Open Access Library Journal
2026, Volume 13, e15505
ISSN Online: 2333-9721
ISSN Print: 2333-9705

Effects of Two Fruit-Fattening Biostimulants on Yield and Fruit Quality of Greenhouse-Grown Saladette Tomato (*Solanum lycopersicum* L.)

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How to cite this paper: Alvarez-Mares, V.D.J., Medina-Montenegro, H.M., López-Velázquez, J.G., López-España, R.G., Rojas-Rojas, P.A., Piña-Soto, A.A. and Gurrola-López, G.H. (2026) Effects of Two Fruit-Fattening Biostimulants on Yield and Fruit Quality of Greenhouse-Grown Saladette Tomato (*Solanum lycopersicum* L.). *Open Access Library Journal*, **13**: e15505.
https://doi.org/10.4236/oalib.1115505

Received: May 19, 2026
Accepted: August 15, 2026
Published: August 18, 2026

Abstract

This study aimed to evaluate the effect of two fruit-fattening biostimulant formulations on tomato (*Solanum lycopersicum* L.) growth, fruit quality, and yield under greenhouse conditions. The experiment was conducted in a gable-type greenhouse at the Technological University of Culiacán, Sinaloa, Mexico. Two fruit-fattening biostimulants (A and B) were evaluated together with an untreated control. The evaluated variables included leaf greenness (SPAD index), fruit firmness (PSI), total soluble solids (˚Brix), fresh fruit weight, and yield per hectare. The results showed that biostimulant application significantly affected fruit firmness, total soluble solids, fresh fruit weight, and yield. Biostimulant A produced the highest fresh fruit weight (221.6 g·fruit^{-1}) and yield (470.8 t·ha^{-1}), followed by Biostimulant B (180.4 g·fruit^{-1} and 367.25 t·ha^{-1}), whereas the control treatment showed the lowest values (139.6 g·fruit^{-1} and 320.8 t·ha^{-1}). No significant differences were observed among treatments for the SPAD index, whereas total soluble solids were significantly increased by Biostimulant A (5.85 ˚Brix) compared with Biostimulant B (4.75 ˚Brix) and the control (4.30 ˚Brix). Fruits from plants treated with Biostimulant A also exhibited the highest firmness (8.48 PSI). Biostimulant A improved tomato yield and enhanced important fruit quality attributes. These findings indicate that Biostimulant A represents a promising agronomic strategy for improving tomato productivity under protected cultivation.

Subject Areas

Agricultural Science

Keywords

Solanum lycopersicum, Biostimulant, Fruit Quality, Yield, Protected Cultivation

1. Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most important crops in Mexico and worldwide due to both its economic significance and its role as a source of vitamins, minerals, and antioxidants, which are essential for human nutrition and health [1]. Since most quality attributes result from the fruit ripening process, understanding the regulatory mechanisms involved in this developmental stage has become essential [2]. Fresh tomatoes and their processed products are widely recognized for their high nutritional value, particularly because of their antioxidant, anti-inflammatory, and anticancer properties [3]. However, environmental stress adversely affects crop growth, yield, and fruit quality [4]. In this regard, Alba *et al.* [5] reported that fruit development occurs in five stages: growth, development, and ripening, followed by softening and senescence. Foliar application of micronutrients has emerged as a promising alternative to improve crop performance because these elements act as enzyme cofactors and are indispensable in several metabolic pathways [6].

Biostimulants are widely used in agriculture because of their ability to stimulate natural plant processes associated with nutrient use efficiency, growth, development, and crop productivity. These products include microorganisms and nutritional substances applied either foliarly or to the soil, promoting physiological processes that may improve nutrient acquisition, tolerance to abiotic stress, crop quality, and yield performance [7] [8]. Among these products, fruit-fattening biostimulants are specifically designed to promote fruit growth and development by enhancing fruit size, weight, and quality attributes. In tomato (*Solanum lycopersicum* L.), these formulations may influence fruit development processes associated with cell expansion and biomass accumulation, resulting in larger and heavier fruits without negatively affecting internal quality parameters. Fruit-fattening formulations enriched with boron (B) and molybdenum (Mo) may contribute to fruit quality, size, and uniformity due to the important roles of these micronutrients in cell wall formation, sugar transport, and nitrogen metabolism. Boron participates in cell wall stability and reproductive processes, whereas molybdenum is involved in enzymatic pathways related to nitrogen assimilation [9] [10]. The combination of these micronutrients with bioactive compounds enables these products to stimulate fruit development even under unfavorable conditions, including water stress, extreme temperatures, and phytotoxicity [11].

Biostimulants enriched with boron and molybdenum have been associated with improvements in fruit development and crop performance under both favorable and adverse growing conditions. Boron is an essential micronutrient involved in cell wall formation, membrane integrity, pollen germination, reproductive development, and the transport of sugars from source to sink tissues. Molybdenum plays a fundamental role in nitrogen metabolism because it acts as a cofactor for enzymes involved in nitrate reduction and assimilation, thereby contributing to protein synthesis and plant growth. When combined with bioactive compounds, these nutrients may stimulate physiological processes related to cell expansion, assimilate translocation, and biomass accumulation, promoting more efficient fruit development and potentially improving commercially important quality attributes such as fruit firmness, soluble solids content, and uniformity [9]-[11].

In addition to their nutritional role, biostimulants have gained considerable attention as sustainable agricultural inputs because they can enhance nutrient use efficiency and improve crop performance under suboptimal environmental conditions. Several studies have reported that these products stimulate metabolic activity, increase tolerance to abiotic stresses such as drought, salinity, and temperature fluctuations, and improve plant vigor without replacing conventional fertilization programs [7] [8] [11]. Consequently, their incorporation into intensive horticultural production systems has become an increasingly attractive strategy for maintaining productivity while reducing the environmental impact associated with excessive fertilizer use.

Among the different categories of plant biostimulants, fruit-fattening formulations are specifically designed to stimulate fruit enlargement during the rapid growth stage. These products generally contain balanced combinations of macro- and micronutrients together with bioactive compounds that promote cell expansion and assimilate partitioning toward developing fruits. As a result, they may increase fruit weight and improve quality attributes that determine market value, including firmness, soluble solids concentration, appearance, and fruit uniformity. Nevertheless, the magnitude of these responses depends on the formulation, application timing, environmental conditions, and crop management practices, making it necessary to evaluate each product under specific production systems.

Despite the increasing commercial availability of fruit-fattening biostimulants, comparative scientific information regarding the effectiveness of different formulations under protected tomato cultivation remains limited. Most available studies have focused on general plant biostimulants or seaweed extracts, whereas fewer investigations have compared formulations specifically developed to enhance fruit growth during the reproductive stage. Generating experimental evidence under greenhouse conditions is therefore essential to determine whether these products consistently improve productive performance and fruit quality while contributing to more efficient and sustainable crop management. Therefore, the objective of this study was to evaluate the effectiveness of two fruit-fattening biostimulants on tomato growth, fruit quality, and yield under greenhouse conditions.

2. Materials and Methods

The experiment was conducted during the 2023-2024 autumn–winter growing season in a chapel-type greenhouse located at the experimental field of the Universidad Tecnológica de Culiacán, situated at km^2 of the Culiacán-Imala highway, Los Ángeles neighborhood, Culiacán, Sinaloa, Mexico (24˚50'30"N, 107˚50'30"W; 58 m above sea level). According to García [12], the regional climate is classified as BS1 (h'), characterized as semi-arid with summer and winter rainfall, an average annual precipitation of 670 mm, a mean annual temperature of 24˚C, summer maximum temperatures of 41˚C, winter minimum temperatures of 5˚C, and an average relative humidity of 66.6%.

An indeterminate-growth F1 saladette tomato (*Solanum lycopersicum* L.) hybrid was used in this study. Before transplanting, seedlings were treated by imbibition in a suspension containing *Trichoderma harzianum*, *Bacillus subtilis*, and *Bacillus thuringiensis* to promote root development and reduce transplant stress, as previously reported for improving crop establishment [13] [14]. Transplanting was carried out on October 10, 2023, using a double-row planting system with 40 cm between plants on raised beds measuring 45 m in length. Plants were trained to two stems using plastic raffia attached to horizontal support wires extending along the greenhouse. Crop nutrition was supplied through fertigation using Steiner's universal nutrient solution, with nutrient concentrations adjusted according to the corresponding phenological stage of the crop [15].

The experiment was established under a completely randomized design with three treatments and three replicates [16]. The evaluated treatments consisted of T1, Biostimulant A; T2, Biostimulant B; and T3, untreated control receiving only Steiner's nutrient solution. Biostimulant A was formulated with potassium (5.1%), boron (13.8%), molybdenum (5.20%), nitrogen (1.80%), and α- and β-expansin synthesis promoters (1.70%). Biostimulant B contained nitrogen (6.0%), phosphorus pentoxide (5.0%), neutral ammonium citrate (5.0%), boron (0.06%), and copper (0.02%). Both products were supplied as water-soluble powders.

The biostimulants were applied through the fertigation system at a dose of 250 g·ha^{-1}, following the manufacturer's recommendations. Applications were performed during the flowering and fruit development stages, when tomato plants exhibit high nutrient demand and active fruit growth. A total of three applications were made at 3-day intervals, ensuring a continuous supply of the products during the fruit enlargement period. The control treatment received the same irrigation, fertigation, and crop management practices as the treated plants, differing only in the absence of biostimulant application.

Each treatment consisted of three replicates, and each replicate comprised 30 plants, which constituted the experimental unit, resulting in a total of 270 experimental plants. All agronomic practices, including irrigation, fertigation, pruning, trellising, and phytosanitary management, were applied uniformly throughout the experiment to minimize environmental variation among treatments.

The evaluated variables included leaf greenness (SPAD index), fruit firmness, total soluble solids (˚Brix), fruit size (polar and equatorial diameters), fresh fruit weight, and yield per hectare.

The SPAD index was determined using a Minolta SPAD-502 chlorophyll meter. Measurements were taken from five randomly selected plants per treatment, using fully expanded leaves located in the middle third of the canopy. Three readings were obtained from each leaf and averaged to obtain a representative SPAD value. Results were expressed as SPAD units, providing an indirect estimate of leaf chlorophyll concentration and crop nitrogen status [17].

Fruit firmness and total soluble solids were evaluated using five fruits randomly selected from each experimental unit at the pink ripening stage, according to the USDA tomato maturity classification. Firmness was determined in the equatorial region of each fruit using a manual penetrometer, and the results were expressed as kilograms-force per square centimeter ($kgf \cdot cm^{-2}$), a parameter commonly used to evaluate tomato postharvest quality [18]. Total soluble solids (TSS) were determined using a HANNA HI96801 portable digital refractometer previously calibrated with distilled water and expressed as degrees Brix (˚Brix) [19].

Fresh fruit weight, polar diameter, equatorial diameter, and total yield were determined using all harvested fruits from each experimental unit. Fruit weight was measured using an Ohaus precision balance (±0.01 g) and expressed as grams per fruit ($g \cdot fruit^{-1}$). Polar and equatorial diameters were measured with a digital caliper and expressed in millimeters (mm). Total yield per hectare ($t \cdot ha^{-1}$) was estimated from the cumulative fruit production of each experimental unit, considering the established planting density.

The data obtained from each experimental unit were subjected to analysis of variance (ANOVA) using the PROC GLM procedure of the SAS statistical software package (Version 6.12) [20]. The experimental unit (30 plants) was considered the unit of analysis for all statistical procedures. When significant treatment effects were detected, means were separated using Duncan's Multiple Range Test at a significance level of $P \leq 0.05$.

3. Results and Discussion

3.1. Leaf Greenness Index

The leaf greenness index (SPAD) was used as an indirect indicator of leaf chlorophyll status in tomato plants. Previous studies have reported a positive relationship between SPAD readings and leaf chlorophyll concentration, as well as plant nitrogen status under different growing conditions [17] [21]. However, the present study evaluated only SPAD values; therefore, chlorophyll concentration and leaf nitrogen content were not determined directly.

As shown in **Table 1**, no significant differences ($P \leq 0.05$) were detected among treatments according to Duncan's Multiple Range Test. These results indicate that the application of the evaluated fruit-fattening biostimulants did not significantly modify the leaf greenness index under the experimental conditions.

Table 1. Chlorophyll content, fruit firmness, and total soluble solids (˚Brix) of tomato plants grown with different fruit-fattening biostimulant formulations. Means followed by the same letter within the same column are not significantly different according to Duncan's Multiple Range Test ($\alpha \leq 0.05$).

Treatments	Leaf Greenness (SPAD)	Fruit Firmness (PSI)	Total Soluble Solids (˚Brix)
Control	49[a]	7.84[ab]	4.3[c]
Biostimulant A	52[a]	8.48[a]	5.85[a]
Biostimulant B	50[a]	7.25[b]	4.75[b]

Although Biostimulant A exhibited the highest numerical value (52 SPAD units), followed by Biostimulant B (50 SPAD units) and the control treatment (49 SPAD units), all treatments were assigned the same statistical grouping ("a"), indicating that the observed numerical differences were not statistically significant. Consequently, these variations should be interpreted only as numerical trends and not as evidence of a treatment effect on leaf greenness.

The SPAD values recorded in this study (49 - 52 units) are within the range reported for greenhouse-grown tomato plants by Jiang *et al.* [22], who observed values between 40 and 55 SPAD units under adequate crop management. Likewise, Rodríguez *et al.* [17] and Padilla *et al.* [21] indicated that SPAD measurements are useful for monitoring leaf greenness and nutritional status in tomato; however, they should be interpreted as indirect estimates because they do not represent direct measurements of chlorophyll concentration or leaf nitrogen content.

Overall, the results indicate that the evaluated fruit-fattening biostimulants did not significantly influence the leaf greenness index during the evaluation period. Under the conditions of the present study, leaf greenness remained within the range considered adequate for tomato cultivation, suggesting that the nutritional management provided through the Steiner nutrient solution maintained a similar physiological status among treatments.

3.2. Fruit Firmness

Fruit firmness is one of the most important quality attributes of fresh-market tomatoes because it influences resistance to mechanical damage during harvesting, handling, transportation, and commercialization. As shown in **Table 1**, significant differences among treatments were detected according to Duncan's Multiple Range Test ($P \leq 0.05$).

Biostimulant A produced the highest fruit firmness, reaching 8.48 PSI, whereas Biostimulant B showed the lowest value (7.25 PSI). The control treatment exhibited an intermediate firmness (7.84 PSI) and did not differ statistically from either Biostimulant A or Biostimulant B, as indicated by the shared letter grouping in **Table 1**. Therefore, only the comparison between Biostimulant A and Biostimulant B showed a statistically significant difference.

To minimize the effect of fruit maturity on firmness measurements, all fruits were evaluated at the pink ripening stage, according to the USDA tomato maturity classification, which is based on the percentage of pink coloration on the fruit surface [23]. Consequently, the differences observed among treatments were determined at the same physiological stage of ripening.

The higher firmness observed in fruits treated with Biostimulant A indicates that this formulation was associated with improved fruit firmness under the conditions of the present study. Conversely, fruits treated with Biostimulant B exhibited the lowest firmness values, while the control treatment showed an intermediate response. Although the numerical difference between Biostimulant A and Biostimulant B was 1.23 PSI, this difference was sufficient to separate both treatments statistically according to Duncan's test.

From a commercial perspective, firmer fruits generally exhibit greater resistance to mechanical damage during postharvest handling and transport. Therefore, the higher firmness obtained with Biostimulant A may represent an advantage for maintaining fruit quality during commercialization. Previous studies have reported that the application of biostimulant compounds can modify physiological processes related to fruit development and quality attributes, including parameters associated with firmness retention and marketability [24]. However, because postharvest storage, cell wall composition, and biochemical changes associated with fruit softening were not evaluated in this study, no conclusions can be drawn regarding the physiological mechanisms responsible for the observed differences.

3.3. Total Soluble Solids Content (˚Brix)

Analysis of variance revealed significant differences among treatments for total soluble solids (TSS) content ($P \leq 0.05$). According to Duncan's Multiple Range Test, Biostimulant A resulted in the highest TSS value (5.85 ˚Brix), followed by Biostimulant B (4.75 ˚Brix), whereas the control treatment showed the lowest value (4.30 ˚Brix) (**Table 1**). The different letter groupings indicate that the treatments were statistically different from each other, confirming that the application of biostimulants influenced this fruit quality parameter under the evaluated conditions.

The TSS values obtained in the present study ranged from 4.30 to 5.85 ˚Brix, which are within the commercial quality range commonly reported for fresh-market tomato cultivars [25]. These values indicate that fruits from all treatments reached an adequate maturity stage and maintained acceptable sweetness levels for fresh consumption. Although the treatments differed statistically, all fruits remained within the quality standards expected for marketable tomatoes, suggesting that the use of biostimulants modified the magnitude of soluble solids accumulation rather than affecting the basic commercial acceptability of the fruits. Similar responses have been described in crops treated with biostimulants, where the stimulation of physiological activity and improved nutrient utilization can con-

tribute to enhanced fruit quality characteristics, including soluble solids content [24].

Among the evaluated treatments, Biostimulant A showed the greatest positive effect on TSS content, while the control treatment exhibited the lowest value. Compared with the control, Biostimulant A increased TSS by 36.0%, whereas Biostimulant B produced an increase of 10.5%. These differences indicate that the response of tomato fruits was dependent on the type of biostimulant applied, suggesting that the formulations may differ in their capacity to influence fruit quality attributes. The greater increase observed with Biostimulant A highlights its potential usefulness as a tool for improving specific quality parameters associated with consumer preference.

Total soluble solids are widely used as an important indicator of tomato fruit quality because they are associated with sweetness perception, flavor intensity, and consumer acceptance. In fresh-market tomatoes, higher ˚Brix values are generally considered desirable because they contribute to improved sensory attributes. Therefore, the higher TSS values observed in fruits treated with Biostimulant A may represent a potential advantage for commercial production systems where fruit quality characteristics are important for market differentiation.

However, the mechanisms responsible for the increase in soluble solids cannot be determined from the present experiment because physiological parameters related to photosynthetic activity, carbohydrate synthesis, sugar transport, or assimilate partitioning were not evaluated. Therefore, although the results demonstrate an effect of biostimulant application on TSS accumulation, further studies including physiological and biochemical analyses are required to elucidate the processes involved in this response.

The observed values are comparable with those reported for greenhouse-grown tomato cultivars, where TSS commonly ranges between 4 and 6 ˚Brix depending on genotype, environmental conditions, and crop management practices [25]. Similar values have been reported in commercial tomato production systems, confirming that the fruits obtained in this study achieved an acceptable quality level. Nevertheless, among all treatments, Biostimulant A consistently promoted the highest soluble solids content, indicating a greater potential for enhancing this important quality attribute under the conditions evaluated.

3.4. Fruit Size (Polar and Equatorial Diameter)

The analysis of variance indicated that polar and equatorial fruit diameters were not significantly affected by the application of Biostimulants A and B compared with the control treatment ($P > 0.05$). According to Duncan's Multiple Range Test ($\alpha \leq 0.05$), no statistical differences were observed among treatments for either fruit dimension (**Table 2**). Nevertheless, fruits treated with Biostimulants A and B showed numerically higher mean values for both polar and equatorial diameter compared with the control, indicating a slight tendency toward greater fruit development under the evaluated conditions.

Table 2. Polar and equatorial diameters of tomato fruits grown with different fruit-fattening biostimulant formulations. Means followed by the same letter within the same column are not significantly different according to Duncan's Multiple Range Test ($\alpha \leq 0.05$).

Treatments	Polar Diameter (mm)	Equatorial Diameter (mm)
Control	69.45[a]	45.08[a]
Biostimulant A	84.02[a]	59.06[a]
Biostimulant B	79.39[a]	57.11[a]

Polar diameter values ranged from 69.45 to 84.02 mm, whereas equatorial diameter values varied from 45.08 to 59.06 mm (Table 2). Based on fruit size classification, tomatoes are considered large when their diameter exceeds 80 mm, medium when diameter ranges from 57 to 79 mm, and small when diameter is ≤56 mm [26]. According to this classification, most fruits obtained in the present study were within the medium-size category, with some treatments reaching values associated with large fruit size based on polar diameter. Similarly, Alvarado *et al.* [27] reported polar and equatorial diameters of 6.85 and 4.84 cm, respectively, in tomatoes produced under protected cultivation systems, values comparable with those observed in the present study.

Although Biostimulants A and B produced numerically higher polar and equatorial diameters, the absence of significant statistical differences indicates that the application of these formulations did not substantially modify fruit size. The observed numerical variation may be related to biological variability among fruits or to a moderate response of fruit growth that was insufficient to generate detectable statistical differences under the experimental conditions.

Fruit size is an important quality attribute because it influences market classification, consumer preference, and commercial value. However, fruit diameter alone does not provide a complete assessment of productivity or yield potential. Therefore, additional parameters such as fruit weight, number of fruits per plant, total yield, and fruit volume should be considered to determine whether the observed tendencies in fruit dimensions have practical implications for commercial production. Although fruit diameter was not significantly affected, the higher fruit weight obtained with Biostimulant A suggests that increases in fruit biomass were associated more with tissue accumulation than with changes in external dimensions. This response may indicate a greater accumulation of water and structural components within the fruit tissues, resulting in heavier fruits without producing proportional increases in fruit diameter. However, because anatomical characteristics, dry matter content, and tissue composition were not evaluated in the present study, this interpretation should be considered a plausible explanation rather than a confirmed physiological mechanism.

Overall, the results suggest that the evaluated biostimulants did not significantly alter tomato fruit dimensions, although Biostimulant A and Biostimulant B showed a tendency toward slightly higher average values compared with the control. Nevertheless, the significant increase in fresh fruit weight observed with Biostimulant

A indicates that this formulation improved fruit biomass accumulation despite the absence of significant changes in external dimensions. Further studies involving different application rates, crop cycles, and physiological measurements, including fruit dry matter accumulation, cell expansion, and tissue development, could help clarify the mechanisms responsible for this response under protected cultivation conditions.

3.5. Fresh Fruit Weight and Yield

Analysis of variance revealed significant differences among treatments for fresh fruit weight and total yield ($P \leq 0.05$) (Table 3). Biostimulant A produced the highest values, with an average fruit weight of 221.6 g and a yield of 470.8 t·ha^{-1}, followed by Biostimulant B, which reached 180.4 g per fruit and a yield of 367.25 t·ha^{-1}. The control treatment exhibited the lowest values, with an average fruit weight of 139.6 g and a yield of 320.8 t·ha^{-1}. According to Duncan's Multiple Range Test ($\alpha \leq 0.05$), the different letter groupings confirmed significant differences among treatments, indicating that the application of biostimulants affected productive performance under the evaluated conditions.

Table 3. Fresh Fruit Weight (g) and yield (t·ha^{-1}) of tomato plants grown with different fruit-fattening biostimulant formulations. Means followed by the same letter within the same column are not significantly different according to Duncan's Multiple Range Test ($\alpha \leq 0.05$).

Treatments	Fresh Fruit Weight (g)	Yield (t·ha^{-1})
Control	139.6^{c}	320.8^{c}
Biostimulant A	221.6^{a}	470.80^{a}
Biostimulant B	180.4^{b}	367.25^{b}

Compared with the control treatment, Biostimulant A increased fresh fruit weight by 58.8% and total yield by 46.8%, whereas Biostimulant B increased fruit weight by 29.2% and yield by 14.5%. These results demonstrate that the response depended on the formulation applied, with Biostimulant A showing the greatest effect on both individual fruit development and accumulated production per unit area.

The increase in fresh fruit weight observed with Biostimulant A indicates a greater accumulation of biomass in the harvested organ, which contributed to higher total yield. Similar responses have been reported in crops treated with biostimulants, where improvements in yield-related parameters have been associated with the presence of bioactive compounds that may influence plant growth and fruit development processes [11]. However, because physiological variables related to photosynthesis, assimilate partitioning, nutrient metabolism, or hormonal regulation were not measured in the present study, the mechanisms responsible for the observed increases cannot be confirmed.

The positive response obtained with Biostimulant B, although lower than that

observed with Biostimulant A, indicates that this formulation also contributed to improving productive attributes compared with the untreated control. The differences between formulations suggest that the composition and concentration of bioactive compounds may influence the magnitude of the crop response, emphasizing the importance of evaluating specific biostimulant formulations under particular production conditions [11] [24].

From an agronomic perspective, the increase in fruit weight and yield associated with Biostimulant A represents a relevant improvement because these parameters directly influence production efficiency and commercial performance. Similar responses have been reported in tomato crops, where the application of biostimulants improved growth, yield, and fruit quality attributes depending on the formulation used [24]. A greater yield per unit area may contribute to increased productivity in intensive tomato production systems; however, additional evaluations, including fruit quality attributes, production costs, and economic analysis, are required to determine the overall profitability of its application [11].

Overall, Biostimulant A was the most effective treatment for improving fresh fruit weight and total yield under the conditions of this experiment. These findings suggest that this formulation has potential as an agronomic tool to enhance tomato productivity during the fruit development stage. Nevertheless, further studies evaluating physiological and biochemical responses are necessary to elucidate the mechanisms associated with the observed productive improvements [11] [24].

4. Conclusions

The application of the evaluated fruit-fattening biostimulants significantly influenced tomato productivity and selected fruit quality attributes under greenhouse conditions. Among the tested formulations, Biostimulant A produced the best agronomic performance, resulting in the highest fresh fruit weight and total yield per hectare. Compared with the untreated control, this formulation substantially increased fruit biomass accumulation and overall productivity, demonstrating its effectiveness during the fruit development stage.

Biostimulant A also improved commercially important quality attributes by producing fruits with significantly greater firmness and higher total soluble solids (˚Brix), indicating enhanced quality for fresh-market production. In contrast, leaf greenness (SPAD index) and fruit size (polar and equatorial diameters) were not significantly affected by the evaluated biostimulants, although slight numerical increases in fruit dimensions were observed.

Overall, the results demonstrate that the response of tomato plants depended on the biostimulant formulation applied, with Biostimulant A consistently outperforming Biostimulant B in most productive and quality variables. These findings suggest that boron- and molybdenum-based biostimulants, particularly Biostimulant A, represent a promising agronomic strategy to improve tomato productivity and fruit quality under protected cultivation. Further studies should investigate the physiological mechanisms underlying these responses and evaluate their

economic feasibility under commercial production conditions.

Acknowledgements

The authors express their sincere gratitude to the Universidad Tecnológica de Culiacán for providing the greenhouse facilities and equipment necessary to conduct this research. The authors also acknowledge the Universidad Autónoma Agraria Antonio Narro and the Universidad Autónoma de Sinaloa for their academic collaboration and institutional support during the development of this study. Special thanks are extended to Bioproductos Agrícolas Smart Agroecology for generously providing the biostimulant formulations evaluated in this research and for their valuable technical support throughout the experimental work.

Author Contributions

VJAM: Conceptualization, methodology development, experimental work, data analysis, and manuscript writing; **HMMM:** Project advising, statistical analysis, interpretation of results, and manuscript review; **JGLV:** Support with the experimental methodology, analysis of results, and manuscript review; **RGLE:** Data collection, organization of information, and manuscript review; **PARR:** Project supervision, critical review of the scientific content, validation of the results, and manuscript review; **AAPS:** Provision of nutrients and products used throughout the project, biochemical analyses, and manuscript review and **GHGL:** Study conceptualization, overall project supervision, and final manuscript review.

Conflicts of Interest

The authors declare no conflicts of interest.

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