Proceedings

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

Ana Coelho [1,2,*], Cláudia Pessoa [1,2], Ana Marques [1,2], Inês Luís [1,2], Diana Daccak [1,2], Maria Manuela Silva [2,3], Manuela Simões [1,2], Fernando Reboredo [1,2], Maria Pessoa [1,2], Paulo Legoinha [1,2], Carlos Galhano [1,2], José Ramalho [2,4], Paula Scotti-Campos [2,5], Isabel Pais [2,5] and Fernando Lidon [1,2]

1 Earth Sciences Department, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal
2 GeoBioTec Research Center, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal
3 Escola Superior de Educação Almeida Garrett, Lisboa, Portugal
4 PlantStress & Biodiversity Lab, Centro de Estudos Florestais, Instituto Superior Agronomia, Universidade de Lisboa, Oeiras, Portugal
5 INIAV, Instituto Nacional de Investigação Agrária e Veterinária, Oeiras, Portugal
* Correspondence: arf.coelho@campus.fct.unl.pt; Tel.: +351-212-948-573

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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, but 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 tremor, 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 cycle 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 index of Mg was 2.01 and 1.71 fold (after spraying with 4% and 8% $MgSO_4$, respectively), being found a synergistic trends only with Zn e Fe, whereas P did not varied significantly among treatments. Among treatments, relevant deviations could not be found for total soluble solids, height, diameter and color, yet minor changes in dry weight were detected. It is concluded that Mg biofortification of tomato variety H1534 can be carried out 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 ca. 300 enzymatic systems (namely in protein and nucleic acid synthesis, energy production, blood pressure or glycemic control) [1,3]. Yet, 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 among 30–420 mg in order to avoid malnutrition [1,3]. Yet, although in foods, green vegetables (like spinach), legumes, seeds and cereals are sources of Mg, grain refinement is an example of food processing techniques that can lower its content [1,2]. In this context, since edible agricultural crops are the main source of this mineral for humans [5], biofortification can be used as a stategy to enhance its Mg contents.

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

Worldwide production of tomato has been growing, having reached about 182.256.458 tones in 2018. The main producers were China, India, United States of America and Turkey (with over 12.150.000 tonnes), making Asia the world's main producer, followed by Americas (14.3%) and Europe (12.8%) [13]. In Portugal, over 90% of total tomato produced in 2018 was destined for industrial use [14]. In this context, selection and enhancement practices have been benefiting tomato cultivars meant for industrial processement [15], and pulp color and soluble solids are taken into consideration besides others factors such as yield, or disease resistance to assure 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 minerals content in the hybrid tomato variety Heinz1534 (H1534) after agronomic biofortification with Mg, being also monitored 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″). The industrial variety Heinz1534 (H1534) of tomato (*Lycopersicum esculentum)*, was selected for natural Mg enrichment. During the agricultural period, from 30th April (planting date) to 28th August of 2019 (harvest date), air temperatures reached a daily average of 20.4/13.8 °C (with maximum and minimum values varying between 5.7/38.9 °C). The average precipitation during the life cycle was 0.80 mm. Besides 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 in 24th June and the remain five applications were performed within 7 days interval. 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 a coupled *AA WinLab software.*

Height, diameter and dry weight was measure in four randomized tomatoes per treatment. Total soluble solids was 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 provides a 40 nm full-width half-max detection, covering the visible region of the electromagnetic spectrum. This sensor has 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 furnished by a white LED covering all the visible region.

3. Results

Mineral content of tomatoes was assessed in H1534 variety, after harvest (Table 1). Relatively to the control, treated tomatoes with 4% and 8% of $MgSO_4$ showed an 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 significantly lower values with 4% $MgSO_4$. Moreover, P did not varied significantly among treatments.

Table 1. Mean values ± S.E. (*n* = 4) of Mg, Zn, Fe, Ca, P and K in tomatoes of *Lycopersicum esculentum*, 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/100g					
Control	58.0b ± 5.8	1.43b ± 0.11	14.9b ± 0.3	36.6a,b ± 1.2	263a ± 1.5	2788a ± 94
4% $MgSO_4$	116.3a ± 14.7	2.57a ± 0.08	17.8a ± 0.3	31.8b ± 1.0	257a ± 5.8	2300b ± 49
8% $MgSO_4$	99.2ab ± 7.7	1.91ab ± 0.25	17.6a ± 0.0	38.5a ± 1.9	256a ± 1.7	2673a ± 64

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

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

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

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

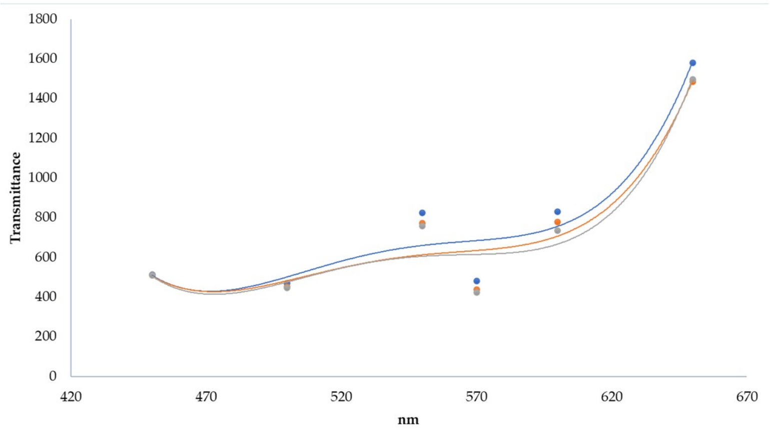

Figure 1. Visible spectra showing the average of transmittance (n = 4) in tomatoes of *Lycopersicum esculentum*, H1534 variety, at harvest (● Control, ● 4% $MgSO_4$ ● 8% $MgSO_4$).

4. Discussion

The mineral content in tomato has an important role in taste, quality, preservation and nutritional value [19]. The application of our Mg biofortification itinerary showed that variety H1534 absorbs and store Mg through foliar application. With the increase of Mg, Zn and Fe also increased significantly. However, to some extend K levels decreased relatively to the control. This tendency can be related to the antagonistic relationship between K and Mg [20]. Regarding Ca, there isn't a clear tendency with the increase of 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 follow this pattern. Furthermore, comparing to other study [23], the values obtained in dry weight are lower, for the same variety.

Regardless the 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 present themselves as the most relevant parameters in tomato [25]. In fact, tomato flavour is quite influenced by total soluble solids [26]. In this context, relatively to the variety catalog (5.2–5.4%) [24], H1534 showed a lower total soluble solids (Table 2), but there was not significant differences between the control and the other treatments. As such, these differences may be due to environmental factors [27].

The colorimetric analysis is considered the most important aspect regarding quality, influencing 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, as lycopene is a carotenoid, present in tomato and tomato-based products, namely ketchup and pizza sauce [28], having a mighty antioxidant activity [29], in spite of Mg biofortification, quality was preserved.

5. Conclusions

Through foliar spraying with $MgSO_4$, Mg contents increased in the tomato variety H1534, being 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, agronomic biofortification of tomato variety H1534 can be applied to increase this nutrient in tomato based processed food products.

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