The biotechnological potential of *Chlorella vulgaris* as an lnnovative biofertilizer for achieving sustainable development goals

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ABSTRACT

Concerns have recently been raised regarding the growth in environmental contamination caused by the widespread use of chemical fertilizers. To reduce these pollutants and improve plant growth, the use of a suitable and environmentally friendly alternative has been encouraged in modern agriculture and supports sustainable development goals, which is *Chlorella vulgaris* algae, due to its high concentration of effective compounds and ability to improve soil fertility and plant productivity. When algae-derived materials are combined with chemical fertilizers, they have a direct impact on plant essential functions. That is, its biological components comprise materials of low molecular weight, which implies that they can impact enzymes.This scientific article aims to fully explain the difference between biological and chemical fertilizers, as well as the benefits of *chlorella vulgaris* and how they compare to the results of chemical fertilizers. It also explains how to choose the type of system. Its advantages and disadvantages, harvesting biofertilizers, and its most significant applications on various types of plant crops, as extensive experimental studies of the use of *Chlorella vulgaris* have proven that it has improved the phenotypic and anatomical characteristics of plants, including the number of leaves, plant lengththe efficiency of the root absorption process of nutrients and chlorophylls, an improvement in metabolic processes, especially the salt stress to which the plant is exposed, and improved soil fertility.

Keywords: biofertilizers, bioreactors, algae, sustainable agriculture, *chlorella vulgaris*

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1-INTRODUCTION

Algae are microorganisms that can undergo photosynthesis in the presence of sunlight and emit oxygen gas (O_2) during respiration. Living species, including humans,many befound in all aquatic and other systems[1] . They come in avariety of forms and size ,with, some being unicellular and others ,and the play avital role in monitoring water multicellular, and they have an important quality[2][3] . In our current time, the process of agricultural production and soil fertility is witnessing very great challenges. This is due to the deterioration of agricultural lands, especially when irrigation contains heavy elements that affect the vital activities of the plant directly, in addition to the occurrence of an imbalance in nutrients[4] . It contributes to improving plant growth and reproduction and increasing productivity, but only within appropriate limits and according to the plant's needs. Excessive use can lead to a clear imbalance in soil properties, thus altering the pH. This encourages the growth of other organisms and reduces the balance of nutrients, causing these components to leak into the environment, resulting in pollution and promoting eutrophication.[5] [6] As for the biofertilizers for algae, they are in the form of a dried powder that is added to the soil as a biostimulant in order to improve the stress that the plant receives during growth, and this depends on the type of plant, the amount of algae added to it, and the method of its applicatio[7] Recent studies have indicated the widespread use of algae as a biofertilizer for soil. It gives strength and stabilizes nitrogen, dissolves phosphorus, preserves organic matter and retains water, [8].

There are studies that have proven that algae products act as an inhibitor of types of pathogens, especially those that infect plants, to protect entire crops from any infection and from different environmental conditions, including dry and non-dry**[**9] [10] Algae fertilizers are rarely replaced with chemical fertilizers, but when they are added to the plant to supplement the nutrients it needs for its physiological effectiveness, thus, biological and chemical fertilizer are combined for the purpose of *maintaining* plant quality and reducing environmental pollution **[**11]

2-*Chlorella vulgaris*

Chlorella vulgaris is a very delicate, single-celled green microalga that lives in aquatic environments when suitable conditions are available. It has the ability to adapt even under harsh conditions [1] Microscopic examination under alight at (40X) magnification showed that *Chlorella vulgaris* (10Mic scalebar)cells were spherical to slightly oval in shape and appeared either as single cells or small cellular aggregates. Chlorophyta Figure(1) Table(1) *chlorella vulgaris* contains bioactive compounds Table(2) including minerals, pigment,amion acid,vitamins&phenolics as showing in This alga requires carbon dioxide, light, nutrients, and a suitable temperature for growth [12][13]. It contains chlorophyll a and b within the chloroplast, which helps carry out photosynthesis and gives the alga its green color. It has one centrally located

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nucleus, vacuoles, mitochondria, starch, and lipids [14]. This alga reproduces asexually through autosporulation, in which the mother cell divides internally into (2–32) daughter cells that are released after maturation [15][16][1]

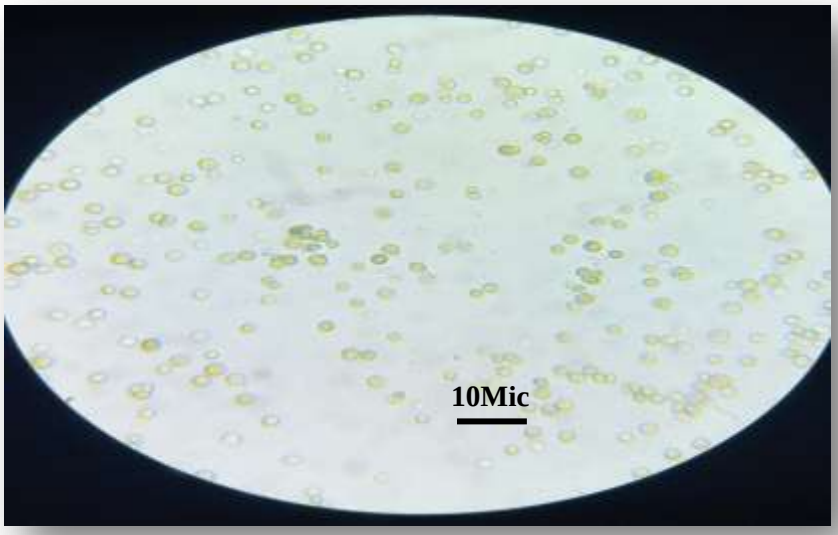


Figure (1). microscopic image of *Chlorella vulgaris* under a light microscope at 40X magnification.[1] **Scale bar 10Mic**.

Table (1). Taxonomic Classification of *Chlorella vulgaris*

Rank	**Classification**
Kingdom	Plantae
Division / Phylum	*Chlorophyta*
Class	*Trebouxiophyceae*
Order	*Chlorellales*
Family	*Chlorellaceae*
Genus	*Chlorella*
Species	*Chlorella vulgaris*

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[17]

Table (2). Bioactive Chemical Components of *Chlorella vulgaris*

Reference	Content / note	Main components in *Chlorella vulgaris*	Chemical point
[18]	The amino acid profile includes essential and non-essential amino acids. One commercial *Chlorella*-powder study reported, for example, leucine 9.1%, lysine 8.7%, valine 5.7%, isoleucine 3.9%, threonine 4.9%, glutamic acid 12.0%, and aspartic acid 9.3% of total amino acids.	Leucine, lysine, valine, isoleucine, threonine, phenylalanine, methionine, tryptophan, alanine, arginine, aspartic acid, glutamic acid, glycine, histidine, proline, serine	Amino acids
[19]	*Chlorella vulgaris* is reported as a source of B-complex vitamins, vitamin-A-related carotenoids, and vitamin-E-related antioxidant compounds.	Vitamin B complex, thiamine B1, riboflavin B2, niacin B3, folic acid B9, provitamin A / beta-carotene, vitamin E / tocopherols	Vitamins
[20]	*Chlorella vulgaris* biomass or extracts can contain phytohormone-related compounds linked with plant biostimulant effects such as improved growth and stress tolerance.	Auxins, cytokinins, abscisic-acid-related compounds, and other growth-regulator-like compounds	Phytohormones plant growth regulators
[21]	Phenolic compounds contribute to antioxidant and anti-inflammatory bioactivity; they are usually reported as total phenolic content or as identified phenolic classes rather than a fixed biomass percentage.	Polyphenols, phenolic acids, catechin-like compounds, chlorogenic-acid-related compounds	Phenolic compounds
[22]	*Chlorella* and other microalgae can provide essential minerals; mineral concentration is strongly affected by growth medium, harvesting, and biomass	Calcium, phosphorus, potassium, magnesium, iron, zinc, manganese, selenium, and other macro- and	Minerals

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	processing.	trace elements	
[23]	Carotenoids and chlorophyll-related pigments are important antioxidant and photosynthetic compounds; their levels vary with salinity, light, and cultivation stage.	Lutein, beta-carotene, total carotenoids, chlorophyll a, chlorophyll b, and related pigments	Carotenoids pigments

3- Advantages and disadvantages of Biofertilizers

Biofertilizers are known as biological compounds that contain very fine living organisms, including algae, fungi, and types of bacteria that are used as biofertilizers or applied to the surfaces of some plants, in order to provide nutrients [24] and work to prepare phosphorus, nitrogen, and other useful minerals as an alternative to chemical fertilizers in order to improve the quality of the crop, maintain the environmental balance, and support sustainable development, Its positivity improves soil fertility, meaning it recycles nutrients and withstands stresses through biological signals, and improves the quality and type of plants[25] Table(2) [26]. Studies have indicated that it reduces inputs, i.e. the process of moving from single-strain products to artificial biological communities, in order to explore performance, and also reduces chemical fertilizers according to complete nutrient management strategies[27] However, its negative side varies in field activities, that is, it depends on the quality of the strain with the crops, the pH and texture of the soil, as well as the climate, the competition of some microorganisms, storage, and the quality of the composition. Therefore, most results appear less predictable when Combined with chemical fertilizers and there are requirements for quality and biological safety, which emphasized periodic monitoring to verify safety and to prevent the occurrence of any contamination that may be unintended before applying it to plants[28]

4- Advantages and disadvantages of chemical fertilizers

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They are called industrial and mineral fertilizers. Chemical fertilizers are artificial nutritional substances rich in phosphorus, nitrogen, potassium, sodium, and others. One of their positive aspects when added to the soil is that [29] it also improves management ,production efficiency ,andcrop performance in intensive agricultural systems. [30] [31] One of its negative aspects is that when chemical fertilizers are added to the soil for a long period of time, it can cause changes in the microbial community and accelerate the pH, especially when it is within a large input of nitrogen, leading to a decrease in the regulatory ability of microorganisms ,Water quality can directly affect the degradation of excess nitrogen and phosphorus in the soil, thus causing a phenomenon of excessive growth of types of algae, especially blue-green and green vegetables, called eutrophication[32] [33] Variations in climate elements also contribute to the loss of reactive nitrogen from the soil in nitrous oxide emissions, and this makes chemical fertilizers an essential tool for reducing Gases[34]

5-The successful cultivation of microalgae depend on several key factors including:

1-Light: Suitable light must be provided and it works on its own, and if the appropriate amount of light does not reach it, it will redue the growth of the *chlorella vulgaris* **[**35**]**.

2-Mixing and hydrodynamics: Algae cells must be preserved. This mass must always be mixed daily to reduce dead algae cells and ensure greater productivity[36]

they accelerate the process of plant germination and support, especially plants that have a high nutritional value, when the time and rate are compatible with the demands of agricultural crops

3-Preparation of carbon dioxide gas: Algae need this gas within limits to complete the process of photosynthesis, and the transfer of biomass between gas and liquid takes place through the neck of a basic glass tube placed inside the systems.[37]

4-Providing nutrients: The main nutrients for algae are phosphate and nitrate. They must be available to maintain increased productivity of the algae, and any external fluctuation that occurs to these nutrients negatively affects the chemical composition of the algae walls[38]

5-Temperature: It is preferable to use ponds with depth, rotation, and a specific operating time in order to achieve the required daily variations in temperature, and that each alga has an optimal temperature for growth**[**39]

6-pH: When planting in these ponds, the pH must be adjusted in order to stabilize and thus reduce the stress that the moss receives[40]

7- Preventing pollution: In order for algae cultivation to be successful, ideal conditions forgrowth must be applied in a very selective manner, a commitment to periodic sterilization of the growth room, especially when adding water, and also an examination of a sample of algae cells under an optical microscope in order to confirm the algae cells and their density *chlorella vulgaris* [41].

8-Harvesting: It is preferable to choose a suitable method, for example the electrochemical method, as it is efficient

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and under ideal conditions such as heat and an appropriate electrical current [42].

6-Types of cultivation systems for *Chlorella vulgaris* and their advantages and disadvantages:

1-Open system: This system is used to grow algae. It is in the form of tubular photoreactors containing flat panels, as in. A recent study has confirmed that choosing the type of system for cultivation is a major factor in order to ensure a balance between cost and control of growth factors [43] [26]. Among the positives of this system is that it is low cost, simple, mechanical and testable, and this facilitates application in different and specific environments[44] . and it depends on sunlight and reduces dependence on current. Electricity provides light, and sewage waste can be utilized as it is rich in various agricultural and industrial materials. This will provide the possibility of high-quality algal biomass and at the same time support the bioeconomy[45] It depends on sunlight and reduces dependence on electric current to provide light. Sewage waste can be utilized as it is rich in various agricultural and industrial materials. This will provide the possibility of high-quality algal biomass and at the same time supports the bioeconomy[46] . As for the negatives of this system, it may cause contamination with other microbes that compete with it for food, especially fungi, whose spores can be transmitted through the air, as they are exposed to various environmental conditions in addition to the difficulty of controlling them, and this is due to the process of water evaporation. The lack of nutrients and thus the productivity of algal biomass decreases[47] .

2- closed system

It is known as a system used for the growth and reproduction of algae of all kinds through (BG-11broth medium) photoreactors, whether they are vertical, tubular, or bioplate reactors, and they are completely controlled, as in Figure (2)[1] such as applications Table (3). in terms of providing the environmental conditions they need, such as heat, light, carbon dioxide gas, pH, phosphorus, and nitrates. Among its positive aspects is the production of a high biomass of algae, unlike the open system, and the lack of pollution in it compared to the open system, in addition to This enables the transfer of biomass between gas and liquid well. Co_2 gas can also be stabilized and the farm can be rotated continuously[48][49] . Its negative side is that it requires high costs and maintenance, such as providing special sensors for the cleaning process, materials, and pumps for water circulation, unlike the open system ,You may face many difficulties within this system, especially when oxygen gas O_2 accumulates. Therefore, it requires continuous monitoring in order to obtain an algae density rich in materials and use it in all applications, whether as biofertilizer, cosmetic products, as food, etc [5] .

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Figure (2). Cultivation of *Chlorella vulgaris* in a small covered glass tank containing BG-11broth culture medium.[1]

Table(3).Applications of *Chlorella vulgaris* as a Biofertilizer and Biostimulant for Different Plant Species

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Reference	Key results	Application method	Plant species
[50]	Fresh root biomass increased by 32% and fruit yield approximately doubled compared with control	Foliar application of *Chlorella vulgaris* extract combined with tannin extract	Strawberry (*Fragaria* × *ananassa*)
[51]	Application of *Chlorella vulgaris* at 2.5 g significantly enhanced biomass accumulation and nutritional quality	Soil application of microalgal biofertilizers	Pak Choi (*Brassica rapa subsp. chinensis*)
[52]	Increased glucosinolate and kaempferol biosynthesis and upregulated gene expression pathways	Foliar spray of *Chlorella* suspension (1–4 g L^{-1}) combined with silver nanoparticles	(*Eruca sativa*)
[53]	Improved germination rate, root development, and seedling uniformity	Seed soaking with microalgal extracts	Sugar beet (*Beta vulgaris*)
[20]	Stimulated root and shoot growth and improved drought tolerance	Application of cell‐free supernatant of *Chlorella* culture	*Arabidopsis* (*Arabidopsis thaliana*)
[54]	Increased chlorophyll content by 1.57 fold and carotenoids by 1.41 fold	Application of biomass and suspension of *Chlorella vulgaris*	Kale (*Brassica napus* var. pabularia)
[55]	Plant height increased from 24.2 to 32.2 cm and leaf area increased to 189.6 cm^2	Foliar application of *Chlorella* extract	Pepper (*Capsicum annuum* L.)
[56]	Significant increase in chlorophyll content and leaf biomass	Foliar and soil application of *Chlorella* suspension (5–10%)	Swiss chard (*Beta vulgaris* var. cicla)
[57]	Increased root length, leaf number, and chlorophyll content	Application of *Chlorella* biofertilizer culture	Tomato (*Solanum lycopersicum*)

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[58]	Root biomass increased from 0.04 to 0.05 g under hydroponic conditions	Hydroponic application of *Chlorella vulgaris* suspension	Cucumber (*Cucumis sativus*)
[59]	Enhanced growth, yield, and antioxidant activity	Foliar spray of microalgal,*Nanno chlotopsis salina,Arthrospir a platensis* extracts (0.25–2%)	Common bean (*Phaseolus vulgaris*)
[60]	Improved soil fertility and crop growth	Application of wastewater- deriv ed *Chlorella vulgaris* biomass with mineral fertilizer	Wheat (*Triticum aestivum*)
[61]	Microalgal extracts increased photosynthetic pigments, biomass, and tolerance index; they reduced electrolyte leakage through antioxidant enzyme activation and increased total phenolic content. *Dunaliella salina* showed the highest efficacy, while *Chlorella vulgaris* was one of the tested microalgal extracts.	Aqueous extracts of *Chlorella vulgaris*, *Dunaliella salina*, and *Arthrospira platensis* applied under saline and non-saline greenhouse conditions.	*Cuminum cyminum* L. (cumin)
[62]	No significant difference was detected in coleoptile development time, root length, or leaf size between *Chlorella vulgaris* and *Anabaena variabilis* treatments; the study concluded that the two biostimulants were interchangeable for Monstera growth and development.	Living and pasteurized *Chlorella vulgaris* inoculum; compared with *Anabaena variabilis* as a microalgal/cyano bacterial biostimulant.	*Monstera deliciosa* Liebm.

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[63]	The 5.0 g,2.0,0.5 L-1 treatment produced the largest increases compared with the control: leaf area 67.4%, root fresh weight 138.7%, root volume 92.1%, and root dry weight 150.0%. It also increased shoot N, P, K, and Fe accumulation.	Weekly application of *Chlorella vulgaris* suspensions in soilless culture at 0.5, 2.0, and 5.0 g L-1.	*Lactuca sativa* cv. Oreja de Mulo (lettuce)
[64]	*Chlorella* biomass significantly improved root development by 34.41% and chlorophyll content by 39.05%. The extracted residue showed weaker growth stimulation but influenced the rhizosphere microbial community, including Cyanobacteria and *Trichoderma*.	Greenhouse treatment with *Chlorella* biomass and lipid-/water-extracted microalgal biomass residue.	*Lactuca sativa* (lettuce seedlings)
[65]	*Chlorella vulgaris* seed treatment increased plant height to 39.83 ± 0.82 cm, pods per plant to 11.65 ± 0.87, and yield to 865.32 ± 31.70 kg ha-1. Yield increased by 40.24% with *Chlorella vulgaris* seed treatment, while foliar application was not significant.	Seed treatment and foliar application using aqueous extracts of Tetradesmus obliquus and *Chlorella vulgaris*.	*Phaseolus vulgaris* (common bean)
[66]	*Chlorella vulgaris* increased plant height, fresh weight at the highest concentration, and promoted earlier flowering. Higher *Chlorella* concentrations were positively correlated with N, P, Mn, and Cu in shoots.	Substrate application of *Chlorella vulgaris* suspensions at 0.5, 2.0, and 5.0 g dry weight L-1.	*Tagetes patula* L. (French marigold)

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CONCLUSION

Numerous studies have proven that *Chlorella vulgaris* algae represents the most important sustainable biofertilizer in the field of modern agriculture, as it is rich in effective compounds that improve the quality of production and also improve the chemical and physical factors of the soil. It is preferable to use a closed system for algae development because it is well controlled, has low pollution, and produces high nutritional value. Accordingly, choosing this alga and the closed system is considered an effective approach and achieves the goals of sustainable development, and preserves the components and texture of the soil. Previous studies have recommended future work on developing systems that combine the advantages of open and closed systems in order to improve plant quality and conducting long-term field experimentsto determine their economic and environmental impacts,future studies focus on evaluating the long term field performance of *chlorella vulgaris* andoptimize its as a use sustainable biofertlizer.

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