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Proceeding Paper

Nutrient Interactions in the Natural Fortification of Tomato with Mg: An Analytical Perspective †

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Abstract: In the human body, about 53% of Mg is involved in the development and maintenance of bone and other calcified tissues, although it also has a physiological role in protein synthesis, muscle and nerve functions, blood glucose control and blood pressure regulation. Nevertheless, Mg deficiency triggers electrolyte disturbance that can result in multiple symptoms, namely, tremors, poor coordination, muscle spasms, loss of appetite, personality changes, and nystagmus. Complications may include seizures or cardiac arrest. To surpass Mg deficiency, biofortification is a strategy that can boost nutrient enhancement in food crops and can increase nutrient uptake and accumulation in the human body. Accordingly, this study aimed to develop a technical itinerary for Mg biofortification in *Lycopersicum esculentum* variety H1534. Tomato biofortification was promoted during the respective life cycles throughout six leaf applications with two different treatments (4% and 8%) of $MgSO_4$, equivalent to 702 and 1404 g ha^{-1}. At harvest, the biofortification indexes of Mg were 2.01- and 1.71-fold higher (after spraying with 4% and 8% $MgSO_4$, respectively), with synergistic trends found only with Zn and Fe, whereas P did not vary significantly among treatments. Among treatments, relevant deviations could not be found for total soluble solids, height, diameter and color; however, minor changes in dry weight were detected. It can be concluded that the Mg biofortification of tomato variety H1534 can be performed to add nutritional value to tomato-based processed food products.

Keywords: *Lycopersicum esculentum*; Mg biofortification; nutrient interactions

1. Introduction

In the human body, Mg prevails in bones (53%), followed by muscles (27%), soft tissues (19%) and serum (1%) [1–3]. It plays a major physiological role, as a co-factor, in approximately 300 enzymatic systems (namely, in protein and nucleic acid synthesis, energy production, blood pressure or glycemic control) [1,3]. However, low levels of this mineral can be linked, among other pathologies, to the development of mental or physical pathologies, such as asthma, Alzheimer's disease, hypertension, cardiovascular diseases, type-2 diabetes and osteoporosis [2]. Taking into consideration the age, sex, or specific situations such as pregnancy or lactation, daily reference intakes of Mg can vary from 30 to 420 mg in order to avoid malnutrition [1,3,4]. However, although in foods, green vegetables (such as spinach), legumes, seeds and cereals are sources of Mg, grain refinement is an example of a food processing technique which can lower its content [1,2]. In this context, because edible agricultural crops are the main source of this mineral for humans [5], biofortification can be used as a strategy to enhance their Mg contents.

Agronomic biofortification focuses on the increase in a target mineral in the edible part of crops, using soil fertilizers or foliar sprays [6]. Although regular applications are needed, compared to breeding or genetic programs, it can be moderately inexpensive, and organic mineral forms are more easily absorbed and less excreted by the organism [6,7]. In plants, Mg is a mobile mineral (mainly in the phloem), involved in photoassimilate synthesis (essential to photosynthesis) and carbohydrate transport from source to sink organs [4,8]. Its deficits in plants can thus compromise photosynthetic activity, plant growth and crop productivity [4,5].

The use of fertilizers containing Mg resulted in increases in yield of about 8.5% over different crop productions and soil conditions [5]. An enhancement in the quality and yield of the hybrid tomato Arka Ananya was also reported after soil applications of $MgSO_4$ [9]. However, in soils, Mg can be prone to leaching, although slow-release Mg fertilizers minimize this risk [8]. In grapevines, foliar applications of $MgSO_4$ (3.86 kg $Mg \cdot ha^{-1}$) or a combination of $MgSO_4$ + K_2SO_4 (1.93 kg $Mg \cdot ha^{-1}$ + 6.22 kg $K \cdot ha^{-1}$) resulted in average yield increases over 3 years of 11.2% and 6.6%, respectively [10]. In faba beans subjected to a suboptimal Mg supply, sprayings with $MgSO_4$ (50 or 200 mM), resulted in yield increases for the highest concentration [11]. Additionally, during tomato growth, through foliar application with $MgSO_4$ (2.6 $g \cdot L^{-1}$), Mg deficiency can be reduced [12].

The worldwide production of tomato has been growing, having reached about 182,256,458 tonnes in 2018. The main producers were China, India, the United States of America and Turkey (with over 12,150,000 tonnes), making Asia the world's main producer, followed by the Americas (14.3%) and Europe (12.8%) [13]. In Portugal, over 90% of the total tomato produced in 2018 was destined for industrial use [14]. In this context, selection and enhancement practices benefit tomato cultivars meant for industrial processing [15], and pulp color and soluble solids are taken into consideration besides others factors such as yield or disease resistance, to ensure the production and quality of concentrated tomato pulp and other tomato-based products for consumers [16].

Considering the impact of tomato (*Lycopersicum esculentum*) in the agroindustrial sector and its consumption worldwide, this study focused on assessing mineral contents in the hybrid tomato variety Heinz1534 (H1534) after agronomic biofortification with Mg, also monitoring some quality parameters.

2. Experiments

The experimental tomato-growing field, in a plot of 10 × 75 m, was located in the center-south of Portugal (37°56′55,360″ N; 8°10′26,092″ W). The industrial variety Heinz1534 (H1534) of tomato (*Lycopersicum esculentum)* was selected for natural Mg enrichment. During the agricultural period, from 30 April (planting date) to 28 August 2019 (harvest date), air temperatures reached a daily average of 20.4/13.8 °C (with maximum and minimum values varying between 5.7 and 38.9 °C). The average precipitation during the life cycle was 0.80 mm. In addition to the control, foliar application was carried out with two concentrations (4% and 8%) of $MgSO_4$, equivalent to 702 and 1404 g ha^{-1}.The first foliar application was carried out on 24th June, and the remaining five applications were performed within 7-day intervals. Four replicates per concentration were planted. Control plants were not sprayed at any time with $MgSO_4$.

At harvest, Mg, Zn, Fe, Ca, P and K contents were determined in randomized tomatoes, in an acid digestion procedure with a mixture of HNO_3–HCl (4:1), according to [17,18], after being cut and dried at 60 °C until constant weight. After filtration, Mg content was quantified by atomic absorption spectrophotometry, using a model *Perkin Elmer AAnalyst 200*, and the absorbency was determined with coupled *AA WinLab software.*

Height, diameter and dry weight were measure in four randomized tomatoes per treatment. Total soluble solids were also measured in the juice of four randomized tomatoes per treatment, using a digital refractometer Atago (Atago, Tokyo, Japan). Colorimetric parameters were determined in four fresh tomatoes per treatment with a scanning spectrophotometric colorimeter (Agrosta, European Union). The sensor provided a 40 nm full width at half-maximum detection, covering the visible region of the electromagnetic spectrum. This sensor had 6 phototransistors with sensibility in a specific region of the spectrum (380 nm—violet; 450 nm—blue; 500 nm—green; 570 nm—yellow; 600 nm—orange; 670 nm—red). Light was provided by a white LED covering the whole visible region.

3. Results

Mineral contents of tomatoes were assessed in the H1534 variety, after harvest (Table 1). Relative to the control, treated tomatoes with 4% and 8% of $MgSO_4$ showed increasing contents of Mg (2.01- and 1.71-fold), Zn (1.80- and 1.34-fold) and Fe (1.20- and 1.18-fold), whereas Ca and K were present in significantly lower values with 4% $MgSO_4$. Moreover, P did not vary significantly among treatments.

Table 1. Mean values ± S.E. (n = 4) of Mg, Zn, Fe, Ca, P and K in *Lycopersicum esculentum* tomatoes, variety H1534, at harvest. Different letters (a, b) indicate significant differences, of each parameter, between treatments ($p \leq 0.05$).

Treatments	**Mg**	**Zn**	**Fe**	**Ca**	**P**	**K**
	mg/100 g					
Control	58.0 b ± 5.8	1.43 b ± 0.11	14.9 b ± 0.3	36.6 a,b ± 1.2	263 a ± 1.5	2788 a ± 94
4% $MgSO_4$	116.3 a ± 14.7	2.57 a ± 0.08	17.8 a ± 0.3	31.8 b ± 1.0	257 a ± 5.8	2300 b ± 49
8% $MgSO_4$	99.2 ab ± 7.7	1.91 ab ± 0.25	17.6 a ± 0.0	38.5 a ± 1.9	256 a ± 1.7	2673 a ± 64

Total soluble solids, height and diameter did not vary significantly (Table 2), ranging from 4.2 to 5.0°Brix, 52.3 to 52.7 mm and 43.3 to 47.7 mm, respectively. Regarding dry weight, foliar spraying with 4% of $MgSO_4$ showed a significantly lower value, relatively to the other treatments (Table 2).

Table 2. Mean values ± S.E. (n = 4) of dry weight, total soluble solids, height and diameter in *Lycopersicum esculentum* tomatoes, variety H1534, at harvest. Different letters (a, b) indicate significant differences, of each parameter, between treatments ($p \leq 0.05$).

Treatments	**Dry Weight (%)**	**Total Soluble Solids (°Brix)**	**Height (mm)**	**Diameter (mm)**
Control	7.1 a ± 0.2	4.2 a ± 0.0	52.7 a ± 1.3	47.7 a ± 2.2
4% $MgSO_4$	5.9 b ± 0.1	5.0 a ± 0.1	52.3 a ± 1.3	44.7 a ± 0.7
8% $MgSO_4$	6.8 a ± 0.2	4.7 a ± 0.6	52.7 a ± 1.5	43.3 a ± 1.7

At harvest, colorimetry analysis showed the highest value at 650 mm, which corresponded to the red color (Figure 1).

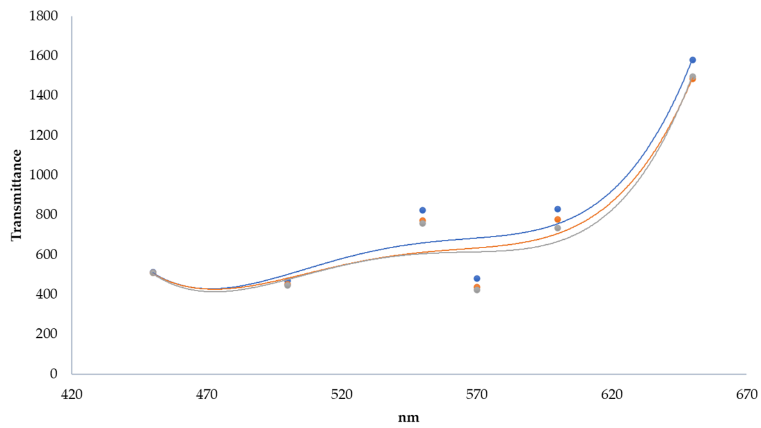

Figure 1. Visible spectra showing the average of transmittance (n = 4) in *Lycopersicum esculentum* tomatoes, H1534 variety, at harvest (● Control, ● 4% $MgSO_4$, ● 8% $MgSO_4$).

4. Discussion

The mineral contents in tomatoes have an important role in taste, quality, preservation and nutritional value [19]. The application of our Mg biofortification itinerary showed that the H1534 variety absorbed and stored Mg through foliar application. With the increase in Mg, Zn and Fe also increased significantly. However, to some extent, K levels decreased relatively to the control. This tendency could be related to the antagonistic relationship between K and Mg [20]. Regarding Ca, there was not a clear tendency with the increase in Mg content. In fact, the interactions of Ca and Mg are rare [21]. Furthermore, Mg biofortification showed no significant differences in P content.

Dry weight in H1534 showed a significantly lower value when a higher content of Mg (4% $MgSO_4$) prevailed. Considering that water is the major component of tomato (93.5 g/100 g of edible portion) [22], the range of our values followed this pattern. Furthermore, compared to other studies [23], the values obtained in dry weight were lower, for the same variety.

Regardless of Mg biofortification, H1534 showed a slightly higher height compared to the diameter, keeping their medium size (corresponding to 70–84 g) and shape classified as "blocky" [24]. However, color and total soluble solids presented themselves as the most relevant parameters in tomato [25]. In fact, tomato flavor is quite strongly influenced by the total soluble solids [26]. In this context, relative to the variety catalog (5.2–5.4%) [24], H1534 exhibited lower total soluble solids (Table 2), but there were no significant differences between the control and the other treatments. As such, these differences may be due to environmental factors [27].

Colorimetric analysis is considered the most important aspect regarding quality, influencing the acceptability of consumers [26]. In all Mg treatments, color analysis kept the highest transmittance at 650 mm, corresponding to the red color (Figure 1), which points the maintenance of a high lycopene content [25,26]. Indeed, because lycopene is a carotenoid, present in tomato and tomato-based products, namely, ketchup and pizza sauce [28], possessing strong antioxidant activity [29], in spite of Mg biofortification, the quality was preserved.

5. Conclusions

Through foliar spraying with $MgSO_4$, Mg contents increased in the tomato variety H1534, with the maximum content obtained at a spray concentration of 4%. Zinc and Fe showed a synergistic pattern of accumulation with Mg. Additionally, Mg biofortification did not show relevant changes in total soluble solids, height, diameter and color. However, minor changes in dry weight occurred in the treatment that showed the highest content of Mg. Accordingly, the agronomic biofortification of tomato variety H1534 can be applied to increase this nutrient in tomato-based processed food products.

Supplementary Materials: The poster presentation is available online at https://www.mdpi.com/article/10.3390/IECPS2020-08724/s1.

Author Contributions: F.C.L. conceived and designed the experiments; A.R.F.C., A.C.M., C.C.P., I.C.L. and D.D. performed the experiments; A.R.F.C. and F.C.L. analyzed the data; M.M.S., M.S., F.H.R., M.F.P., P.L., C.G., J.C.R., P.S.C., I.P.P. and F.C.L. contributed the reagents/materials/analysis tools; A.R.F.C. and F.C.L. wrote the paper. All authors have read and agreed to the published version of the manuscript.

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