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# Correlation of blossom end rot incidence with biomass production and fruit quality parameters in tomato plants treated with foliar nutrients

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## ABSTRACT

Tomato is one of the most relevant fresh crops worldwide, and its production is affected by blossom end rot (BER), a physiological disorder caused by insufficient calcium translocation into the fruit. Strategies have been proposed to mitigate BER, including foliar nutrient applications and the use of plants with improved nutrient uptake and higher biomass production; however, it remains unclear whether these approaches are effective or might exacerbate BER incidence. This study aimed to evaluate the impact of foliar Ca, Mg, B, and Zn in both grafted and non-grafted tomato plants with differential biomass production in relation to BER incidence, biomass production, and postharvest fruit quality, as well as to establish correlations between studied variables. Results showed that foliar nutrition, including calcium, did not reduce BER incidence. Instead, it led to smaller fruit size and higher total soluble solids (TSS). Grafted plants exhibited significantly higher BER incidence and biomass production than nongrafted ones, with a strong positive correlation between BER incidence and plant height (r = 0.996, $P \le 0.01$). Treatments with the highest BER incidence produced tomatoes with reduced firmness values (r = -0.763, $P \le 0.01$), suggesting compromised cell integrity. The results show that grafted tomato plants with high biomass production may be unsuitable for cultivation in nutrient-poor soils, as their increased growth rate may outpace nutrient availability, triggering BER. Additionally, foliar nutrient applications were insufficient to mitigate BER.

**Keywords:** calcium, grafting, plant nutrition, postharvest

## INTRODUCTION

Tomato fruit (*Solanum lycopersicum* L. Mill) is one of the most demanded crops worldwide due to its organoleptic features and culinary versatility (Vasileva and Mitova, 2023). Mexico ranks seventh in tomato world production, with approximately 4.4 million tons, and more importantly, holds the first place in tomato exportation, generating a profit of around $ 3 billion in 2023 (FAOSTAT, 2025). In this sense, tomato commercialization represents a remarkable source of income. On the other hand, there are many limitations to the quality and quantity of tomato production.

Among the most important limitations can be included phytopathologies, poor postharvest handling, deformities, and physiological disorders (Gatahi, 2020). One of the most detrimental physiological disorders that decreases tomato production is blossom end rot (BER). This disorder manifests as a sunken dark spot at the fruit base (blossom end). Over time, the spot gets bigger, becomes black, and develops a hard texture (Kyriacou et al., 2017).

BER is frequently misdiagnosed as fungal fruit rot, particularly black mold rot caused by *Alternaria* spp. (Wei et al., 2025).

The physiology behind BER is complex, and it is mainly associated with calcium deficiency in the fruit. A decreased calcium concentration in the tissue compromises cellular compartmentalization due to cell wall and the middle lamella weakening (Cardona et al., 2005). Moreover, it is reported that calcium deficiency triggers ethylene biosynthesis, accelerating fruit decay. Calcium is absorbed by the roots and translocated to the aerial parts through the xylem. Calcium is one of the most abundant chemical elements in the Earth's crust; however, it is absorbed and translocated at a lower rate compared to other elements due to its divalent charge (Kyriacou et al., 2017). Calcium translocation is affected by many factors, such as water mobility, excessive presence of monovalent ions in the soil, fruit size, and plant growth rate (Taylor and Locascio, 2004).

Deficiencies or imbalances of nutrients such as magnesium, boron, and zinc can intensify calcium-related disorders even when calcium is present in the soil. Magnesium may compete with calcium at the root level. Boron deficiency in roots has been shown to impair calcium signalling and transport processes, indirectly reducing calcium translocation to developing tissues, and zinc absence may accelerate oxidative processes associated with BER. In addition, high relative humidity reduces transpiration-driven calcium transport to developing fruits, which are weak transpiring organs, thereby increasing BER susceptibility under greenhouse conditions (Taylor and Locascio, 2004; Vera-Maldonado et al., 2024).

In the literature, there are many reports on treatments to reduce BER incidence in tomato fruit. A common strategy against BER is foliar nutrition. This method arises as a promising option due to its advantages. Among the most important can be mentioned the reduction of fertilizer and soil acidification and salinization (Niu et al., 2021). On the other hand, it is relevant to mention that the application method and frequency are key to obtaining the desirable results. Additionally, foliar nutrient mobilization from the leaves or the outer fruit layers can be scarce (Cardona et al., 2005).

Foliar nutrition with chemical elements such as calcium, magnesium, boron, and zinc provides key benefits for tomato plant development and fruit quality (Niu et al., 2021). Among the benefits of these nutrients, it can be highlighted that foliar calcium application contributes to greater firmness and structural resistance of the fruit by strengthening cell walls. Magnesium, essential for chlorophyll synthesis, supports vegetative development and enhances photosynthetic efficiency during critical growth stages (Kazemi, 2014a). Boron plays a role in cell division, membrane integrity, fruit structure, and calcium absorption. Zinc is essential for the activation of antioxidant enzymes, influencing the ability to trigger defense mechanisms against stress. In addition, these nutrients can optimize the crop phenological expression and improve fruit quality parameters such as firmness, and the prevention of physiological disorders like BER (Alshaal and El-Ramady, 2017).

Another strategy to address poor soil quality is the implementation of grafted tomato varieties with an extensive root system, which allows them to absorb nutrients efficiently, even under biotic or abiotic stress conditions. Additionally, plants are selected based on their high potential to produce biomass, e.g. plant height and fruit yield, which is achieved through the selection of specific rootstocks (root system). Meanwhile, the fruit characteristics depend on the scion (upper part). Grafted plants with such features are commonly employed in many regions in Mexico, observing relevant BER incidence values; however, it is unknown if BER incidence is correlated with biomass production or postharvest quality. Additionally, it is still unclear whether foliar nutrition could affect BER values. Therefore, this paper aimed to evaluate the effect of foliar nutrition on BER incidence, biomass production, and postharvest quality parameters of tomato fruits from nongrafted and grafted plants with differential biomass production and establish a correlation between BER incidence and variables related to plant productivity and fruit quality.

## MATERIALS AND METHODS

### *Plant material*

Plant materials included in this study were nongrafted and grafted tomato plants (*Solanum lycopersicum* L. Mill) producing saladette tomatoes. The nongrafted plants corresponded to the cultivar Vanesa (Hazera). Grafted plants comprised the cultivar Vanesa grafted onto the rootstock INTERCEPTOR (high biomass producer). "Agricola Chaparral" kindly donated the seedlings from their own professional cultivation. Ungrafted and grafted tomato seedlings were produced simultaneously under the same conditions. All seedlings were grown in the same substrate and under the same environmental, irrigation, and fertilization regimes. Grafting was carried out manually when both scion and rootstock seedlings were 25 days old, with stem diameters of approximately 1.8–2.2 mm. Silicone grafting clips (F-type) were used to secure the graft union. Seedlings were transplanted into the greenhouse 45 days after sowing.

### *Plant growth experiment*

The experiment was conducted during 22 weeks in a greenhouse at the Technological University of Culiacan in Culiacan, Sinaloa, México (24°51'38.6''N, 107°20'54.3''E, and 57 m above sea level). The soil was clayey, had a pH of 7.26, an electrical conductivity of 1.73 dS/m, and an organic matter content of 1.36%. Calcium levels were normal (around 3,000 ppm), while magnesium, boron, and zinc were within low-to-moderate ranges (188, 2.15 and 1.2 ppm, respectively). During the growing season (October to March), mean monthly temperatures ranged from 18 to 29 °C, while relative humidity varied between 59 and 72% (Table 1). Plants were transplanted in furrows on October 10 at 0.80 m row spacing, spaced 0.45 m apart, and grown vertically. Irrigation and moisture conditions were monitored using moisture sensors. Fertigation was performed with the Steiner universal nutrient solution, and concentrations were adjusted to their respective phenological phase (Steiner, 1980). Salts included in the nutrient solution were the following: calcium nitrate [$Ca(NO_3)_2$], potassium nitrate ($KNO_3$), monopotassium phosphate ($KH_2PO_4$), ammonium sulfate [$(NH_4)_2SO_4$], iron ethylenediaminetetraacetic acid (Fe-EDTA), manganese sulfate ($MnSO_4$), copper sulfate ($CuSO_4$), and sodium molybdate ($Na_2MoO_4$). Magnesium sulfate ($MgSO_4$), zinc sulfate ($ZnSO_4$) and boric acid ($H_3BO_3$) were excluded to generate nutrient-limiting conditions and trigger BER incidence. Calcium nitrate is included in the nutrient solution to observe the effect on calcium translocation and not calcium deficiency. Additionally, ions were selected to evaluate the effect of nutrient foliar application (control, calcium, magnesium, boron, and zinc) on BER incidence, biomass production and tomato quality. Analyses were carried out on symptom-free tomatoes, except for BER incidence and fruit yield.

**Table 1.** Mean and standard deviation of temperatures and relative humidity during the growing season in the employed greenhouse.

| Month | Temperature (°C) | Relative humidity (%) |
|---|---|---|
| October | 29.65 ± 7.34 | 65.33 ± 19.20 |
| November | 23.68 ± 8.02 | 69.44 ± 15.92 |
| December | 21.08 ± 9.80 | 72.80 ± 18.89 |
| January | 18.16 ± 8.43 | 72.41 ± 18.19 |
| February | 21.24 ± 11.36 | 61.01 ± 19.90 |
| March | 21.82 ± 10.47 | 59.15 ± 19.19 |

### *Treatment application*

Starting from week 7, furrows containing the nongrafted or grafted tomato plants were treated once a week with foliar nutrition. Solutions included: distilled water (control), calcium oxide, magnesium oxide, boron-ethanolamine, and zinc-fulvic acids. Each treatment was prepared at 0.15 mg/mL. Applications were carried out early in the morning by soaking leaves with a motorized backpack sprayer.

### *Blossom end rot incidence*

For BER evaluation, all tomato fruits that had reached at least stage II of ripening (Thengane and Gawande,

2018) were harvested. BER incidence was recorded starting from the week when the first fruit with BER symptoms appeared. From that point onward, BER incidence was calculated at every harvesting day (once a week). Incidence was visually assessed for each treatment using the following formula (Kazemi, 2014b):

$$\text{BER incidence (\%)} = \frac{\text{Number of fruit with BER}}{\text{Total of fruit per treatment}} \times 100$$

**_Biomass production_**

*Plant height*

Plant height values were obtained every two weeks employing a measuring tape, and reporting the results in cm.

*Yield*

For yield evaluation, tomato fruit (stage II to VI of ripening) were harvested from each treatment throughout the producing cycle. Harvesting occurred once a week, and the fruits were weighed using a weighing scale (Ciziyiheng, E.U.A.). The total fruit yield for each plant was calculated by summing the weight of all harvested fruits (Turhan et al., 2011). Data were reported as kilograms of fruit per plant (kg/plant).

*Dry fruit mass*

Fruits were weighed, sliced (about 1 cm in thickness) and placed in a forced-air oven at 80 ± 3 °C until reaching constant weight (around 72 hours). After drying, each sample was weighed using an analytical balance (Sartorius, Germany) (Ji et al., 2020). The percentage of dry fruit mass was calculated with the following formula:

$$\text{Dry fruit mass (\%)} = \frac{\text{Dried fruit weight}}{\text{Fresh fruit weight}} \times 100$$

**_Fruit size_**

Polar and equatorial diameter determination of the fruit was carried out with a digital Vernier (SURTEK, U.S.A.), and results were expressed in mm.

**_Postharvest quality parameters_**

*Firmness*

Firmness was assessed on the harvesting day as described by Cardona et al. (2005) with some modifications. A texturometer (Brookfield Ametek, U.S.A.) with a metallic sphere (12.7 mm in diameter) was employed to evaluate tomato firmness. Measurements were carried out at a constant penetration speed (1 mm/s to a depth of 5 mm). For each fruit, three measurements were performed along its equator. Results were expressed as maximum compression force in Newtons (N).

*Total soluble solids*

Total soluble solids (TSS) content was determined using a digital refractometer (Hanna Instruments, Italy). Three measurements were carried out per fruit, and the results were reported as °Brix (Vega García et al., 2025).

*Weight loss*

For the determination of weight loss, the weight of the tomatoes was recorded using an analytical balance (Sartorius, Germany) before and after seven days of storage at 25 °C (López-Velázquez et al., 2022). Results were reported as a percentage of weight loss (%). Values were calculated using the following formula:

$$\text{Weight loss (\%)} = \frac{\text{Initial weight-final weight}}{\text{Initial weight}} \times 100$$

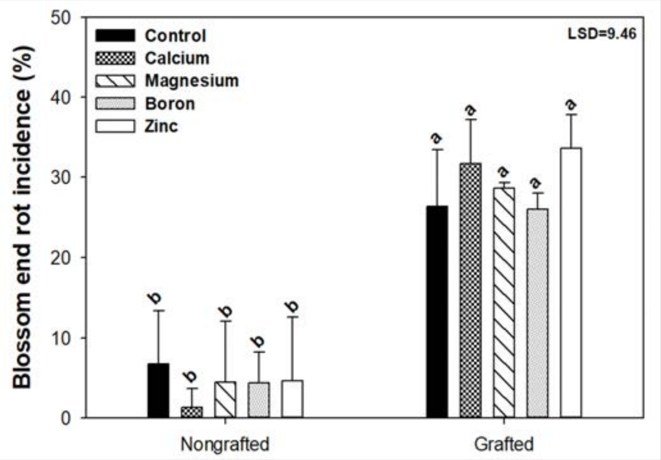
**_Statistical analysis_**

A completely random design with three replicas was employed. Each treatment and replica consisted of 20 plants. For dry fruit mass, fruit size, and postharvest parameters, 10 fruits (stage II and III of ripening) for each treatment and replicate were evaluated. The design included two factors: type of plant (nongrafted and grafted tomato plant), and nutrient foliar application (Control, calcium, magnesium, boron, and zinc).

## RESULTS

### *Blossom end rot incidence*

BER incidence started to appear on the sixth inflorescence. For nongrafted plants, BER incidence in tomatoes remained under 7%, while tomatoes from grafted plants exhibited higher BER incidence (from 26 to 33%) (Figure 1). No statistically significant differences were detected when foliar nutrition was applied, indicating that this factor did not affect BER incidence.



Mean comparisons were performed using the Fisher test with a significance level of 5% (*P*≤0.05). Pearson correlations were carried out between the response variables evaluated. The data were analyzed with Minitab 14 software. Different letters indicate significant differences among treatments (*P*≤0.05).

**Figure 1.** Blossom end rot incidence in tomato fruit from nongrafted and grafted plants treated with foliar nutrition

### *Biomass production*

*Plant height*

Plant height followed a similar trend among treatments throughout every evaluation day in the growing season (Data not shown). Figure 2A focuses on the effect of the evaluated factors on tomato plant height 120 days after transplanting. Nongrafted plants showed values between 179 and 192 cm, whereas grafted plants showed values between 274 and 292 cm, presenting significant differences. As observed for BER incidence, foliar nutrition did not have an effect on this parameter. Regarding the correlations obtained (Table 2), plant height had a correlation coefficient of 0.966 (*P*≤0.01) with BER incidence.

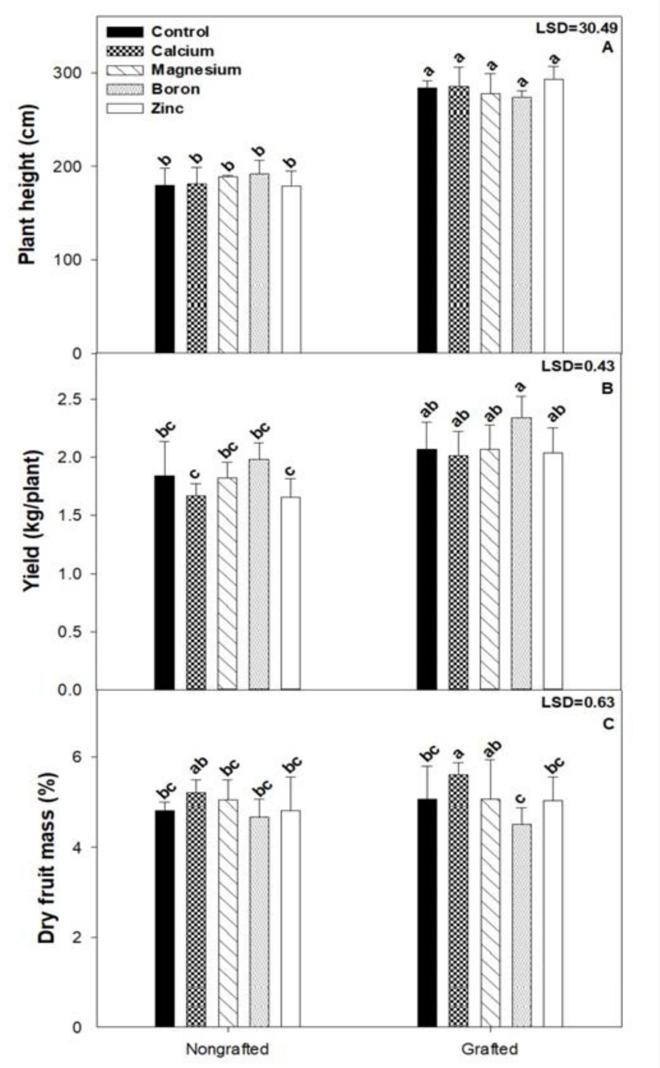


**Figure 2.** Plant height (A), yield (B) and dry fruit mass (C) from nongrafted and grafted tomato plants treated with foliar nutrition (different letters indicate significant differences among treatments (*P*≤0.05))

*Yield*

For nongrafted tomato plants, fruit yield ranged between 1.65 and 1.98 kg/plant. Meanwhile, grafted plants ranged from 2.01 to 2.33 kg/plant (Figure 2B). Among the nongrafted treatments, foliar nutrition did not have a significant effect, and a similar behavior was observed for grafted plants. On the other hand, grafted plants treated with calcium, boron, and zinc had higher yield values compared to the nongrafted plants treated with the same nutrients. The yield values presented a correlation with BER incidence and plant height, showing correlation coefficients of 0.715 and 0.782, respectively (*P*≤0.05) (Table 2).

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**Table 2.** Pearson correlation between response variables evaluated on nongrafted and grafted tomato plants treated with foliar nutrition

| | | Physiological disorder | Biomass production | | | Fruit size | | Postharvest quality | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Blossom end rot | Plant height | Yield | Dry fruit mass | Polar diameter | Equatorial diameter | Firmness | Total soluble solids | Weight loss |
| Physiological disorder | Blossom end rot | | | | | | | | | |
| Biomass production | Plant height | 0.966** | | | | | | | | |
| | Yield | 0.715* | 0.782** | | | | | | | |
| | Dry fruit mass | - | - | - | | | | | | |
| Fruit size | Polar diameter | - | - | - | - | | | | | |
| | Equatorial diameter | - | - | - | - | 0.887** | | | | |
| Postharvest quality | Firmness | -0.763** | -0.756* | -0.642* | - | - | - | | | |
| | Total soluble solids | - | - | - | - | - | -0.634* | - | | |
| | Weight loss | - | - | - | - | - | - | - | - | |

- Non-significant correlation
* *P*≤0.05
** *P*≤0.01

*Dry fruit mass*

On nongrafted tomato plants, any of the foliar applications have a significant effect (*P*>0.05) on dry fruit mass (Figure 2C). For the grafted plants, foliar calcium was the only treatment to increase dry matter.

### *Fruit size*

*Polar diameter*

The polar diameter of tomatoes ranged from 55 to 76 mm. Generally, nutrient foliar applications led to a reduction in the polar diameter of tomato fruit (Figure 3A). Foliar applications of calcium, magnesium, and boron reduced the polar diameter in tomatoes from nongrafted plants. Meanwhile, in grafted plants, boron and zinc similarly reduced the polar diameter.

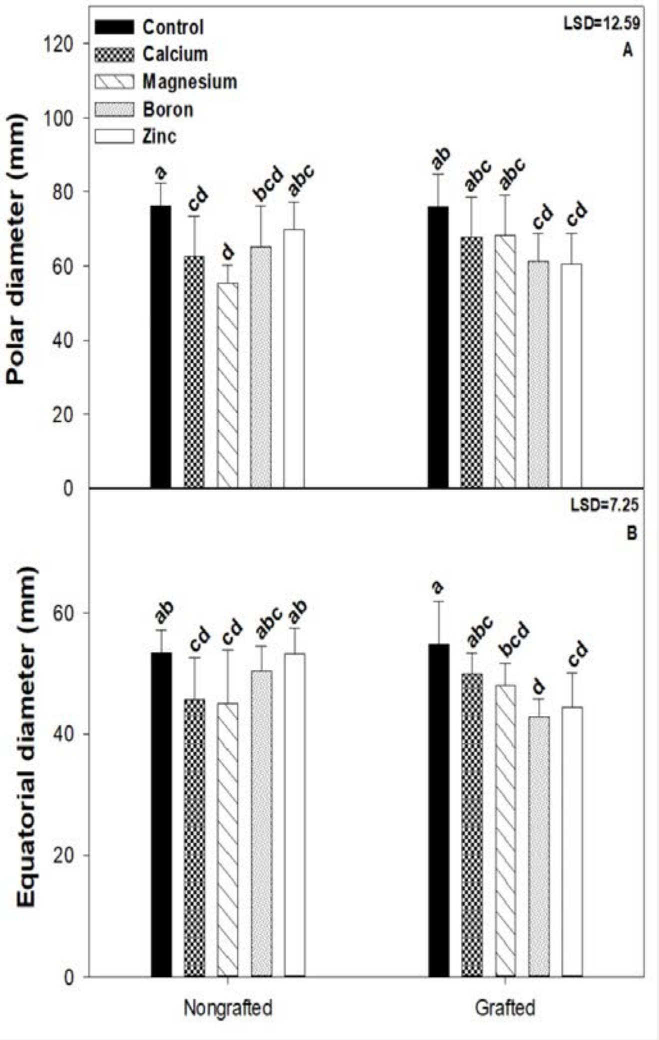
*Equatorial diameter*

Results from equatorial diameter had a similar tendency compared to polar diameter measurements (Figure 3B). Foliar application tended to reduce equatorial diameter in some treatments. Polar and equatorial diameters had a correlation coefficient of 0.887 (*P*≤0.01) (Table 2). These parameters were not correlated to BER incidence.

### *Postharvest quality parameters*

*Firmness*

The firmness values of tomatoes from nongrafted plants ranged from 23.91 to 28.58 N, and boron applications led to a significant increase in firmness (*P*≤0.05) (Figure 4A). The firmness values for grafted plants ranged from 18.32 to 23.18 N, and foliar boron reduced this parameter. Tomato fruits from grafted plants treated with magnesium, boron, and zinc exhibited lower firmness values (*P*≤0.05) compared to those from nongrafted plants treated with the respective nutrients. A significant Pearson correlation was found between firmness and BER incidence, plant height, and yield, with correlation coefficients of -0.763, -0.756, and -0.642, respectively (Table 2).

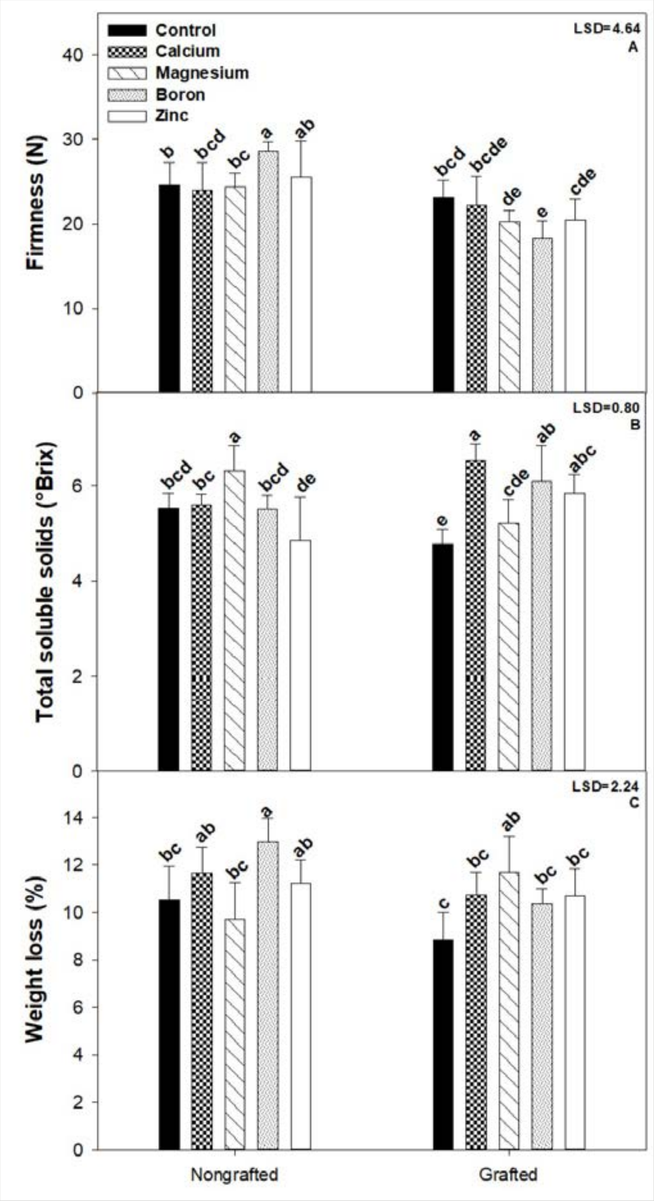


Different letters indicate significant differences among treatments (*P*≤0.05)

**Figure 3.** Polar (A) and equatorial diameter (B) of tomato fruit from nongrafted and grafted plants treated with foliar nutrition

*Total soluble solids*

The foliar nutrient applications had a more pronounced effect on the TSS of tomatoes from grafted plants than in nongrafted plants (Figure 4B). On tomatoes from nongrafted plants, magnesium treatment increased TSS content. Meanwhile, on grafted plants, foliar applications with calcium, boron, and zinc increased the TSS in tomato fruits. This parameter had a significant correlation (*P*≤0.05) with the equatorial diameter (-0.634) (Table 2).



Different letters indicate significant differences among treatments (*P*≤0.05)

**Figure 4.** Firmness (A), total soluble solids (B) and weight loss (C) of tomato fruit from nongrafted and grafted plants treated with foliar nutrition

### *Weight loss*

Weight loss presented changes among treatments. Boron and magnesium applications increased weight loss in tomato fruits from nongrafted and grafted plants, respectively. No significant changes were observed on the other foliar treatments (*P*>0.05).

## DISCUSSION

### *Blossom end rot incidence*

The beginning of BER incidence until the sixth inflorescence is caused by the inefficiency of calcium translocation into the fruit blossom end once the plant reaches a certain length and develops more foliage, which hinders calcium translocation into the fruits (Cardona et al., 2005). In this study, BER incidence was deliberately promoted by nutrient deficiency in the soil. Moreover, this physiological disorder may be exacerbated by high relative humidity values, as observed in December and January (Table 1), limiting calcium translocation during critical growth phases (Taylor and Locascio, 2004).

Interestingly, on nongrafted plants, BER incidence was under control (<7%) considering the induced nutrient deficiency. This suggests that the preexisting soil nutrients were sufficient, allowing them to reach the fruit tissue. On the other hand, grafted plants presented a remarkable BER incidence under the same nutrition conditions. It is reported that BER susceptibility changes depending on factors such as growth rate, calcium translocation efficiency, and xylem tissue development (Taylor and Locascio, 2004).

Previous reports have shown that the employment of grafted tomato plants can have a different outcome upon BER incidence depending on the growing conditions and the genotype of the rootstock (Kyriacou et al., 2017). Therefore, the chosen rootstock for the present study may be inadequate to translocate calcium under the nutritional conditions employed. As shown in the results section, weekly foliar nutrition did not have an effect on BER incidence. Contrary to our results, Peralta Manjarrez et al. (2023) reported that tomatoes from grafted plants had higher calcium concentration than nongrafted. Moreover, preharvest foliar and fruit calcium application in tomato plants effectively increased leaf and fruit calcium concentration (Barke, 1968; Cardona et al., 2005). For their part, Kazemi (2014a) and Haleema et al. (2018) observed that a few foliar calcium, zinc, and boron applications reduced the incidence of BER in nongrafted tomato plants under optimal soil nutrient conditions.

### Biomass production

*Plant height*

Higher plant height values for grafted plants indicate a higher growth rate than nongrafted ones (Al-Harbi et al., 2018; Zhu et al., 2008). This is attributed to the rootstock INTERCEPTOR employed in the grafting process and its efficiency in absorbing nutrients, even under abiotic stress conditions, due to its extensive root system (Top Seeds International, 2025). Contrary to our results, foliar nutrition is reported to increase biomass production. Niu et al. (2021) demonstrated that foliar nutrients such as zinc, copper, and iron can increase plant weight in different plant models.

Regarding the correlation between the studied variables, it is relevant to state that correlation does not imply causality, and some additional unstudied factors may be involved. BER susceptibility and growth rate are two variables strongly related to the mechanism of calcium translocation in plant tissue (Cardona et al., 2005). This relationship is observed in the present study as a strong positive correlation coefficient (r=0.966) between BER incidence and tomato plant height. This behavior may be a result of a phenomenon known as the dilution effect (Jarrell and Beverly, 1981). This phenomenon may be playing a key role in this correlation, given that grafted plants showed a higher growth rate than nongrafted ones, and in this sense, producing a lower nutrient concentration in some tissues, as has been reported for calcium in fruits, especially under nutrient-limited conditions (Kaspari and Welti, 2024). Additionally, Reitz et al. (2021) found that BER was associated with water-related factors. In our study, calcium transport in the plant could be affected because grafted and nongrafted plants received the same irrigation regime, which had a greater impact on the grafted plants due to their higher biomass compared to the non-grafted ones.

*Yield*

The higher fruit yield performance on grafted plants has been previously reported, authors attribute this to efficient nutrient absorption by the selected rootstock (Turhan et al., 2011). Contrary to our results, Haleema et al. (2018) and Arunkumar et al. (2022) reported an increased yield with foliar nutrition on tomato and strawberry plants, respectively. For its part, Kazemi (2014b) reported that other nutrients, such as potassium nitrate, can enhance fruit yield.

The positive correlation between yield and BER incidence indicates that treatments producing the highest tomato quantity also showed the highest BER incidence. Under the nutrient-limiting conditions employed, these results suggest that BER could be triggered in plants with a high rate of soil nutrient consumption, depleting nutrients such as boron that are key to calcium absorption (Vera-Maldonado et al., 2024). It is relevant to mention that the removal of old leaves was carried out and as a result, the plant likely lost significant calcium reserves. Additionally, as shown in Table 1, relative humidity levels were high during the experiment, which may have further impaired calcium translocation from the soil to the fruit (Malone et al., 2002).

The suggestion of nutrient depletion is further supported by the plant height results, as a greater amount of biomass produced in grafted plants is associated with higher nutrient consumption (Figure 2A). For the correlation between plant height with fruit yield, it is reported that these variables are associated due to the rootstock INTERCEPTOR's ability to absorb nutrients and generate biomass over time (Zhu et al., 2008).

*Dry fruit mass*

Foliar calcium applications on grafted plants had a positive effect on this parameter. The increase in dry matter could be associated with calcium absorption. Barke (1968) and Cardona et al. (2005) report that foliar calcium applications lead to calcium absorption in both leaves and fruits.

### Fruit size

Overall, foliar applications had a negative effect on polar and equatorial diameter, reducing the values of these parameters. Contrary to our results, Al-Obeed et al. (2018) observed that foliar boron and zinc applications increased the fruit size of mandarins. Moreover, Davarpanah et al. (2018) reported that preharvest calcium applications did not have a significant effect on pomegranate weight.

It is worth mentioning that fruit size was not correlated to BER incidence, indicating that even though grafted plants produced a higher fruit quantity, both types of plants (untreated grafted and nongrafted) were producing similar-sized tomatoes. Fruit size can be a relevant parameter in the development of BER in tomato fruit. Larger fruits have a lower surface-to-volume ratio than smaller ones, which opposes transpiration and calcium accumulation in the fruit tissue (Taylor and Locascio, 2004). In this sense, BER has not been reported on tomato wild cultivars, which are smaller than the commercial ones and do not experience a phase of rapid growth (Hagassou et al., 2019). Regarding the differences between grafted and nongrafted plants, Rouphael et al. (2010) stated that this factor does not have a clear influence on the physical fruit parameters.

### *Postharvest quality parameters*

#### *Firmness*

Regarding the differences between grafted and nongrafted plants, the highest firmness values were registered on tomatoes from nongrafted plants. The behavior may be linked to a lower calcium concentration in fruits from grafted plants. It is widely reported that calcium plays a key role in maintaining the cellular structure, as this element forms ionic bonds among the demethylated pectin present in the middle lamella and cell wall (Cardona et al., 2005; López-Velázquez et al., 2022). In this sense, calcium increases the deformation resistance, obtaining higher firmness values. Lower fruit calcium content can be associated with a deficiency of boron in the soil. It is reported that boron deficiency decreases cytosolic calcium in roots (González-Fontes et al., 2014). Moreover, compromises the expression of genes associated with cell wall assembly (Vera-Maldonado et al., 2024).

Regarding the correlation obtained for firmness evaluation, the highest height values and BER incidence produced tomatoes with the lowest firmness values (fruits without visible symptoms were evaluated). The negative correlation coefficient obtained between firmness values and plant height and yield further supports the hypothesis about the dilution effect on plant and fruit tissue. It is relevant to mention that calcium analysis is necessary to confirm such a hypothesis.

#### *Total soluble solids*

All foliar nutrient applications, except for magnesium, had a significantly positive effect on TSS content in fruit from grafted plants. Ahmad et al. (2016) reported that foliar application of calcium and potassium increased osmolyte production through the activation of the antioxidant system in chickpea exposed to abiotic stress. Additionally, Hasani et al. (2012) reported that zinc foliar applications increased TSS content in pomegranate fruit. For their part, Kazemi (2014a) observed increased TSS values in tomato fruit when plants were treated with calcium chloride. Interestingly, equatorial diameter was negatively correlated with this parameter. The correlation indicates that wider fruit had a lower TSS content. Similar results have been reported on orange cultivars. Quaggio et al. (2006) observed a dependence between TSS content and fruit size, obtaining quadratic models with R-squared values between 0.92 and 0.98.

#### *Weight loss*

Weight loss is a critical postharvest parameter. This parameter describes water evaporation through stomata, lenticels, or degraded cell walls and cuticle; therefore, higher water loss indicates higher cell degradation and decay (López-Velázquez et al., 2022). The slight changes among treatments could suggest that these factors did not intervene in the cell organization or fruit maturation process.

## CONCLUSION

Foliar nutrition did not significantly affect BER incidence, and its influence on biomass-related variables was inconsistent. Foliar nutrient applications reduced fruit size but increased TSS content. A higher incidence of BER was observed in grafted plants, which was positively correlated with greater biomass production. This correlation appears to be associated with a dilution effect and nutrient depletion. Fruit firmness was also correlated with both BER incidence and biomass production, suggesting a negative impact on fruit quality, even in asymptomatic fruit. Therefore, tomato plant varieties with high biomass production efficiency should be avoided on soils with poor nutrient availability or high salinity, as these conditions impair mineral uptake and may exacerbate physiological disorders like BER. However, this does not imply that grafted plants should be avoided. Grafted plants may be advantageous under adequate nutrient availability.

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