plant Science, 2020; Volume 1, p. 15. 10.3390/IECPS2020-08724.
16. Agarwala, S.C.; Mehrotra, S.C. Iron-magnesium antagonism in growth and metabolism of radish. *Plant Soil* **1984**, *80*, 355–361. https://doi.org/10.1007/bf02140042.

17. Fageria, N.K. Influence of micronutrients on dry matter yield and interaction with other nutrients in annual crops. *Pesqui. Agropecu. Bras* **2002**, *37*, 1765–1772. https://doi.org/10.1590/S0100-204X2002001200013.
18. Weih, M.; Liu, H.; Colombi, T.; Keller, T.; Jack, O.; Vallenback, P.; Westerbergh, A. Evidence for magnesium–phosphorus synergism and co-limitation of grain yield in wheat agriculture. *Sci. Rep.* **2021**, *11*, 9012. https://doi.org/10.1038/s41598-021-88588-8.
19. Kleiber, T.; Golcz, A.; Krzesinski, W. Effect of magnesium nutrition on onion (*Allium cepa* L.). Part I. *Yielding and nutrient status. Ecol. Chem. Eng.* **2012**, *19*, 97–105. https://doi.org/10.2478/v10216-011-0010-2.
20. Armstrong, D.L.; Griffin, K.P.; Danner, M. Better Crops with Plant Food. Vol. LXXXII (82) 1998, No. 3. Available online: http://www.ipni.net/publication/bettercrops.nsf/0/E90E04A957EA624285257980007CD63C/$FILE/BC-1998-3.pdf (accessed on).
21. Xie, K.; Cakmak, I.; Wang, S.; Zhang, F.; Guo, S. Synergistic and antagonistic interactions between potassium and magnesium in higher plants. *Crop J.* **2021**, *9*, 249–256.
22. Jarquín-Enríquez, L.; Mercado-Silva, E.M.; Maldonado, J.L.; Lopez-Baltazar, J. Lycopene content and color index of tomatoes are affected by the greenhouse cover. *Sci. Hortic. Amst.* **2013**, *155*, 43–48. https://doi.org/10.1016/j.scienta.2013.03.004.
23. Cebrino, F.G.; Ruiz, M.L.; Yuste, M.C.A.; García, M.J.B.; Gómez, D.G. Characterization of traditional tomato varieties grown in organic conditions. *Span J. Agric. Res.* **2011**, *2*, 444–452.
24. Heinz Company. 2016. Available online: https://www.heinzseed.com/hs_about (accessed on 17 December 2021).
25. Helyes, L.; Pék, Z.; Lugasi, A. Function of the variety technological traits and growing conditions on fruit components of tomato (*Lycopersicon lycopersicum* L. Karsten). *Acta Aliment. Hung.* **2008**, *37*, 427–436. https://doi.org/10.1556/aalim.2008.0010.