Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Chemical standardization in marine microalgae cultivation: implications for reproducibility and biotechnological applications

Suzana T. Cunha Lima

stcunhalima@ufba.br

UFBA https://orcid.org/0000-0002-9099-324X

Monica P. Carnaúba

UFBA https://orcid.org/0000-0002-5025-3060

Lucas C.L. Rodrigues

UFBA

Edson Delgado Rodrigues

UFBA

Carlos Eduardo S. Guedes

UFBA

Systematic Review

Keywords: Chemically defined media, Cultivation standardization, Marine microalgae, Artificial seawater, Experimental reproducibility

Posted Date: June 9th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9771413/v2

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: The authors declare no competing interests.

Abstract

Marine microalgae culture collections are essential for biodiversity preservation and the development of biotechnological applications involving pigments, bioactive compounds, biofuels, aquaculture, and environmental biotechnology. However, maintaining stable *in vivo* cultures remains challenging due to physiological instability, contamination risks, and environmental variability associated with cultivation systems. Traditional marine media commonly rely on natural seawater, whose physicochemical composition may vary according to seasonality, geographic location, and anthropogenic contamination, potentially affecting microalgal growth, metabolism, and experimental reproducibility. In this context, chemically standardized synthetic media and artificial seawater formulations have emerged as promising alternatives for improving cultivation control and reducing environmental variability. This systematic review evaluated the role of synthetic media in marine microalgae cultivation, emphasizing their effects on physicochemical stability, physiological responses, and biotechnological applications. The review followed PRISMA guidelines using the Scopus, PubMed, and ScienceDirect databases, considering studies published between 2000 and 2026. The selected studies demonstrated that chemically standardized cultivation systems contribute to improved consistency, enhanced biomass and metabolite production, and greater experimental standardization. In addition, standardized media may support long-term culture maintenance and increase the reliability of marine microalgae biotechnological processes. Overall, chemically controlled cultivation systems represent an important strategy for advancing scalable, standardized, and reliable marine microalgae biotechnology.

Key Points

• Chemically defined media improve cultivation consistency and experimental reliability.

• Artificial seawater systems reduce environmental variability in marine microalgae cultivation.

• Cultivation standardization supports scalable and reproducible biotechnological applications.

Introduction

Marine microalgae have attracted increasing scientific and industrial interest due to their wide biotechnological potential and capacity to produce high-value biomolecules, including pigments, polyunsaturated fatty acids, antioxidants, polysaccharides, proteins, vitamins, and other bioactive compounds. The growing exploration of these microorganisms in aquaculture, nutraceuticals, pharmaceuticals, cosmetics, environmental biotechnology, and biofuel production has increased the demand for reliable and reproducible cultivation systems capable of maintaining physiological stability and consistent biochemical performance. In addition to their economic relevance, marine microalgae play a fundamental ecological role in primary production and biogeochemical cycling in aquatic ecosystems. Consequently, the maintenance of microalgal culture collections has become increasingly important not only for biodiversity preservation and taxonomic and physiological studies, but also for the development of standardized and reproducible biotechnological processes.

The long-term maintenance of marine microalgae under *in vivo* cultivation conditions remains a major challenge for biological collections and experimental systems, particularly due to the need to preserve physiological stability and cultivation consistency over time. Culture performance may be affected by contamination events, physiological drift, nutrient imbalance, salinity fluctuations, and environmental variability associated with cultivation media. Traditionally, marine microalgae are cultivated using enriched natural seawater supplemented with synthetic nutrient formulations such as Conway, Guillard f/2, ESAW, and related media. Although these media are widely used in laboratory and industrial cultivation systems, the chemical composition of natural seawater itself may vary considerably according to geographical location, seasonality, river discharge, rainfall, anthropogenic influence, and coastal circulation patterns, potentially affecting cultivation consistency and experimental comparability.

In recent years, increasing evidence has demonstrated the growing contamination of coastal and estuarine environments by anthropogenic compounds, including pesticides, hydrocarbons, heavy metals, antifouling biocides, pharmaceutical residues, domestic effluents, and plastic-associated contaminants. Such contamination may directly alter the physicochemical characteristics of seawater used in marine cultivation systems, potentially compromising cultivation stability and experimental reliability. Studies performed in Brazilian estuarine and coastal systems have identified the occurrence of herbicides and pesticides such as atrazine, diuron, irgarol, chlorfenvinphos, and isoproturon in surface waters, with some compounds detected ubiquitously and associated with significant ecological risks (Viana et al. 2024). Additionally, contaminants derived from antifouling paints, domestic sewage, harbor activities, and industrial residues have contributed to elevated concentrations of heavy metals including zinc, copper, cadmium, chromium, nickel, manganese, and arsenic in coastal lagoons and estuarine sediments (Cardoso et al. 2025; Teixeira et al. 2026).

Marine pollution associated with plastics and fishing debris also represents an additional source of chemical contamination in marine ecosystems, contributing to the increasing complexity and variability of seawater composition. Plastic residues collected from Brazilian coastal environments have been shown to accumulate pesticides and heavy metals, potentially acting as vectors for contaminant dispersion and bioavailability in aquatic systems (Gubert et al. 2025). Similarly, oil spill events have introduced high concentrations of aliphatic hydrocarbons and polycyclic aromatic hydrocarbons (PAHs) into marine environments, generating chronic toxicological effects on marine organisms and coastal ecosystems. Systematic evaluations of oil spill impacts have further demonstrated that petrochemical contamination may disrupt ecosystem functioning, alter biological interactions, and affect the recovery capacity of marine habitats (Lima et al. 2025). The major sources of environmental contamination potentially affecting seawater quality and marine microalgae cultivation systems, together with their potential impacts on physiological stability and cultivation reliability, are summarized in Fig. 2.

Environmental contamination may directly influence the physicochemical characteristics of seawater used in cultivation systems, potentially affecting microalgal physiology, metabolism, and biochemical composition. Toxicological studies performed in tropical coastal systems have demonstrated that seawater quality and ecotoxicological responses can vary significantly according to rainfall, salinity,

contaminant concentration, and anthropogenic influence (Souza-Santos et al. 2025). Such variability may compromise cultivation consistency and experimental reliability, leading to inconsistent outcomes in studies involving biomass composition, bioactive compound production, lipid accumulation, pigment synthesis, and physiological performance. In biotechnological applications, these fluctuations may directly affect process reliability, metabolic stability, and the comparability of experimental data between cultivation systems and laboratories. In this context, chemically standardized synthetic media and artificial seawater formulations have emerged as promising alternatives for improving cultivation control, reducing environmental variability, and increasing experimental stability in marine microalgae research. The use of defined cultivation systems may minimize the influence of unknown contaminants and uncontrolled environmental fluctuations, contributing to greater physicochemical stability and more reliable biotechnological applications. Figure 1 summarizes the contrasting effects of natural seawater variability and chemically standardized cultivation systems on microalgal physiology, cultivation reliability, and biotechnological performance. Despite the increasing adoption of artificial seawater systems and chemically defined media, studies addressing their impacts on reproducibility, physiological stability, and biotechnological performance remain fragmented in the literature.

Therefore, this systematic review aims to critically analyze the role of chemically standardized synthetic media in marine microalgae cultivation, emphasizing their implications for cultivation standardization, experimental consistency, physiological and biochemical stability, and the reliability of biotechnological applications.

Materials and Methods

Study Selection and PRISMA Flow

The study selection process was conducted according to the PRISMA guidelines (Page et al. 2021), including the stages of identification, screening, eligibility assessment, and inclusion of studies in the final qualitative synthesis (Fig. 3).

Databases and Search Strategy

The literature search was conducted in the Scopus, PubMed, and ScienceDirect databases, considering peer-reviewed studies published between 2000 and 2026. The search strategy combined terms related to marine microalgae cultivation, chemically standardized media, and artificial seawater systems using Boolean operators. The following search string was applied, with minor adaptations according to the requirements of each database: (“marine microalgae”) AND (“synthetic media” OR “artificial seawater” OR ESAW OR Conway OR “f/2”) AND (“culture collection*” OR cultivation).

A total of 61 records were initially identified from the selected databases, including Scopus (n = 12), PubMed (n = 28), and ScienceDirect (n = 21). After duplicate removal (n = 16), 45 records remained for title and abstract screening. Following the initial screening, 30 studies were retained for full-text eligibility

assessment. Subsequently, 15 articles were excluded after full-text evaluation due to insufficient methodological detail, absence of clearly defined synthetic media composition, lack of cultivation-related data, or incompatibility with the scope of this review. Finally, 15 studies were included in the final thematic qualitative synthesis.

Inclusion and Exclusion Criteria

Studies focusing on marine microalgae cultivated in synthetic or chemically standardized media were considered eligible for inclusion in this review. Original research articles published in peer-reviewed journals and available in full text were included. Studies involving undefined cultivation media, freshwater systems not associated with artificial seawater approaches, conference abstracts, editorials, book chapters, patents, and studies not directly related to cultivation systems, experimental reproducibility, cultivation standardization, or biotechnological applications were excluded from the final analysis.

Data Extraction and Analysis

Data extracted from the selected studies included microalgal species, cultivation media composition, seawater source, cultivation conditions, physiological and biochemical responses, biotechnological applications, and aspects related to experimental robustness and cultivation standardization. The selected studies were comparatively and thematically analyzed to identify recurring patterns associated with the use of chemically standardized synthetic media in marine microalgae cultivation, particularly regarding cultivation stability, physiological performance, and biotechnological reliability.

Additionally, complementary literature addressing marine environmental contamination, seawater quality, and ecotoxicological impacts was consulted to support the contextual and interpretative framework of the selected studies. These references were used exclusively for theoretical background and contextual interpretation and were not included in the PRISMA-based systematic selection process.

Results

Synthetic media and cultivation standardization

The studies included in this systematic review revealed a broad diversity of synthetic and chemically standardized cultivation systems used in marine microalgae biotechnology. Several studies reported the development of customized cultivation strategies designed to improve physiological stability, biomass productivity, and metabolite accumulation under controlled conditions, including low-cost artificial seawater formulations and nutrient-optimized media (Song et al. 2020; An et al. 2024; Grubišić et al. 2024). The main characteristics of the selected studies are summarized in Table 1, while Fig. 4 provides a comparative overview of the principal synthetic cultivation media and their strategic applications in marine microalgae biotechnology.

Comparative analyses between conventional cultivation media demonstrated that different microalgal species exhibit distinct physiological and biochemical responses depending on medium composition and nutrient availability. Studies involving *Tetraselmis chuii*, *Dunaliella tertiolecta*, *Dunaliella salina*, *Isochrysis sp*., *Pavlova sp*., and *Chaetoceros sp*. showed that Conway and f/2 media frequently promoted different patterns of biomass accumulation, lipid production, pigment synthesis, and cellular growth. These findings indicate that cultivation performance is strongly species-dependent and that no universal cultivation medium is equally optimal for all marine microalgae (Lananan et al. 2013; Colusse et al. 2020; Ahmad et al. 2024).

Several studies emphasized the importance of chemically defined cultivation systems for improving experimental consistency, cultivation control, and reproducibility in marine microalgae cultivation. Artificial seawater formulations supplemented with controlled nutrient concentrations enabled the optimization of specific cultivation parameters such as pH, salinity, inoculum density, carbon-to-nitrogen ratio, and macronutrient availability (Song et al. 2020; Santos et al. 2012; Panahi et al. 2019). In particular, the NX medium developed for *Haslea ostrearia* cultivation (Nghiem Xuan et al. 2020) demonstrated that optimization of calcium, magnesium, and iron concentrations significantly improved biomass and marennine productivity in photobioreactor systems. Similarly, optimization of silicon, nitrogen, and phosphorus ratios in modified Guillard f/2 medium substantially enhanced biomass production in *Nitzschia sp*. S5 during batch and fed-batch cultivation (Grubišić et al. 2024).

Overall, the reviewed studies demonstrated that chemical standardization of cultivation media plays a central role in controlling physiological variability and improving process reliability in marine microalgae cultivation systems. The adoption of defined nutrient compositions and controlled seawater formulations contributed to greater cultivation stability, enhanced metabolite production, and more consistent experimental outcomes across different biotechnological applications, reinforcing the importance of chemically standardized systems for reliable and scalable marine microalgae biotechnology.

Environmental variability and cultivation reliability

The reviewed studies demonstrated that environmental variability associated with seawater composition may significantly influence cultivation performance and experimental reliability in marine microalgae systems. Although natural seawater is traditionally used in cultivation media, its physicochemical composition may vary according to salinity, seasonal dynamics, river discharge, coastal circulation, and anthropogenic contamination, introducing uncontrolled variability into cultivation systems and potentially affecting the comparability of experimental outcomes.

The importance of chemically controlled seawater formulations was particularly evident in studies comparing artificial and natural seawater systems. He et al. (2015) demonstrated that artificial seawater supported hydrogen production in *Chlorella pyrenoidosa* strains, whereas natural seawater altered physiological responses and prevented the establishment of anaerobic conditions required for H2

production. The authors suggested that unknown factors present in natural seawater interfered with hydrogenase activation and microalgal metabolism, highlighting how environmental variability may directly compromise cultivation reproducibility and physiological performance.

Controlled salinity conditions also strongly influenced metabolic responses and biomass productivity in marine microalgae cultivation systems. Decamp et al. (2023) reported that salinity modulation altered polysaccharide production in *Porphyridium cruentum*, while Yao et al. (2013) demonstrated that salinity manipulation combined with nitrogen limitation enhanced starch accumulation in *Tetraselmis subcordiformis*. Similarly, modified artificial seawater media prevented mineral precipitation and improved cultivation stability under elevated pH and salinity conditions in *Neochloris oleoabundans* (Santos et al. 2012; Panahi et al. 2019).

Complementary environmental studies further demonstrated that coastal and estuarine waters are increasingly affected by pesticides, hydrocarbons, heavy metals, antifouling biocides, sewage discharges, and plastic-associated contaminants, all of which may interfere with seawater quality and cultivation systems (Viana et al. 2024; Cardoso et al. 2025; Gubert et al. 2025). In addition, ecotoxicological studies have shown considerable temporal variability in seawater toxicity associated with rainfall, salinity, and contaminant dynamics (Souza-Santos et al. 2025). Together, these findings reinforce the importance of chemically standardized synthetic media as a strategy to improve cultivation stability, comparability of results, and reliability in marine microalgae biotechnology.

Physiological and biochemical responses to cultivation conditions

The reviewed studies demonstrated that cultivation medium composition directly influences the physiological performance and biochemical profile of marine microalgae. Variations in nutrient availability, salinity, pH, and macronutrient ratios were consistently associated with changes in biomass productivity, lipid accumulation, pigment synthesis, carbohydrate production, and metabolite composition across different species and cultivation systems. These findings highlight the central role of chemically standardized cultivation conditions in modulating metabolic pathways and maintaining physiological and biochemical stability in marine microalgae biotechnology.

Several studies reported that nutrient limitation strategies promoted the accumulation of specific biomolecules of biotechnological interest. Song et al. (2020) demonstrated that optimization of glucose concentration, inoculum density, and C/N ratio enhanced DHA production in *Crypthecodinium cohnii*, while Schulze et al. (2016) observed increased lipid and carbohydrate accumulation in *Scenedesmus obtusiusculus* cultivated under reduced nitrate conditions. Nitrogen-deficient media also promoted higher lipid, carotenoid, and phenolic compound accumulation in *Nannochloropsis gaditana* and *Chlorella* sp. SM1, demonstrating the strong influence of nutrient availability on metabolic regulation, antioxidant activity, and biochemical profiles (Khemiri et al. 2022).

Salinity and physicochemical parameters were also important modulators of metabolic responses in marine microalgae cultivation systems. Controlled salinity conditions altered polysaccharide production in *Porphyridium cruentum* (Decamp et al. 2023) and enhanced starch productivity in *Tetraselmis subcordiformis* under nitrogen depletion (Yao et al. 2013). Likewise, Santos et al. (2012) and Panahi et al. (2019) reported increased lipid accumulation under elevated salinity and alkaline pH conditions in *Neochloris oleoabundans* cultivated in modified artificial seawater media. These findings reinforce the importance of controlled physicochemical conditions for optimizing metabolic performance and cultivation stability in marine microalgae biotechnology.

Differences in cultivation media also resulted in distinct biochemical profiles among microalgal species. Conway medium frequently promoted higher biomass and lipid productivity in *Dunaliella salina* and *Tetraselmis chuii*, whereas Johnson medium enhanced pigment accumulation in *D. salina* (Colusse et al. 2020; Ahmad et al. 2024). Overall, the reviewed studies demonstrated that cultivation conditions and chemically standardized media strongly modulate metabolic pathways and biochemical composition, directly influencing physiological stability and the biotechnological potential of marine microalgal biomass.

Biotechnological applications of chemically standardized cultivation systems

The studies included in this review demonstrated that chemically standardized cultivation systems have been applied in a wide range of marine microalgae biotechnological processes, including the production of biofuels, nutraceuticals, pigments, polysaccharides, antioxidants, and bioactive compounds. Across different applications, controlled cultivation conditions were consistently associated with improved biomass productivity, metabolite accumulation, physiological stability, and greater process consistency.

Biofuel-related applications represented one of the most recurrent approaches among the reviewed studies. Lipid accumulation for biodiesel production was investigated in species such as *Scenedesmus obtusiusculus*, *Dunaliella salina*, *Synechocystis* sp., *Nannochloropsis salina*, and *Neochloris oleoabundans* cultivated under nutrient limitation, salinity modulation, or optimized artificial seawater conditions (Schulze et al. 2016; Cai et al. 2013; Colusse et al. 2020; Santos et al. 2012; Panahi et al. 2019). In addition, Patel et al. (2009) demonstrated that a fertilizer-based AG11 medium promoted high oil yield in *Dunaliella tertiolecta* at lower production costs, highlighting the industrial relevance of low-cost chemically standardized media for scalable biofuel production.

Several studies also explored the production of high-value biomolecules for nutraceutical and pharmaceutical applications. Song et al. (2020) optimized DHA production in *Crypthecodinium cohnii* using chemically defined artificial seawater medium supplemented with controlled carbon and nitrogen sources. Similarly, Khemiri et al. (2022) demonstrated enhanced accumulation of carotenoids, phenolic compounds, and antioxidant activity in *Nannochloropsis gaditana* and *Chlorella* sp. cultivated under nitrogen-deficient conditions, while Nghiem Xuan et al. (2020) reported increased production of

marennine, a bioactive blue pigment with potential applications in aquaculture and cosmetics, using the NX artificial seawater medium. These findings demonstrate that chemically standardized cultivation systems can be strategically optimized to enhance the production of commercially valuable biomolecules and bioactive metabolites.

Controlled cultivation systems were also associated with emerging environmental and industrial applications. Ahmad et al. (2024) demonstrated that *Tetraselmis chuii* and *Dunaliella tertiolecta* cultivated in synthetic media, particularly in association with bacterial consortia, were capable of degrading several emerging pollutants, including pharmaceutical residues and pesticides. Additionally, He et al. (2015) reported that artificial seawater systems supported biological hydrogen production in *Chlorella pyrenoidosa* strains, whereas natural seawater compromised physiological performance and H2 generation. These findings further reinforce the importance of chemically standardized cultivation systems for improving process stability, metabolic performance, and reproducibility in emerging marine microalgae biotechnological applications.

Overall, the reviewed studies demonstrated that standardized cultivation media contribute not only to improved cultivation stability and experimental consistency, but also to the optimization of biomass composition and metabolite production. The adoption of controlled cultivation systems therefore represents an important strategy for the development of reliable, scalable, and physiologically stable marine microalgae biotechnological processes.

Discussion

Despite the advances demonstrated in the reviewed studies, several challenges still limit the large-scale implementation of chemically defined cultivation systems for marine microalgae. Nevertheless, the available evidence consistently indicates that chemical standardization plays a central role in reducing cultivation variability and improving the reliability of biotechnological processes. One of the main limitations involves the absence of a universal cultivation medium capable of simultaneously supporting optimal growth, physiological stability, and metabolite production across different taxonomic groups. The reviewed studies demonstrated species-specific physiological and biochemical responses to nutrient composition, salinity, pH, and macronutrient availability, reinforcing the need for customized and species-oriented cultivation strategies (Lananan et al. 2013; Colusse et al. 2020; Ahmad et al. 2024).

Economic constraints also remain a major limitation for industrial-scale marine microalgae cultivation. Although several studies reported improved productivity under chemically standardized conditions, the costs associated with nutrients, vitamins, trace metals, and controlled cultivation infrastructure may still limit large-scale commercial feasibility (Patel et al. 2009; Colusse et al. 2020; Ahmad et al. 2024). In this context, the development of low-cost synthetic media and optimized nutrient formulations emerges as a key strategy for improving scalability while maintaining cultivation consistency, physiological performance, and experimental reliability.

Another major challenge involves the environmental variability associated with natural seawater-based cultivation systems. The reviewed studies demonstrated that fluctuations in salinity, nutrient composition, and unidentified environmental components may significantly alter physiological responses, metabolic performance, and cultivation stability (He et al. 2015; Santos et al. 2012; Panahi et al. 2019). Complementary environmental studies further indicate increasing contamination of coastal waters by pesticides, hydrocarbons, heavy metals, sewage-derived pollutants, and plastic-associated contaminants, all of which may interfere with seawater quality, biomass consistency, and cultivation standardization (Viana et al. 2024; Cardoso et al. 2025; Gubert et al. 2025; Lima et al. 2025). Together, these findings reinforce the importance of artificial seawater systems and chemically controlled cultivation media as strategies for minimizing uncontrolled environmental interference and improving cultivation reliability.

Future perspectives in marine microalgae biotechnology should focus on the development of more stable, scalable, and economically feasible cultivation systems integrating nutrient optimization, artificial seawater standardization, and controlled bioprocess strategies. Figure 5 presents an integrated conceptual framework summarizing the main strategies required to improve standardization, physiological stability, and scalability in marine microalgae cultivation systems. Additional studies investigating long-term physiological stability, consistency among laboratories, and the impacts of environmental contaminants on biomass composition and metabolic performance will be essential for improving the reliability and comparability of marine microalgae biotechnological applications.

Conclusions

Taken together, the reviewed studies reinforce the strategic importance of chemically standardized cultivation systems for advancing marine microalgae biotechnology. The evidence analyzed in this review demonstrated that cultivation parameters such as medium composition, salinity, nutrient availability, pH, and seawater source directly influence biomass productivity, physiological stability, metabolic performance, and the accumulation of compounds of biotechnological interest, including lipids, pigments, polysaccharides, antioxidants, and other bioactive molecules. These findings highlight the central role of controlled cultivation conditions in improving cultivation consistency and supporting more reliable biotechnological processes.

Artificial seawater systems and chemically defined media were consistently associated with improved cultivation control, greater physicochemical stability, and enhanced experimental consistency when compared with natural seawater-based cultivation systems. In contrast, environmental variability and contamination derived from anthropogenic activities may interfere with seawater quality, alter physiological responses and metabolic performance, and compromise biomass consistency and cultivation reliability.

Overall, the adoption of chemically standardized cultivation approaches represents an important strategy for the development of scalable, reliable, and physiologically stable marine microalgae biotechnological

processes. Future studies should prioritize the development of economically feasible artificial seawater formulations and long-term assessments of cultivation stability. In addition, cultivation strategies should be adapted to species-specific physiological and metabolic requirements in order to improve consistency among laboratories and industrial production systems. As marine microalgae biotechnology continues to expand, chemically controlled cultivation systems may become increasingly important for ensuring experimental reliability, biomass quality, and comparability across biotechnological applications.

Declarations

Competing Interests

The authors declare that they have no competing interests.

Funding

This study was supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), under CHAMADA CNPq/MCTI Nº 44/2024, Process No. 403058/2025-2.

Author Contributions

Suzana T. Cunha Lima conceived the study, organized the methodology, interpreted the data, and wrote the manuscript. Lucas C.L. Rodrigues and Monica P. Carnaúba performed the literature screening and study selection. Carlos Eduardo S. Guedes supervised the screening process and revised the manuscript. Edson D. Rodrigues contributed to manuscript revision and discussion. All authors read and approved the final manuscript.

Acknowledgements

The authors acknowledge the support of the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) through the doctoral scholarship granted to Monica Pereira Carnaúba.

Data Availability

The data supporting the findings of this study are available within the article and its supplementary materials. Additional information related to the reviewed studies may be provided by the corresponding author upon reasonable request.

References

1. Ahmad A, Amin KA, Ashraf SS (2024) Biological effects of culture medium on *Tetraselmis chuii* and *Dunaliella tertiolecta*: implications for emerging pollutants degradation. Chemosphere 363:142868. https://doi.org/10.1016/j.chemosphere.2024.142868
2. An SM, Cho K, Kang NS, Kim ES, Ki H, Choi G, An HS, Go GM (2024) Development of a cost-effective medium suitable for the growth and fucoxanthin production of the microalgae *Odontella aurita* using Jeju lava seawater and agricultural fertilizers. Biomass Bioenergy 188:107310. https://doi.org/10.1016/j.biombioe.2024.107310
3. Cai T, Ge X, Park SY, Li Y (2013) Comparison of *Synechocystis sp*. PCC6803 and *Nannochloropsis salina* for lipid production using artificial seawater and nutrients from anaerobic digestion effluent. Bioresour Technol 144:255–260. https://doi.org/10.1016/j.biortech.2013.06.101
4. Cardoso FD, De Paula Ramos EA, Fonseca AL, Costa PG, Bianchini A, Padial AA (2025) Arsenic and heavy metals contamination by effluent dam rupture in a subtropical coastal lagoon. Mar Pollut Bull 214:117794. https://doi.org/10.1016/j.marpolbul.2025.117794
5. Colusse GA, Mendes CRB, Duarte MER, Carvalho JC, Noseda MD (2020) Effects of different culture media on physiological features and laboratory scale production cost of *Dunaliella salina*. Biotechnol Rep 27:e00508. https://doi.org/10.1016/j.btre.2020.e00508
6. Decamp A, Martineau E, Grizeau D, Pruvost J, Gonçalves O (2023) Effects of salinity on the biosynthesis of polysaccharides in the marine microalga *Porphyridium cruentum*. Algal Res 71:103089. https://doi.org/10.1016/j.algal.2023.103089
7. Grubišić M, Šantek B, Kuzmić M, Čož-Rakovac R, Ivančić Šantek M (2024) Enhancement of biomass production of diatom *Nitzschia sp*. S5 through optimisation of growth medium composition and fed-batch cultivation. Mar Drugs 22(1):46. https://doi.org/10.3390/md22010046
8. Gubert G, de Ramos B, de Oliveira RC, Araújo KB, Gabriel AM, Ribeiro KA, Cordeiro ES, Aragão DS, Silva JDS, Costa MF, Camargo ER, Fragoso WD, Lemos SG, Souza ECP, Gubert P (2025) Plastic dispersion in Northeast Brazil beaches and plastic contaminant detection in Brazilian coast fishing nets. Mar Pollut Bull 218:118221. https://doi.org/10.1016/j.marpolbul.2025.118221
9. He M, Li L, Liu J, Zhang L (2015) Improvement of H2 photoproduction in *Chlorella pyrenoidosa* in artificial and natural seawater by addition of acetic acid and control of nutrients. Algal Res 10:104–109. https://doi.org/10.1016/j.algal.2015.04.018
10. Khemiri S, Bouchech I, Berrejeb N, Mejri M, Smaali I, Khelifi N (2022) Effects of growth medium variation on the nutri-functional properties of microalgae used for the enrichment of ricotta. Food Technol Biotechnol 60(1):29–40. https://doi.org/10.17113/ftb.60.01.22.7105
11. Lananan F, Jusoh A, Ali N, Lam SS, Endut A (2013) Effect of Conway medium and f/2 medium on the growth of six genera of South China Sea marine microalgae. Bioresour Technol 141:75–82. https://doi.org/10.1016/j.biortech.2013.03.006

12. Lima MCS, Silva J, Magalhães KM (2025) Oil spill effects on seagrass ecosystems: a systematic review. Hydrobiologia 852(12):3171–3190. https://doi.org/10.1007/s10750-024-05748-3
13. Nghiem Xuan R, Safitri I, Mouget JL, Pruvost J, Turpin V, Jaouen P (2020) Design of an artificial culture medium to optimize *Haslea ostrearia* biomass and marennine production. Algal Res 45:101653. https://doi.org/10.1016/j.algal.2019.101653
14. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, Chou R, Glanville J, Grimshaw JM, Hróbjartsson A, Lalu MM, Li T, Loder EW, Mayo-Wilson E, McDonald S, McGuinness LA, Stewart LA, Thomas J, Tricco AC, Welch VA, Whiting P, Moher D (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 372:n71. https://doi.org/10.1136/bmj.n71
15. Panahi Y, Khosroushahi AY, Sahebkar A, Heidari HR (2019) Impact of cultivation condition and media content on *Chlorella vulgaris* composition. Adv Pharm Bull 9(2):182–194. https://doi.org/10.15171/apb.2019.022
16. Patel B, Gami B, Bhimani H (2009) Formulation of commercially feasible marine microalgae cultivation media for biofuel production. Int J Energy Clean Environ 10(1–4):167–179. https://doi.org/10.1615/InterJEnerCleanEnv.2011002449
17. Santos AM, Janssen M, Lamers PP, Evers WAC, Wijffels RH (2012) Growth of oil accumulating microalga *Neochloris oleoabundans* under alkaline-saline conditions. Bioresour Technol 104:593–599. https://doi.org/10.1016/j.biortech.2011.10.084
18. Schulze C, Reinhardt J, Wurster M, Ortiz-Tena JG, Sieber V, Mundt S (2016) A one-stage cultivation process for lipid- and carbohydrate-rich biomass of *Scenedesmus obtusiusculus* based on artificial and natural water sources. Bioresour Technol 218:498–504. https://doi.org/10.1016/j.biortech.2016.06.109
19. Song P, Kuryatov A, Axelsen PH (2020) A new synthetic medium for the optimization of docosahexaenoic acid production in *Crypthecodinium cohnii*. PLoS ONE 15(3):e0229556. https://doi.org/10.1371/journal.pone.0229556
20. Souza-Santos LP, Carneiro YMM, Da Silva ASX (2025) Weekly variation of seawater ecotoxicity on marine sandy beaches in relation to coliform densities. Mar Pollut Bull 213:117694. https://doi.org/10.1016/j.marpolbul.2025.117694
21. Teixeira M, Cesar R, Souza Abessa DM, Moreno-Garrido I, Fernandes Y, Alexandre K, Carneiro M, Rodes SH, Castro JV, Prieto C, Lino A, Parente C, Machado W (2026) Ecotoxicological assessment of metal pollution using aquatic organisms in surface sediments from a tropical urbanized lagoon system. Estuaries Coasts 49(3):71. https://doi.org/10.1007/s12237-026-01675-9
22. Viana JLM, Santos SRV, Santos LHMLM, Jaén-Gil A, Rodríguez-Mozaz S, Barceló D, Franco TCRS (2024) Pesticide contamination and associated ecological risks in estuarine waters of Brazil's Legal Amazon. Environ Sci Pollut Res 32(2):617–633. https://doi.org/10.1007/s11356-024-35778-2
23. Yao CH, Ai JN, Cao XP, Xue S (2013) Salinity manipulation as an effective method for enhanced starch production in the marine microalga *Tetraselmis subcordiformis*. Bioresour Technol 146:663–

671. https://doi.org/10.1016/j.biortech.2013.07.134

Figures

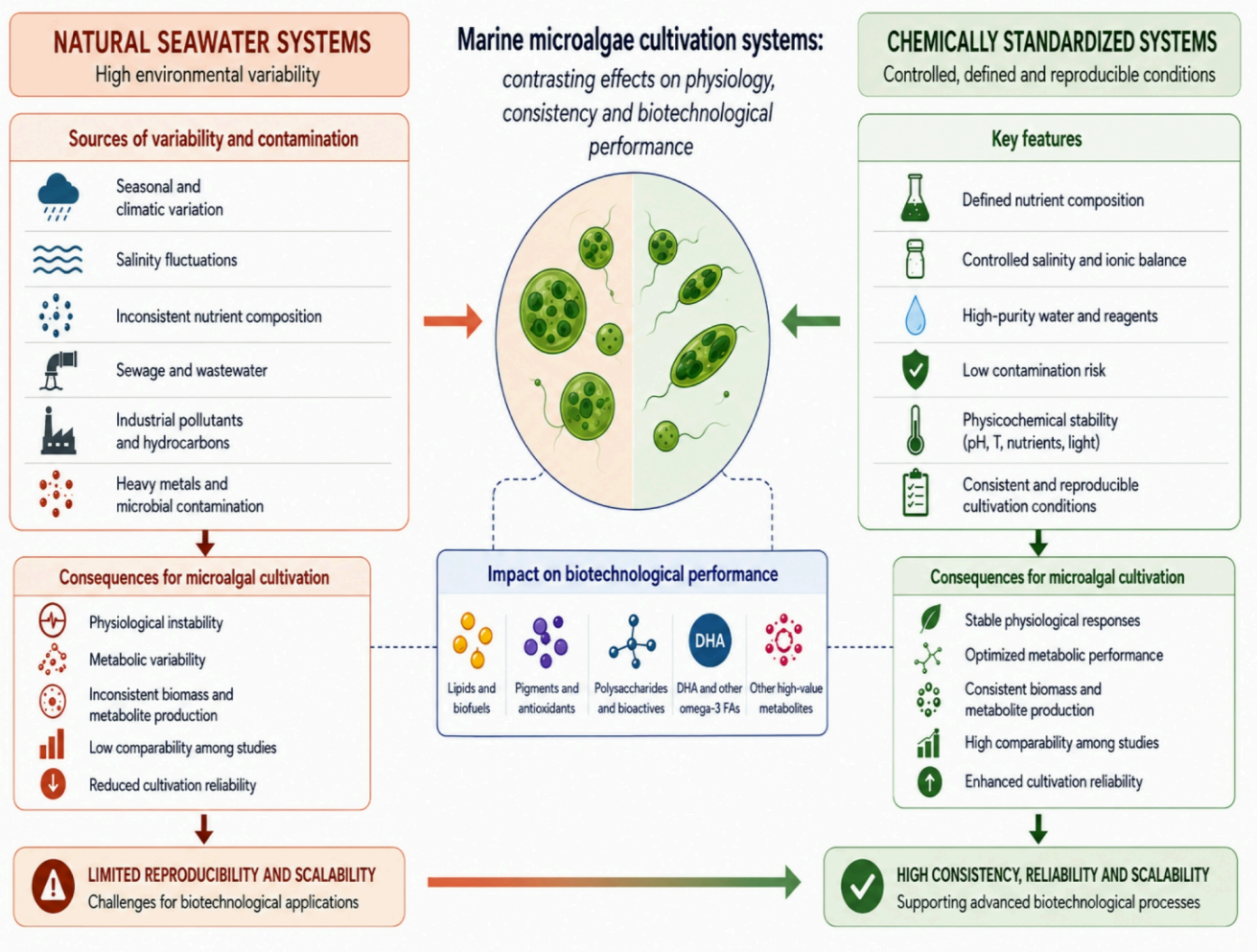


Figure 1

Contrasting effects of natural seawater and chemically standardized cultivation systems on marine microalgae physiology, cultivation reliability, and biotechnological performance. Environmental variability associated with natural seawater may compromise cultivation stability and metabolic consistency, whereas chemically controlled systems improve cultivation consistency, reliability, and scalability for biotechnological applications.

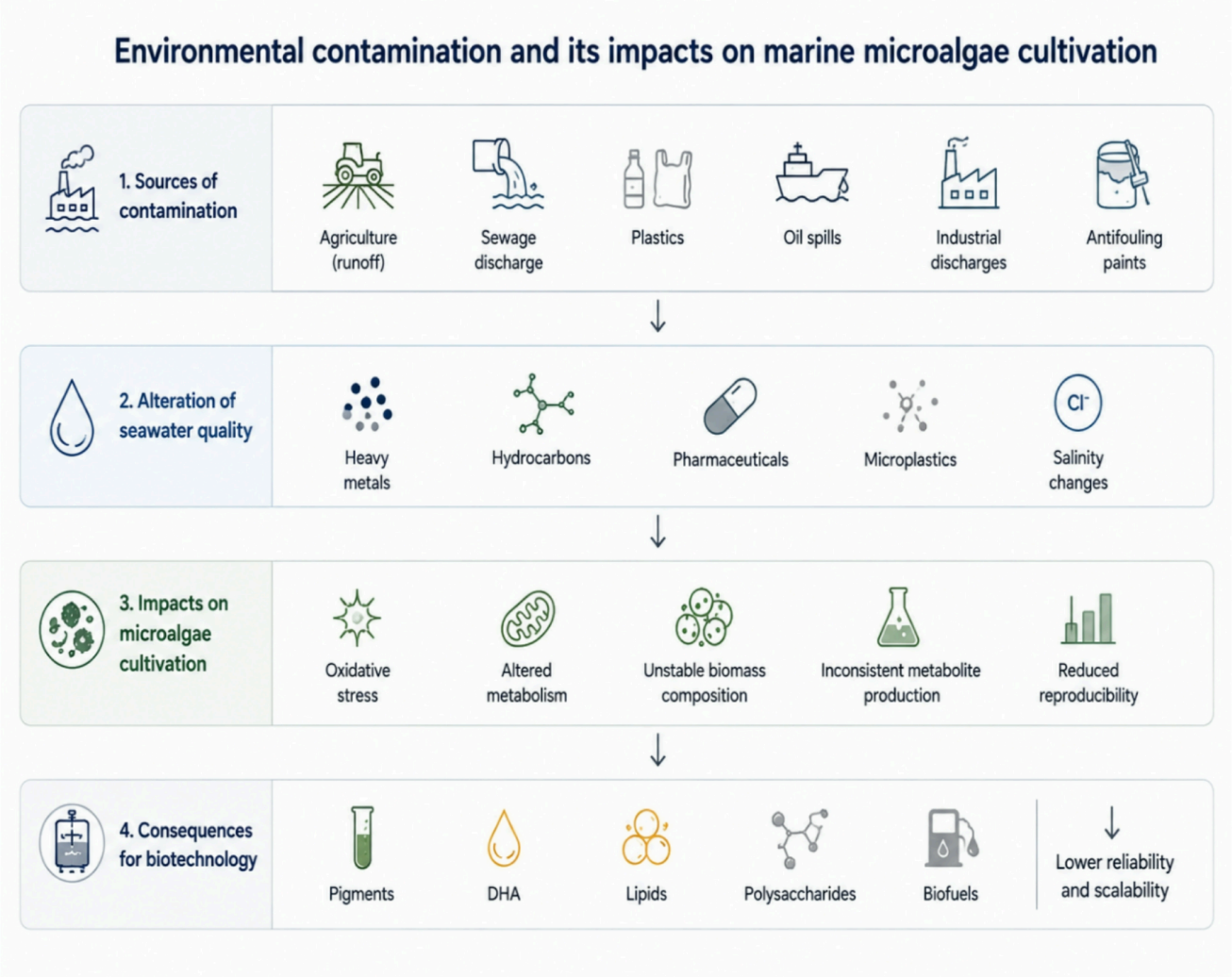


Figure 2

Environmental contamination sources and their potential impacts on marine microalgae cultivation systems. Variability in seawater quality caused by pollutants and anthropogenic activities may alter microalgal physiology and metabolic stability, compromising cultivation reproducibility and the reliability of biotechnological applications.

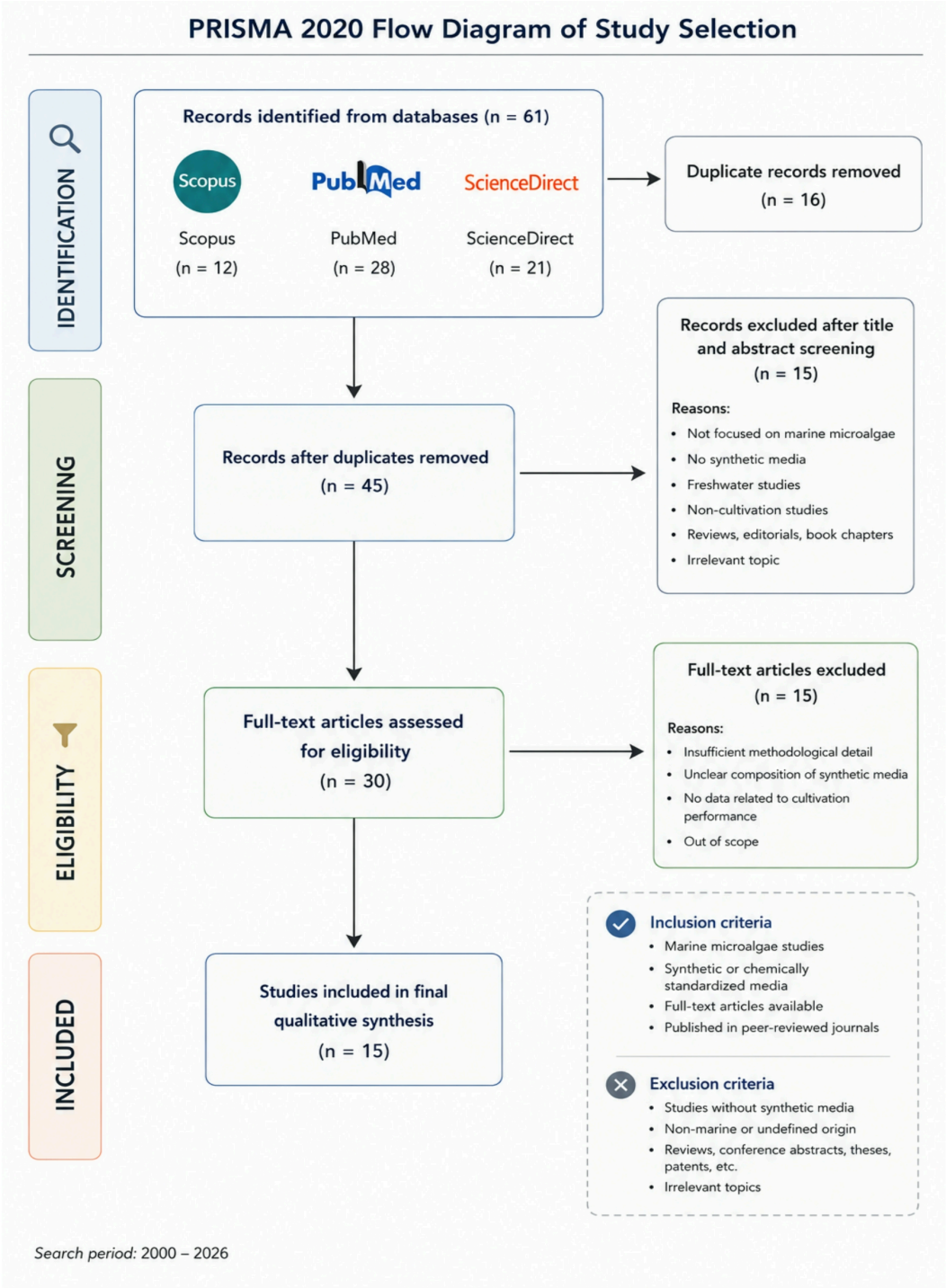


Figure 3

PRISMA 2020 flow diagram of the study selection process for the systematic review on synthetic media for marine microalgae cultivation

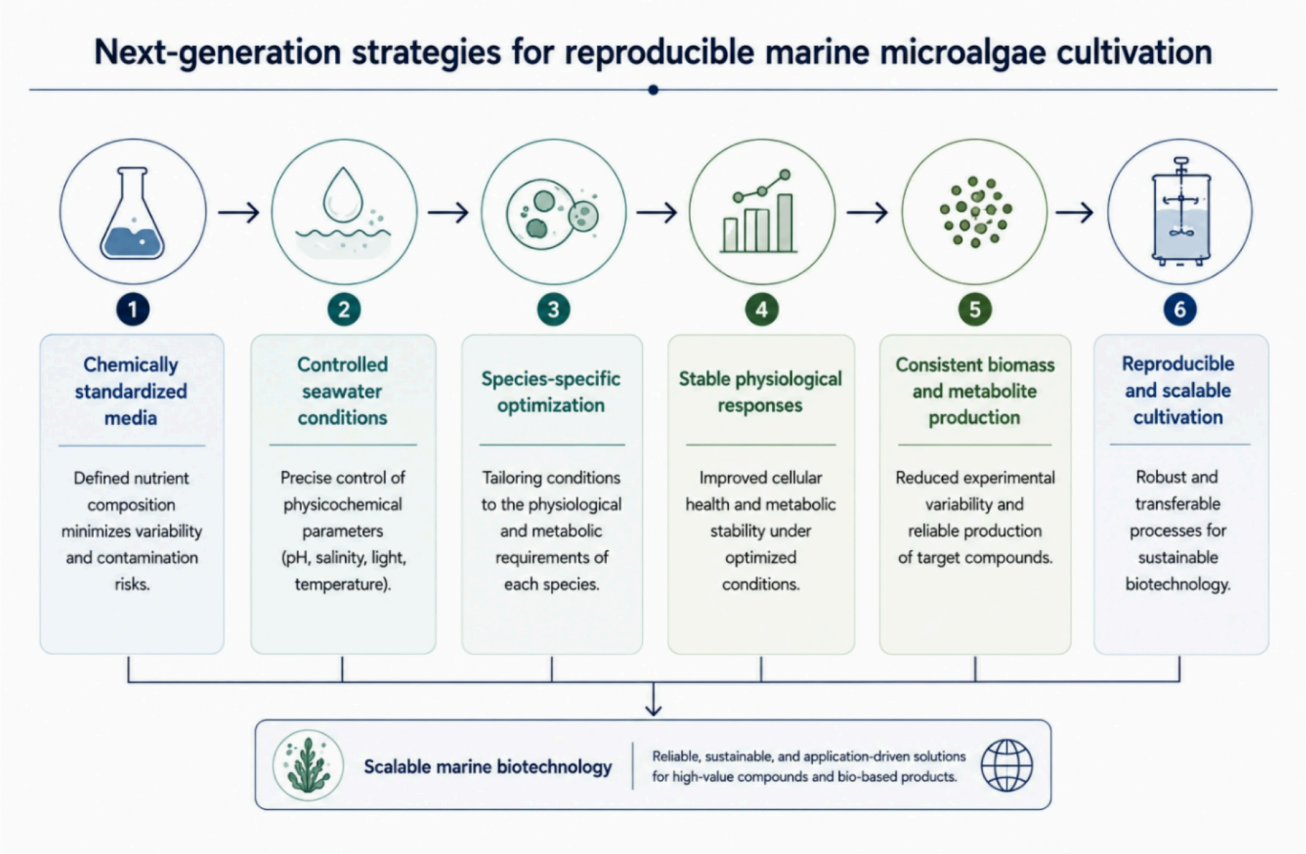


Figure 4

Comparative overview of synthetic cultivation media and their strategic applications in marine microalgae biotechnology.

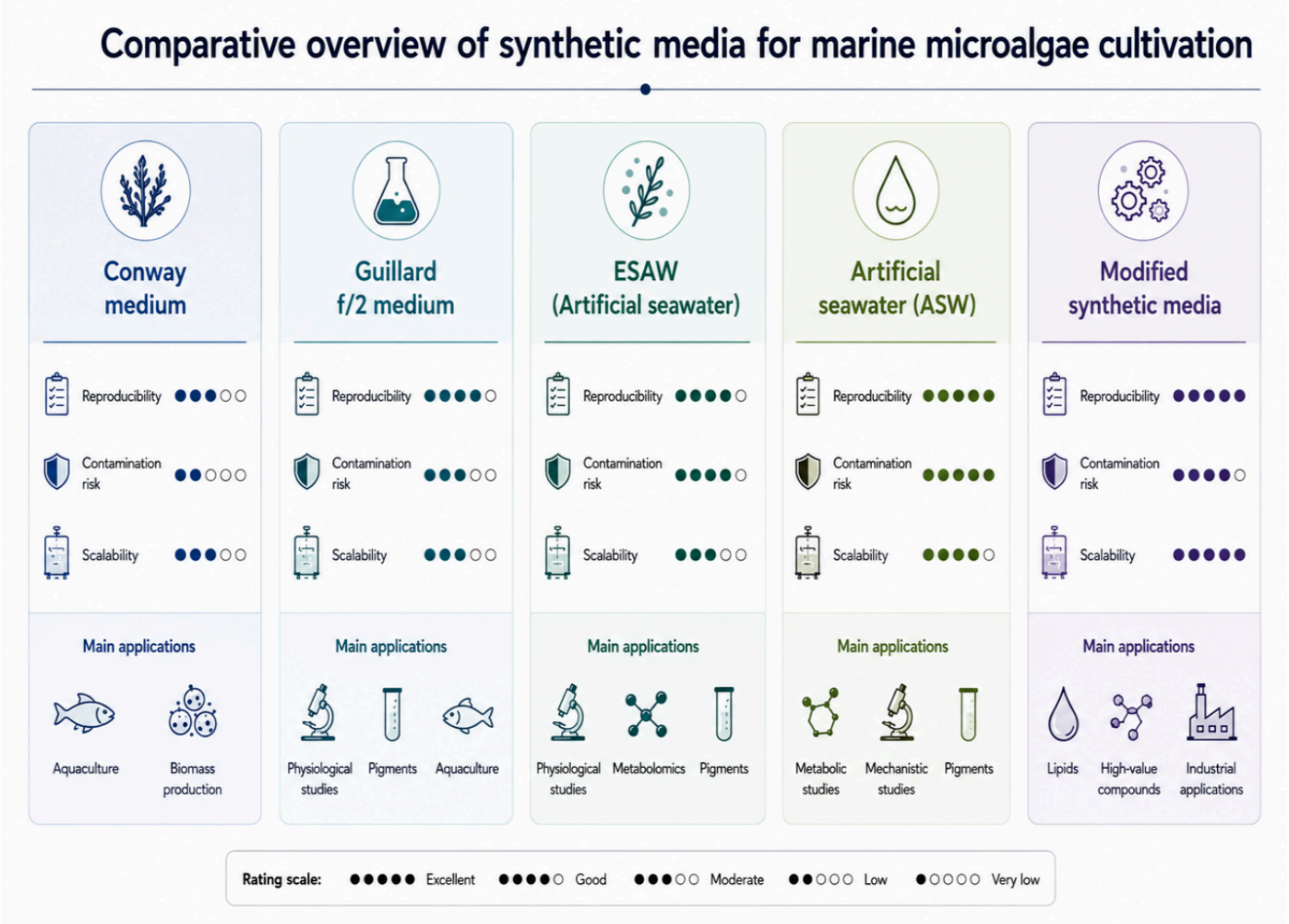


Figure 5

Conceptual framework illustrating integrated strategies to improve cultivation standardization, physiological stability, and scalability in marine microalgae systems through controlled cultivation approaches.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1SyntheticMediaMicroalgae.docx