Universidade Federal Rural do Semi-Árido
Pró-Reitoria de Pesquisa e Pós-Graduação
https://periodicos.ufersa.edu.br/index.php/caatinga
ISSN 1983-2125 (online)

http://dx.doi.org/10.1590/1983-21252026v3915557rc

Scientific Article

Biostimulants and *Bacillus* spp. modulate growth, nutrient accumulation, and yield of beet under semi-arid conditions

Bioestimulantes e *Bacillus* spp. modulam crescimento, acúmulo de nutrientes e produtividade da beterraba no semiárido

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ABSTRACT – Combining biostimulants and plant growth-promoting bacteria (PGPB) can modulate plant physiology and increase crop yield in semi-arid regions. This study aimed to evaluate the agronomic performance of beet (*Beta vulgaris* L.) under isolated and combined applications of biostimulants and PGPB under semi-arid conditions. Two field experiments were conducted in 2024 and 2025 using a randomized complete block design with nine treatments (control, Biotrio®, Onix OG®, Acadian®, Stimulate®, Biotrio® + Acadian®, Biotrio® + Stimulate®, Onix OG® + Acadian®, and Onix OG® + Stimulate®) and four replications. Photosynthetic pigments, growth, nutrient accumulation, yield, and postharvest quality of the storage roots were evaluated. Soluble solids were the only variable analyzed in this study that was not influenced by the interaction between treatments and growing seasons. In 2024, greater plant growth, biomass and nutrient accumulation, and yield were observed. In 2025, the agronomic performance of beet declined; however, some treatments showed greater physiological and yield stability. The combination of *Bacillus methylotrophicus* (Onix OG®) and *Ascophyllum nodosum* (Acadian®) showed the most consistent performance in terms of growth, nutrient accumulation, and yield, promoting greater dry matter and nutrient accumulation, as well as marketable yields of 15.15 and 12.41 t ha^{-1} in 2024 and 2025, respectively. Betalain and total soluble sugar contents were also influenced, indicating that the bioinputs affected storage-root quality. The combined application of *Bacillus* spp. and biostimulants improved several agronomic traits of beets, with responses that depend on water availability.

Keywords: *Beta vulgaris* L.. Abiotic stress. Bioinputs. Production.

RESUMO – Combinar bioestimulantes e bactérias promotoras de crescimento de plantas (BPCP) pode modular a fisiologia e aumentar a produtividade das culturas em regiões semiáridas. Objetivou-se avaliar o desempenho agronômico da beterraba (*Beta vulgaris* L.) submetida à aplicação isolada e combinada de bioestimulantes e BPCP em condições semiáridas. Dois experimentos de campo foram conduzidos (2024 e 2025), delineado em blocos casualizados, com nove tratamentos (controle, Biotrio®, Onix OG®, Acadian®, Stimulate®, Biotrio® + Acadian®, Biotrio® + Stimulate®, Onix OG® + Acadian®, and Onix OG® + Stimulate®) e quatro repetições. Foram avaliados os pigmentos fotossintéticos, o crescimento, o acúmulo de nutrientes, a produtividade e a qualidade pós-colheita das raízes tuberosas. Os sólidos solúveis foi a única variável que não foi influenciada pela interação entre os tratamentos e os ciclos de cultivo. Em 2024, houve maior crescimento das plantas, acúmulo de biomassa e nutrientes e maior produtividade. Em 2025, o desempenho agronômico da beterraba reduziu; entretanto, alguns tratamentos apresentaram maior estabilidade fisiológica e produtiva. A combinação de *Bacillus methylotrophicus* (Onix OG®) *Ascophyllum nodosum* (Acadian®) apresentou o desempenho mais consistente em termos de crescimento, acumulação de nutrientes e produtividade, promovendo maior acúmulo de matéria seca e nutrientes, além de produtividades comerciais de 15,15 e 12,41 t ha^{-1} em 2024 e 2025, respectivamente. Os teores de betalaínas e açúcares solúveis totais também foram influenciados, indicando efeito dos bioinsumos sobre a qualidade da raiz tuberosa. A aplicação combinada de *Bacillus* spp. e bioestimulantes melhorou várias características agronômicas da beterraba, com respostas que dependem da disponibilidade de água.

Palavras-chave: *Beta vulgaris* L.. Estresse abiótico. Bioinsumos. Produção.

Conflict of interest: The authors declare no conflict of interest related to the publication of this manuscript.

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Received for publication in: August 4, 2026.
Accepted in: November 4, 2026.

Editor in Chief: Aurélio Paes Barros Júnior

Data Availability: The data that support the findings of this study can be made available, upon reasonable request, from the corresponding author.

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INTRODUCTION

In Brazil, the average beet (*Beta vulgaris* L.) yield ranges from 35 to 50 t ha^{-1} (TRANI et al., 2018). In semi-arid regions, however, yields often fall below this range, varying from 17 to 32 t ha^{-1} (COSTA et al., 2024). This lower yield may be associated with the adverse environmental conditions characteristic of these regions, particularly high temperatures and limited water availability.

Climate change, by altering temperature and precipitation patterns, tends to intensify these constraints, especially in environments that are already inherently stressful (LI et al., 2026). Water stress, in particular, can affect plant growth and physiological processes, thereby influencing crop yield and food quality. In this context, the use of biostimulants and plant growth-promoting bacteria (PGPB) has stood as a promising strategy to mitigate the effects of abiotic stress and improve crop performance under adverse conditions (SILVA et al., 2023; HENDERSON; SANDERSON; FOWLES, 2025).

Biostimulants can be classified as microbial and non-microbial and promote beneficial effects such as enhanced nutrient uptake, increased stress

tolerance, and improved yield and crop quality (AZZAM et al., 2026). PGPB, in turn, stimulate plant growth through root development, increased nutrient availability, and phytohormone production, contributing to improved plant nutritional status, even under stress conditions (ANWAR et al., 2024). Moreover, these microorganisms can also enhance yield under non-stress conditions (MONTEIRO et al., 2019), which highlights their potential across different cropping environments.

Biostimulants based on plant growth regulators, such as kinetin, gibberellic acid, and auxins, are widely used, either individually or in combination, primarily promoting cell division and elongation (ANWAR et al., 2024). Algal extracts, such as *Ascophyllum nodosum*, also stand out as effective biostimulants, influencing plant physiology, nutritional efficiency, growth, and stress tolerance (DIAS et al., 2026). In addition, they can stimulate root exudation, enhancing microbial activity in the rhizosphere and promoting interactions with PGPB (SELVARAJ et al., 2025). Among these microorganisms, species of the genus *Bacillus* are particularly notable for promoting plant growth, improving nutrient availability, and inducing tolerance to abiotic stress (AIJAZ et al., 2024). Their relevance to beet cultivation is supported by studies reporting beneficial effects of *Bacillus* inoculation on sugar beet growth and rhizosphere conditions, as well as identifying bacterial species of this genus with plant growth-promoting traits associated with the crop (SUN et al., 2026).

The combined application of microbial and non-microbial biostimulants may represent an alternative approach to improving crop performance by integrating different mechanisms of plant growth promotion. In this context, the association of *Bacillus*-based inoculants with *A. nodosum* seaweed extract or plant growth regulator formulations containing GA_3, kinetin, and IBA may provide complementary effects on plant development, nutrient accumulation, and productivity. However, the effectiveness of these combinations may vary according to environmental and soil conditions, particularly under semi-arid conditions. Therefore, evaluating these products individually and in combination is important to determine their potential benefits for beet cultivation.

Although the individual effects of biostimulants and PGPB are well documented, studies evaluating their combined application remain limited. Their interaction may result in synergistic effects, enhancing physiological processes related to growth, nutrition, and stress tolerance, particularly under semi-arid conditions. The objective of this study was to evaluate the effects of separate and combined applications of plant-growth-promoting bacteria of the genus *Bacillus* and non-microbial biostimulants on the growth, biomass, and nutrient accumulation, as well as the yield and postharvest quality of beet under field conditions in a semiarid region.

MATERIAL AND METHODS

Experimental Site Description

Field experiments were conducted from September to November 2024 and from August to October 2025 at the Rafael Fernandes Experimental Farm of the Federal Rural University of the Semi-Arid Region, located in Mossoró, Rio Grande do Norte, Brazil (5°06′37″ S, 37°23′50″ W; altitude 72 m). Although both experiments were conducted at the same experimental site, they took place during different periods of the year, which may have resulted in differences in environmental conditions. The climate of the region is classified as BSh according to Köppen's classification. Climate data for the experimental periods were obtained from a weather station installed at the experimental site (Figure 1).

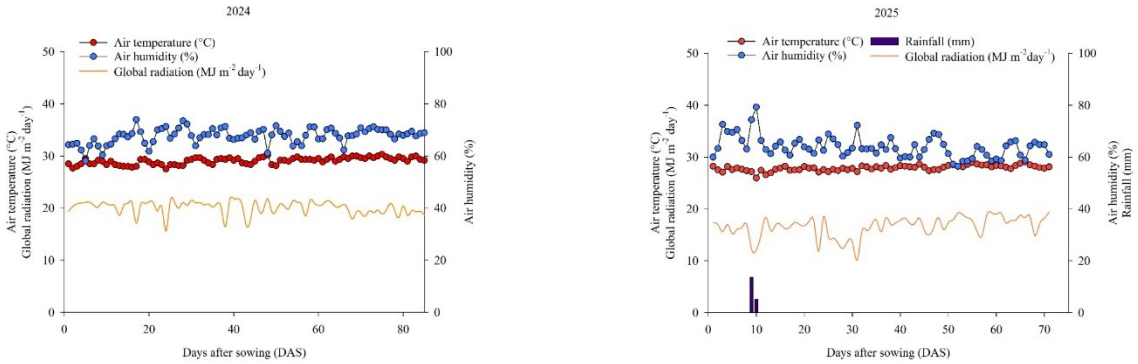


Figure 1. Climate records in the experimental areas of the Rafael Fernandes Experimental Farm during the months of September to November 2024 and August to October 2025, in Mossoró, State of Rio Grande do Norte, Brazil.

The soil in the experimental area is classified as an Argissolo in the Brazilian Soil Classification System (SANTOS et al., 2025). Before the establishment of each experiment, soil samples were collected from the 0–20 cm layer for chemical characterization. In each experimental area, 20 sampling points were distributed across the area and sampled. The samples were combined into a composite sample per growing season. Soil chemical analyses were performed to determine the properties presented in Table 1.

Table 1. Chemical characterization of the soil in the experimental area of the Rafael Fernandes Experimental Farm at a depth of 0–20 cm.

Years	pH	EC	O.M	Fe	Cu	Zn	Mn
	H_2O	dS m^{-1}	g kg^{-1}	mg dm^{-3}			
2024	5.26	0.03	3.72	89.10	0.26	3.72	17.32
2025	6.68	0.04	3.92	78.59	0.27	3.92	21.84

	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	(H+Al)	SB	CEC	V
	mg dm^{-3}			cmol dm^{-3}						%
2024	5.8	3.91	0.001	0.97	0.77	0	0.7	1.751	2.451	71.4
2025	8.0	7.82	0.003	1.28	0.97	0	1.0	2.273	3.273	69.4

pH: Hydrogen potential; O.M.: Organic matter; EC: Electrical conductivity; Extractor Melich ($HCl+H_2SO_4$): P, K^+ e Na^+; Ca^{2+}, Mg^{2+} e Al^{3+}: KCl 1M; S: Ca (H_2PO_4); H+Al: Potential acidity; SB: Sum of bases; CEC: Cation exchange capacity; V: Base saturation.

Experimental Design and Plant Material

The experiments were carried out in a randomized complete block design with nine treatments and four replications. Both isolated and combined applications of PGPB and biostimulants were evaluated: T1: control; T2: Biotrio®; T3: Onix OG®; T4: Acadian®; T5: Stimulate®; T6: Biotrio® + Acadian®; T7: Biotrio® + Stimulate®; T8: Onix OG® + Acadian®; and T9: Onix OG® + Stimulate®.

The PGPB used were *Bacillus pumilus* CCTB05, *Bacillus subtilis* CCTB04, and *Bacillus amyloliquefaciens* CCTB09 (Guaranteed concentration: 1 × 10^8 CFU mL^{-1}; Biotrio® – BIOTROP®), and *Bacillus methylotrophicus* UFPEDA 20 (Minimum concentration: 1 × 10^8 CFU mL^{-1}; Onix OG® – Lallemand Plant Care®), applied at a rate of 1.5 L ha^{-1} via fertigation. Prior to application, the bacterial suspensions were prepared in clean plastic containers by diluting the commercial products in water according to the rates established for each treatment, followed by manual mixing to ensure uniform distribution of the microorganisms. The solutions were applied through the irrigation system using a Venturi-type injector, allowing direct delivery to the plant root zone and promoting initial rhizosphere colonization. After injection of the suspensions, the irrigation system remained in operation for a sufficient period to ensure homogeneous distribution of the microorganisms throughout the experimental plots and to minimize losses through runoff in the lateral lines. Applications were performed at 14, 21, and 28 days after sowing (DAS).

The biostimulants used consisted of two products. Acadian® (Koppert®), a seaweed extract derived from *Ascophyllum nodosum*, water-soluble K_2O: 5.3% (61.46 g L^{-1}); total organic carbon: 6.0% (69.60 g L^{-1}), was applied at a rate of 2.5 L ha^{-1}. Stimulate® (Stoller®), a plant growth regulator formulation containing gibberellic acid (concentration: 50 mg L^{-1}; GA_3), kinetin (concentration: 90 mg L^{-1}), and indole-3-butyric acid (concentration: 50 mg L^{-1}; IBA), was applied at a rate of 450 mL ha^{-1}.

The soil was prepared by plowing, harrowing, and raising the beds. At planting, 190 kg ha^{-1} of P_2O_5 (SILVA et al., 2019) was applied as single superphosphate (18% P_2O_5, 12% Ca, and 10% S). Topdressing fertilization was carried out through fertigation. In 2024, 86.94 kg ha^{-1} of N, 101.14 kg ha^{-1} of K_2O, 59.52 kg ha^{-1} of Ca, 17.61 kg ha^{-1} of Mg, and 23.48 kg ha^{-1} of S were applied. In 2025, 77.59 kg ha^{-1} of N, 85.91 kg ha^{-1} of K_2O, 52.91 kg ha^{-1} of Ca, 15.65 kg ha^{-1} of Mg, and 18.17 kg ha^{-1} of S were applied. Urea (45% N), potassium chloride (58% K_2O), calcium nitrate (15% N and 18% Ca), and magnesium sulfate (12% S and 9% Mg) were used as nutrient sources. Micronutrients were not applied because the experimental area had already received these nutrients in previous experiments. Fertilizer application rates differed between growing seasons because they were adjusted according to the results of the soil chemical analyses performed before each experiment, considering the nutrient availability in each experimental area.

Each plot measured 3.0 m × 1.0 m and consisted of four rows spaced 0.25 m apart, with 0.10 m between plants. Four seed clusters of the 'Early Wonder' cultivar were sown per hole at a depth of 2 cm. Thinning was performed at 20 DAS, when plants had three to four true leaves, leaving one plant per hole, resulting in approximately 120 plants per plot. Only plants from the two central rows were considered for evaluation, excluding border plants, which resulted in 56 plants evaluated per plot.

Drip irrigation was used, with three drip lines per bed spaced 0.50 m apart. Emitters were pressure-compensating, spaced 0.30 m apart, with a flow rate of 1.5 L h^{-1}. Irrigation depths were determined based on crop evapotranspiration. Total applied water depths were 733.66 mm in 2024 and 458.87 mm in 2025.

This difference resulted from operational failures in the water supply system of the experimental farm during part of the 2025 growing season, causing temporary interruptions in water availability and preventing the full replacement of the crop evapotranspiration demand. Despite this limitation, the irrigation system remained operational throughout the experiment, allowing the plants to be grown under controlled conditions of moderate water deficit, consistent with the production reality of semi-arid regions. Furthermore, the water restriction conditions observed in 2025 did not impair crop development or treatment evaluation, but instead allowed the assessment of the agronomic performance of biostimulants and plant growth-promoting bacteria under a scenario of greater abiotic stress, thereby increasing the practical relevance of the results obtained.

Weeds were controlled by manual hoeing, and crop protection was performed using chemical control. Cercospora leaf spot (*Cercospora beticola*) was managed with fungicides Cabrio Top® (pyraclostrobin + metiram) and Amistar Top® (azoxystrobin + difenoconazole), while leafminers (*Liriomyza* spp.) were controlled using Delegate® (spinetoram). Harvest was performed at 85 DAS in 2024 and 71 DAS in 2025, when plants showed signs of physiological senescence.

Experimental Analyses

At 55 DAS, chlorophyll *a*, chlorophyll *b*, total chlorophyll, and carotenoid contents were determined using the 80% acetone extraction method (LICHTENTHALER, 1987). Growth variables were evaluated one day before harvest. Plant height (cm) and number of leaves per plant were recorded. Dry matter accumulation (g per plant) was determined for shoots, tuberous roots, and total biomass after drying in a forced-air oven at 65 °C until constant weight.

The dried samples were ground in a Wiley-type mill with a 2.0-mm-mesh screen and subjected to sulfuric acid digestion for macronutrient determination (SILVA, 2009). Nitrogen was determined using the Kjeldahl method; phosphorus by colorimetry using a UV–VIS spectrophotometer (UV-5100 METAHS®); and potassium by flame photometry (DM-62 DIGIMED®). Nutrient accumulation in shoots, tuberous roots, and total biomass was expressed in kg ha^{-1}.

At harvest, tuberous roots were classified by diameter (HORTBRASIL, 2006), and commercial, non-commercial, and total yields (t ha^{-1}) were calculated.

Postharvest quality analyses were performed using commercial roots. Samples were washed, sanitized, and processed to obtain juice extract. Soluble solids (SS) were measured using a digital refractometer (PR-100®, Atago®, Japan) and expressed as %. Total soluble sugars (TSS) were determined by the anthrone method (YEMM; WILLIS, 1954). Titratable acidity (TA) was determined by titration with 0.1 N NaOH at pH 8.14 (LATIMER, 2023) and expressed as mEq 100 g^{-1}. Betalain content (mg g^{-1}) was determined according to the Beer–Lambert–Bouguer law (TANG; NORZIAH, 2007).

Statistical Analyses

Data from each experiment were subjected to analysis of variance using the F-test at 5% significance level. Normality of residuals was assessed using the Shapiro-Wilk test, while homogeneity of variances was evaluated using Levene's test, both at 5% significance level. For variables that met the assumptions of normality and homogeneity of variances, a combined analysis across years was performed. Means were grouped using the Scott–Knott test at 5% probability level. All statistical analyses were performed using SISVAR software v.5.6 (FERREIRA, 2019).

RESULTS AND DISCUSSION

In 2024, chlorophyll *a* contents ranged from 0.241 to 0.326 mg g^{-1}, with no significant differences among treatments. In contrast, during the 2025 growing season, characterized by greater water restriction, the treatments Biotrio® + Acadian®, Biotrio® + Stimulate®, and Onix OG® + Acadian® showed lower chlorophyll *a* contents, whereas the control had the highest value (0.352 mg g^{-1}). Furthermore, these combinations showed reduced chlorophyll *a* levels compared to the previous growing season (Table 2).

Table 2. Concentration of chlorophyll a (Chl a), chlorophyll b (Chl b), total chlorophyll (Chl t), and carotenoids (CAR) in beet leaves under the application of biostimulants and bacteria of the genus *Bacillus*.

Treatment	Chl a (mg g^{-1})		Chl b (mg g^{-1})		Chl t (mg g^{-1})		CAR (mg g^{-1})	
	2024	2025	2024	2025	2024	2025	2024	2025
Control	0.326Aa	0.352Aa	0.120Aa	0.061Bb	0.445Aa	0.394Aa	3.664Aa	3.620Ba
Biotrio®	0.250Aa	0.310Aa	0.076Ba	0.083Aa	0.344Ba	0.328Aa	2.572Bb	4.640Aa
Onix OG®	0.248Aa	0.292Aa	0.080Ba	0.096Aa	0.309Ba	0.345Aa	2.577Bb	4.155Aa
Acadian®	0.301Aa	0.251Aa	0.082Ba	0.071Aa	0.365Ba	0.172Cb	3.038Ba	1.946Cb
Stimulate®	0.241Ab	0.328Aa	0.089Ba	0.093Aa	0.323Ba	0.390Aa	2.488Bb	4.280Aa
Biotrio®+Acadian®	0.285Aa	0.119Bb	0.104Aa	0.034Cb	0.394Aa	0.155Cb	2.680Ba	1.690Cb
Biotrio®+Stimulate®	0.281Aa	0.161Bb	0.088Ba	0.061Bb	0.382Aa	0.266Bb	2.494Ba	2.333Ca
Onix OG®+Acadian®	0.270Aa	0.141Bb	0.079Ba	0.038Cb	0.346Ba	0.156Cb	2.465Ba	1.842Cb
Onix OG®+Stimulate®	0.260Aa	0.309Aa	0.080Ba	0.095Aa	0.339Ba	0.348Aa	2.775Ba	1.706Cb

For each characteristic, means followed by the same letter, uppercase within columns and lowercase within rows, do not differ according to the Scott–Knott test at the 1% and 5% probability levels.

For chlorophyll *b*, in 2024, the control (0.120 mg g^{-1}) and the Biotrio® + Acadian® treatment (0.104 mg g^{-1}) showed the highest values. However, in 2025, the treatments Biotrio®, Onix OG®, Acadian®, Stimulate®, and Onix OG® + Stimulate® had higher mean values (0.083–0.095 mg g^{-1}) compared to the control (0.061 mg g^{-1}) (Table 2).

Total chlorophyll contents showed a pattern similar to that observed for the individual chlorophylls. In 2024, the control treatment showed the highest mean value (0.445 mg g^{-1}), not differing statistically from the combinations Biotrio® + Acadian® and Biotrio® + Stimulate®. In 2025, greater variation among treatments was observed, although the control maintained the highest value (0.394 mg g^{-1}) (Table 2).

Carotenoids showed a distinct pattern between growing seasons. In 2024, all treatments had lower values compared to the control (3.664 mg g^{-1}). In contrast, in 2025, the highest contents were observed in the Biotrio® (4.640 mg g^{-1}), Onix OG® (4.155 mg g^{-1}), and Stimulate® (4.280 mg g^{-1}) treatments (Table 2).

Photosynthetic pigments reflected this interaction between treatments and environment. In the 2024 growing season, chlorophyll *a* content did not differ significantly among treatments. This result indicates that the treatments did not produce detectable differences in chlorophyll *a* content under the experimental conditions. However, this finding alone does not establish whether photosynthetic activity was maintained or limited. In 2025, however, some combinations between PGPB and biostimulants reduced chlorophyll *a*, suggesting partial destabilization of the photosynthetic apparatus under water deficit. The combined application of biostimulants and *Bacillus* spp. may have intensified metabolic regulation beyond the plant's adjustment capacity, increasing energy costs and contributing to greater oxidative stress (CORDEIRO et al., 2024). Under water deficit, increased production of reactive oxygen species (ROS), such as hydrogen peroxide (H_2O_2) and superoxide (O_2^-), can accelerate chlorophyll degradation and compromise photosynthetic efficiency (AHMED et al., 2025).

In contrast, the treatment combining *B. methylotrophicus* (Onix OG®) and plant regulators (Stimulate®) maintained chlorophyll *a* level, even under greater water restrictions, indicating better metabolic adjustment and greater physiological stability. This effect is likely associated with the combined action of *B. methylotrophicus* and the plant growth regulators present in the biostimulant, which may contribute to maintaining photosynthetic activity, stomatal regulation, and water use efficiency (BEGUM et al., 2022; ANWAR et al., 2024).

Chlorophyll *b* showed a complementary pattern to chlorophyll *a*. In 2024, its reduction in most treatments suggests a lower requirement for expansion of light-harvesting complexes under optimal conditions. In contrast, in the 2025 growing season, the increase in chlorophyll *b* in some treatments indicates adjustments in the photosynthetic apparatus in response to stress. Increased chlorophyll *b* in some treatments may reflect enhanced capacity for light capture and energy redistribution, contributing to the maintenance of photosynthetic efficiency under stress.

Carotenoid responses support this interpretation. In 2024, lower levels of this pigment compared to the control indicate a reduced demand for photoprotective mechanisms, consistent with more favorable conditions for plant growth and metabolism. In 2025, however, treatments containing *Bacillus* spp. (such as Biotrio® and Onix OG®) and plant growth regulators (Stimulate®) promoted increases of up to 28.2% in carotenoid contents compared to the control. This increase in carotenoid content may reflect a potential contribution to antioxidant protection, as carotenoids are known to participate in the mitigation of oxidative stress in plants (ZHANG et al., 2021; ORSÁK et al., 2023; ŠOLA et al., 2025). However, this interpretation remains hypothetical because antioxidant activity and ROS levels were not measured in the present study. On the other hand, the reduction in carotenoid contents in treatments containing *A. nodosum* extract associated with *Bacillus* spp. may indicate greater efficiency in stress mitigation, reducing the need for the synthesis of photoprotective compounds.

Leaf number was higher in all treatments compared to the control (6.4 leaves per plant) during the 2024 growing season, with Biotrio® + Stimulate® showing the highest value (8.0 leaves per plant). In 2025, no differences were observed among treatments, with values ranging from 7.5 to 8.0 leaves per plant. Differences between growing seasons were observed only for the control and Onix OG® + Acadian®, both of which showed higher mean values in 2025 (Table 3).

Table 3. Number of leaves (NL), shoot dry matter (SDM), tuberous root dry matter (TRDM), and total dry matter (TDM) of beet under the application of biostimulants and bacteria of the genus *Bacillus*.

Treatment	NL		SDM		TRDM		TDM	
	per plant		g per plant					
	2024	2025	2024	2025	2024	2025	2024	2025
Control	6.4Bb	7.9Aa	6.83Ca	7.13Ba	11.05Ca	11.13Aa	17.88Ca	18.25Aa
Biotrio®	7.4Aa	7.7Aa	10.29Ba	7.65Ab	13.30Ba	11.13Ab	23.60Ba	17.78Ab
Onix OG®	7.8Aa	7.5Aa	9.57Ba	6.26Bb	14.82Ba	9.39Ab	24.39Ba	15.65Bb
Acadian®	7.7Aa	8.0Aa	9.67Ba	8.00Ab	13.55Ba	10.45Ab	23.22Ba	18.45Ab
Stimulate®	7.6Aa	7.7Aa	9.72Ba	6.38Bb	13.78Ba	10.05Ab	23.50Ba	16.43Bb
Biotrio® + Acadian®	7.7Aa	8.0Aa	9.27Ba	7.73Ab	13.86Ba	9.20Ab	23.13Ba	16.94Bb
Biotrio® + Stimulate®	8.0Aa	7.8Aa	9.90Ba	7.12Bb	12.00Ca	10.70Aa	21.87Ba	17.82Ab
Onix OG® + Acadian®	7.2Ab	8.0Aa	11.51Aa	7.42Ab	16.40Aa	10.61Ab	27.91Aa	18.03Ab
Onix OG® + Stimulate®	7.2Aa	7.6Aa	9.7Ba	8.37Ab	14.05Ba	11.24Ab	23.75Ba	19.62Ab

For each characteristic, means followed by the same letter, uppercase within columns and lowercase within rows, do not differ according to the Scott–Knott test at the 1% and 5% probability levels.

A similar pattern was observed for shoot dry matter accumulation. Shoot dry matter was highest in Onix OG® + Acadian® (11.51 g per plant) and lowest in the control (6.83 g per plant) in 2024. In 2025, the values decreased overall, with Onix OG® showing the lowest value (6.26 g per plant), while the highest value was observed in Onix OG® + Stimulate® (8.37 g per plant). Except for the control, all treatments showed higher shoot dry matter accumulation in 2024 (Table 3).

Tuberous root dry matter differed among treatments only in 2024, with the lowest values in the control (11.05 g per plant) and Biotrio® + Stimulate® (12.0 g per plant), and

the highest values in Onix OG® + Stimulate® (16.40 g per plant). In 2025, the values ranged from 9.20 to 11.24 g per plant, with no differences among treatments. Most treatments showed higher values in 2024 (Table 3).

Total dry matter showed a similar trend. In 2024, the Onix OG® + Acadian® treatment (27.91 g per plant) provided the highest accumulation, whereas the control (17.88 g per plant) showed the lowest mean value. In the 2025 growing season, the values decreased, with less distinction among treatments, and the maximum value reached 19.62 g per plant in the Onix OG® + Stimulate® treatment (Table 3).

These physiological responses were directly reflected in plant growth and biomass accumulation. In the 2024 growing season, the treatments increased leaf number and dry matter accumulation in both shoots and tuberous roots, indicating greater physiological efficiency under favorable conditions. In 2025, no significant differences were observed in leaf number, while biomass accumulation was reduced in most treatments. Nevertheless, the partial maintenance of shoot dry matter in some treatments raises the possibility that bio-input application may have contributed to plant responses under the prevailing water-limited conditions. Potential explanations include acclimation mechanisms or more efficient use of available resources; however, these remain hypotheses because water-use efficiency, nutrient-use efficiency, carbon assimilation, and physiological acclimation responses were not directly measured in this study.

The absence of significant differences in tuberous root dry matter in 2025 may be associated with limited cell expansion during the root-filling stage under water deficit conditions, restricting reserve accumulation. In addition, under stress conditions, plants tend to prioritize metabolic maintenance and survival processes rather than tuberous root growth.

Bacillus spp. are known to stimulate root growth, enhance water and nutrient uptake, and mitigate abiotic stress effects (BEGUM et al., 2022). Likewise, *A. nodosum* extracts can improve stress tolerance and regulate plant metabolism (CORDEIRO et al., 2024; DIAS et al., 2026), in addition to stimulating root exudation and promoting microbial activity in the rhizosphere (SELVARAJ et al., 2025). Plant growth regulators such as gibberellic acid (GA_3), kinetin, and indole-3-butyric acid (IBA), present in Stimulate®, further contribute to cell division and elongation (WANG et al., 2025). Together, these mechanisms can enhance overall plant physiological efficiency and the adaptive capacity under semi-arid conditions.

In the shoot, N accumulation differed among treatments only in 2024, with the highest values in Onix OG® + Acadian® (64.01 kg ha^{-1}), without differing statistically from Stimulate®, Biotrio® + Stimulate®, and Onix OG® + Stimulate®, and the lowest value in the control (33.58 kg ha^{-1}). In 2025, no differences were observed. Phosphorus followed a similar trend, with higher accumulation in Onix® + Acadian® (6.09 kg ha^{-1}) in 2024 and no differences in 2025. Potassium also showed higher accumulation in 2024, particularly in Onix OG® + Acadian® (101.43 kg ha^{-1}), whereas in 2025 there was a reduction in the values and less differentiation among treatments (Table 4).

Table 4. Nitrogen (N), phosphorus (P), and potassium (K) accumulation in the shoot of beet under the application of biostimulants and bacteria of the genus *Bacillus*.

Treatment	N		P		K	
	kg ha^{-1}					
	2024	2025	2024	2025	2024	2025
Control	33.58Cb	47.85Aa	3.05Da	2.42Aa	63.16Ca	53.31Ba
Biotrio®	53.60Ba	46.61Aa	4.24Ca	2.82Ab	88.97Aa	63.06Ab
Onix OG®	51.59Ba	37.89Ab	3.80Ca	2.22Ab	72.03Ca	53.22Bb
Acadian®	53.34Ba	52.25Aa	4.35Ca	2.58Ab	85.73Aa	63.06Ab
Stimulate®	60.98Aa	40.76Ab	4.02Ca	2.33Ab	82.01Ba	50.14Bb
Biotrio + Acadian®	49.77Ba	45.18Aa	4.25Ca	2.72Ab	75.82Ba	64.43Aa
Biotrio + Stimulate®	58.82Aa	42.35Ab	5.10Ba	2.63Ab	95.19Aa	59.59Ab
Onix OG® + Acadian®	64.01Aa	48.12Ab	6.09Aa	2.64Ab	101.43Aa	64.74Ab
Onix OG® + Stimulate®	59.83Aa	48.40Ab	5.46Ba	3.12Ab	81.47Ba	74.09Aa

For each characteristic, means followed by the same letter, uppercase within columns and lowercase within rows, do not differ according to the Scott–Knott test at the 1% and 5% probability levels.

In the tuberous root, N, P, and K accumulations were higher in 2024. Onix® + Acadian® showed the highest N (97.07 kg ha^{-1}) and K (65.75 kg ha^{-1}), while Onix® showed the highest P (11.65 kg ha^{-1}). In 2025, no differences were observed among treatments (Table 5).

Total nutrient accumulation followed a similar trend, being higher in the 2024 growing season, especially in the Onix OG® + Acadian® treatment, which showed the highest values for N (161.08 kg ha^{-1}), P (17.66 kg ha^{-1}), and K (167.19 kg ha^{-1}). In 2025, significant differences were observed only for K, with higher values in Onix OG® + Acadian® (117.08 kg ha^{-1}) and Onix OG® + Stimulate® (129.28 kg ha^{-1}) (Table 6).

Table 5. Nitrogen (N), phosphorus (P), and potassium (K) accumulations in the tuberous root of beet under the application of biostimulants and bacteria of the genus *Bacillus*.

Treatment	N		P		K	
	kg ha^{-1}					
	2024	2025	2024	2025	2024	2025
Control	48.06Da	39.40Aa	8.02Ca	4.13Ab	37.31Cb	51.04Aa
Biotrio®	68.86Ba	38.89Ab	11.10Aa	4.68Ab	50.93Ba	49.46Aa
Onix OG®	76.55Ba	33.34Ab	11.65Aa	3.78Ab	56.96Ba	43.61Ab
Acadian®	75.44Ba	33.62Ab	11.44Aa	4.25Ab	50.82Ba	46.96Aa
Stimulate®	71.43Ba	35.48Ab	11.33Aa	4.39Ab	51.40Ba	48.21Aa
Biotrio® + Acadian®	76.86Ba	35.85Ab	11.45Aa	4.65Ab	51.52Ba	42.81Ab
Biotrio® + Stimulate®	63.69Ca	37.81Ab	9.60Ba	4.84Ab	48.10Ba	47.69Aa
Onix OG® + Acadian®	97.07Aa	44.01Ab	11.57Aa	5.10Ab	65.75Aa	52.34Ab
Onix OG® + Stimulate®	76.28Ba	43.46Ab	10.04Ba	5.10Ab	54.03Ba	55.20Aa

For each characteristic, means followed by the same letter, uppercase within columns and lowercase within rows, do not differ according to the Scott–Knott test at the 1% and 5% probability levels.

Table 6. Total accumulation of nitrogen (N), phosphorus (P), and potassium (K) in beet under the application of biostimulants and bacteria of the genus *Bacillus*.

Treatment	N		P		K	
	kg ha^{-1}					
	2024	2025	2024	2025	2024	2025
Control	81.64Ca	87.25Aa	11.07Ca	6.55Ab	100.48Ca	104.36Ba
Biotrio®	122.46Ba	85.50Ab	15.34Ba	7.50Ab	139.91Ba	112.52Bb
Onix OG®	128.14Ba	71.22Ab	15.45Ba	6.00Ab	128.99Ba	96.84Bb
Acadian®	128.79Ba	85.88Ab	15.80Ba	6.83Ab	136.56Ba	110.02Bb
Stimulate®	132.42Ba	76.24Ab	15.35Ba	6.72Ab	133.42Ba	98.34Bb
Biotrio® + Acadian®	126.63Ba	81.03Ab	15.70Ba	7.37Ab	127.34Ba	107.24Bb
Biotrio® + Stimulate®	122.52Ba	80.16Ab	14.71Ba	7.46Ab	143.29Ba	107.29Bb
Onix OG® + Acadian®	161.08Aa	92.13Ab	17.66Aa	7.74Ab	167.19Aa	117.08Ab
Onix OG® + Stimulate®	136.12Ba	91.86Ab	15.49Ba	8.22Ab	135.50Ba	129.28Aa

For each characteristic, means followed by the same letter, uppercase within columns and lowercase within rows, do not differ according to the Scott–Knott test at the 1% and 5% probability levels.

Nutrient accumulation followed the same pattern observed for plant growth and biomass accumulation. In 2024, the treatments, especially the combinations of biostimulants and *Bacillus*, promoted greater accumulation of N, P, and K, indicating improved nutritional efficiency, likely associated with enhanced root development and increased metabolic activity. The combination of *B. methylotrophicus* (Onix OG®) and *A. nodosum* extract (Acadian®) promoted increases of approximately 97.3%, 59.5%, and 66.4% in total N, P, and K accumulation, respectively, compared to the control. In 2025, N and P accumulation did not differ significantly from the control, whereas K showed higher values. The greater K accumulation under water restriction reinforces the importance of this nutrient in stress tolerance, especially in processes related to osmotic adjustment, stomatal regulation, and assimilate transport. In 2025, the combination of *B. methylotrophicus* (Onix OG®) and plant growth regulators (Stimulate®) promoted an increase of approximately 23.9% in total K accumulation compared to the control, demonstrating that some treatments maintained a greater capacity for nutrient uptake and redistribution even under water limitation. The absence of differences in nutrient accumulation in the tuberous root in 2025 suggests that, under water deficit conditions, plants prioritized the maintenance of shoot growth and photosynthetic activity rather than nutrient storage in the roots.

In the 2024 growing season, the highest commercial yields were obtained with Onix OG® and all combined treatments, particularly Onix OG® + Acadian®, which reached 15.15 t ha^{-1}. In 2025, commercial yields were reduced and

showed less differentiation among treatments, ranging from 6.48 t ha^{-1} in Onix OG® to 12.41 t ha^{-1} in Onix® + Acadian®. Non-commercial yield increased in 2024 compared to the control, reaching 2.34 t ha^{-1} with Stimulate®, while in 2025 only Onix OG® differed (3.12 t ha^{-1}) from the other treatments. Total yield was highest in Onix OG® + Acadian® in both years (17.06 and 13.90 t ha^{-1}) (Table 7).

Table 7. Commercial yield (CY), non-commercial yield (NCY), and total yield (TY) of beet under the application of biostimulants and bacteria of the genus *Bacillus*.

Treatment	CY (t ha^{-1})		NCY (t ha^{-1})		TY (t ha^{-1})	
	2024	2025	2024	2025	2024	2025
Control	12.11Ca	10.74Bb	1.0Ba	1.36Ba	13.11Ca	12.10Ba
Biotrio®	12.01Ca	9.66Cb	2.03Aa	1.41Ba	14.05Ca	11.07Cb
Onix OG®	14.37Aa	6.48Eb	0.81Bb	3.12Aa	15.17Ba	9.60Cb
Acadian®	12.55Ca	8.09Db	0.91Bb	2.18Ba	13.45Ca	10.27Cb
Stimulate®	13.31Ba	11.88Ab	2.34Aa	1.84Ba	15.66Ba	13.72Ab
Biotrio® + Acadian®	13.79Aa	10.91Bb	0.84Ba	1.55Ba	14.63Ca	12.46Bb
Biotrio® + Stimulate®	15.01Aa	9.16Cb	0.75Bb	1.90Ba	15.76Ba	11.05Cb
Onix OG® + Acadian®	15.15Aa	12.41Ab	1.91Aa	1.49Ba	17.06Aa	13.90Ab
Onix OG® + Stimulate®	13.42Ba	11.05Bb	1.59Aa	1.36Ba	15.02Ba	12.41Bb

For each characteristic, means followed by the same letter, uppercase within columns and lowercase within rows, do not differ according to the Scott–Knott test at the 1% and 5% probability levels.

Yield responses mirrored these physiological and nutritional processes. In 2024, most treatments increased both commercial and total yield, likely due to improvements in vegetative growth, nutrient uptake, and hormonal regulation promoted by the bio-inputs. The combination of *B. methylotrophicus* (Onix OG®) and *A. nodosum* extract (Acadian®) stood out by promoting increases of approximately 25.1% in commercial yield and 30.13% in total yield compared to the control. In 2025, however, water limitation significantly reduced yield, highlighting the strong dependence of beet on water availability during tuberous root development.

Despite the yield reduction observed in 2025, combinations involving *B.* methylotrophicus showed better agronomic performance and greater stability between growing seasons, indicating greater tolerance to water stress conditions. While the isolated application of *B. methylotrophicus* (Onix OG®) resulted in a reduction of more than 54.9% in commercial yield between seasons, its association with *A. nodosum* extract (Acadian®) showed a more moderate reduction, demonstrating a greater capacity to maintain productive performance under water restriction.

This response may be attributed to the ability of *B. methylotrophicus* to reduce ROS levels (e.g., H_2O_2 and O_2^-) (HOU et al., 2018), combined with the role of *A. nodosum* in promoting osmoprotective compounds such as free amino acids, which improve stomatal regulation and water use efficiency (CORDEIRO et al., 2024; DIAS et al., 2026). In addition, the greater nutritional efficiency observed in these treatments may have contributed to the maintenance of plant growth and yield even under water restriction.

The treatment Onix OG® + Stimulate® showed the highest betalain concentrations in both years (66.70 and 54.20 mg g^{-1}, respectively). Regarding total soluble sugars, a distinct pattern was observed among treatments. In 2024, Onix OG® + Stimulate® also showed the lowest TSS (6.65%), while Biotrio® and Acadian® showed the highest values (11.73% and 11.44%, respectively). This pattern was maintained in 2025, indicating greater stability of these treatments regarding TSS accumulation in the tuberous roots. Soluble solids were highest in Biotrio® + Acadian® and Onix OG® + Stimulate® (12.87%) (Table 8).

Postharvest quality was also influenced by the interaction between treatments and environmental conditions. In 2024, the reduction in betalain levels in some treatments suggests a lower requirement for the activation of antioxidant mechanisms under more favorable conditions. In 2025, the greater variation among treatments indicates different physiological strategies in response to stress. The combination of *B. methylotrophicus* (Onix OG®) and plant growth regulators (Stimulate®) showed the highest betalain concentrations in both growing seasons, with increases of approximately 9.7% compared to the control in 2024, suggesting greater activation of antioxidant mechanisms associated with stress tolerance (LI et al., 2019).

For total soluble sugars, the greater variation observed in 2024 suggests higher metabolic activity under favorable conditions. Treatments containing *Bacillus* spp. (Biotrio®) and *A. nodosum* extract (Acadian®) showed increases greater than 40% in total soluble sugar contents compared to the combination of *B. methylotrophicus* (Onix OG®) and plant growth regulators (Stimulate®), indicating a greater capacity for soluble carbohydrate accumulation in the roots. In 2025, water deficit likely limited plant metabolism, resulting in greater uniformity among treatments. Soluble solids, in turn, showed low sensitivity to environmental variations, remaining relatively stable between growing seasons.

Table 8. Concentration of betalains (BET), total soluble sugars (TSS), and soluble solids (SS) in the tuberous root of beet under the application of biostimulants and bacteria of the genus *Bacillus*.

Treatment	BET (mg g^{-1})		TSS (%)		SS (%)
	2024	2025	2024	2025	
Control	60.80Aa	48.73Bb	9.37Ca	10.37Bb	12.00B
Biotrio®	49.71Ca	48.95Ba	11.73Aa	11.69Aa	12.43B
Onix OG®	54.27Ba	45.16Cb	10.73Ba	10.73Ba	12.62A
Acadian®	61.51Aa	58.15Aa	11.44Aa	11.50Aa	12.77A
Stimulate®	54.94Ba	37.37Cb	10.78Ba	10.72Ba	12.32B
Biotrio® + Acadian®	46.78Ca	47.88Ba	9.00Cb	10.43Ba	12.87A
Biotrio® + Stimulate®	48.35Ca	40.41Cb	8.21Db	9.97Ba	12.27B
Onix OG® + Acadian®	57.05Aa	48.92Bb	10.78Ba	10.69Ba	11.87B
Onix OG® + Stimulate®	66.70Aa	54.20Ab	6.65Eb	10.30Ba	12.87A

For each characteristic, means followed by the same letter, uppercase within columns and lowercase within rows, do not differ according to the Scott–Knott test at the 1% and 5% probability levels.

The lower irrigation depth in the 2025 season limited beet growth, nutrient accumulation, and yield, in addition to modifying plant responses to the application of *Bacillus*-based PGPB and biostimulants compared to the 2024 season. These results highlight the strong influence of environmental conditions on the effectiveness of bio-inputs, especially in semi-arid regions. Under adequate water availability (2024), treatments enhanced plant growth and metabolism, whereas under water limitation (2025), their effectiveness depended on their ability to modulate physiological and biochemical mechanisms related to stress tolerance.

Overall, the results demonstrate that the effectiveness of biostimulants and plant growth-promoting bacteria of the genus *Bacillus* in beet cultivation varied between growing seasons. The differences in plant growth, nutrient accumulation, and yield may be associated with the distinct environmental and soil conditions observed in each experiment, including differences in irrigation water availability, growing-season timing, and soil chemical properties. In particular, soil pH increased from 5.26 in 2024 to 6.68 in 2025, which may have influenced nutrient availability and plant responses to the applied treatments. Therefore, the differences between growing seasons cannot be attributed exclusively to water availability, since the individual contributions of soil properties and other environmental factors were not isolated in this study. These findings highlight the importance of considering the environmental and edaphic conditions when evaluating and recommending bio-inputs for beet production under semi-arid conditions.

CONCLUSIONS

The application of *Bacillus*-based plant growth-promoting bacteria and biostimulants influenced the agronomic performance of beet under semi-arid conditions, with responses varying between growing seasons. In 2024, when irrigation water availability was greater, several treatments increased plant growth, dry matter accumulation, and nutrient accumulation. In 2025, under lower irrigation availability, treatment responses were more variable, and the benefits observed in 2024 were not consistently maintained across all variables. Among the evaluated treatments, the combination of *B. methylotrophicus* (Onix OG®) and *A. nodosum* extract (Acadian®) showed the most consistent overall performance, resulting in the highest total yield in both growing seasons (17.06 and 13.90 t ha^{-1} in 2024 and 2025, respectively), as well as high dry matter and nutrient accumulation. These findings indicate that this combination is a promising option for beet cultivation under the conditions evaluated, although further experiments are needed to establish its effectiveness under different levels of water availability.

REFERENCES

AHMED, A. F. et al. Enhancing metabolic processes and water deficit stress tolerance of maize plants through biochar addition and foliar application of zinc nanoparticles. **Russian Journal of Plant Physiology**, 72: 10, 2025.

AIJAZ, N. et al. Improving salinity tolerance in wheat plants via inoculation with *Azospirillum brasilense* and *Bacillus subtilis* for enhanced biomass, growth and physiological process. **Acta Physiologiae Plantarum**, 46: 103, 2024.

ANWAR, T. et al. Synergistic effects of gibberellic acid, biochar, and rhizobacteria on wheat growth under heavy metal and drought stress. **BMC Plant Biology**, 24: e1168, 2024.

AZZAM, C. R. et al. Biostimulants in modern agriculture: a comprehensive review of microbial and non-microbial categories, mechanisms, and sustainability implications. **Journal of Plant Nutrition**, 1: 22, 2026.

BEGUM, N. et al. Co-inoculation of arbuscular mycorrhizal fungi and the plant growth-promoting rhizobacteria improve growth and photosynthesis in tobacco under drought stress by up-regulating antioxidant and mineral nutrition metabolism. **Microbial Ecology**, 83: 971-988, 2022.

CORDEIRO, E. C. et al. Can Ascophyllum nodosum extract application before or at drought stress trigger different metabolic adaptation responses in soybean plants?. **Journal of Applied Phycology**, 36: 2293-2293, 2024.

COSTA, R. M. C. et al. Fertirrigation with copper in beet crop in a semi-arid region. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 28: e276908, 2024.

DIAS, M. C. et al. *Ascophyllum nodosum* extract enhances olive fruit quality under contrasting irrigation regimes. **Journal of Applied Phycology**, 38: 765-777, 2026.

FERREIRA, D. F. Sisvar: a computer analysis system to fixed effects split plot type designs. **Revista Brasileira de Biometria**, 37: 4, 2019.

HENDERSON, B. C. R.; SANDERSON, J. M.; FOWLES, A. A review of the foliar application of individual amino acids as biostimulants in plants. **Discover Agriculture**, 3: 69, 2025.

HORTBRASIL – Centro de qualidade de horticultura. **Norma de classificação da beterraba (*Beta vulgaris* L.)**. São Paulo, SP: CQH/ CEAGESP, 2006.

HOU, X. et al. *Bacillus methylotrophicus* CSY-F1 alleviates drought stress in cucumber (*Cucumis sativus*) grown in soil with high ferulic acid levels. **Plant Soil**, 431: 89-105, 2018.

LATIMER, G. W. **Official methods of analysis of AOAC international**. 22. ed. New York: Oxford University Press, 2023.3750 p.

LI, G. et al. Research progress of betalain in response to adverse stresses and evolutionary relationship compared with anthocyanin. **Molecules**, 24: 3078, 2019.

LI, J. et al. The optimization of crop response to climatic stress through modulation of plant stress response mechanisms. Opportunities for biostimulants and plant hormones to meet climate challenges. **Research Review**, 249: 130-151, 2026.

LICHTENTHALER, H. K. Chlorophylls and carotenoids: Pigments of photosynthetic biomembranes. In: PACKER, L.; DOUCE, R. (Eds.). **Methods in enzymology**. San Diego: Academic Press, 1987. v. 148, cap. 34, p. 350-382.

MONTEIRO, G. C. et al. Aplicação de bioestimulantes proporciona melhoria no cultivo da beterraba (*Beta vulgaris* L). **Revista de Ciências Agrárias**, 42: 1025-1031, 2019.

ORSÁK, M. et al. Effect of long-term drought and waterlogging stress on photosynthetic pigments in potato. **Plant, Soil and Environment**, 69: 152-160, 2023.

SANTOS, H. G. et al. **Sistema Brasileiro de Classificação de Solos**. Brasília, DF: Embrapa, 2025. 393 p.

SELVARAJ, V. K. et al. *Ascophyllum nodosum* based plant biostimulant shapes the bacterial community in the rhizosphere of corn. **BMC Plant Biology**, 25: 1263, 2025.

SILVA, F. C **Manual de análises químicas de solos, planas e fertilizantes**. 2. ed. Brasília, DF: Embrapa Informação Tecnológica, 2009. 627 p. 2009. 627 p. 627 p.

SILVA, G. A. et al. Agronomic performance of beet cultivars as a function of phosphorus fertilization. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 23: 518-523, 2019.

SILVA, R. A. et al. Physiological and productive role of biostimulants in alleviating hypoxia stress in soybean grown under field conditions. **Gesunde Pflanzen**, 75: 2713-2721, 2023.

ŠOLA, I. et al. Impact of water stress on metabolic intermediates and regulators in broccoli sprouts, and cellular defense potential of their extracts. **International Journal of Molecular Sciences**, 26: 632, 2025.

SUN, Y. et al. Effects of *Bacillus* on continuous cropping of sugar beets and their rhizosphere microbial community. **Scientific Reports**, 16: 1160, 2026.

TANG, C. S.; NORZIAH, M. H. Stability of betacyanin pigments from red purple pitaya fruit (*Hylocereus polyrhizus*): influence of pH, temperature, metal ions and ascorbic acid**.** **Indonesian Journal of Chemistry**, 7: 327-331, 2007.

TRANI, P. E. et al. **Hortaliças: recomendações de calagem e adubação para o Estado de São Paulo**. Campinas, SP: CATI, 2018. 88 p.

WANG, X. et al. Regulatory effects of gibberellin and cytokinin on citrus peel cell wall metabolism. **BMC Plant Biology**, 25: 750, 2025.

YEMM, E. W.; WILLIS, A. J. The estimation of carbohydrates in plant extracts by anthrone. **The Biochemical Journal**, 57: 508-514, 1954.

ZHANG, R. et al. Effects of simulated drought stress on carotenoid contents and expression of related genes in carrot taproots. **Protoplasma**, 258: 379-390, 2021.