

# The Potential of Algal Consortium as an Innovative and Effective Biofertilizer for Sustainable Agriculture in India

## Abstract

The growing demands of agriculture and the necessity to reduce the environmental impacts of chemical fertilizers have brought algal biofertilizers to the forefront as a sustainable solution. Algal consortium-based biofertilizers, in particular, hold promise due to their capacity to improve soil health, increase crop yield, and contribute to sustainable agricultural practices. This paper examines the potential of algal consortium as a unique biofertilizer, emphasizing the roles of different algal species, the mechanisms they employ in nutrient enrichment, and the overall impact on soil and plant health. Improved nutrient availability (i.e., N, P, K, Zn, and S), phytohormone modulation, phytopathogen biocontrol, and reduction of biotic and abiotic stressors are some of the advantageous mechanisms of improved plant growth. Sustainable agriculture depends on the interaction between plants and microbes, and these microbes may play a crucial role as ecological engineers in lowering the use of chemical fertilizers. Inoculum preparation, the addition of cell protectants like glycerol, lactose, and starch, a suitable carrier material, appropriate packaging, and the most effective delivery techniques are some of the steps involved in producing a solid-based or liquid biofertilizer formulation. Furthermore, entrapment/microencapsulation, nano-immobilization of microbial bioinoculants, and biofilm-based biofertilizers are examples of recent formulation advancements. Thus, using the resources at hand, inoculation with advantageous microbes has become a cutting-edge, environmentally friendly method of feeding the world's population. By analyzing the effectiveness of algal consortium-based biofertilizers and comparing them with traditional synthetic fertilizers, this paper highlights their advantages, challenges, and future research directions in sustainable agriculture.

**Keywords:** Algal Consortium, Effective Biofertilizer, sustainable agriculture, India

## Introduction

The modern agricultural sector faces substantial challenges, including soil degradation, increased pest resistance, and climate change. Chemical fertilizers have long been relied upon

to boost crop productivity, but they often lead to environmental degradation, reduce soil fertility over time, and pollute water resources through leaching. Biofertilizers, especially those based on algal consortia, offer a sustainable alternative that can mitigate these issues by enriching soil naturally, enhancing microbial diversity, and promoting plant growth without harmful side effects. Algal biofertilizers leverage the beneficial properties of algae, which are capable of nitrogen fixation, nutrient enrichment, and producing growth-promoting substances. Global food security is seriously threatened by a number of issues facing modern intensive agricultural practices. Chemical fertilizers and pesticides are widely used to boost crop production in order to meet the nutritional needs of the world's growing population. However, careless agrochemical use has contaminated the environment and put public health at risk. Furthermore, the quality and physical characteristics of agricultural soils, along with their chemical (nutrient imbalance) and biological health, are continuously deteriorating. Plant-associated microbes with their plant growth-promoting traits have enormous potential to solve these challenges and play a crucial role in enhancing plant biomass and crop yield (Alobwede et al., 2019). Improved nutrient availability, phytohormone modulation, phytopathogen biocontrol, and reduction of biotic and abiotic stressors are some of the advantageous processes of improved plant growth. Entrapment/microencapsulation, nano-immobilization of microbial bioinoculants, and biofilm-based biofertilizers are examples of recent formulation advancements.

An algal consortium consists of multiple algal species that work synergistically to enhance soil health and plant growth. Such consortia are particularly beneficial as they improve nutrient cycling, increase soil fertility, and provide essential compounds that enhance plant resilience (Gonçalves et al., 2023). This paper explores the potential benefits, challenges, and applications of algal consortium-based biofertilizers.

Algae are versatile microorganisms that exist in various environments, including soil, water, and plant surfaces. They play a crucial role in the ecosystem by fixing nitrogen, producing oxygen, and contributing to the food web. Algae are rich in essential nutrients, such as nitrogen, phosphorus, potassium, and a range of trace elements that are essential for plant growth (Chatterjee, et al., 2017).

### **Materials and Methods:**

### **Field Applications and Case Studies**

Several field studies and trials have demonstrated during months of January to March the effectiveness of algal consortium biofertilizers:

### **Application of Liquid consortium on *Solanum melongena* plant:**

Seedlings aged 10-15 days were collected from the nursery and transplanted into pots. Uniform-sized plants were selected for transplantation. A total of nine pots were used for the study. A consortium of pre-prepared algal biofertilizer was applied 15 days after planting. Seven different algal consortia were administered, each to a different plant. One pot was treated with chemical fertilizer, while another was left untreated as a control. Following treatment were applied to brinjal plant: B0: Control, B1: Chemical fertilizer (NPK fertilizer), B2: *Chlorella* + *Chlamydomonas*, B3: *Chlorococcum* + *Gloeocapsa*, B4: *Chlorococcum* + *Chlorella*, B5: *Chlorococcum* + *Chlamydomonas*, B6: *Scenedesmus* + *Gloeocapsa*, B7: *Scenedesmus* + *Chlorella*, B8: *Chlorococcum* + *Chlamydomonas*

### **Applications of Solid consortium**

#### **Preparation of immobilized algal bead:**

Three grams of algal biomass were mixed with 100 ml of 3% sodium alginate. This mixture was then placed in a syringe and added dropwise to a cold 0.7% CaCl<sub>2</sub> solution. The resulting beads were placed in a 0.7% CaCl<sub>2</sub> solution and stored at 4°C for 2 hours. Afterward, the beads were washed with 0.2M phosphate buffer (pH 7), following the protocols of Da Costa et al. (1991) and Soares et al. (2022). The beads were then stored at 4°C for further analysis and later coated with chitosan. All algal beads were sun-dried and stored for future analysis.

**Application of immobilized beads on Brinjal plant:** 8-10 days old crop were collected from the nursery and sapling of plants in pot. Uniform size plants were selected for the sapling. 12 pots were taken for the pot study. Consortium of prepared algal beads were applied after 15 days of planting. 10 different algal consortium beads were applied for the different plant one pot taken as chemical fertilizer and one pot remains untreated as control. Following treatment were applied to brinjal plant: A0: Control, A1: Chemical fertilizer (NPK Fertilizer), A2: *Chlorococcum* + *Scenedesmus*, A3: *Chlorococcum* + *Gloeocapsa*, A4: *Chlorococcum* + *Chlorella*, A5: *Chlorococcum* + *Chlamydomonas*, A6: *Scenedesmus* + *Gloeocapsa*, A7: *Scenedesmus* + *Chlorella*, A8: *Scenedesmus* + *Chlamydomonas*, A9: *Gloeocapsa* + *Chlorella*, A10: *Gloeocapsa* + *Chlamydomonas* and A11: *Chlorella* + *Chlamydomonas*.

**Plant growth parameter:** Plant growth parameters like plant height, width and number of leaves were measured at different time interval.

#### **Biochemical analysis:**

Study of nutrient like Carbon, Nitrogen, Sulphur and Phosphorous content were measured from the soil of *Solanum melongena* (Alef, K., & Nannipieri, P., 1995).

Chlorophyll content was measured from the leaves at flowering stage (Parry et al., 2014).

### Hormone analysis:

Plant growth hormones like IAA and Gibberellin were estimated. Plant hormone IAA concentration was analyzed by using method Gordon & Weber (1951) and Gibberellin were measured by using Graham & Henderson (1961).

### Result and Discussion:

#### Plant growth parameter:

Measured plant height in centimeters (cm) from the base of the stem to the top of the canopy, or the highest part of the plant. Width is distance from front to back. And also measured number of leaves present per plant.

**Table 1:** Measurement of plant growth parameter at different days

Treatments	Plant height (cm)			Plant width (cm)			Number of leaves/ plant		
	30 days	60 days	90 days	30 days	60 days	90 days	30 days	60 days	90 days
B0	22	33	37	70	110	115	16	18	22
B1	21	28	30	62	95	102	11	9	12
B2	20	33	34	67	97	99	10	9	15
B3	19	23	26	50	92	98	5	8	17
B4	20	30	35	65	105	112	9	20	25
B5	24	36	40	72	115	125	17	19	27
B6	24	29	32	75	117	123	18	22	27
B7	20	29	34	65	107	115	10	16	33
B8	19	37	43	57	102	113	7	14	32

Throughout the experiment, plant growth parameters treated with various algal consortia were compared to a control. At day 30, plants treated with B5 and B6 exhibited significantly greater height than the control, a trend that continued through day 60, with B5 and B8 leading to taller

plants. By day 90, B5 and B8 achieved the maximum plant height, indicating their effectiveness in promoting height growth throughout the experimental period.

In terms of plant width, treatments B5 and B6 showed the widest growth from day 30 onwards, consistently outperforming the control at all stages up to day 90. This suggests B5 and B6 were particularly effective in promoting broad, healthy growth.

Regarding the number of leaves, plants treated with B5 and B6 had the highest leaf counts at days 30 and 60, stimulating early leaf production. By day 90, B5, B6, B7, and B8 all contributed to higher leaf production compared to the control, with B8 also demonstrating significant benefits in height and leaf production.

In summary, B5 and B6 consistently provided superior results in plant height, width, and leaf number through the first 60 days, while B8 showed promising results in height and leaf production by day 90 (Table 1). In similar study Ramya et al., 2015 evaluate the biofertilizing efficiency of liquid extracts from the brown marine alga *Stoechospermum marginatum* on brinjal (eggplant). Various concentrations of the extracts were prepared and applied as foliar sprays to brinjal seedlings grown in experimental pots under natural conditions. After 30 and 180 days, several growth and biochemical parameters and yield attributes were monitored. The results indicated that a 1.5% concentration of *S. marginatum* extract significantly enhanced shoot and root length, leaf area.

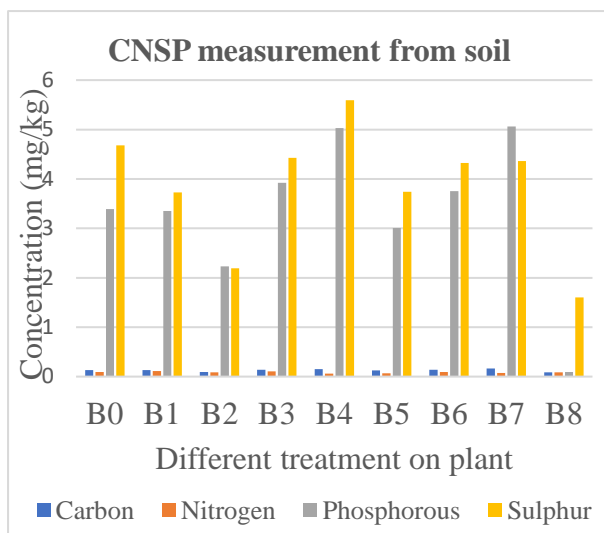
#### **Nutrient content measurement from soil:**

Carbon content was higher in B3, B4, B6, and B7 compared to the control (B0), indicating a higher accumulation of carbon in these treatments.

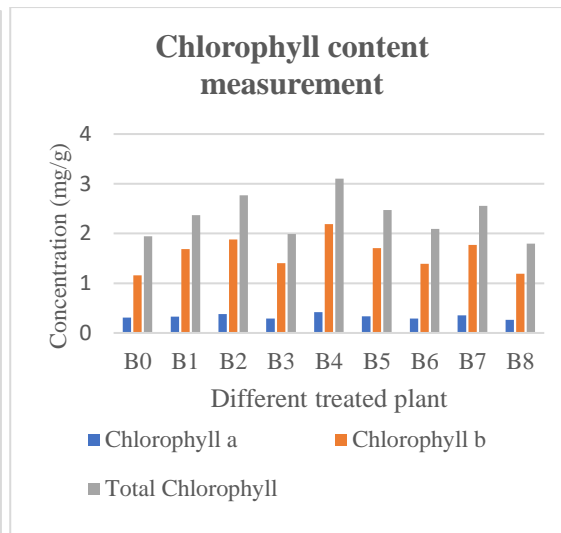
Nitrogen content was elevated in all treatments except B4 and B7 when compared to the control, suggesting a general increase in nitrogen levels across most treatments.

Phosphorous content was higher in B1, B3, B4, B6, and B7 relative to the control, indicating increased phosphorus levels in these treatments.

Sulphur content was notably higher in B4 compared to the control, indicating an increase in sulphur in this treatment.



**Figure 1: CNSP measurement from soil after application of biofertilizer**

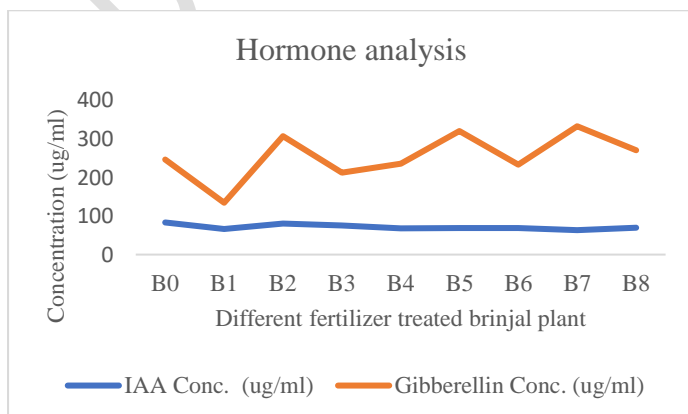


**Figure 2: Chlorophyll content estimation from brinjal plant**

**Chlorophyll measurement:**

Chlorophyll a, chlorophyll b, and total chlorophyll content were significantly higher in brinjal plants treated with B2, B4, B5, and B7 compared to both the control and the chemical fertilizer-treated plants. This suggests that these treatments were more effective in promoting chlorophyll synthesis, which is essential for photosynthesis, compared to the conventional chemical fertilizer. The increased chlorophyll content in B2, B4, B5, and B7-treated plants likely contributed to better overall plant health and growth, as higher chlorophyll levels typically indicate enhanced photosynthetic efficiency and improved nutrient uptake (Fig. 2). Hajnal-Jafari et al., 2020 explored the application of the microalga *Chlorella vulgaris* S45 and its impact on plant growth and pigment content in Swiss chard. The treatments involved spraying 5% and 10% algal suspensions on plants and soil, respectively. The application of *C. vulgaris* S45 can enhance plant growth and pigment content in Swiss chard, making it a beneficial alternative in agriculture.

**Plant growth hormone analysis:**



### Figure 3: Hormone analysis of Brinjal plant

The analysis of key plant growth hormones, IAA (Indole-3-acetic acid) and Gibberellin, revealed notable differences between treatments. Control plants had the highest IAA concentration, indicating naturally higher IAA production without treatment. However, plants treated with algal biofertilizers (B2, B4, B5, and B7) showed significantly increased IAA levels compared to those treated with chemical fertilizers, suggesting these biofertilizers effectively enhanced IAA production, promoting better root development and overall growth.

For Gibberellin, plants treated with B2, B5, and B7 exhibited higher concentrations than the control, indicating these treatments effectively boosted gibberellin levels. Gibberellin promotes stem elongation and overall growth, and its levels were consistently higher in algal biofertilizer-treated plants compared to those treated with chemical fertilizers, highlighting the superior potential of algal biofertilizers in hormone regulation. Bhattarai et al., 2021 examined the effects of phytohormones and micronutrients on the growth and yield of brinjal (*Solanum melongena*, L.). study involved thirteen treatments with varying concentrations of phytohormones and micronutrients, tested on brinjal plants. The use of phytohormones and micronutrients can significantly enhance the growth and yield of brinjal. Specifically, 25 ppm GA3 were most effective for improving various growth and yield parameters.

### Applications of Solid consortium

#### Plant growth parameter:

Measured plant height in centimeters (cm) from the base of the stem to the top of the canopy, or the highest part of the plant. Width is distance from front to back. And also measured number of leaves present per plant.

**Table 2: Measurement of plant growth parameter at different days**

Treatments	Plant height (cm)			Plant width (cm)			Number of leaves/ plant		
	30 days	60 days	90 days	30 days	60 days	90 days	30 days	60 days	90 days
A0	22	25	27	35	115	119	4	16	30
A1	21	22	22	25	120	135	3	28	56
A2	14	20	21	40	107	112	3	11	17
A3	20	30	34	42	108	118	2	15	22
A4	20	25	25	23	97	106	8	14	17
A5	21	26	28	45	102	111	4	13	17

A6	20	27	30	43	115	127	7	15	22
A7	21	25	27	41	105	112	4	10	27
A8	17	27	32	38	103	105	2	8	25
A9	21	20	25	42	118	130	7	24	35
A10	17	26	28	40	106	109	3	10	25
A11	19	26	30	42	106	115	6	21	26

At the harvesting stage, notable differences in plant growth metrics were observed among various treatments compared to the control group. Specifically, plant height significantly increased with treatments A3, A5, A6, A7, A8, A10 and A11 indicating these treatments were more effective in promoting vertical growth than the control.

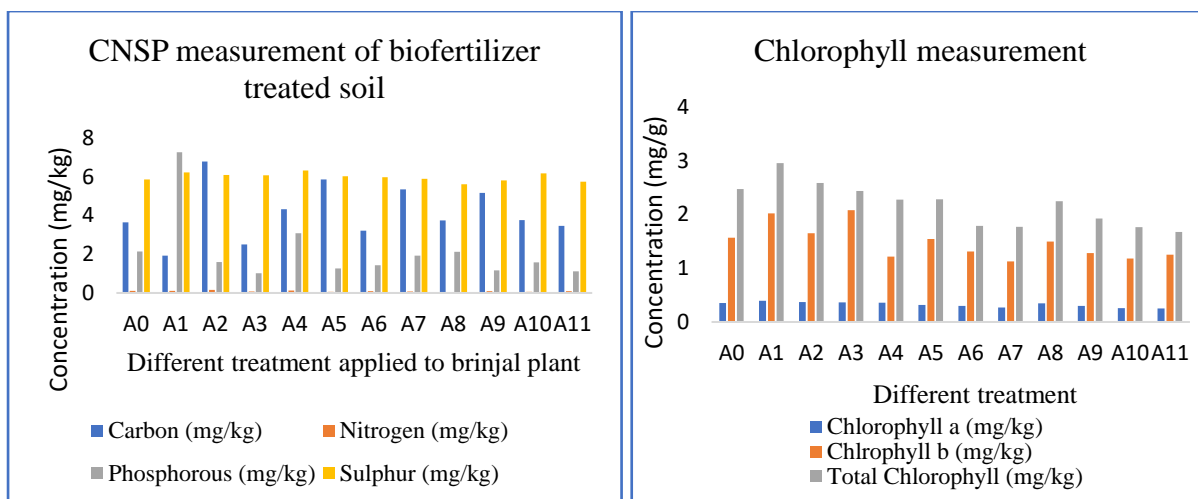
Plant width, measuring lateral expansion, was significantly greater in treatments A1, A6, and A9 compared to the control, suggesting these treatments had a beneficial effect on the plants' overall spread.

Additionally, the number of leaves, a critical parameter indicating plant health and photosynthetic capacity, showed significant improvement with treatments A1, A7, A8, A9, A10, and A11, resulting in a higher leaf count compared to the control.

Overall, these observations highlight the positive impact of certain treatments on plant height, width, and leaf number, suggesting specific combinations or types of treatments can significantly enhance plant development compared to control conditions.

Salve (2019) study emphasizes the efficacy of using algal foliar spray to boost the yield of crops, particularly eggplant. Results indicated that a 20% (w/v) concentration of the algal extract was the most effective. This suggests that algal extract could serve as a viable alternative to chemical fertilizers.

**Nutrient content measurement from soil of brinjal plant:**



**Figure 4: CNSP measurement from soil of brinjal plant after application of biofertilizer**

**Figure 5: Chlorophyll measurement from Brinjal plant**

Study of Carbon, Nitrogen, Sulphur and Phosphorous content of soil from *Solanum melongena*. The analysis of soil nutrient content shows that different treatments impact brinjal plant nutrient levels in distinct ways. Immobilized beads significantly increased soil carbon content, enhancing fertility and plant growth. Nitrogen levels were notably higher in plants treated with A2 and A4 beads, boosting nitrogen availability crucial for protein synthesis and plant health. Chemical fertilizers resulted in the highest phosphorous content, providing essential nutrients in higher concentrations. Sulphur content was significantly elevated in soils treated with A4 beads, highlighting their unique benefit in enhancing sulphur availability for plant metabolic processes (Fig. 4). Overall, immobilized beads effectively improve carbon and nitrogen levels, chemical fertilizers are more efficient for phosphorous, and A4 beads are particularly beneficial for sulphur enrichment, demonstrating the varied efficacy of these treatments in meeting specific soil nutrient needs.

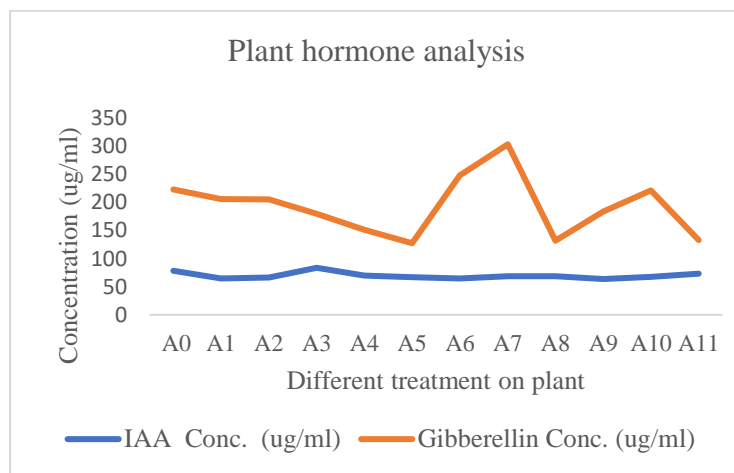
### **Chlorophyll content measurement**

Chlorophyll content was measured in the leaves of brinjal plants at the flowering stage, assessing Chlorophyll a, Chlorophyll b, and total chlorophyll content. Treatment A1 resulted in the highest Chlorophyll a content, while A2 had the highest Chlorophyll b content. Overall, A1-treated plants exhibited the highest total chlorophyll content compared to the control and second higher in A2.

A1 treatment effectively enhanced Chlorophyll a level, crucial for capturing light energy during photosynthesis. A2 treatment increased Chlorophyll b content, broadening the light absorption spectrum and improving light energy capture (Fig. 5). Kumar et al., 2017 studied that the CO-

2 variety, which is susceptible to infestation, had a higher chlorophyll content. In the first year, the CO-2 brinjal variety exhibited the highest total chlorophyll content in its leaves at 0.920 mg g<sup>-1</sup>, while the Swarna Prabha and Utkal Tarani varieties had the lowest at 0.786 mg g<sup>-1</sup>. In the second year, CO-2 again recorded the highest chlorophyll content at 0.922 mg g<sup>-1</sup>, with Arka Keshav showing the minimum at 0.790 mg g<sup>-1</sup>. A significant positive correlation was observed between total chlorophyll content and shoot infestation in both years, indicating that higher chlorophyll levels led to increased shoot infestation.

#### Plant hormones:



**Figure 6: Hormone analysis from brinjal plant**

IAA concentration was higher in all algal biofertilizer treated plant as compared to Chemical fertilizer treated plant and control plant whereas, Gibberellin concentration was maximum in A6 and A7 treated plant as compared to chemical fertilizer treated plant and control plant.

These examples highlight the potential of algal consortia in diverse climatic conditions and crop systems, proving their adaptability and effectiveness in real-world agricultural scenarios.

Afrin et al., 2024 studied that a foliar application of 200 ppm GA3 significantly enhanced brinjal growth, yield, and quality compared to other treatments with different plant growth regulators (PGRs).

#### Conclusion:

Plants require vital nutrients from fertile soil, which supports a diverse biotic population that helps resist environmental degradation. For high productivity, soil must be fertile. Increasing soil nutrient content and organic matter through biofertilizers is a key aspect of sustainable agriculture. Micro and macroalgae are considered the best bio-based fertilizers for pollution-free applications. Macroalgae excel in large-scale aquatic media, while microalgae are more effective as soil biofertilizers. Algal consortium-based biofertilizers naturally enhance soil fertility, improve plant growth, and reduce environmental impact by working synergistically.

Despite production and application challenges, algal biofertilizers offer a promising alternative to synthetic fertilizers. The study conclusively demonstrates that algal biofertilizers and specific nutrient treatments significantly enhance plant growth, nutrient content, and chlorophyll synthesis in brinjal plants. Treatments B5, B6, and B8 were particularly effective in promoting plant height, width, and leaf production. The use of immobilized beads was shown to improve soil carbon and nitrogen levels effectively, while chemical fertilizers were more efficient in phosphorus enrichment. Algal biofertilizers also positively influenced key plant hormones, underscoring their potential in enhancing overall plant health and productivity. These findings highlight the adaptability and effectiveness of algal consortia and biofertilizers in diverse agricultural scenarios, offering a sustainable and eco-friendly alternative to conventional chemical fertilizers.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

- 1.
- 2.
- 3.

### Reference:

1. Chatterjee, A., Singh, S., Agrawal, C., Yadav, S., Rai, R., & Rai, L. C. (2017). Role of algae as a biofertilizer. In *Algal green chemistry* (pp. 189-200). Elsevier.
2. Alobwede, E., Leake, J. R., & Pandhal, J. (2019). Circular economy fertilization: Testing micro and macro algal species as soil improvers and nutrient sources for crop production in greenhouse and field conditions. *Geoderma*, 334, 113-123.

3. Gonçalves, J., Freitas, J., Fernandes, I., & Silva, P. (2023). Microalgae as biofertilizers: a sustainable way to improve soil fertility and plant growth. *Sustainability*, *15*(16), 12413.
4. Gordon, S. A., & Weber, R. P. (1951). Colorimetric estimation of indoleacetic acid. *Plant physiology*, *26*(1), 192.
5. Graham, H. D., & Henderson, J. H. M. (1961). Reaction of gibberellic acid & gibberellins with Folin-Wu phosphomolybdic acid reagent & its use for quantitative assay. *Plant physiology*, *36*(4), 405.
6. Alef, K., & Nannipieri, P. (Eds.). (1995). *Methods in applied soil microbiology and biochemistry* (pp. xix+576).
7. Da Costa, A. C. A., & Leite, S. G. F. (1991). Metals biosorption by sodium alginate immobilized *Chlorella homosphaera* cells. *Biotechnology Letters*, *13*, 559-562.
8. Parry, C., Blonquist Jr, J. M., & Bugbee, B. (2014). In situ measurement of leaf chlorophyll concentration: analysis of the optical/absolute relationship. *Plant, cell & environment*, *37*(11), 2508-2520.
9. Soares, R. C., Zangirolami, T. C., Giordano, R. L., Demeke, M. M., Thevelein, J. M., & Milessi, T. S. (2022). Cell immobilization using alginate-based beads as a protective technique against stressful conditions of hydrolysates for 2G ethanol production. *Polymers*, *14*(12), 2400.
10. Ramya, S. S., Vijayanand, N., & Rathinavel, S. (2015). Foliar application of liquid biofertilizer of brown alga *Stoechospermum marginatum* on growth, biochemical and yield of *Solanum melongena*. *International Journal of Recycling of Organic Waste in Agriculture*, *4*, 167-173.
11. Hajnal-Jafari, T., Seman, V., Stamenov, D., & Đurić, S. (2020). Effect of on Growth and Photosynthetic Pigment Content in Swiss Chard (. subsp.). *Polish journal of microbiology*, *69*(2), 235-238.
12. Bhattarai, B. R., Pal, A. K., & Amgain, L. P. (2021). Response of varying levels of phytohormones and micro-nutrients on growth and yield of brinjal (*Solanum melongena* L.) in subtropical Terai region of India. *Journal of Agriculture and Natural Resources*, *4*(2), 40-47.
13. Salve, A. N. (2019). EFFECT OF ALGAL FOLIAR FERTILIZATION ON THE GROWTH AND YIELD OF *Solanum melongena* L. *Journal of Environmental Research And Development*, *13*(03), 236.
14. Kumar, K., Singh, N., Raju, S., Prakash, P., & Mishra, V. K. (2017). Shoot and fruit borer, *Leucinodes orbonalis* incidence as influenced by total chlorophyll content in different brinjal varieties. *Journal of Entomology and Zoology Studies*, *5*(5), 360-363.
15. Afrin, S., Islam, N., Mustaki, S., Araf, T., & Choudhury, S. (2024). Impact of Micronutrients and Plant Growth Regulators on Brinjal (*Solanum melongena* L.) Growth, Yield and Quality. *Asian Journal of Soil Science and Plant Nutrition*, *10*(2), 72-79.

UNDER PEER REVIEW