
BIOFARM
Jurnal Ilmiah Pertanian
ISSN Print: 0216-5430; ISSN Online: 2301-6442
Vol. 22, No. 2, Oktober 2026

Low-Dose *Sargassum* spp. Extract as A Physiological Biostimulant for Lowland Green Curly Lettuce (*Lactuca sativa* L. Var. *Grand Rapids*)

Shella Laudy Y. Marpaung[1], Muhammad Ardin Dwinata[1], Cindyjocelyn[1], Yovi Avianto*[1]
[1]Department of Agrotechnology, Faculty of Agriculture, Institut Pertanian Stiper Yogyakarta
*Korespondensi Penulis: yovi@instiperjogja.ac.id

ABSTRACT
Green curly lettuce (*Lactuca sativa* L. var. *Grand Rapids*) is sensitive to the high temperature and evaporative demand typical of lowland cultivation. This study evaluated the dose-response of Sargassum spp. extract (0, 5, 10, and 20 g L^{-1}). The treatments were applied four times, once in a week by root drench in a completely randomized design with ten replications. Growth, biomass, gas exchange-related traits, nitrate reductase activity, chlorophyll, and soil nutrient status were evaluated by one-way ANOVA followed by Tukey's HSD ($p < 0.05$). The 5 g L^{-1} treatment produced the highest means for plant height (19.43 cm). In contrast, 10 g L^{-1} maximized photosynthetic rate (15.87 ± 0.32 µmol CO_2 m^{-2} s^{-1}), transpiration (3.69 ± 0.09 mmol H_2O m^{-2} s^{-1}), respiration (1.99 ± 0.07 µmol CO_2 m^{-2} s^{-1}), and nitrate reductase activity (1.36 ± 0.05 µmol NO_2^- g^{-1} FW h^{-1}). Chlorophyll fractions, fresh and dry biomass did not differ among the measured extract treatments. These results distinguish a 5 g L^{-1} growth optimum from a 10 g L^{-1} physiological-activity optimum.

Keywords: biostimulant, grand rapids lettuce, lowland cultivation, physiological response, Sargassum spp.

INTRODUCTION

Lettuce (*Lactuca sativa* L. var. *Grand Rapids*) is one of the most widely consumed leafy vegetables because of its short production cycle and fresh-market preference. This vegetable also supports nutritional contribution as a source of vitamins, minerals, dietary fiber, and health-promoting phytochemicals (Kim et al., 2016; Riyadi et al., 2026). Grand Rapids is classified as a leaf lettuce type, characterized by green, curly leaves, non-heading growth, and relatively fast vegetative development, making it suitable for intensive vegetable production systems in both soil-based and soilless cultivation (Akbar et al., 2025; Anwary et al., 2019).

Although lettuce has promising market prospects, its cultivation is strongly influenced by microclimatic conditions. Lettuce generally performs better in cool, humid environments, whereas lowland cultivation is frequently exposed to higher air temperatures, greater radiation load, and higher evapotranspiration. These conditions can restrict leaf expansion, reduce canopy development, accelerate water loss, and increase the risk of premature bolting, thereby reducing both yield quantity and visual quality (Avianto et al., 2024; Avianto & Saputra, 2024; Wijaya & Fajriani, 2022). Therefore, lowland lettuce production requires cultivation inputs that are not only growth-promoting but also capable of supporting physiological adjustment under suboptimal environments (Formisano et al., 2021).

Plant biostimulants are increasingly used in sustainable horticulture because they enhance plant performance through physiological and biochemical regulation rather than functioning solely as nutrient sources (Martínez-Lorente et al., 2024). According to Asif et al. (2023), biostimulants may improve nutrient-use efficiency, root activity, photosynthetic capacity, antioxidant defense, and tolerance to abiotic stress. This mode of action distinguishes biostimulants from conventional fertilizers, because their benefits are often associated with metabolic modulation, signaling molecules, and

improved plant-soil interactions (Ali et al., 2021; Rouphael & Colla, 2020)

Brown seaweeds, particularly *Sargassum* spp., represent a locally relevant biomass resource for biostimulant development in Indonesia. As stated by Shanab & Shalaby (2021), seaweed extracts contain a complex mixture of bioactive compounds, including auxin-like, cytokinin-like, and gibberellin-like substances, amino acids, polysaccharides, betaines, micronutrients, and phenolic compounds. These compounds are associated with cell division, cell elongation, root proliferation, chlorophyll maintenance, and improved stress tolerance. Previous Indonesian studies also reported that *Sargassum*-derived liquid organic products could support crop growth of maize (Fitriyah et al., 2022)

Seaweed-based biostimulants can improve lettuce growth, photosynthetic performance, nitrogen assimilation, and water relations. Its effects depend on extract composition, concentration, application route, genotype, and environment (Ali et al., 2021; Puglisi et al., 2020). Recent lettuce studies have reported increased fresh biomass and chlorophyll after *Sargassum*-based formulations (Ramdin et al., 2024) and improved biomass, stomatal activity, water productivity, and nitrogen-use efficiency after marine algal extracts (Di Serio et al., 2025). Evidence remains limited for Grand Rapids lettuce under lowland soil cultivation. Therefore, this study evaluated the dose-dependent effects of *Sargassum* spp. extract on the physiological and vegetative responses of lettuce. It also identified the concentrations associated with optimal vegetative growth and peak physiological activity.

MATERIALS AND METHODS

Time and location

The study was conducted for two months at the MBKM Field of INSTIPER Yogyakarta for plant cultivation and field observation, and at the Agronomy Laboratory, Faculty of Agriculture, Institut Pertanian STIPER (INSTIPER) Yogyakarta, for supporting laboratory analyses.

Materials and equipment

The materials consisted of *Sargassum* spp. extract, Grand Rapids lettuce seeds, soil, manure, acetone, distilled water, pH buffers, and reagents for nitrate reductase activity and soil N and P analyses. Cultivation equipment included a 3 m × 3 m shade-net structure (50 %), seedling trays, polybags, watering equipment, measuring tools, labels, and laboratory glassware.

Experimental design

The experiment used a one-factor completely randomized design. The treatment factor was the concentration of *Sargassum* spp. extract, consisting of four levels: 0 g L^{-1} (control), 5 g L^{-1}, 10 g L^{-1}, and 20 g L^{-1}. Each treatment was replicated ten times, resulting in 40 experimental units. The experimental units were arranged randomly to minimize environmental bias within the cultivation area.

Preparation of growing media and planting area

Before transplanting, the shade net structure was installed to reduce excessive radiation and stabilize the microclimate during lowland cultivation. Soil and manure (2:1) were mixed evenly and placed into polybags. The medium was watered to field capacity before transplanting to reduce transplanting stress.

Seedling and transplanting

Grand Rapids lettuce seeds were sown in seedling trays and maintained until the seedlings developed 3-4 true leaves. Uniform seedlings with healthy morphology were selected and transplanted into polybags. The seedlings were then acclimatized before treatment application to ensure that early growth differences were not caused by transplant shock.

The *Sargassum* spp. extract was diluted according to the treatment concentrations. Application was performed once a week starting from 7 to 28 day after transplanting using root drenching around the rhizosphere zone. Control plants received water without *Sargassum* extract.

Growth, biomass, and physiological observations

Plant height, leaf number, leaf width, greenness score, canopy diameter, shoot fresh weight, shoot dry weight, and the consumption index were recorded at harvest (35 DAT). Photosynthetic rate, transpiration rate, and nitrate reductase activity were measured at 21 DAT during the active vegetative phase. Chlorophyll a, chlorophyll b, and total chlorophyll were quantified from acetone extracts.

Data analysis

Each experimental unit was treated as one replicate (n = 10). Data were analyzed separately for each response variable using one-way analysis of variance at α = 0.05. When the treatment effect was significant, means were separated using Tukey's honestly significant difference test at $p < 0.05$. Results are reported as mean ± standard deviation. All statistical analysis were calculated using R software version 4.5.2.

RESULTS AND DISCUSSION

Vegetative growth response of Grand Rapids lettuce

Tables 1–3 summarize the vegetative, physiological, and biomass responses. The results reveal two distinct optimal dose, 5 g L^{-1} produced the strongest final growth means, whereas 10 g L^{-1} produced the highest physiological activity at 35 days after transplanting.

Table 1. Vegetative growth parameters of Grand Rapids lettuce treated with *Sargassum* spp. extract

Sargassum spp. Dose (g L^{-1})	Plant height (cm)	Leaf number	Greenness score	Canopy diameter (cm)	Leaf width (cm)
0	13.14 ± 1.12 c	4.38 ± 0.64 a	2.00 ± 0.00 a	12.73 ± 2.60 a	3.63 ± 0.82 a
5	19.43 ± 1.35 a	5.98 ± 0.78 a	2.00 ± 0.00 a	19.71 ± 4.20 a	6.87 ± 1.45 a
10	16.53 ± 1.21 b	5.00 ± 0.71 a	2.00 ± 0.00 a	13.93 ± 3.10 a	4.63 ± 1.10 a
20	10.77 ± 0.96 d	3.76 ± 0.56 a	2.00 ± 0.00 a	11.43 ± 2.50 a	3.29 ± 0.75 a

Note: Values are mean ± SD (n = 10). Means followed by the same letter within a column are not significantly different by Tukey's HSD ($p < 0.05$).

The response differed among trait groups (Tables 1–3). 5 g L^{-1} produced the highest mean of plant height, whereas 10 g L^{-1} produced the highest photosynthetic, transpiration, and nitrate reductase rates. Thus, the concentration that maximized instantaneous physiological activity was not the concentration associated with the largest final canopy and biomass means.

Plant height differed significantly among all concentrations, with 5 g L^{-1} exceeding the control by 47.9%, while leaf number and visual greenness did not differ significantly (Table 1). The improvement in plant height may be associated with the biostimulatory compounds contained in brown algal extracts. *Sargassum*-based formulations have been reported to increase lettuce growth and chlorophyll content (Ramdin et al., 2024). Bioactive carbohydrates, hormone-like compounds, amino acids, minerals, and elicitor molecules in seaweed extracts may regulate cell division, cell expansion, root activity, and nutrient acquisition rather than acting solely as conventional fertilizers (Ali et al., 2021).

The application of 20 g L^{-1} resulted in the lowest plant height, indicating that increasing the extract concentration did not produce a linear growth response. Seaweed extracts are chemically complex, and excessive concentrations may alter ionic strength, osmotic conditions, or the balance of signaling compounds. Consequently, a concentration that stimulates one physiological process may not maximize integrated plant growth throughout the cultivation period (Ali et al., 2021). The present data cannot identify the specific compound or

mechanism responsible for the inhibitory response at 20 g L^{-1}.

Leaf number, visual greenness, canopy diameter, and leaf width were not significantly affected by *Sargassum* extract application (Table 1). This trait-specific response suggests that the extract influenced stem elongation more strongly than leaf initiation or lateral leaf expansion. According to Ma et al. (2025), leaf number is determined by the rate of leaf initiation and developmental stage, whereas canopy diameter and leaf width depend on the cumulative expansion and spatial orientation of individual leaves. Consequently, stimulation of physiological activity does not necessarily produce simultaneous changes in all morphological traits. Similar response specificity has been reported in lettuce by Carillo et al. (2022). In which biostimulant concentration affected photosynthesis, leaf area, and root growth differently, while leaf-number responses depended on the applied dose.

Table 2. Physiological responses of Grand Rapids lettuce to *Sargassum* spp. extract

Parameter	Unit	0 g L^{-1}	5 g L^{-1}	10 g L^{-1}	20 g L^{-1}
Photosynthetic rate	μmol CO_2 m^{-2} s^{-1}	8.46 ± 0.29 d	11.64 ± 0.28 c	15.87 ± 0.32 a	13.11 ± 0.29 b
Transpiration rate	mmol H_2O m^{-2} s^{-1}	2.14 ± 0.09 d	2.88 ± 0.07 c	3.69 ± 0.09 a	3.20 ± 0.09 b
Nitrate reductase activity	μmol NO_2^- g^{-1} FW h^{-1}	0.65 ± 0.04 d	0.94 ± 0.03 c	1.36 ± 0.05 a	1.11 ± 0.03 b
Chlorophyll a	mg L^{-1}	15.23 ± 4.68 a	17.18 ± 4.65 a	16.04 ± 4.58 a	14.37 ± 8.46 a
Chlorophyll b	mg L^{-1}	3.46 ± 2.87 a	7.90 ± 2.28 a	7.52 ± 2.39 a	1.52 ± 7.18 a
Total chlorophyll	mg L^{-1}	.18.86 ± 9.14 a	25.07 ± 6.93 a	23.55 ± 6.95 a	15.88 ± 10.47 a

Note: Values are mean ± SD (n = 10). Different letters within a row indicate significant differences by Tukey's HSD ($p < 0.05$).

Table 3. Biomass and consumption index

Parameter	Unit	0 g L^{-1}	5 g L^{-1}	10 g L^{-1}	20 g L^{-1}
Fresh weight	g $plant^{-1}$	18.03 ± 15.10 a	62.49 ± 56.69 a	24.03 ± 22.41 a	5.03 ± 4.73 a
Dry weight	g $plant^{-1}$	1.40 ± 1.25 a	5.32 ± 4.82 a	1.60 ± 1.57 a	0.32 ± 0.29 a
Consumption index	-	0.91 ± 0.03 a	0.93 ± 0.01 a	0.94 ± 0.00 a	0.94 ± 0.01 a

Note: Values are mean ± SD (n = 10). Means followed by the same letter within a row are not significantly different by Tukey's HSD ($p < 0.05$).

The absence of significant differences in visual greenness may reflect both the similar chlorophyll concentrations among the measured *Sargassum* treatments and the limited sensitivity of categorical visual scoring (Table 2). Subtle variations in chlorophyll content may not produce sufficiently distinct color changes to be assigned to different visual categories. Objective SPAD measurements are strongly correlated with chlorophyll a, chlorophyll b, and total chlorophyll concentrations in lettuce. Therefore it is more suitable for detecting small pigment differences than visual assessment (Terassi et al., 2023). Because chlorophyll concentrations did not differ significantly, the higher photosynthetic rate at 10 g L^{-1} cannot be statistically attributed to increased chlorophyll content. It may instead be associated with stomatal regulation, photochemical efficiency, photosynthetic enzyme activity, or leaf developmental stage (Li et al., 2023).

Application of 10 g L^{-1} increased the photosynthetic rate by 87.7%, transpiration rate by 72.7%, and nitrate reductase activity by 110.8% compared with the control, and all three variables differed significantly among treatments (Table 2). The parallel increases in photosynthesis and nitrate reductase activity

are physiologically coherent because nitrate reduction requires reductants and carbon skeletons generated through active carbon metabolism (Nguyen et al., 2026; Yang et al., 2025). Algal extracts can act as metabolic modulators rather than merely supplying nutrients, with their effects depending on extract composition, concentration, and plant species (Corrado et al., 2026). In addition, marine algal extracts have been reported to regulate genes associated with nitrogen uptake and assimilation (Di Mola et al., 2019; Di Serio et al., 2025).

The decline in physiological responses at 20 g L^{-1} may indicate excessive metabolic stimulation. Some algal extracts can modify redox homeostasis, H_2O_2 accumulation and the production of defense-associated metabolites (Corrado et al., 2026). Other studies have demonstrated that algal extracts alter antioxidant enzymes, osmoprotectants, phenolic compounds, and other secondary metabolites in lettuce, although the direction of these responses depends on the extract composition and growing conditions (Aloui et al., 2023; Chanda et al., 2026). Therefore, a supraoptimal concentration may divert carbon and energy from growth and primary metabolism toward cellular protection.

The higher photosynthetic rate at 10 g L^{-1} did not result in a significant increase in final biomass. The higher transpiration rate at 10 g L^{-1} may have increased water loss, particularly under lowland conditions. Repeated gas-exchange measurements and quantitative leaf-area observations are required to determine whether the physiological enhancement was maintained throughout the cultivation period.

Fresh weight, dry weight, and consumption index did not differ significantly among treatments (Table 3). This phenomena may be related to substantial variation among plants. The absence of significant biomass differences is consistent with previous studies of algal biostimulants in lettuce. Ammaturo et al. (2023) found no significant differences in the fresh and dry biomass of either the aerial parts or roots following the application of *Chlorella vulgaris* and *Ulva lactuca* extracts. Similarly, leaf dry weight did not differ significantly among lettuce plants treated with different seaweed-based formulations (Cuchca Ramos et al., 2025). Gómez & Gómez (2022) also reported that *Sargassum* spp. extract did not significantly affect shoot fresh weight or shoot and root dry weight in hydroponically grown lettuce. These findings indicate that algal biostimulants do not necessarily produce a statistically detectable biomass response, as their effectiveness depends on the extract composition, application rate, cultivation system, and environmental conditions.

CONCLUSION

Sargassum spp. extract produced a dose-dependent and trait-specific response in Grand Rapids lettuce. The 5 g L^{-1} concentration was associated with the greatest plant height, whereas 10 g L^{-1} produced the strongest physiological activity. Further studies should include repeated physiological measurements, quantitative leaf-area assessment, and oxidative-stress indicators to confirm the optimum concentration and clarify the inhibitory response at higher doses.

REFERENCES

Akbar, M., Kurniasih, R., Kanny, P. I., & Farhah, N. (2025). Response of Growth and Yield of Several Varieties of Lettuce Plants (*Lactuca sativa* L.) at Different Concentrations of Nutrients with Smart Aeroponic System. *International Journal on Food, Agriculture and Natural Resources*, *6*(3), 22–29. https://doi.org/10.46676/ij-fanres.v6i3.478

Ali, O., Ramsubhag, A., & Jayaraman, J. (2021). Biostimulant Properties of Seaweed Extracts in Plants: Implications towards Sustainable Crop Production. *Plants*, *10*(3), 531. https://doi.org/10.3390/plants10030531

Aloui, D., Kalleli, F., M'Hamdi, M., Manaa, M., Abid, G., & Karmous, C. (2023). Marine Algal Extract as a Biostimulant to Improve Tolerance to Salinity in Lettuce Plants. *Emirates Journal of Food and Agriculture*. https://doi.org/10.9755/ejfa.2023.3199

Ammaturo, C., Pacheco, D., Cotas, J., Formisano, L., Ciriello, M., Pereira, L., & Bahcevandziev, K. (2023). Use of *Chlorella vulgaris* and *Ulva lactuca* as Biostimulant on Lettuce. *Applied Sciences*, *13*(16), 9046. https://doi.org/10.3390/app13169046

Anwary, M. N., Slamet, W., & Kusmiyati, F. (2019). Pertumbuhan Selada Merah (*Lactuca sativa* L. var. *Red Rapid*) dan Selada Hijau (*Lactuca sativa* L. *Grand Rapids*) dengan Sistem Hidroponik Apung dengan Pemberian Dosis Pupuk Organik Cair (POC) Bioslurry dan AB Mix yang Berbeda. *Buletin Anatomi Dan Fisiologi*, *4*(2), 160–167. https://doi.org/10.14710/baf.4.2.2019.160-167

Asif, A., Ali, M., Qadir, M., Karthikeyan, R., Singh, Z., Khangura, R., Di Gioia, F., & Ahmed, Z. F. R. (2023). Enhancing crop resilience by harnessing the synergistic effects of biostimulants against abiotic stress. *Frontiers in Plant Science*, *14*, 1276117. https://doi.org/10.3389/fpls.2023.1276117

Avianto, Y., Pratama, A. B., Noviyanto, A., & Fauzi, F. R. (2024). Analyzing the Influence of Altitudinal Gradients on Clove Physiology and Yield in the Menoreh Highlands. *Jurnal Biologi Tropis*, *24*(4), 352–364. https://doi.org/10.29303/jbt.v24i4.7562

Avianto, Y., & Saputra, B. F. (2024). Perbandingan Ekofisiologis Pucuk Teh pada Ketinggian Rendah dan Menengah di DIY. *Jurnal Agrosains Dan Teknologi*, *9*(2), 59–69. https://doi.org/https://doi.org/10.24853/jat.9.2.%25p

Carillo, P., De Micco, V., Ciriello, M., Formisano, L., El-Nakhel, C., Giordano, M., Colla, G., & Rouphael, Y. (2022). Morpho-Anatomical, Physiological, and Mineral Composition Responses Induced by a Vegetal-Based Biostimulant at Three Rates of Foliar Application in Greenhouse Lettuce. *Plants*, *11*(15), 2030. https://doi.org/10.3390/plants11152030

Chanda, M. J., Soidihane, A., Mounaimi, S., Alaoui, M. H., Lamaden, H., Lyamlouli, K., & Arroussi, H. E. (2026). Microalgal extracts optimize lettuce quality through extraction-method-dependent modulation of primary and secondary metabolism. *BMC Biotechnology*, *26*(1), 20. https://doi.org/10.1186/s12896-025-01097-8

Corrado, G., Ciriello, M., Pagliaro, L., D'Ambrosio, G., Chiaiese, P., Carillo, P., Colla, G., De Pascale, S., & Rouphael, Y. (2026). Metabolic profiling reveals distinct modes of action of microalgal biostimulants in lettuce and tomato. *Scientia Horticulturae*, *362*, 114871. https://doi.org/10.1016/j.scienta.2026.114871

Cuchca Ramos, S., García, L., Barboza, J. I., Bustamante, D. E., & Calderon, M. S. (2025). Effects of seaweed-based biostimulants on the morphophysiological profile of lettuce (*Lactuca sativa* L.). *Cogent Food & Agriculture*, *11*(1), 2448594. https://doi.org/10.1080/23311932.2024.2448594

Di Mola, I., Cozzolino, E., Ottaiano, L., Giordano, M., Rouphael, Y., Colla, G., & Mori, M. (2019). Effect of Vegetal- and Seaweed Extract-Based Biostimulants on Agronomical and Leaf Quality Traits of Plastic Tunnel-Grown Baby Lettuce under Four Regimes of Nitrogen Fertilization. *Agronomy*, *9*(10), 571. https://doi.org/10.3390/agronomy9100571

Di Serio, A., Alfano, V., Tava, A., Biazzi, E., Cappetta, E., Del Regno, C., Ambrosone, A., & Ronga, D. (2025). Marine microalgae extracts as plant biostimulant to boost baby leaf lettuce production. *Scientific Reports*, *15*(1), 32825. https://doi.org/10.1038/s41598-025-18104-9

Fitriyah, F., Aziz, M. A., Wahyuni, S., Fadila, H., Luktyansyah, I. M., Sulastri, S., Priyono, P., & Siswanto, S. (2022). Biostimulant Activity of *Sargassum* sp. Extracts on Early Growth of *Zea mays* L. and the Phytohormones Content Analysis. *Journal of Tropical Biodiversity and Biotechnology*, *7*(2),

69178. https://doi.org/10.22146/jtbb.69178

Formisano, L., Ciriello, M., Cirillo, V., Pannico, A., El-Nakhel, C., Cristofano, F., Duri, L. G., Giordano, M., Rouphael, Y., & De Pascale, S. (2021). Divergent Leaf Morpho-Physiological and Anatomical Adaptations of Four Lettuce Cultivars in Response to Different Greenhouse Irradiance Levels in Early Summer Season. *Plants*, *10*(6), 1179. https://doi.org/10.3390/plants10061179

Gómez, S., & Gómez, C. (2022). Evaluating the Use of Biostimulants for Indoor Hydroponic Lettuce Production. *HortTechnology*, *32*(4), 348–355. https://doi.org/10.21273/HORTTECH05045-22

Kim, M. J., Moon, Y., Tou, J. C., Mou, B., & Waterland, N. L. (2016). Nutritional value, bioactive compounds and health benefits of lettuce (*Lactuca sativa* L.). *Journal of Food Composition and Analysis*, *49*, 19–34. https://doi.org/10.1016/j.jfca.2016.03.004

Li, R., He, Y., Chen, J., Zheng, S., & Zhuang, C. (2023). Research Progress in Improving Photosynthetic Efficiency. *International Journal of Molecular Sciences*, *24*(11), 9286. https://doi.org/10.3390/ijms24119286

Ma, Z., Buckley, T. N., & Sack, L. (2025). The determination of leaf size on the basis of developmental traits. *New Phytologist*, *246*(2), 461–480. https://doi.org/10.1111/nph.20461

Martínez-Lorente, S. E., Martí-Guillén, J. M., Pedreño, M. Á., Almagro, L., & Sabater-Jara, A. B. (2024). Higher Plant-Derived Biostimulants: Mechanisms of Action and Their Role in Mitigating Plant Abiotic Stress. *Antioxidants*, *13*(3), 318. https://doi.org/10.3390/antiox13030318

Nguyen, N. T. T., Habibi, N., Sediqui, N., Almeida, O. L. D., Dabirimirhosseinloo, M., Terada, N., Sanada, A., & Koshio, K. (2026). LED Light Intensity Regulates Nitrogen Assimilation Enzyme Activity and Metabolic Responses in Iceberg and Leaf Lettuce (*Lactuca sativa* L.). *Plants*, *15*(9), 1321. https://doi.org/10.3390/plants15091321

Puglisi, I., La Bella, E., Rovetto, E. I., Lo Piero, A. R., & Baglieri, A. (2020). Biostimulant Effect and Biochemical Response in Lettuce Seedlings Treated with A Scenedesmus quadricauda Extract. *Plants*, *9*(1), 123. https://doi.org/10.3390/plants9010123

Ramdin, T.-M., Ali, O., Ramsubhag, A., & Jayaraman, J. (2024). *Sargassum* spp. And *Ascophyllum nodosum* seaweed extract formulations improve plant growth and alter the bacterial dynamics in hydroponically cultivated lettuce. *Journal of Applied Phycology*, *36*(6), 3769–3782. https://doi.org/10.1007/s10811-024-03361-4

Riyadi, F., Ully, P. W. D., & Avianto, Y. (2026). Photoperiod Extension Enhances Lettuce Performance Across LED Spectra in an Indoor Vertical Farming Setup. *Jurnal Biologi Tropis*, *26*(2), 269–280. https://doi.org/10.29303/jbt.v26i2.11752

Rouphael, Y., & Colla, G. (2020). Editorial: Biostimulants in Agriculture. *Frontiers in Plant Science*, *11*, 40. https://doi.org/10.3389/fpls.2020.00040

Shanab, S. M., & Shalaby, E. A. (2021). Production of Plant Hormones from Algae and Its Relation to Plant Growth. In H. I. Mohamed, H. E.-D. S. El-Beltagi, & K. A. Abd-Elsalam (Eds.), *Plant Growth-Promoting Microbes for Sustainable Biotic and Abiotic Stress Management* (pp. 395–423). Springer International Publishing. https://doi.org/10.1007/978-3-030-66587-6_14

Terassi, D. D. S., Rezende, R., Wenneck, G. S., Lourenço De Freitas, P. S., Andrade Gonçalves, A. C., Villa E Vila, V., Barion Alves Andrean, A. F., Salim Lozano Menezes, C., & Saath, R. (2023). Correlation of the SPAD index with absolute leaf pigments in irrigated lettuce culture in the Northwest Paraná, Brazil. *Journal of Plant Nutrition*, *46*(20), 4657–4663.

https://doi.org/10.1080/01904167.2023.2240816

Wijaya, A., & Fajriani, S. (2022). Pertumbuhan Dan Hasil Selada (*Lactuca sativa* L.) Pada Metode Hidroponik Sistem Sumbu Dengan Kerapatan Naungan Dan Konsentrasi Nutrisi Yang Berbeda. *Produksi Tanaman*, *010*(10), 541–549. https://doi.org/10.21776/ub.protan.2022.010.10.02

Yang, Z., Yan, H., Liu, H., Yang, L., Mi, G., & Wang, P. (2025). Enhancing Crop Nitrogen Efficiency: The Role of Mixed Nitrate and Ammonium Supply in Plant Growth and Development. *Biology*, *14*(5), 546. https://doi.org/10.3390/biology14050546