BIWWEC
Borneo International
Water & Wastewater
Exhibition & Conference 2024
Flowing Future

Curtin University
Malaysia

BIWWEC 2024

Water-Energy Nexus

Advancements in Wastewater Treatment: Exploring the Benefits of ***Phycoremediation*** *with Microalgae*

Paran Gani
PhD, P.Tech, M.IEM

25 October 2024
(Friday)

Outline

❑What is Phyco-remediation?

❑Wastewater Treatment Facilities.

❑Details about Phycoremediation.

❑Factors Effects.

❑Integration with Conventional Treatment.

❑Advantages of this Technology.

❑Practical Limitations.

❑Way Forward.

Phycoremediation?

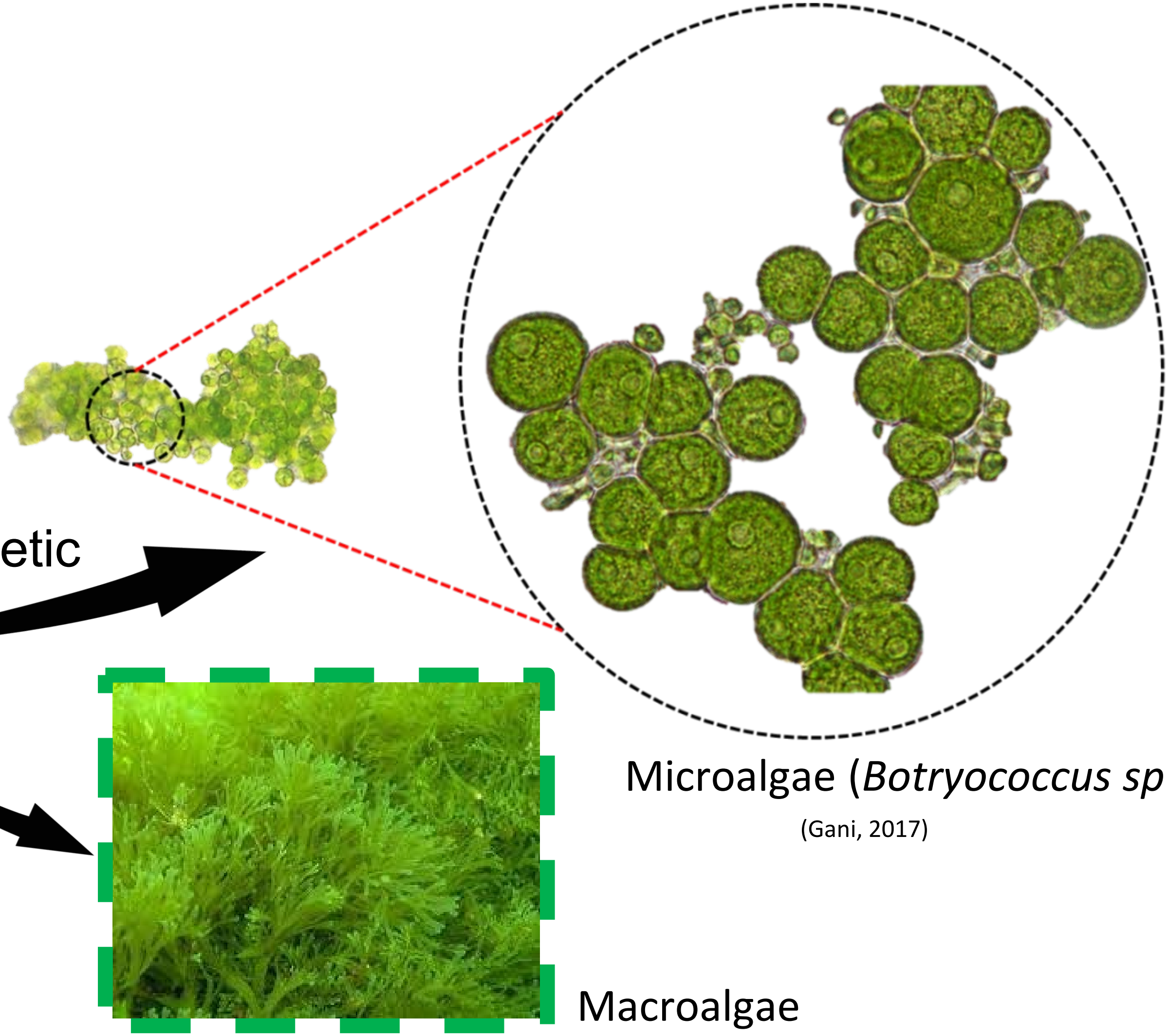
Defined as used microalgae or macroalgae for biotransformation of pollutants from various environmental sources – wastewater and waste air.

Prokaryotic and eukaryotic photosynthetic organisms - chlorophyll a and other photosynthetic pigments – O_2 release

In 1988 highlighting the potential of microalgae for municipal wastewater treatment.

Algae

>60 years: 1957 by Oswald

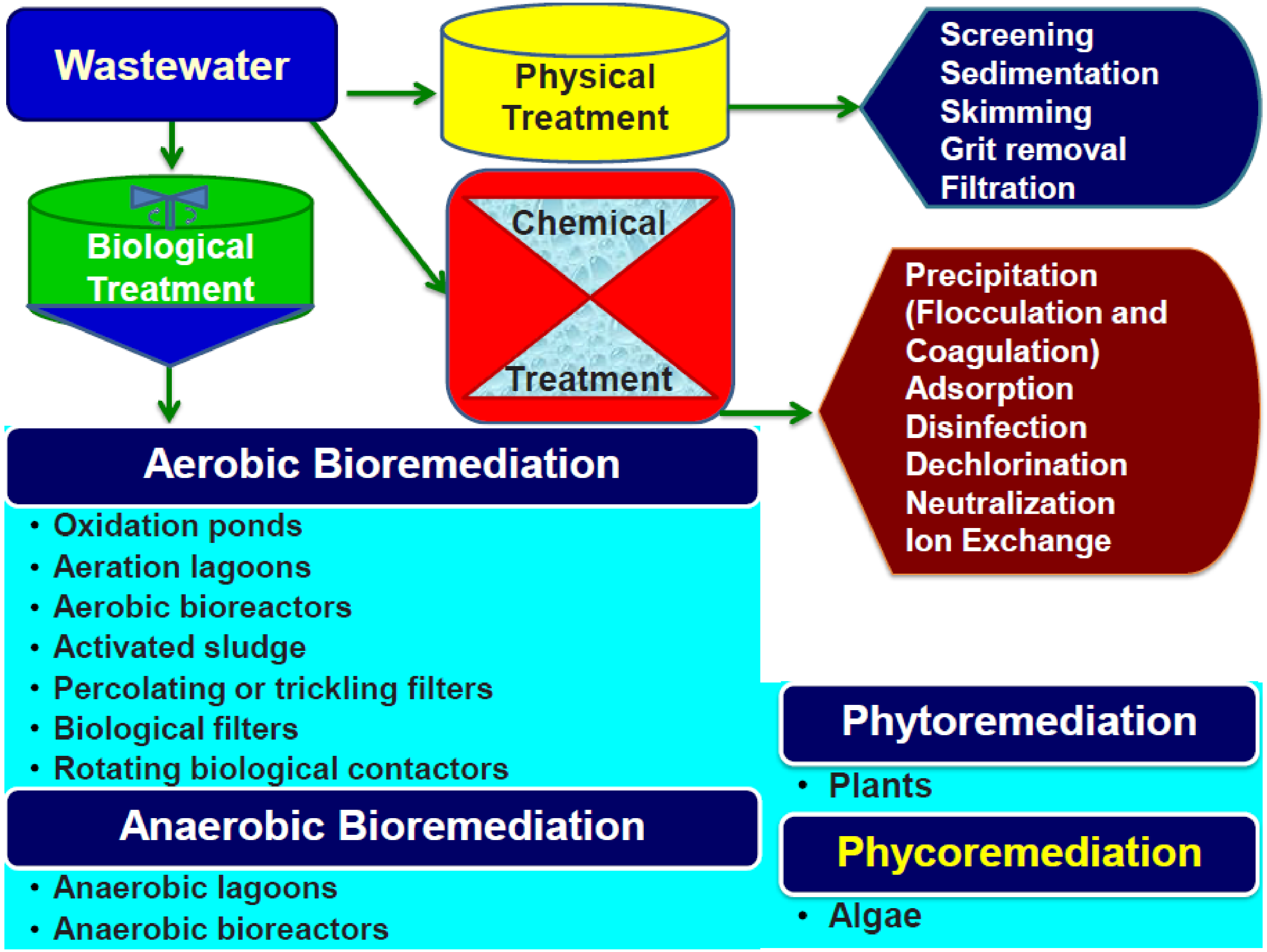


Microalgae (*Botryococcus sp.*)

(Gani, 2017)

Macroalgae

Wastewater Treatment Facilities



Wastewater

Physical Treatment

- Screening
- Sedimentation
- Skimming
- Grit removal
- Filtration

Chemical Treatment

- Precipitation (Flocculation and Coagulation)
- Adsorption
- Disinfection
- Dechlorination
- Neutralization
- Ion Exchange

Biological Treatment

Aerobic Bioremediation

- Oxidation ponds
- Aeration lagoons
- Aerobic bioreactors
- Activated sludge
- Percolating or trickling filters
- Biological filters
- Rotating biological contactors

Anaerobic Bioremediation

- Anaerobic lagoons
- Anaerobic bioreactors

Phytoremediation

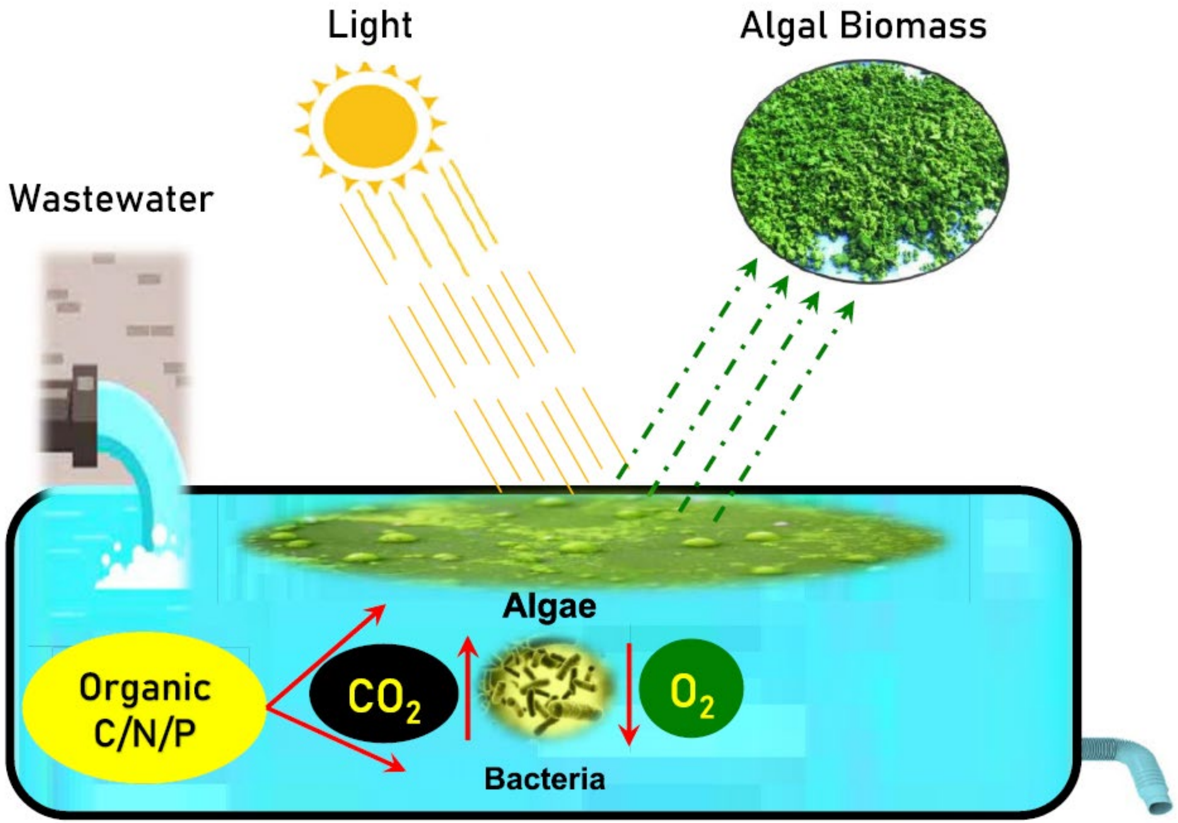
- Plants

Phycoremediation

- Algae

(Priyadharshini *et al.,* 2021)

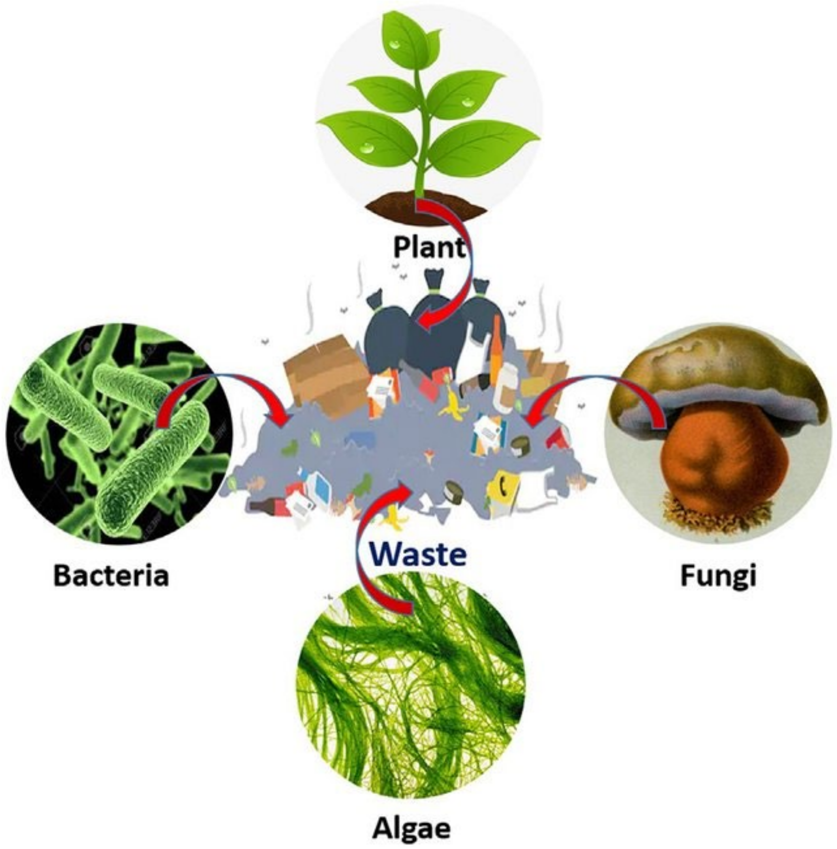
Basic outline of Phycoremediation



(Priyadharshini *et al.*, 2021)

- ❑ Phyco means “algae” in Greek
- ❑ Algae utilise the CO_2 and fix the carbon from CO_2 and discharge oxygen (O_2) into the environment

Bioremediation vs Phycoremediation



Method in which biological organisms (bacteria, fungi and algae) are utilized to remove or mitigate an environmental contaminant through metabolic processes.

Vs

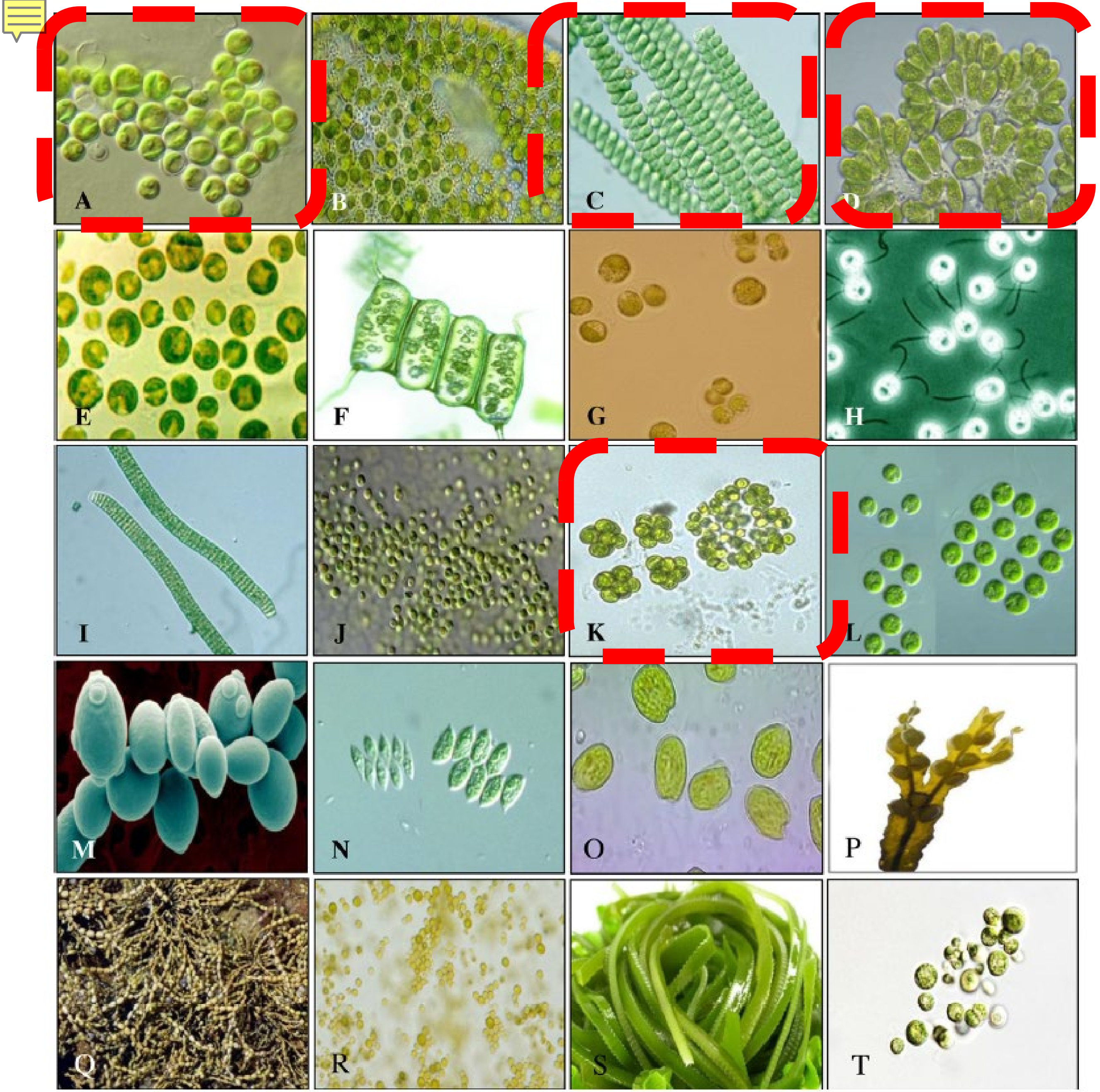
Through **phycoremediation**, nutrient enrichment promotes the development of the native algae found in all water bodies. The O_2 released by algae stimulates the growth of indigenous bacteria, which behave similarly to bacteria used in bioremediation methods.

Bioremediation serving as a sub-process of phycoremediation at best. Thus, in bioremediation, bacteria degrade the organic matter contained in sewage, dead algae, and weeds.

Tyagi & Kumar (2021)

Curtin University
Malaysia

Algal species deployed in wastewater treatment



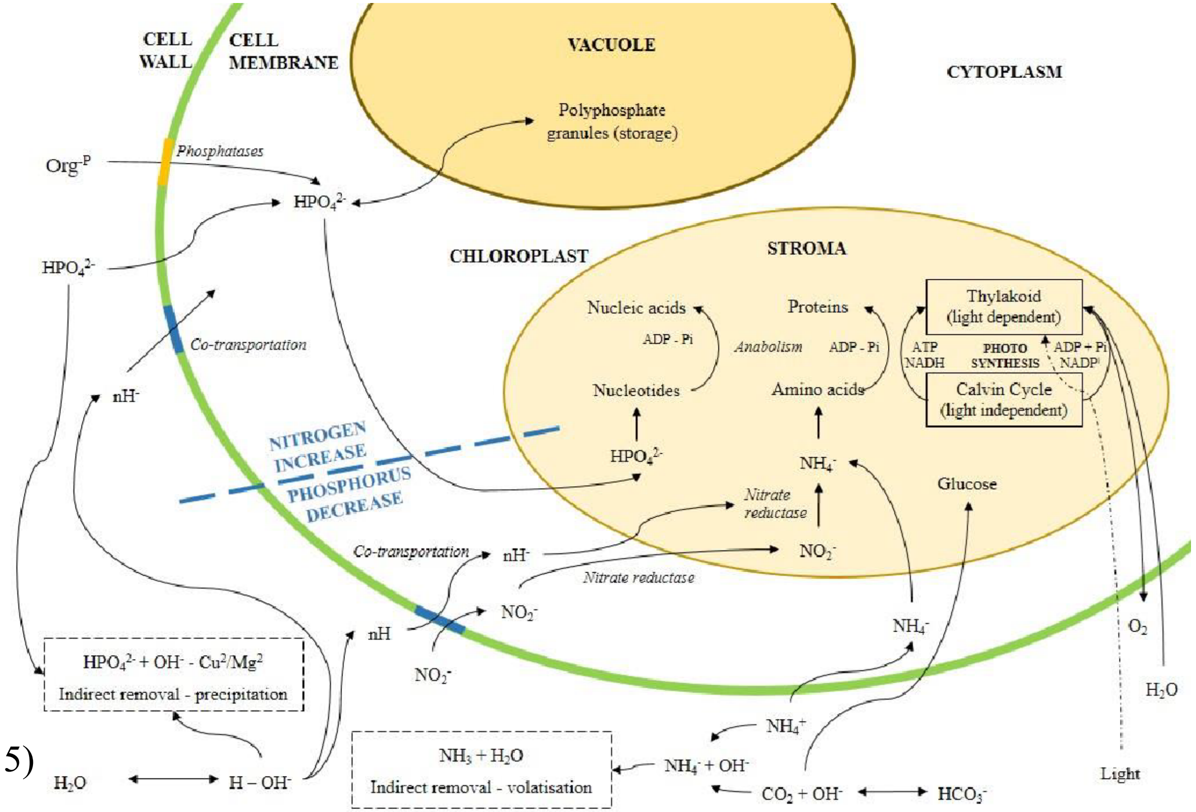
A	*Chlorella vulgaris*	K	*Scenedesmus rubescens*
B	*Chlorella pyrenoido*	L	*Chlamydomonas reinhardtii*
C	*Spirulina platensis*	M	*S. cerevisiae*
D	*Botryococcus braunii*	N	*Scenedesmus acutus*
E	*Chlorella variabilis*	O	*Tetraselmis chuil*
F	*Scenedesmus obliquus*	P	*Fucus vesiculosus*
G	*Diplosphaera sp. MM1*	Q	*Ascophyllum nodosum*
H	*C. reinhardtii*	R	*Chlorella zofingiensis*
I	*Oscillatoria sp.*	S	*Laminaria japonica*
J	*Nannochloropsis sp.*	T	*Scenedesmus rubescens*

Chlorella - heavy metals like cadmium, lead, and mercury

Scenedesmus - removing excess nutrients like nitrogen and phosphorus from wastewater to avoid eutrophication.

Spirulina - capability to degrade and transform various organic pollutants, including some pesticides and hydrocarbons

Botryococcus braunii is unique in its ability to produce and accumulate large amounts of hydrocarbons, specifically long-chain hydrocarbons.



(Whitton *et al.*, 2015)

Biochemical pathway of nitrogen and phosphorus remediation

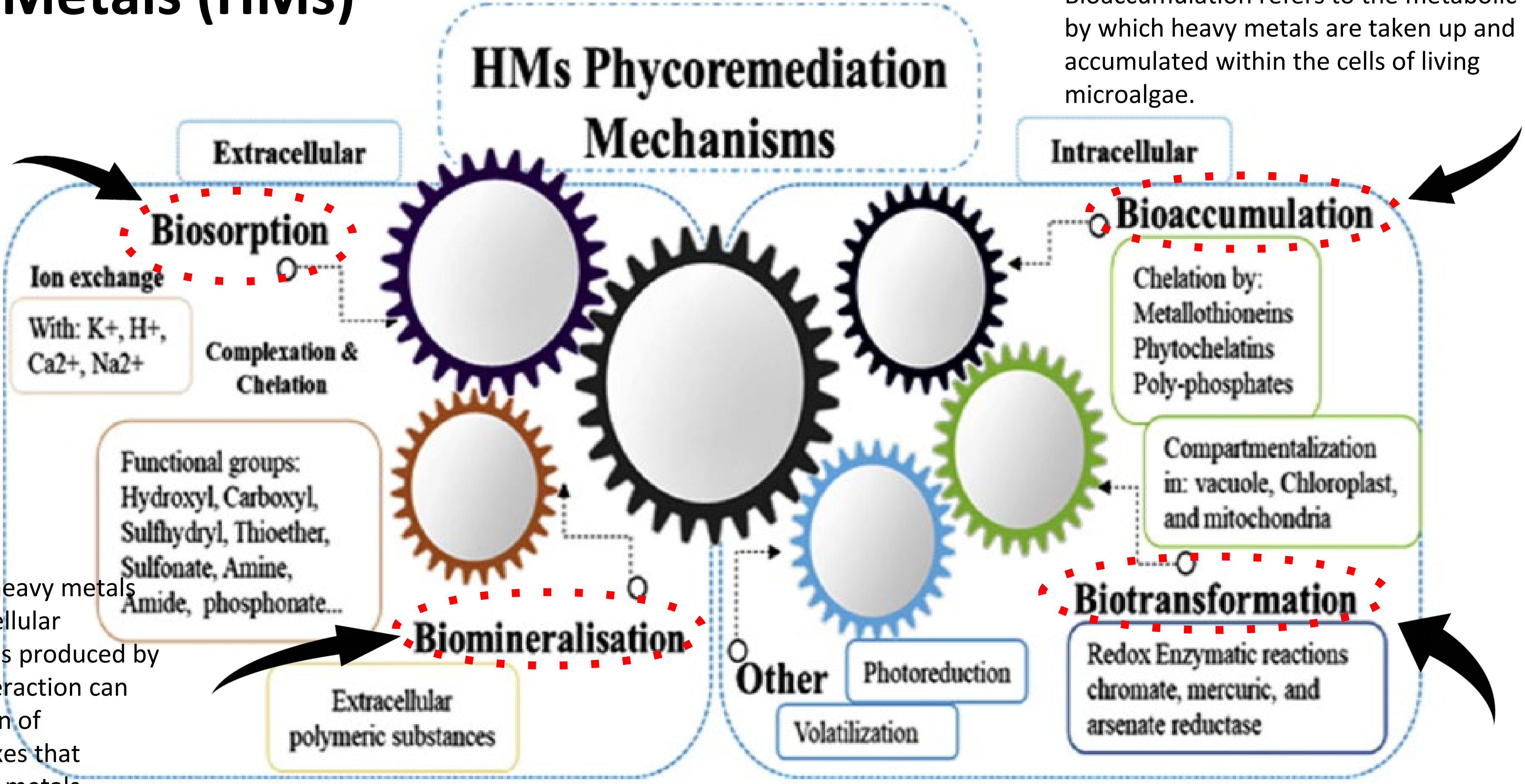
- Nutrients - nitrogen (N), phosphorus (P) and carbon (C).
- Micronutrients - sodium, magnesium, potassium and iron.
- Algae cell for the uptake of nutrients into the biomass

These pathways involve the metabolic processes within the algal cell that lead to the uptake and assimilation of nutrients into biomass, either for storage or for biotransformation into nucleic acids and proteins during photosynthesis, ultimately contributing to biomass growth.

Nitrogen assimilation is a critical process in the formation of biological substances within microalgae. In this process, inorganic nitrogen forms—such as nitrite (NO2-), nitrate (NO3-), and ammonium (NH4+)—are absorbed across the cell membrane and converted into organic nitrogen.

Heavy Metals (HMs)

This process involves the physicochemical properties of the microalgae cell surface, which bind to heavy metal ions (HMs) from the solution.



In this mechanism, heavy metals interact with extracellular polymeric substances produced by microalgae. This interaction can lead to the formation of mineralized complexes that sequester the heavy metals.

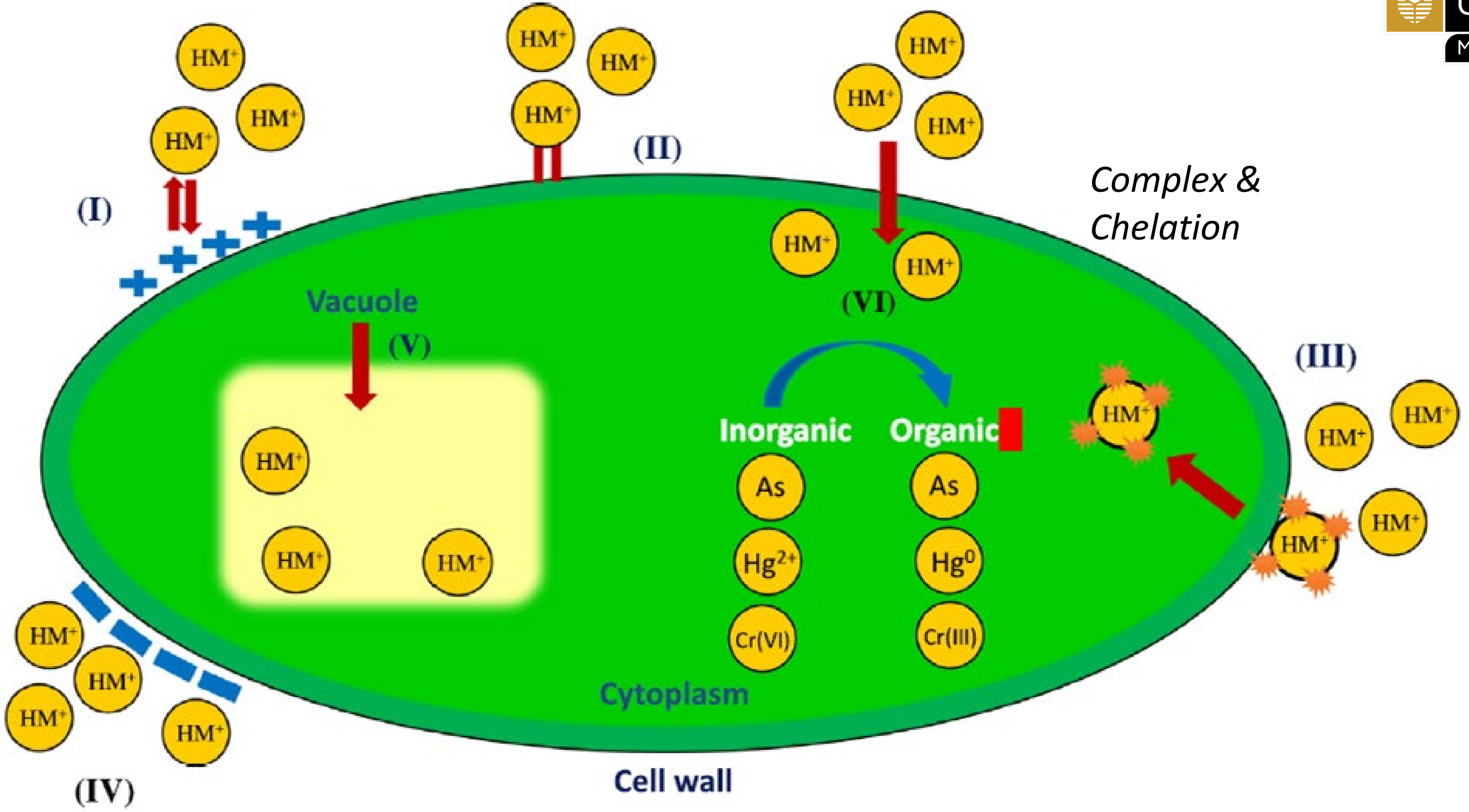
Bioaccumulation refers to the metabolic process by which heavy metals are taken up and accumulated within the cells of living microalgae.

Biotransformation in the context of HM phycoremediation refers to the metabolic pathways by which xenobiotic or endobiotic chemicals are transformed into less toxic products

Covalent bond

Cation exchange

Complex & Chelation



Bioaccumution/biotransformation

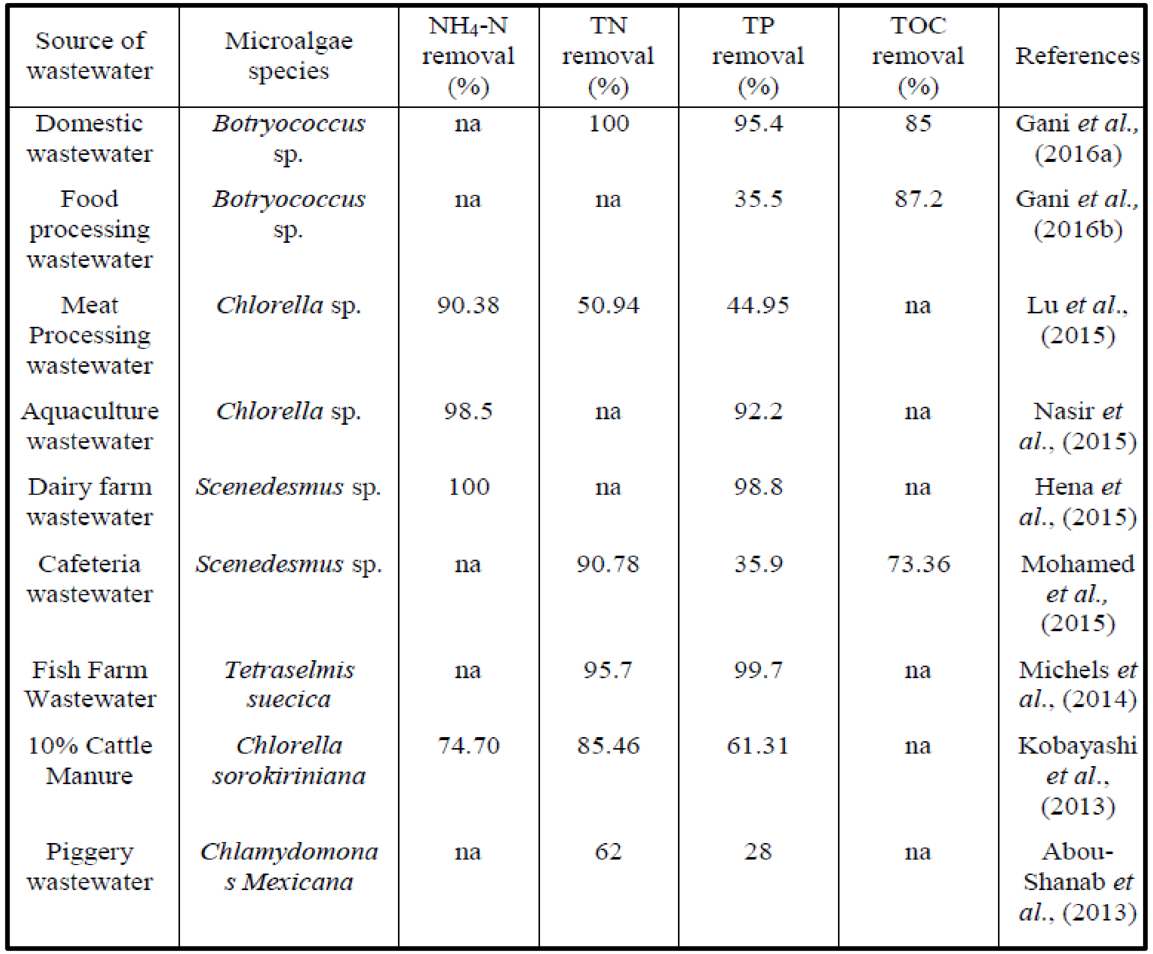
The cell wall of microalgae is made up of lipids, organic proteins, and polysaccharides like cellulose and alginate, which have special groups that can bind to heavy metals (HMs).

Heavy metal adsorption by microalgae happens quickly and through several processes. One process is the formation of covalent bonds between the heavy metals and the ionized parts of the cell wall.

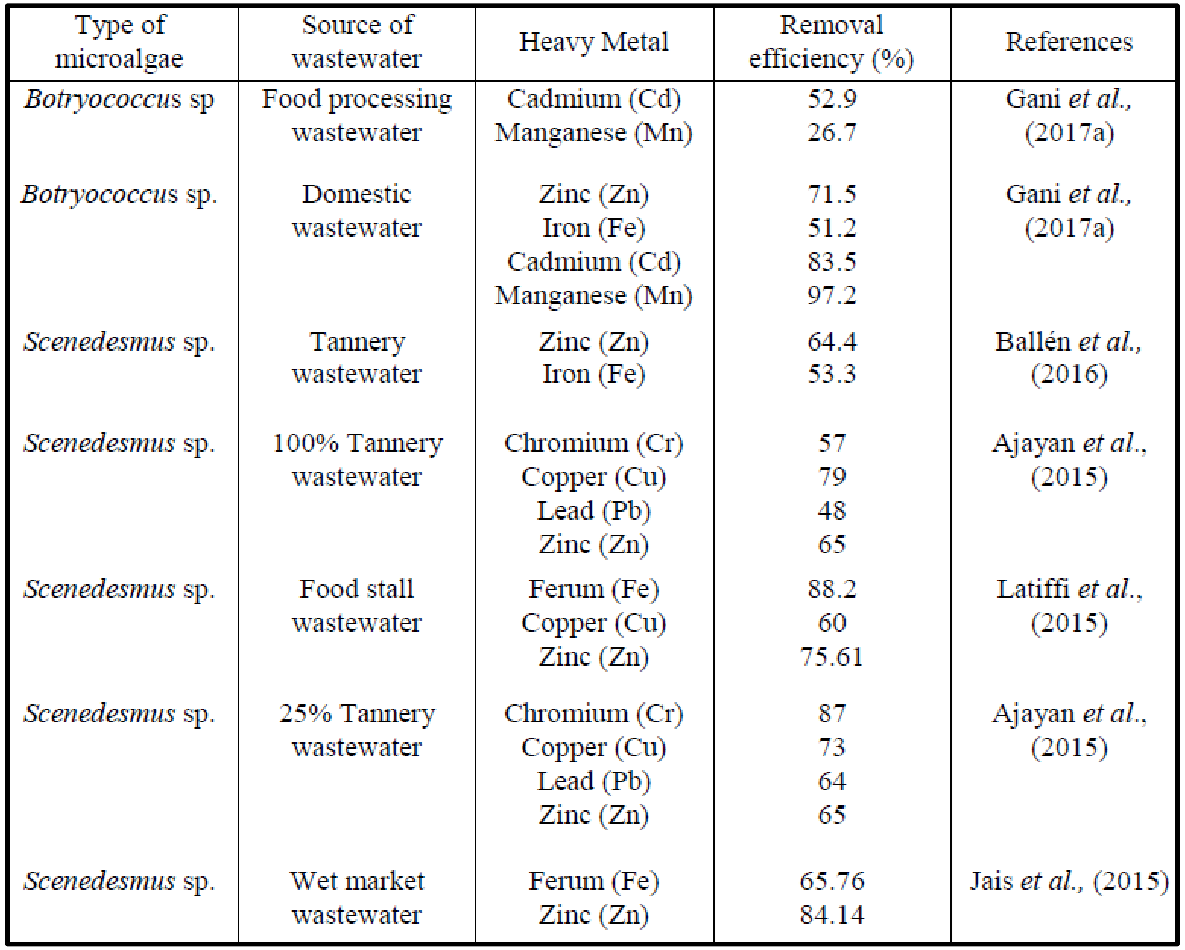
(Koul *et al.*, 2022)

Phycoremediation Efficiency

(Apandi, 2019)

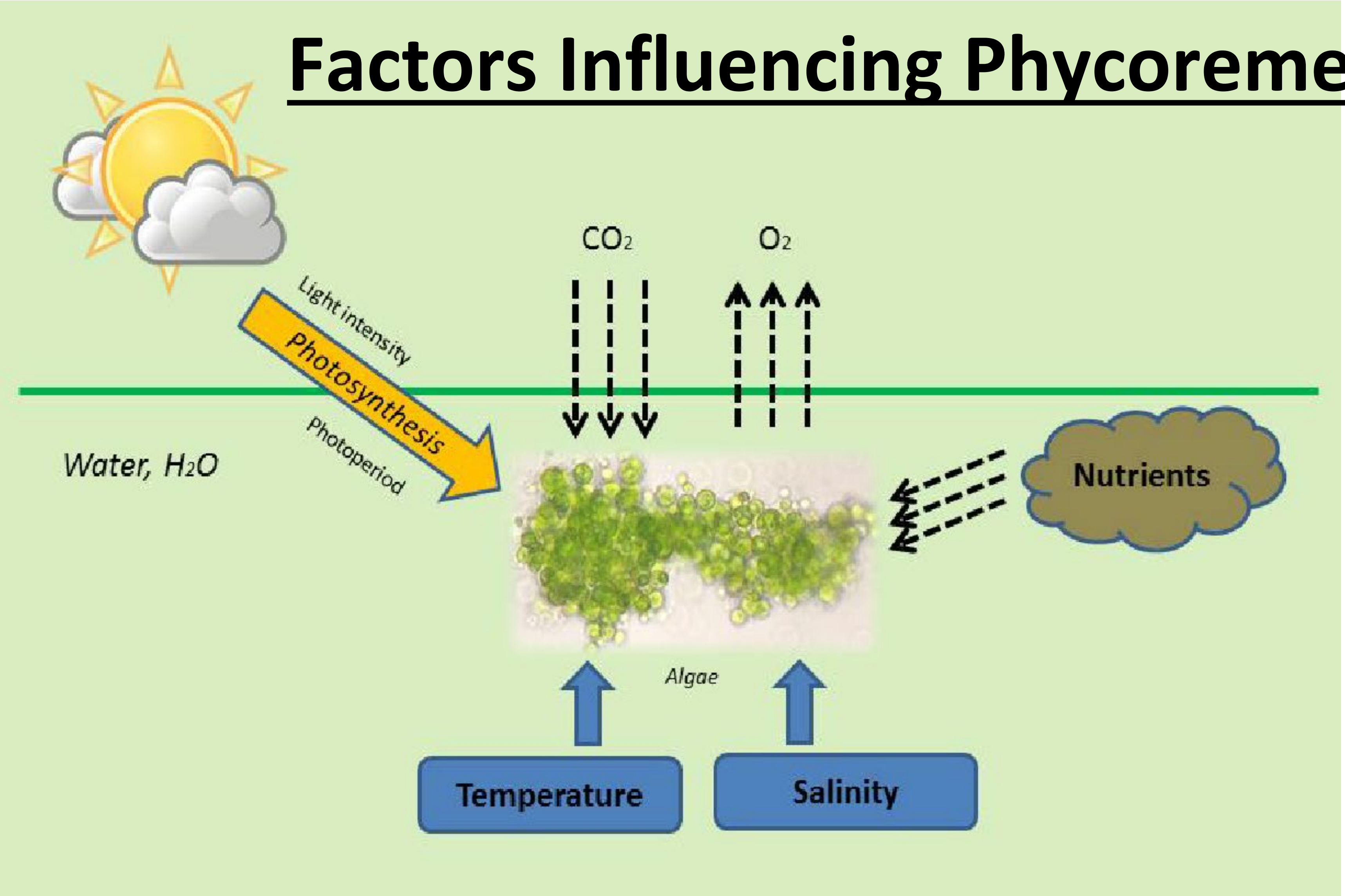


Source of wastewater	Microalgae species	NH_4-N removal (%)	TN removal (%)	TP removal (%)	TOC removal (%)	References
Domestic wastewater	*Botryococcus* sp.	na	100	95.4	85	Gani *et al.*, (2016a)
Food processing wastewater	*Botryococcus* sp.	na	na	35.5	87.2	Gani *et al.*, (2016b)
Meat Processing wastewater	*Chlorella* sp.	90.38	50.94	44.95	na	Lu *et al.*, (2015)
Aquaculture wastewater	*Chlorella* sp.	98.5	na	92.2	na	Nasir *et al.*, (2015)
Dairy farm wastewater	*Scenedesmus* sp.	100	na	98.8	na	Hena *et al.*, (2015)
Cafeteria wastewater	*Scenedesmus* sp.	na	90.78	35.9	73.36	Mohamed *et al.*, (2015)
Fish Farm Wastewater	*Tetraselmis suecica*	na	95.7	99.7	na	Michels *et al.*, (2014)
10% Cattle Manure	*Chlorella sorokiriniana*	74.70	85.46	61.31	na	Kobayashi *et al.*, (2013)
Piggery wastewater	*Chlamydomonas Mexicana*	na	62	28	na	Abou-Shanab *et al.*, (2013)



Type of microalgae	Source of wastewater	Heavy Metal	Removal efficiency (%)	References
Botryococcus sp	Food processing wastewater	Cadmium (Cd) Manganese (Mn)	52.9 26.7	Gani *et al.*, (2017a)
Botryococcus sp.	Domestic wastewater	Zinc (Zn) Iron (Fe) Cadmium (Cd) Manganese (Mn)	71.5 51.2 83.5 97.2	Gani *et al.*, (2017a)
Scenedesmus sp.	Tannery wastewater	Zinc (Zn) Iron (Fe)	64.4 53.3	Ballén *et al.*, (2016)
Scenedesmus sp.	100% Tannery wastewater	Chromium (Cr) Copper (Cu) Lead (Pb) Zinc (Zn)	57 79 48 65	Ajayan *et al.*, (2015)
Scenedesmus sp.	Food stall wastewater	Ferum (Fe) Copper (Cu) Zinc (Zn)	88.2 60 75.61	Latiffi *et al.*, (2015)
Scenedesmus sp.	25% Tannery wastewater	Chromium (Cr) Copper (Cu) Lead (Pb) Zinc (Zn)	87 73 64 65	Ajayan *et al.*, (2015)
Scenedesmus sp.	Wet market wastewater	Ferum (Fe) Zinc (Zn)	65.76 84.14	Jais *et al.*, (2015)

Factors Influencing Phycoremediation



Algae Species

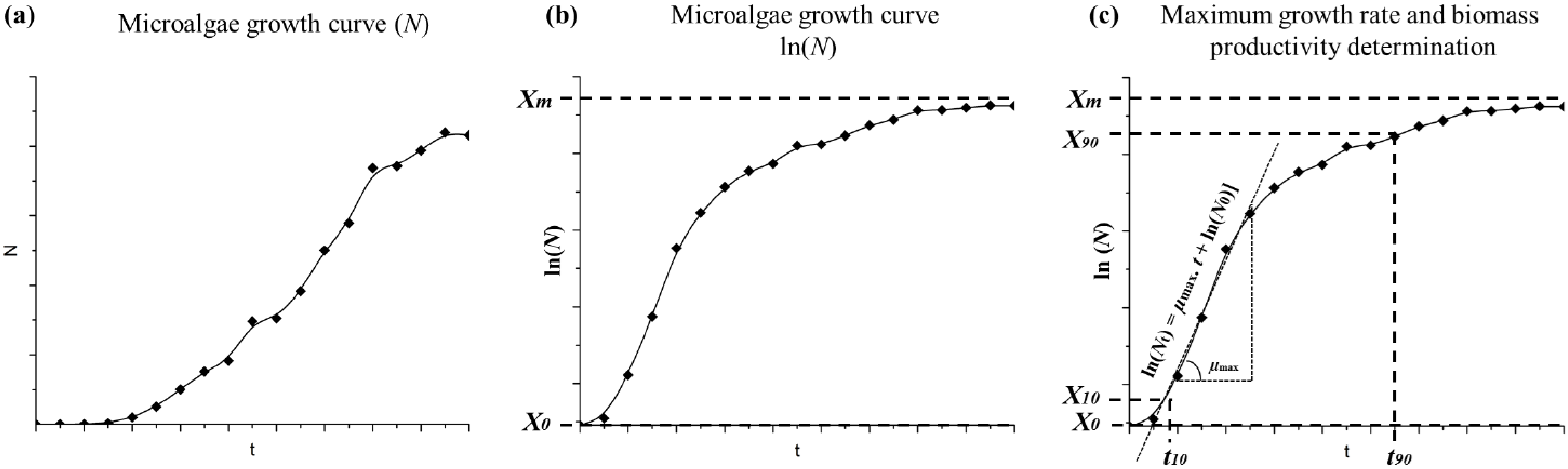
Nutrients

Cell concentration

Environmental Factors

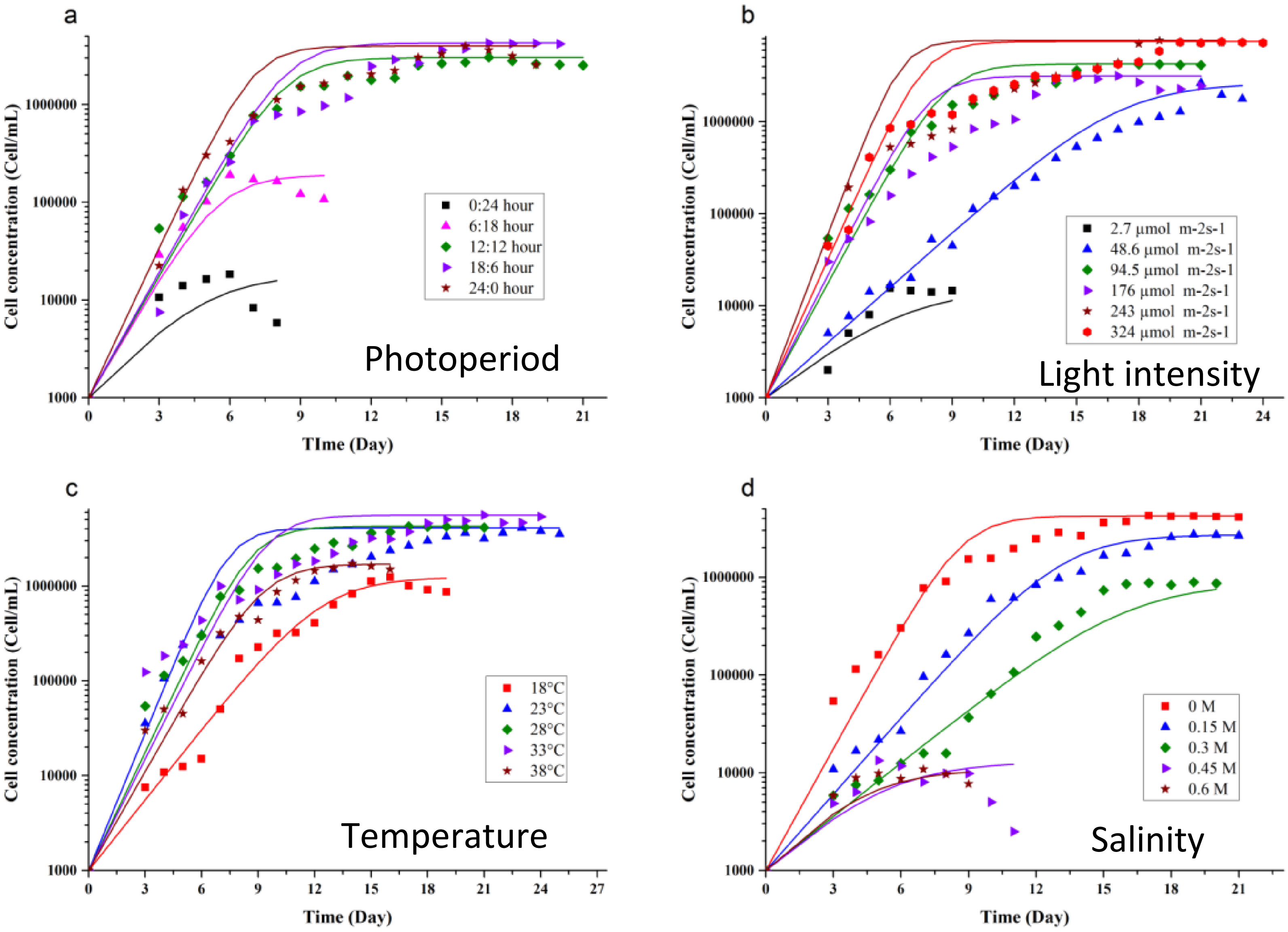
(Gani *et al.*, 2019)

Biomass productivity measurement



Demonstration of maximum growth rate measurement. (a) Typical microalgae growth curve (N), (b) growth curve in the form of ln(N) and (c) maximum growth rate and biomass productivity determination.

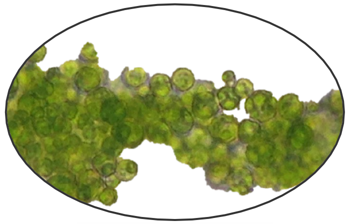
(Gani *et al.*, 2019)



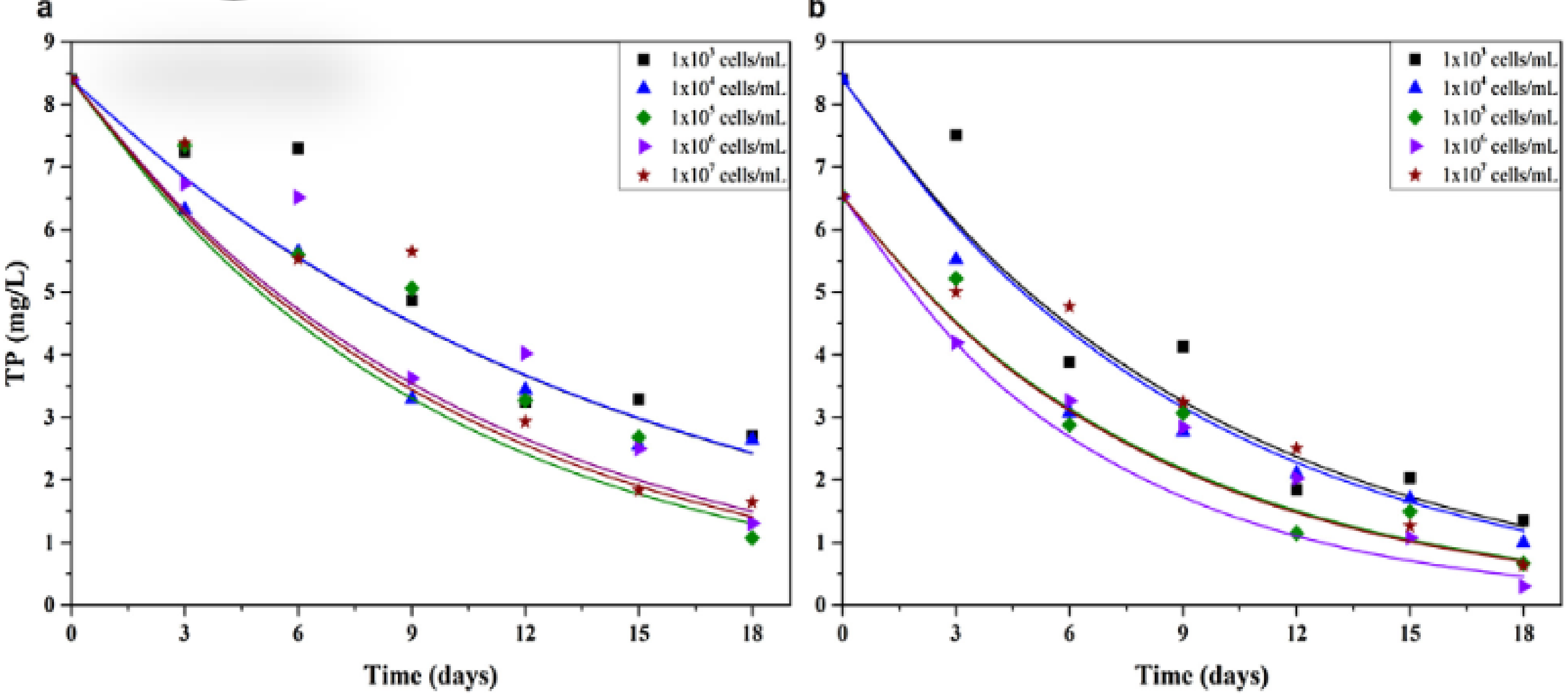
1) Growth rate and biomass production increased when exposed much longer to light in terms of either duration exposure or light intensity;
2) The growth rate decreased when exposed to too much light intensity;
3) The growth rate tolerated temperatures between 23°C and 33°C and the samples grew well without any addition of salinity concentration.

(Gani *et al.*, 2019)

Eg. Total Phosphorus Removal



Botryococcus sp.

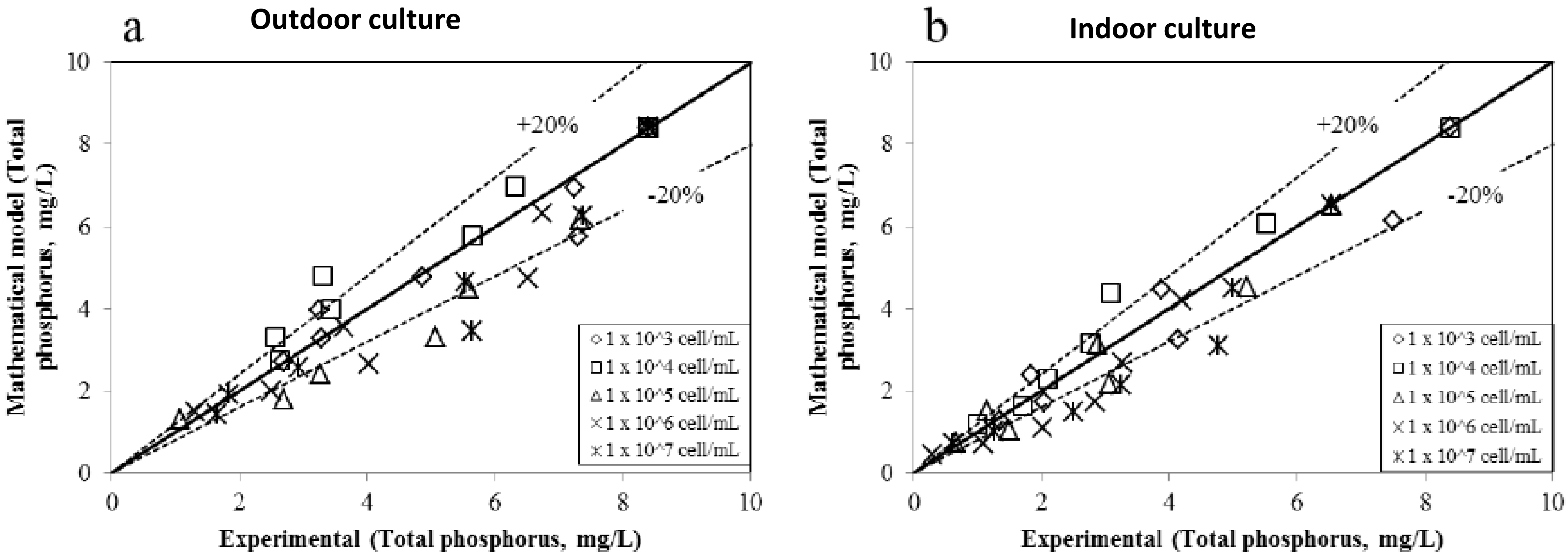


Outdoor culture

Indoor culture

- The highest TP removal is at a concentration of 10^6 cells/mL with total removal of 95.4% for the indoor culture.
- Outdoor culture, the most efficient TP removal is up to 85.5% at a concentration of 10^5 cells/mL.

(Gani *et al.*, 2019)



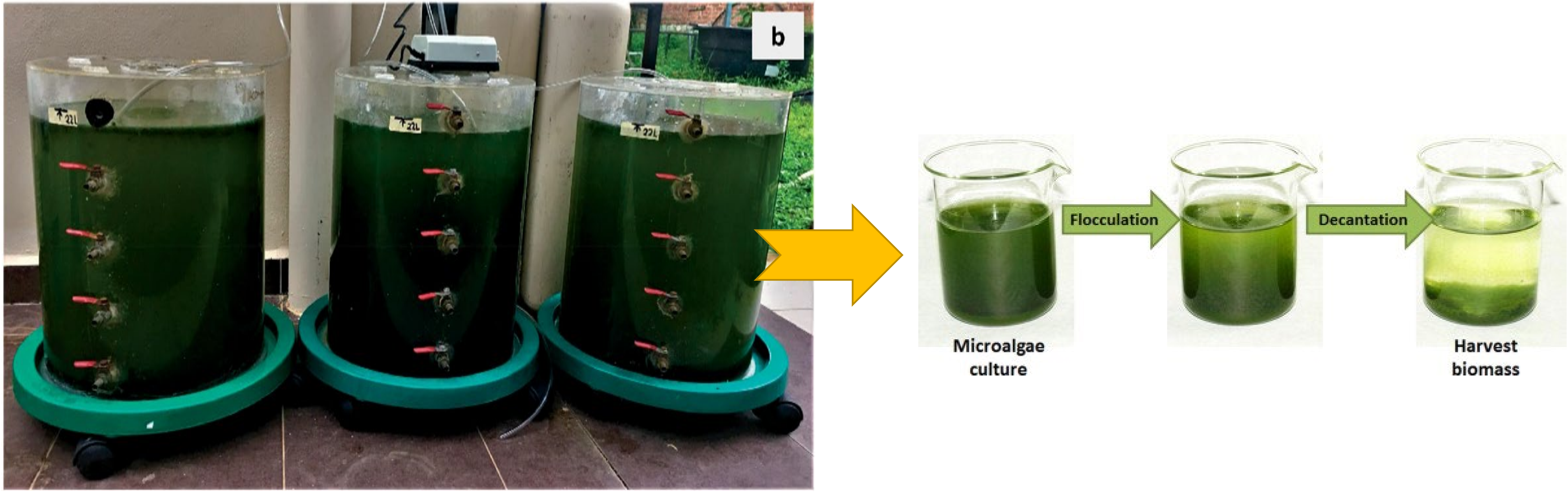
The mathematical model patterns for TP in both outdoor and indoor cultures showed a consistent decrease with increasing phycoremediation time.

The figure indicates that the TP reduction model comparison plot was uniformly distributed around the datum line, demonstrating a strong correlation between the mathematical model and the experimental data.

The scatter points reveal that the error was within ±20% accuracy

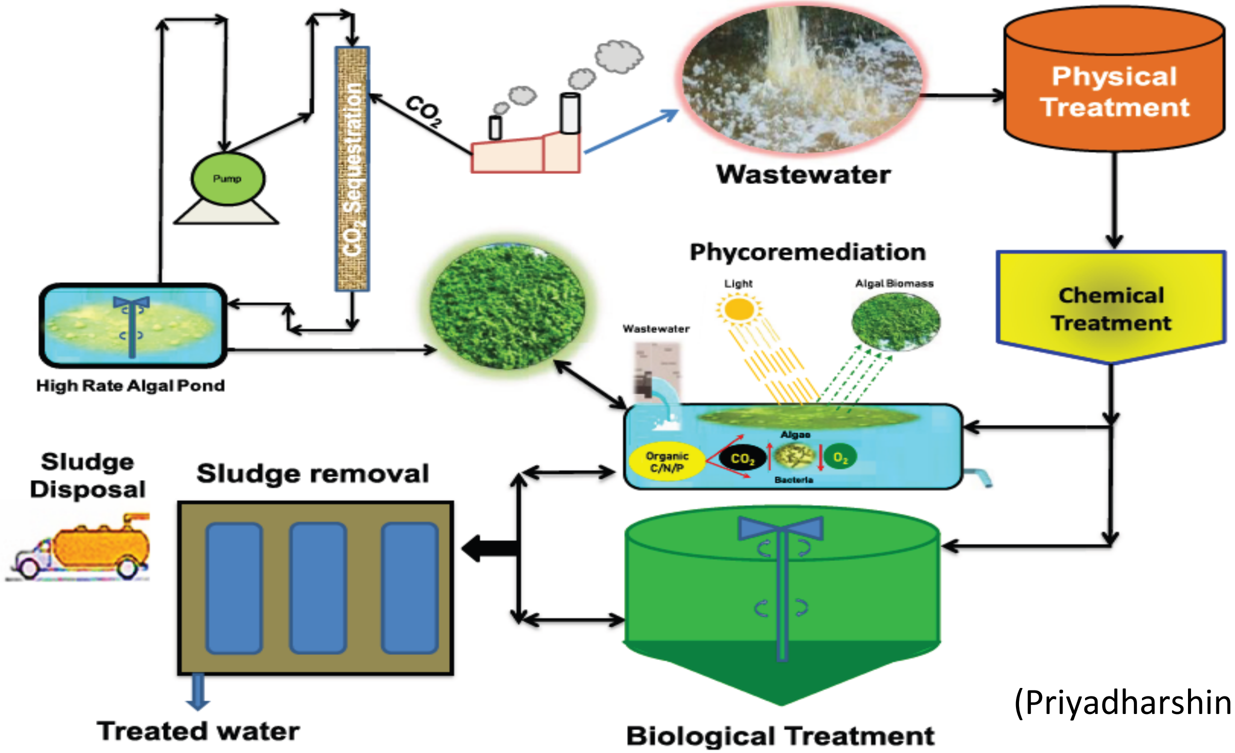
(Gani *et al.,* 2019)

MICROALGAE BIOMASS PRODUCTION- Laboratory Upscale



(Gani *et al.*, 2022)

Strategies for the Sustainable Utilisation of Phycoremediation



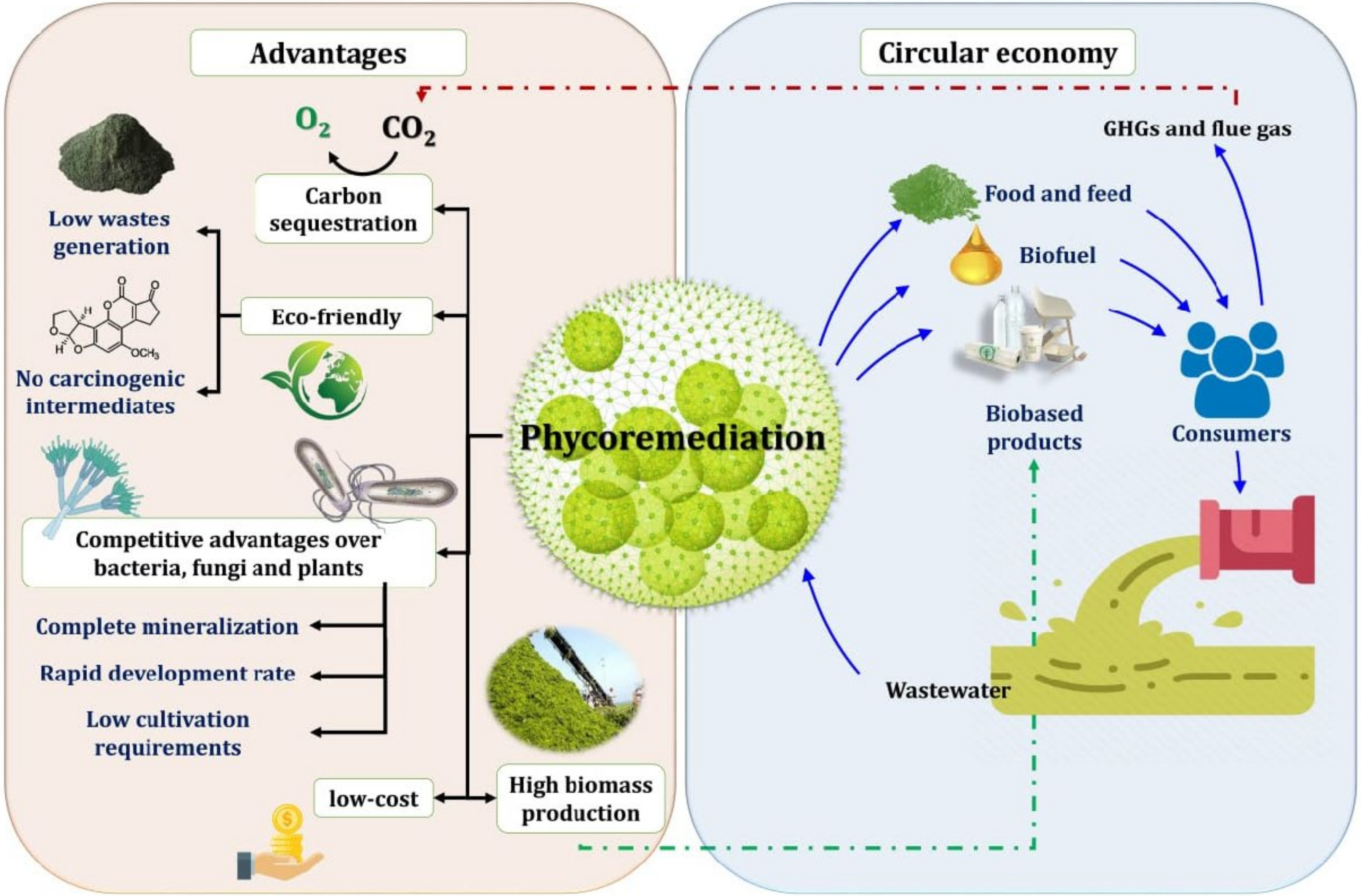
(Priyadharshini *et al.*, 2021)

Integration of phycoremediation with conventional treatment facilities

To fully remove pollutants like COD, color, contaminants, and heavy metals, advanced techniques like phycoremediation need to be combined with physical and chemical treatments. While this may increase costs and environmental impact, it can still be a sustainable solution if the by-products are managed correctly.

Advantages of Phycoremediation Treatment

Incorporating a circular economy into phycoremediation enhances sustainability by turning waste into valuable resources like biomass for biofuel or fertilizers. It reduces environmental impact, lowers operational costs, and minimizes reliance on raw materials, creating a closed-loop system that supports both economic and environmental goals.



(Touliabah *et al.*, 2021)

Practical Issues in Phycoremediation Technologies

Space needed for algal growth and the system of the operation - cultivation facilities to meet the demand.

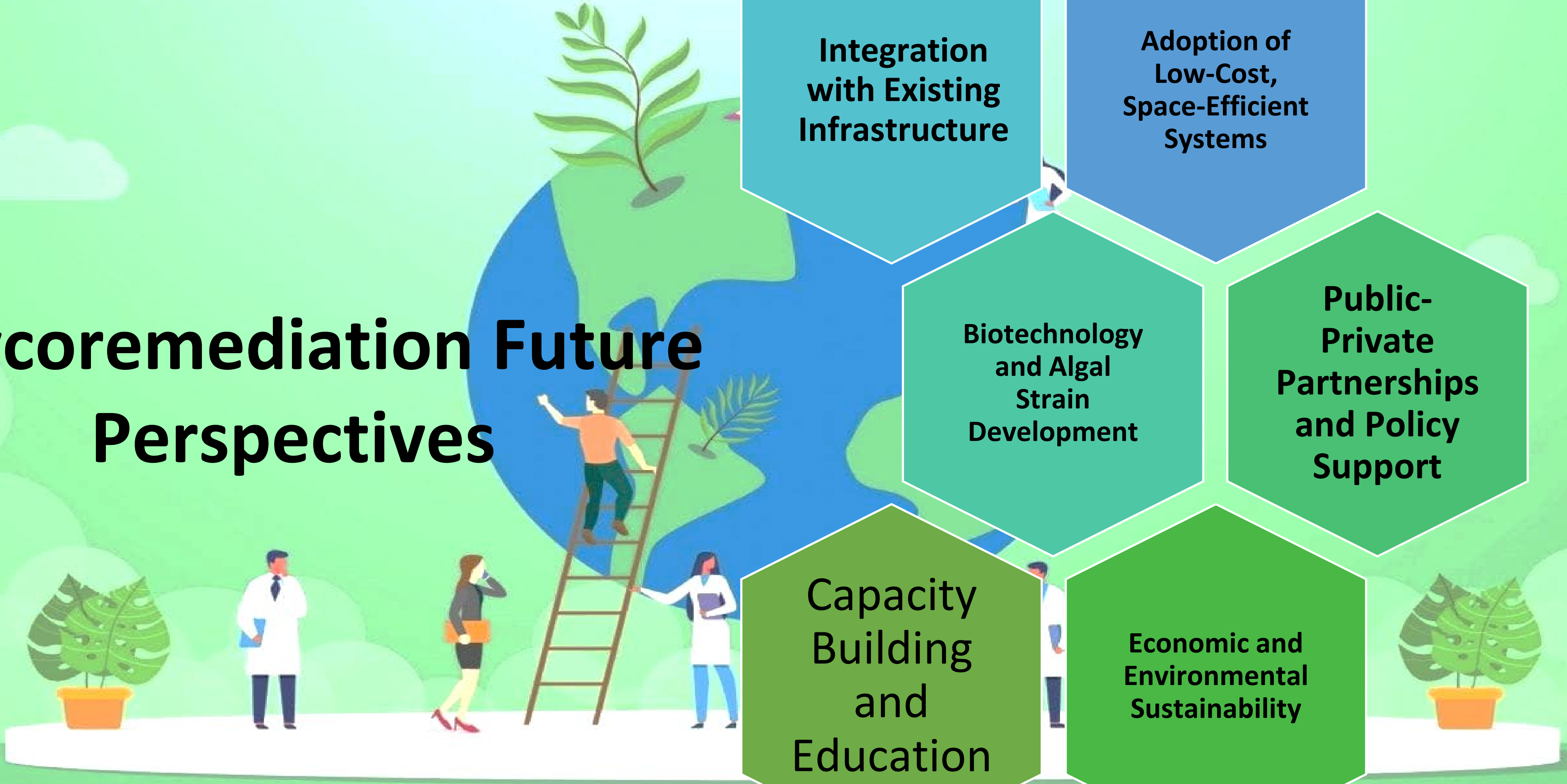
Shortfall is the insufficient volume of these products produced in algal cells - inadequate to satisfy market needs

Bacterial contamination associated with algal biomass production is one of the major issues.

Cultivating algae in an effective photobioreactor requires considerable effort and is costly.

Downstream processing parameters are expensive - extraction and recovery of valuable secondary metabolites

Phycoremediation Future Perspectives



Integration with Existing Infrastructure

Adoption of Low-Cost, Space-Efficient Systems

Biotechnology and Algal Strain Development

Public-Private Partnerships and Policy Support

Capacity Building and Education

Economic and Environmental Sustainability

Curtin University
Malaysia

SUSTAINABLE DEVELOPMENT GOALS

Way Forward

Strategic integration

Locally adapted systems

Research and development

Education and sustainability

The future of phycoremediation in Malaysia depends on a strategic approach that integrates this technology into existing wastewater treatment systems, enhancing their efficiency.

Investing in research and forming partnerships between the government, universities, and industries will help improve the technology and solve current challenges. This includes creating better algal strains, finding cost-effective ways to grow algae, and improving how algae are processed.

Education and training are also important to ensure that the technology is used properly and widely understood. By focusing on sustainability, Malaysia can make phycoremediation a key tool in addressing environmental issues.

By prioritizing these areas—integration, local adaptation, research and collaboration, education, and sustainability—Perhaps we can fully utilize phycoremediation to tackle environmental challenges and build a more sustainable future.

Thank you!

Paran Gani

Email: paran.gani@curtin.edu.my

“Unlock the potential of nature with phycoremediation, where microalgae turn waste into wealth, cleansing our environment and paving the way for a greener future"

References

- Ansari, F. A., Singh, P., & Guldhe, A. (2017). Phycoremediation of wastewater: A sustainable and effective approach towards environmental restoration. Environmental Technology & Innovation, 8, 431-440.
- Malaysian Investment Development Authority (MIDA). (2020). Sustainable wastewater management in Malaysia: Exploring opportunities in green technology.
- Molazadeh, M., Ahmadzadeh, H., Pourianfar, H. R., Lyon, S., & Rampelotto, P. H. (2019). The use of microalgae for coupling wastewater treatment with CO2 biofixation. Frontiers in Bioengineering and Biotechnology, 7, 42
- Touliabah, H. E. S., El-Sheekh, M. M., Ismail, M. M., & El-Kassas, H. (2022). A review of microalgae-and cyanobacteria-based biodegradation of organic pollutants. Molecules, 27(3), 1141.
- Koul, B., Sharma, K., & Shah, M. P. (2022). Phycoremediation: A sustainable alternative in wastewater treatment (WWT) regime. Environmental Technology & Innovation, 25, 102040.
- Tyagi, B., & Kumar, N. (2021). Bioremediation: Principles and applications in environmental management. In Bioremediation for environmental sustainability (pp. 3-28). Elsevier.
- Danouche, M., El Ghachtouli, N., & El Arroussi, H. (2021). Phycoremediation mechanisms of heavy metals using living green microalgae: physicochemical and molecular approaches for enhancing selectivity and removal capacity. Heliyon, 7(7).
- Priyadharshini, S. D., Babu, P. S., Manikandan, S., Subbaiya, R., Govarthanan, M., & Karmegam, N. (2021). Phycoremediation of wastewater for pollutant removal: a green approach to environmental protection and long-term remediation. Environmental Pollution, 290, 117989.
- Gani, P., Apandi, N. M., Mohamed Sunar, N., Matias-Peralta, H., Hua, A. K., Apandi, A. M., ... & Mohd Dzulkifli, S. N. (2023). Characterisation of bio-oil extracted from microalgae Botryococcus sp. biomass grown in domestic and food processing wastewaters for valuable hydrocarbon production. Biofuels, 14(5), 433-444.
- Gani, P., Apandi, N. M., Mohamed Sunar, N., Matias-Peralta, H. M., Kean Hua, A., Mohd Dzulkifli, S. N., & Parjo, U. K. (2022). Outdoor phycoremediation and biomass harvesting optimization of microalgae Botryococcus sp. cultivated in food processing wastewater using an enclosed photobioreactor. International Journal of Phytoremediation, 24(13), 1431-1443.
- Apandi, N. M., Gani, P., Sunar, N. M., Mohamed, R. M. S. R., AlGheethi, A., Apandi, A. M., ... & Rahman, R. A. (2022). Scenedesmus sp. harvesting by using natural coagulant after phycoremediation of heavy metals in different concentrations of wet market wastewater for potential fish feeds. Sustainability, 14(9), 5090.