





Yield components and agronomic performance of red onion (*Allium cepa* L.) under foliar application of biostimulants in Andean agriculture

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ABSTRACT

Red onion (*Allium cepa* L.) is economically vital in Ecuador, yet yields remain suboptimal. This study evaluated the morpho-agronomic response of red onion to foliar biostimulants (fulvic acids, seaweed extract, amino acids, and Si) applied at two doses every 15 d. Plant height, leaf number, bulb size, yield, and thrips incidence were assessed. The seaweed extract (5 mL L⁻¹) elicited the best performance, followed by amino acids (1.5 g L⁻¹) and fulvic acids (5 mL L⁻¹). These treatments caused significant increases ($p < 0.05$) in vegetative growth, improving plant height by up to 9.22% and leaf number by 10.68%. Harvest variables similarly improved, with bulb diameter and yield increasing by 6.37% and 6.95% over the control. Notably, while growth promoters enhanced yield, only Si treatments significantly reduced thrips (*Thrips tabaci* Lindeman) incidence. These results validate biostimulants as a sustainable management strategy to enhance onion productivity and resilience under Andean conditions.

Key words: Amino acids, crop stress seaweed, fulvic acids, silicon, thrips incidence, yield.

INTRODUCTION

Onion (*Allium cepa* L.) is an economically important herbaceous crop cultivated worldwide. Although originally from Central Asia, its global distribution reflects its broad use as a culinary ingredient and its recognized therapeutic properties (Bedir et al., 2025). In Ecuador, 1689 ha of red onion were cultivated in 2022, producing a total of 28 508 t and resulting in a national average yield of 16.88 t ha⁻¹. The average yield over the last 5 yr up to 2022 was 14.69 t ha⁻¹, showing that this production trend was stable. Key producing provinces in the highlands include Carchi, Chimborazo, Loja, Tungurahua, and Cotopaxi (Ministerio de Agricultura y Ganadería, 2023).

One rapidly advancing technological innovation in agriculture is the foliar application of biostimulants, including humic substances, seaweed and botanic extracts, amino acids, and beneficial elements. These substances are applied to plants to enhance nutrient use efficiency and increase tolerance to abiotic stress (du Jardin, 2015). The effectiveness of these tools has been recently highlighted in challenging environments; for instance, Mukhlis et al. (2025) demonstrated that employing biostimulants in marginal areas like tidal swamp lands can significantly enhance crop yield and fertilizer efficiency, mitigating the negative impacts of soil stress. To reduce these effects, biostimulants contain bioactive compounds capable of modulating physiological and metabolic processes, leading to improved growth and plant biomass, enhanced morpho-agronomic traits, and higher yield and crop quality across a variety of crops (Rouphael and Colla, 2020).

Fulvic acids improve protein metabolism, enzymatic activity, C assimilation, chlorophyll synthesis, and drought tolerance (Zhu et al., 2025). Some studies have shown that foliar applications of fulvic acids can increase yields and promote vegetative plant growth, suggesting that fulvic acid may be a sustainable alternative to synthetic fertilizers in agroecological systems (Mahdy et al., 2024).

Seaweed extracts have been widely reported to improve crop performance, including increased yields and also improved resistance to various stress conditions. Among the most commonly used seaweeds is *Ascophyllum nodosum* L., a brown alga whose extracts show strong biological activity. These extracts function as biostimulants, potentially modulating plant hormone levels, enhancing nutrient uptake and translocation, and improving the plant's adaptability to stress (Khan et al., 2009). Additionally, various reviews of seaweed applications indicate that incorporating seaweed extracts into crops, such as onions, can increase root biomass, enhance water use efficiency, and improve yield (Pérez-Madruga et al., 2020). Regarding amino acid treatments, Abdel-Rahim et al. (2019) reported that foliar application of a free amino acid solution at 45, 60, and 75 d after transplanting in onion significantly increased plant height and total yield compared to the control.

Silicon (Si) is another biostimulant with many benefits for crops. Its use promotes sustainable agriculture and fits well within organic management practices and agroecological production. Silicon strengthens plants and increases their resistance to biotic and abiotic stress enabling more efficient use of fertilizers (Epstein, 1999). According to Venancio et al. (2022), Si fertilization increased onion bulb yield, weight, and polar diameter, while also improving the crop's tolerance to saline stress. In addition, Si enhances plant resistance and lowers the damage caused by pests, making plant tissues harder for insect chewing and penetration (Alhousari and Greger, 2018). Some studies also report decreased damage and incidence of thrips, suggesting that Si could be a potentially useful tool in thrips management in different crops (Bloese et al., 2024).

This study, therefore, aims to evaluate the agronomic responses of red onion to foliar applications of these four biostimulants under local growing conditions. Similar research has been conducted in other countries, but limited information is available for Ecuador. For that reason, this study provides relevant and useful information to support farmers and stakeholders interested in the application of biostimulants in onion production.

We hypothesized that repeated foliar applications of biostimulants would enhance onion growth and yield by improving physiological efficiency and stress resilience.

MATERIALS AND METHODS

The experiment took place in a research plot located in the parish of San Rafael (0°26'43" N, 77°54'40" W, 2290 m a.s.l.), Bolívar canton, Carchi province, Ecuador. The area has an average annual temperature of 16.45 °C. During the experimental period, which spanned from April to October (day of the year 92 to 304), the climate was characterized by an average maximum temperature of 19.3 °C and an average minimum of 8.7 °C (Figure 1). Cumulative rainfall during the trial reached 626.18 mm. Precipitation was concentrated at the beginning of the cycle, with the highest values in April (199.11 mm) and May (166.05 mm), followed by a drier period between June and September where monthly rainfall averaged 47.7 mm. The soil corresponds to an Andisol with loamy texture, typical of the Andean region. A randomized complete block design (RCBD) was employed, with blocks separated by vegetative strips to prevent potential nutrient drift that could affect the measurements. A total of three blocks and nine treatments per block were implemented, resulting in 27 experimental units, each measuring 2 m².

Commercial red onion (*Allium cepa* L.) hybrid seed 'Rasta' was obtained from an authorized distributor, who certified the quality and safety of the material. Seeds had been pre-treated with the fungicide thiram. Sowing was carried out manually in a 24 m² seedbed, with rows spaced 0.2 m apart. The seedlings were managed in the seedbed for 2 mo before being transplanted to the experimental plots. From the seedbed stage, preventive applications of fungicides and insecticides were carried out every 7 d, rotating products based on their modes of action to prevent the development of resistance.

Four different products were used, each containing only the active biostimulant specific to the treatment, to ensure that the results were not altered. Treatments T1 and T2 received 30% fulvic acids (w/w) (Ktionic, Grupo Bioquímico Mexicano S.A., Monterrey Mexico); T3 and T4 received 99.65% *Ascophyllum nodosum* L. extract (w/w) (Miros, Acadian Seaplants Limited, Nova Scotia, Canada); T5 and T6 received 90% free amino acids (w/w) (Biomax Solid, AGRInova Science, Almeria, Spain); and finally, treatments T7 and T8 received 36% silicon dioxide (orthosilicic acid, H₄SiO₄) (w/v) (Manvert Silikon, BIOVERT S.A., Lleida, Spain).

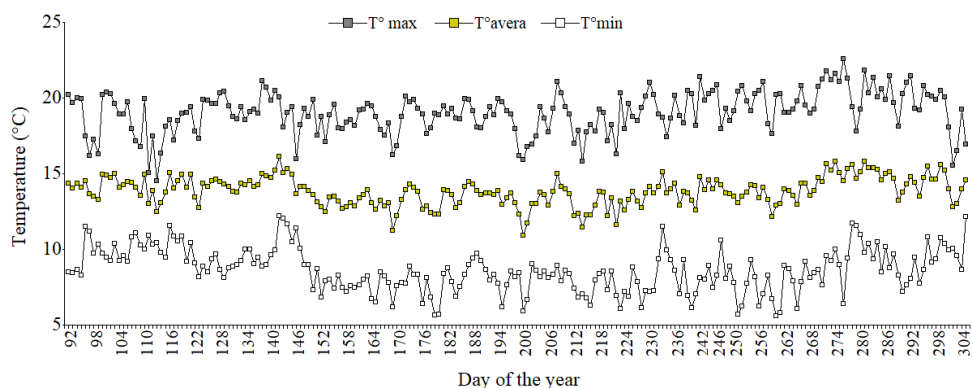


Figure 1. Maximum, average, and minimum temperature records Bolívar canton, Carchi province, Ecuador (April to October 2023).

A total of eight treatments and an untreated control were established, resulting from the biostimulants applied at the two recommended doses (Table 1), according to the manufacturer's guidelines.

In each experimental unit, onion plants were transplanted with 0.15 m between plants and 0.2 m between rows. The total duration of the crop cycle from transplanting to harvest was 110 d. Irrigation and fertilization were applied through a fertigation system three times per week throughout the cycle, with the program adjusted according to each phenological stage. Foliar applications of the biostimulants began 15 d after transplanting (DAT) and were repeated every 15 d for a total of five applications, making sure the leaves were completely covered each time. Phytosanitary applications were targeted to the specific areas of the plant where pests and diseases typically occur to enhance control efficacy.

Table 1. Treatment description.

Treatment	Composition and dose
T1	Fulvic acids, 2.5 mL L ⁻¹
T2	Fulvic acids, 5 mL L ⁻¹
T3	Seaweed extract, 2.5 mL L ⁻¹
T4	Seaweed extract, 5 mL L ⁻¹
T5	Amino acids, 0.75 g L ⁻¹
T6	Amino acids, 1.5 g L ⁻¹
T7	Si, 1 mL L ⁻¹
T8	Si, 2 mL L ⁻¹
T0	Control

A total of five measurements were taken during the crop cycle, with a final measurement at harvest. The variables analyzed included plant height, number of leaves per plant, polar and equatorial bulb diameter, thrips (*Thrips tabaci* Lindeman) incidence, and yield per hectare. Yield was measured in each experimental unit and extrapolated to per hectare values.

Statistical analyses were conducted using InfoStat version 2020 (Grupo InfoStat, FCA, Universidad Nacional de Córdoba, Argentina), employing general and mixed linear models. Mean comparisons were performed using the LSD-Fisher test ($\alpha = 0.05$), as all data met the assumptions of normality and homogeneity of variance. Results are graphically using bar plots to show treatment effects and variability.

RESULTS

Plant height generally increased in response to biostimulant applications during the crop cycle. From 45 DAT, after three foliar applications, all treatments began to show a positive response, with the superior performance of T4 starting to become evident. By 60 DAT, T4 and T6 were significantly higher than the control, although nonsignificant difference was observed between them. At this time, T4 and T6 reached 55.57 and 54.83 cm, respectively, while the control did not exceed 52 cm. At 75 DAT, all treatments except T7 were significantly taller than the control. The tallest plants were found in T4 (71.78 cm), T6 (71.37 cm) and T2 (70.49 cm), representing increases of 9.22%, 8.59% and 7.26% over the control (65.72 cm). Although T4 had the highest plant height among all treatments, it was not significantly different from T6 and T2 (Figure 2).

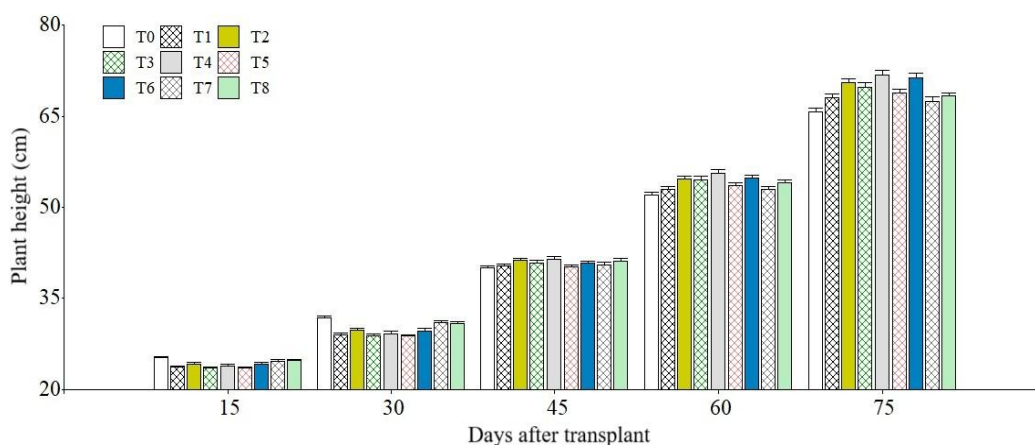


Figure 2. Plant height of red onion measured at five time points during the crop cycle. T0: Control; T1: Fulvic acids, 2.5 mL L⁻¹; T2: Fulvic acids, 5 mL L⁻¹; T3: Seaweed extract, 2.5 mL L⁻¹; T4: Seaweed extract, 5 mL L⁻¹; T5: Amino acids, 0.75 g L⁻¹; T6: Amino acids, 1.5 g L⁻¹; T7: Si, 1 mL L⁻¹; T8: Si, 2 mL L⁻¹.

The number of leaves also increased under biostimulant applications, with the effect being more evident from 60 DAT, particularly for T4, which reached 8.81 leaves per plant, being significantly superior to all other treatments, including the control, which did not exceed 8.06 leaves. At 75 DAT, the end of vegetative growth, all treatments except T7 and T8 were significantly different from the control. The T4 stood out with 10.88 leaves per plant, significantly higher than the other treatments, followed by T6 with 10.56 leaves per plant, while the control reached 9.83 leaves, representing increases of 10.68% and 7.43%, respectively (Figure 3).

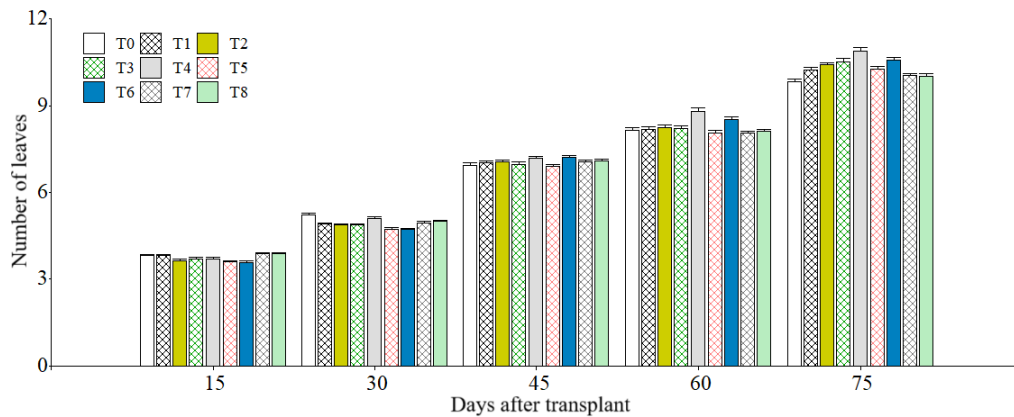


Figure 3. Number of leaves per plant of red onion measured at five time points during the crop cycle. T0: Control; T1: Fulvic acids, 2.5 mL L⁻¹; T2: Fulvic acids, 5 mL L⁻¹; T3: Seaweed extract, 2.5 mL L⁻¹; T4: Seaweed extract, 5 mL L⁻¹; T5: Amino acids, 0.75 g L⁻¹; T6: Amino acids, 1.5 g L⁻¹; T7: Si, 1 mL L⁻¹; T8: Si, 2 mL L⁻¹.

Regarding the variables measured at harvest, biostimulant treatments positively responded to the applications, with all treatments being significantly higher than the control. The highest equatorial bulb diameter was observed in T4 (7.85 cm), representing an increase of 6.37% over the control (7.38 cm), followed by T6 (7.81 cm), T2 (7.76 cm), T3 (7.73 cm) and T5 (7.68 cm), which did not differ significantly among them (Figure 4).

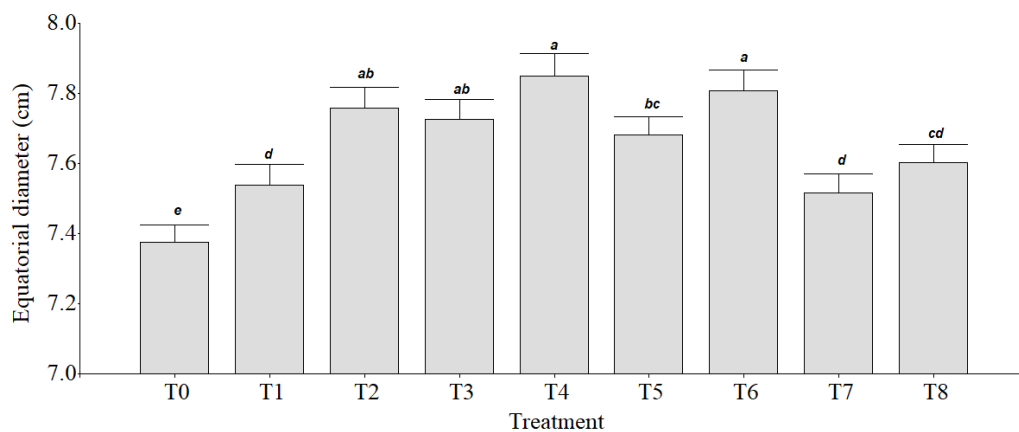


Figure 4. Equatorial bulb diameter of red onion measured at harvest. T0: Control; T1: Fulvic acids, 2.5 mL L⁻¹; T2: Fulvic acids, 5 mL L⁻¹; T3: Seaweed extract, 2.5 mL L⁻¹; T4: Seaweed extract, 5 mL L⁻¹; T5: Amino acids, 0.75 g L⁻¹; T6: Amino acids, 1.5 g L⁻¹; T7: Si, 1 mL L⁻¹; T8: Si, 2 mL L⁻¹. Values followed by the same letter are not significantly different based on LSD Fisher test ($p < 0.05$).

A similar trend was observed for polar bulb diameter, with all biostimulant treatments being significantly higher than the control. The highest diameter was recorded in T4 (7.39 cm), representing an increase of 4.82% over the control (7.05 cm), followed by T6 (7.37 cm) and T2 (7.33 cm), which did not differ significantly among them (Figure 5).

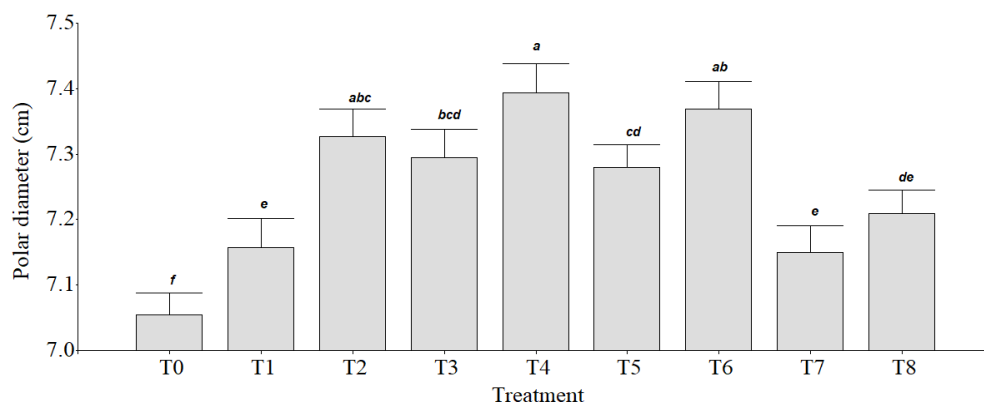


Figure 5. Polar bulb diameter of red onion at harvest. T0: Control; T1: Fulvic acids, 2.5 mL L⁻¹; T2: Fulvic acids, 5 mL L⁻¹; T3: Seaweed extract, 2.5 mL L⁻¹; T4: Seaweed extract, 5 mL L⁻¹; T5: Amino acids, 0.75 g L⁻¹; T6: Amino acids, 1.5 g L⁻¹; T7: Si, 1 mL L⁻¹; T8: Si, 2 mL L⁻¹. Values followed by the same letter are not significantly different based on LSD Fisher test ($p < 0.05$).

Higher bulb size generally resulted in higher yields, with all treatments except T1 being significantly higher than the control. The highest yield was recorded in T4 (43.83 t ha⁻¹), representing an increase of 6.95% over the control (40.98 t ha⁻¹), followed by T6 (43.49 t ha⁻¹), T2 (43.17 t ha⁻¹) and T3 (43.16 t ha⁻¹), which did not differ significantly among them (Figure 6).

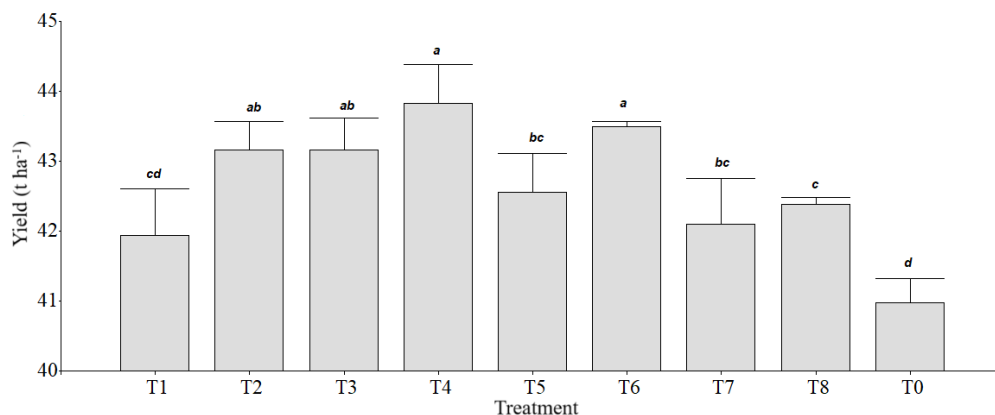


Figure 6. Estimated yield per hectare at harvest. T0: Control; T1: Fulvic acids, 2.5 mL L⁻¹; T2: Fulvic acids, 5 mL L⁻¹; T3: Seaweed extract, 2.5 mL L⁻¹; T4: Seaweed extract, 5 mL L⁻¹; T5: Amino acids, 0.75 g L⁻¹; T6: Amino acids, 1.5 g L⁻¹; T7: Si, 1 mL L⁻¹; T8: Si, 2 mL L⁻¹. Values followed by the same letter are not significantly different based on LSD Fisher test ($p < 0.05$).

For thrips incidence, it was observed that at 15 DAT the pest incidence was above 87% in all treatments, including the control. At this time, as well as at 30 DAT, nonsignificant differences were detected among treatments. By 45 DAT, incidence decreased due to weekly phytosanitary applications across the experimental area, and a positive response was observed in treatments T7 and T8, with 15.56% and 20.00% of plants showing thrips presence, respectively; these were the only treatments significantly different from the others. At 75 DAT, treatments T7 (23.33%) and T8 (21.11%) maintained lower incidence levels compared to the control and the remaining treatments, which did not exhibit a favorable response for this variable and had incidences above 35% (Figure 7).

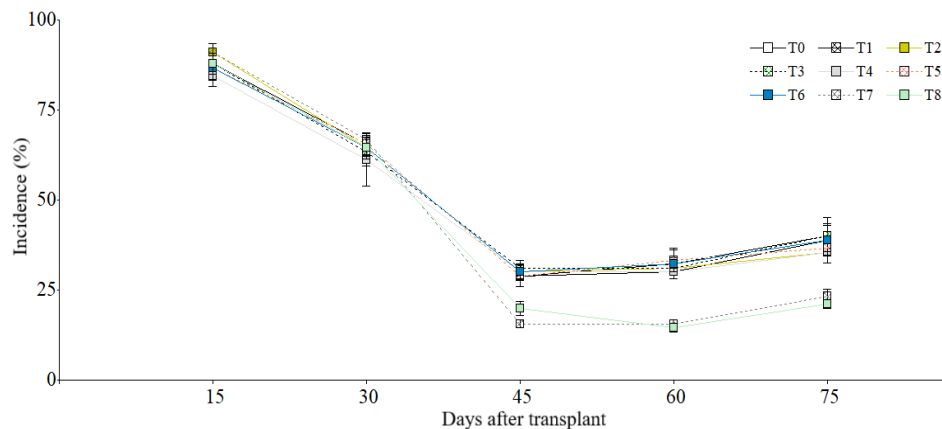


Figure 7. Thrips (*Thrips tabaci* L.) incidence measured as the percentage of plants infested at five different time points. T0: Control; T1: Fulvic acids, 2.5 mL L⁻¹; T2: Fulvic acids, 5 mL L⁻¹; T3: Seaweed extract, 2.5 mL L⁻¹; T4: Seaweed extract, 5 mL L⁻¹; T5: Amino acids, 0.75 g L⁻¹; T6: Amino acids, 1.5 g L⁻¹; T7: Si, 1 mL L⁻¹; T8: Si, 2 mL L⁻¹.

DISCUSSION

Seaweed (*Ascophyllum nodosum* L.) extracts and crop performance

Morpho-agronomic variables measured during the vegetative stage, such as plant height and leaf number are key indicators of growth performance and vigor in onion (*Allium cepa* L.) crops, reflecting the effects of biostimulants applications (Zhang et al., 2025). The positive effect on plant growth can be associated with the bioactive compounds present in brown seaweed (*Ascophyllum nodosum* L.) extracts, especially growth regulators such as cytokinins, auxins, betaines, brassinosteroids, and polyamines; whose combined effect can potentially promote cell division and elongation, nutrient uptake, and consequently leaf development (Khan et al., 2009).

In addition, alginic acid, polyphenols, and polysaccharides such as laminarin improve water retention, nutrient availability and mitigate oxidative stress (Kumari et al., 2023), contributing together to a notable increase in the vegetative parameters evaluated in the present study. The significant increases in vegetative growth observed in this study align with previous findings in onion plants. Alvarez et al. (2020) reported similar enhancements in plant height, while Szczepanek et al. (2017) observed comparable increases in the number of leaves per plant with foliar applications of seaweed extracts applied multiple times using similar doses to those evaluated in this research. Taken together, our results suggest that *A. nodosum* extracts act as powerful biostimulants. They not only promote growth parameters, but also may support physiological processes such as chlorophyll accumulation and photosynthetic activity, as reported in previous studies, which may help improve crop performance (Khan et al., 2009).

Amino acids in plant development

The present investigation demonstrated that amino-acid based biostimulants can also show a significant improvement in growth parameters of onion. When applied externally, amino acids (AAs) are absorbed by plants through leaves or roots and can enter metabolic processes, serving as structural components of proteins (Abdel-Rahim et al., 2019). The AAs promote enzyme activity, and serve as precursors for plant hormones and secondary metabolites, working together on robust plant development, as noted in peach (*Prunus persica* (L.) Batsch) (Al-Saif et al., 2024).

Previous studies may explain the higher values observed in the vegetative parameters measured in this investigation, showing that AAs improve fertilizer assimilation, water uptake and photosynthesis in a wide range of different crops, which can lead to better vegetative growth, flowering, fruit set, yield and quality (Abdelkader et al., 2023). The stimulatory effect observed in this experiment, could be related to the presence of free AAs

such as glycine and glutamic acid, which contribute in chlorophyll synthesis and plant tissue development (El-Metwally et al., 2022) as well as proline, which enhances defense mechanisms under stress conditions, as observed in lettuce (*Lactuca sativa* L.) (Kalisz et al., 2024). These AAs are commonly found in commercial protein hydrolysates, such as the one used in this study. Moreover, AAs have been shown to mitigate abiotic stress and act as signaling agents, influencing different physiological pathways that improved crop performance in castor bean (*Ricinus communis* L.) (Esmailian et al., 2023). The positive response of onion plants to AAs observed in this study is consistent with previous findings. Abdel-Rahim et al. (2019) also found significant improvements in onion plant height when applying a free amino acid source at three different times after transplanting.

Fulvic acids and their role in plant growth

In this experiment, we also found positive effects for treatments that received fulvic acids (FAs). The effectiveness of the foliar applications of FAs performed in this study may be due to its lower molecular weight compared to humic acids, which facilitates the penetration to the cell membrane and formation complexes with cations, promoting nutrient uptake and consequently improving crop performance (Zhu et al., 2025).

Studies in sweet potato (*Ipomoea batatas* (L.) Lam.), have shown that FAs act as biostimulants by contributing to nutrient and water absorption, thereby improving plant metabolic processes, enzymatic activity and stress resistance (Ibrahim and El-Metwaly, 2025). Furthermore, our results align with reports showing that various humic substances can significantly influence diverse agronomic parameters such as plant height, biomass accumulation, and yield components of different crop species (El-Shaieny et al., 2023). Moreover, studies in oat (*Avena sativa* L.) have shown that FAs enhances drought tolerance by boosting antioxidant activity and overall crop performance (Zhu et al., 2024) and in tea (*Camellia sinensis* (L.) Kuntze) plants by promoting flavonoid biosynthesis, which contributes to antioxidant defense (Sun et al., 2020). The vegetative increases observed in this study are consistent with findings in onion plants, where foliar spraying with FAs significantly improved plant height and leaf number (Marey and Elmasry, 2024).

Vegetative growth and bulb yield relationship

The increases observed in vegetative parameters, as a consequence of the applied biostimulant treatments, helped to improve bulb development, with significant higher bulb size which eventually reflected in greater yields, suggesting the important role of vegetative vigor in determining final crop performance. The close relationship between vegetative growth and ultimate bulb yield in onion represents a key area of study for improving crop productivity (Dutta et al., 2024).

In this context, the vigor and size of vegetative structures in onion, such as leaf number, plant height and leaf sheath diameter, are closely associated with bulb growth (Nourbakhsh and Cramer, 2022) further supporting the findings of our study, as more developed vegetative structures lead to higher photosynthetic capacity and nutrient allocation efficiency (Younes et al., 2023). Moreover, the increase in bulb size may be attributed to the accumulation of fructo-oligosaccharides produced in the aerial part of the plant, which are later translocated to the leaf sheaths to form the bulbs (Oku et al., 2019). The bulb size and yield increases observed in this study are in line with the findings of Abbas et al. (2020), who reported bulb diameter increases in three different onion cultivars under the application of biostimulants; while Ahmed et al. (2019) found significantly higher vegetative growth and consequently greater yields, particularly for the seaweed and amino acid treatments, which showed the best performance. Similarly, other agronomic strategies such as biofortification aim to enhance the nutritional value of onions without compromising their productivity. In this sense, Machado et al. (2024) demonstrated that soil applications of Se (up to 1.6 kg Se ha⁻¹) did not significantly affect total or commercial bulb yield, nor did they alter physicochemical quality parameters like pH or soluble solids, while successfully increasing the Se content in the bulbs to produce a nutritionally superior product.

Silicon and pest resistance

Silicon (Si), as observed in this experiment, also showed effects on plant agronomic performance, mainly by reducing pest incidence. This reduction may be attributed to Si strengthening cell walls by reinforcing epidermal tissues and forming a protective layer that limits the penetration and feeding of different pests, thereby improving plant resistance to biotic stress (Song et al., 2021).

Furthermore, Si supplied at the concentrations evaluated in this study strengthened the plant by forming a mechanical barrier of silica crystals (Epstein, 1999). Studies in maize (*Zea mays* L.) have shown that foliar Si reduces damage caused by fall armyworm (*Spodoptera frugiperda* J.E. Smith) while also improving crop yield (Srinivasan et al., 2023). Similarly, Si application reduced the development of sugarcane borer (*Diatraea saccharalis* Fabr.) in sugarcane (*Saccharum officinarum* L.) while enhancing plant growth (Sousa et al., 2023). The present study also aligns with the findings of Kandil et al. (2020) in onion cultivation, where foliar applications of Si, applied three times every 15 d after transplanting, significantly reduced the thrips population density.

Dose-dependent effect of biostimulants

The response of crops to biostimulant doses strongly depends on factors such as product concentration, application frequency, cultivar, and edaphoclimatic conditions. In this study, higher doses generally resulted in better outcomes, but this trend cannot be conclusive. Previous studies reported that the intermediate dose of *A. nodosum* extract showed the best growth and yield in tomato plants (Subramaniyan et al., 2023). In contrast, higher doses of an organic biostimulant improved overall growth and yield in lettuce (Bulgari et al., 2019).

The magnitude of these dose-dependent effects is closely related to the biochemical composition of biostimulants, physiological state of plants and environmental interactions (Yuan and Dickinson, 2024). This variability in dose response is also observed in biofortification programs; for example, Machado et al. (2024) found a linear increase in Se accumulation in onion bulbs as the applied dose increased from 0 to 1.6 kg ha⁻¹, confirming that nutrient uptake can be highly responsive to the concentration of the element provided in the soil. It is also important to consider the concept of “hormesis”, where low doses may stimulate beneficial responses while excessive concentrations could potentially cause phytotoxicity or nutrient imbalances, although such negative effects were not observed in our trial. Our findings further highlight the importance of testing different doses while keeping them within the ranges recommended by the manufacturer, as these suggestions are usually delivered from extensive performance trials across different crops and growing conditions. From an economic perspective, identifying the optimal biological dose is crucial to maximize the return on investment for farmers, avoiding unnecessary input costs.

CONCLUSIONS

This study showed that foliar applications of biostimulants every 15 d in onion crops elicited a positive agronomic response, with notable variations observed in all evaluated morpho-agronomic traits and a clear tendency toward lower values in the control. Treatment with seaweed extracts at a dose of 5 mL L⁻¹ demonstrated the best performance, increasing yields and being statistically superior to the control across all analyzed variables. Regarding the incidence of *Thrips tabaci*, only treatments with Si at 1 and 2 mL L⁻¹ showed a significant reduction of the pest from the third foliar application onward, whereas the remaining biostimulant treatments exhibited no effect on this variable.

Notably, the beneficial effects of biostimulants became evident only after multiple applications, with most variables showing measurable responses from the third application onward.

Author contribution

Conceptualization: A.A.A.A., J.K.P. Methodology: A.A.A.A., I-S.S.C., M.A-I. Validation: J.K.P. Formal analysis: A.A.A.A., J.K.P. Investigation: A.A.A.A., I-S.S.C., M.A-I. Resources: A.A.A.A. Data curation: A.A.A.A., I-S.S.C., J.K.P. Writing-original draft preparation: A.A.A.A. Writing-review and editing: I-S.S.C., J.K.P. Visualization: A.A.A.A., I-S.S.C. Supervision: M.A-I. All co-authors reviewed the final version and approved the manuscript before submission.

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