Comparative Assessment of Estimated Cellular Carbon and Growth Performance of Live-Feed Microalgae Used in Aquaculture

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ABSTRACT

Microalgae have gained increasing attention as a sustainable solution for carbon capture due to their high photosynthetic efficiency and rapid biomass production. In aquaculture systems, microalgae are widely used as live feeds; however, their carbon sequestration potential (CSP) has not been systematically evaluated. This study aimed to assess the CSP of six microalgal species (*Chaetoceros*, *Thalassiosira*, *Chlorella*, *Nannochloropsis*, *Tetraselmis*, and *Isochrysis*) based on growth performance and biomass production, and to analyze the relationships among growth rate, cell density, and CSP. Microalgae were cultivated under controlled laboratory conditions (25±1°C, 28 psu, 12L:12D photoperiod, ~3,000 Lux) for 15 days, and key growth parameters, including growth rate, maximum cell density, and biomass production, were determined. CSP was estimated indirectly using cell density and literature-derived carbon conversion factors, and relationships among variables were analyzed using Pearson's correlation. Growth rate showed no significant direct relationship with estimated carbon content across all species ($P>0.05$). Biomass production, estimated from changes in cell density, showed strong positive correlations with estimated carbon content ($r = 0.64$-0.98, $P<0.05$-0.01), indicating its relevance to comparative carbon accumulation potential CSP. Because carbon was estimated from cell density and literature-derived carbon conversion factors rather than directly quantified, the results should be interpreted as comparative estimates. These findings provide a comparative framework for evaluating carbon accumulation potential among live feed microalgae and support their potential integration into sustainable, low-carbon aquaculture systems.

Keywords: Biomass productivity/ Carbon capture capacity/ CO_2 fixation/ Live feed culture/ Marine microalgae

1. INTRODUCTION

Climate change, driven by the accumulation of carbon dioxide (CO_2) in the atmosphere, was intensified by human activities such as fossil fuel consumption, urban expansion, and deforestation. These processes led to global warming and widespread ecosystem imbalances [1]. Consequently, carbon capture and sequestration strategies became increasingly important for mitigating these impacts.

Among carbon sequestration approaches, biotechnology utilizing photosynthetic organisms, particularly microalgae, attracted considerable attention due to their high efficiency in CO_2 fixation through photosynthesis and their ability to rapidly convert carbon into biomass compared to terrestrial plants [2]. Furthermore, microalgae demonstrated strong potential for applications across various sectors, including food, animal feed, bioenergy, and other bioproducts, positioning them as a key component of the bioeconomy and greenhouse gas emission reduction strategies [3]. However, the selection of microalgal species in hatchery systems was often primarily based on growth performance and nutritional value, while their carbon sequestration potential had not been systematically evaluated. This was despite growing evidence that microalgae could utilize nutrients in wastewater to enhance both biomass production and carbon sequestration [4].

Although numerous studies had examined the carbon sequestration potential of microalgae in the context of bioenergy and environmental applications [5-9], there remained a lack of research explicitly linking microalgal growth to carbon sequestration potential (CSP), particularly among species used as live feed in aquaculture systems. Furthermore, the direct measurement of carbon fixed by microalgae at the laboratory scale was constrained by several limitations, as it required specialized analytical

instruments that were costly, time-consuming, and demanded technical expertise. Consequently, the comprehensive acquisition of direct carbon data was not always feasible in many studies. Therefore, the evaluation of CSP in this study was conducted using indirect indicators, including cell growth rate, cell density, and biomass production in terms of cell proliferation rate, which more practically reflected the capacity of microalgae to accumulate carbon in the form of biomass for comparative purposes [10]. Accordingly, this study addressed the question of how different microalgal species used as live feed differed in their CSP based on their growth characteristics, and which species was most suitable for application in sustainable aquaculture systems.

The objectives of this study were to (1) assess the CSP of individual microalgal species using growth and biomass-related indicators, and (2) analyze the relationships among growth rate, cell density, and CSP. This study was expected to address existing knowledge gaps in the assessment of microalgal CSP within the context of aquaculture, and to support the development of integrated approaches linking aquaculture feed production with carbon management. Ultimately, these efforts were anticipated to contribute to the advancement of sustainable aquaculture systems aligned with climate change adaptation strategies.

2. METHODOLOGY

2.1 Experimental design

The experiment was conducted at the Phytoplankton Laboratory of the Klongwan Fisheries Research Station (PL-KFRS), Prachuap Khiri Khan Province, Thailand, using a multi-species design to evaluate growth performance and carbon sequestration potential in marine microalgae. A completely randomized design (CRD) with ten replicates (n=10) was applied.

Six marine microalgal species—diatoms (*Chaetoceros calcitrans* and *Thalassiosira weissflogii*), green microalgae (*Chlorella* spp. and *Nannochloropsis oculata*), and flagellates (*Tetraselmis suecica* and *Isochrysis galbana*)—were obtained from the Prachuap Khiri Khan Coastal Fisheries Research and Development Center, Department of Fisheries, Thailand.

Cultures were initially grown in 250 mL Erlenmeyer flasks containing sterilized seawater (28 psu) enriched with Conway medium, with silicate added for diatoms only. The inoculation volume was 10% (v/v), and cultures were maintained at 25±1°C under a 12L:12D photoperiod and light intensity of approximately 3,000 Lux. Once cell density reached ~10^6 cells/mL, cultures were scaled up to 1 L glass bottles.

Experimental batch cultivation was conducted in 1 L glass bottles under controlled conditions (25±1°C, 28 psu, 12L:12D, ~3,000 Lux) for 15 days. All cultures were initiated at approximately 1-2 × 10^5 cells/mL, with continuous aeration applied to maintain homogeneous conditions and prevent cell sedimentation. During the experiment, algal cell samples were collected daily to estimate cell density and maximum cell density in cells/mL. Cells were fixed with 5% formalin and counted using a hemacytometer under a compound microscope at 40× magnification.

2.2 Microalgae growth analysis

2.2.1 Maximum cell density

The maximum cell density was determined as the highest value recorded during the culture period.

2.2.2 Growth rate

The growth rate of micr oalgae was calculated based on changes in cell density over time, following the method of Xavier et al. [11], using the equation 1:

$$\mu = \ln N2 - \ln N1 / t2 - t1 \quad (1)$$

2.2.3 Biomass production

The biomass production rate was estimated from changes in cell density per unit time, following the method of Xavier et al. [11], using the equation 2:

$$P = N2 – N1 / t2 – t1 \quad (2)$$

Where; μ = the growth rate (/day), P = the biomass production rate expressed as cell proliferation (cells/mL/day), N1 = the cell count at time t1 (cells/mL), N2 = the cell count at time t2 (cells/mL), t1 = the first sampling time (day), t2 = the second sampling time (day), and ln indicates the Napierian logarithm.

2.3 Assessment of carbon sequestration potential (CSP)

As carbon content was not directly measured in this study, CSP was estimated using an indirect approach based on microalgal growth data combined with conversion factors, following Montagnes et al. [10].

2.3.1 Carbon content per cell

The carbon content per cell (picograms of carbon per cell; pg C/cell) for the six microalgal species was derived from published literature using representative literature-based values. To improve consistency between the selected values and the reported literature ranges, representative values were selected from within the corresponding reported ranges, using the midpoint when a defined range was available. Accordingly, the values used for the baseline estimation were CC (25 pg C/cell), TH (150 pg pg C/cell), CH (12.5 pg C/cell), NAN (6 pg C/cell), TE (100 pg C/cell), and ISO (50 pg C/cell). Because cellular carbon content can vary with species, cell size, and physiological or culture conditions, these values were treated as comparative conversion factors rather than species-invariant measurements. The corresponding literature ranges and references are provided in Table 1.

Table 1. Carbon conversion factors for microalgae species

Species	Taxonomic group	Reported carbon content (pg C/cell)	Reference
Chaetoceros (CC)	Division: Ochrophyta Class: Bacillariophyceae (Diatoms)	15-40	Menden-Deuer & Lessard [12]
Thalassiosira (TH)	Division: Ochrophyta Class: Bacillariophyceae (Diatoms)	50-250	Linacre et al. [13]
Chlorella (CH)	Division: Chlorophyta Class: Chlorophyceae	5-20	Yap et al. [14]
Nannochloropsis (NAN)	Division: Ochrophyta Class: Eustigmatophyceae	2-10	Yap et al. [14]
Tetraselmis (TE)	Division: Chlorophyta Class: Chlorodendrophyceae	50-150	Reitan et al. [15]
Isochrysis (ISO)	Division: Haptophyta Class: Prymnesiophyceae	20-80	Zhou et al. [16]

Note: Values represent literature-reported ranges of cellular carbon content. Representative values used for the baseline carbon estimation were selected within these ranges, using the midpoint when a defined range was available (see Section 2.3.1). 1 pg = 1×10^{-12} g. 1 pg = 1×10^{-12} g.

2.3.2 Carbon estimation

The estimated cellular carbon content was calculated from maximum cell density and literature-derived carbon content per call, the carbon-to-volume framework of Menden-Deuer & Lessard [12], as described in Equation 3:

$$C_{est} = N \times CF \quad (3)$$

Where; C_{est} = the estimated carbon content (µg C/mL), N = the maximum cell density (cells/mL), and CF = the carbon content per cell (pg C/cell).

2.3.3 CO_2 fixation potential

The estimated carbon content was subsequently converted to CO_2 equivalents using the molecular weight ratio (44/12), as recommended by IPCC [17], using the following equation 4:

$$CO_2 = C_{est} \times (44/12) \quad (4)$$

The assessment of CSP in this study was based on an indirect estimation approach using conversion factors derived from published literature, and did not involve direct measurement of carbon content using analytical instruments such as CHN analyzers or total organic carbon (TOC) analysis. Therefore, the results were expressed as comparative estimations rather than absolute values.

2.4 Data analysis

One-way analysis of variance (ANOVA) was used to compare differences in growth rate, cell density, and CSP among microalgal species, with statistical significance set at $P<0.05$. In addition, relationships among variables, including growth rate, cell density, and CSP, were analyzed using Pearson's correlation coefficient. All statistical analyses were performed using IBM SPSS Statistics for Windows (version 26.0; IBM Corp., Armonk, NY, USA).

3. RESULTS AND DISCUSSION

3.1 Growth performance of microalgae

In this study, the initial cell densities of all microalgal species ranged from 1.07 to 1.11 × 10^5 cells/mL and did not differ significantly among treatments ($P>0.05$), indicating uniform starting conditions (Table 2).

Significant differences in growth performance were observed among species ($P<0.05$). *Chlorella* exhibited the highest maximum cell density, followed by *Nannochloropsis* and *Isochrysis*. In contrast, *Tetraselmis* showed the lowest maximum density. Similarly, the growth rate differed significantly among species, with *Chlorella* and *Nannochloropsis* showing the highest values, while *Thalassiosira* exhibited the lowest growth rate. Biomass production, expressed as cell-density increase per unit time, followed a similar trend, with *Chlorella* achieving the highest production rate (14.96 cells/mL/day), followed by *Nannochloropsis* (10.36 cells/mL/day), whereas *Tetraselmis* showed the lowest biomass production rate (0.70 cells/mL/day) (Table 2).

3.2 Estimated cellular carbon content and CO_2 equivalent

Significant differences in estimated cellular carbon content and CO_2 equivalent were observed among microalgal species ($P<0.05$). The ranking of species varied according to the literature-derived carbon conversion factors used in the estimation. Using the representative baseline factors, *Isochrysis*, *Thalassiosira* and *Chlorella* showed relatively high estimated carbon values, respectively, whereas *Tetraselmis*, *Chaetoceros* and *Nannochloropsis* showed lower values (Table 2). These estimates should be interpreted as comparative values because cellular carbon content was not directly measured in the present study.

Table 2. Growth performance and carbon sequestration potential (CSP) of live feed microalgae (*Chaetoceros* [CC], *Thalassiosira* [TH], *Chlorella* [CH], *Nannochloropsis* [NAN], *Tetraselmis* [TE], and *Isochrysis* [ISO]) expressed as mean ± standard deviation (SD) (n=10)

Parameter	Microalgae species					
	CC	TH	CH	NAN	TE	ISO
Initial density (× 10^5 cells/mL)	1.07^{a} (±0.08)	1.11^{a} (±0.13)	1.07^{a} (±0.03)	1.10^{a} (±0.12)	1.08^{a} (±0.11)	1.07^{a} (±0.11)
Max. density (× 10^5 cell/mL)	33.84^{d} (±4.38)	23.95^{de} (±8.23)	205.37^{a} (±42.32)	134.95^{b} (±15.52)	11.40^{e} (±1.98)	102.29^{c} (±17.16)
Growth rate (/day)	0.35^{b} (±0.02)	0.30^{c} (±0.02)	0.39^{a} (±0.03)	0.38^{ab} (±0.04)	0.32^{c} (±0.01)	0.32^{c} (±0.19)
Biomass (cells/mL/day)	3.35^{d} (±0.46)	2.19^{e} (±0.52)	14.96^{a} (±2.30)	10.36^{b} (±1.38)	0.70^{f} (±0.13)	7.03^{c} (±1.08)
C_{est} (µg C/mL)	846.04^{d} (±109.69)	$3,592.49^{b}$ (±1,234.56)	$2,567.18^{c}$ (±529.01)	809.73^{d} (±93.17)	$1,140.57^{d}$ (±198.30)	$5,114.84^{a}$ (±858.09)
CO_2 equivalent (µg CO_2/mL)	$3,096.51^{d}$ (±401.47)	$13,148.54^{b}$ (±4,518.51)	$9,395.90^{c}$ (±1,936.19)	$2,963.63^{d}$ (±341.00)	$4,174.51^{d}$ (±725.79)	$18,720.32^{a}$ (±3,140.61)

Means in each row followed by different letters indicate a significant difference (P<0.05).

3.3 Correlation between growth performance and estimated CSP

Pearson's correlation analysis showed that growth rate was not significantly correlated with estimated carbon content (C_{est}) across the six microalgal species (P>0.05), with correlation coefficients ranging from -0.42 to 0.47. Biomass production showed positive correlations with C_{est} across all species (r=0.64-0.98, P<0.05-0.01), indicating a consistent association between biomass production and estimated CSP (Table 3).

The previously observed perfect correlation between maximum cell density and C_{est} (r = 1.00) was not interpreted as an independent biological relationship because C_{est} was calculated directly from maximum cell density and the assigned carbon conversion factor. Similarly, correlations between other variables and CO_2 equivalent were not reported separately because CO_2 equivalent was calculated directly from C_{est} using the constant molecular-weight conversion factor of 44/12 and therefore provides no additional independent correlation information.

Table 3. Pearson's correlation coefficients between growth performance, biomass production and estimated carbon content (C_{est}) in six microalgal species used as live feeds in aquaculture

Species	Growth rate vs C_{est} (r)	Biomass vs C_{est} (r)
Chaetoceros	0.20 (ns)	0.82**
Thalassiosira	-0.39 (ns)	0.93**
Chlorella	-0.42 (ns)	0.88**
Nannochloropsis	-0.06 (ns)	0.64*
Tetraselmis	0.47 (ns)	0.98**
Isochrysis	0.24 (ns)	0.93**

Note: values represent Pearson's correlation coefficients (r). *indicates significance at P<0.05, and ** indicates significance at P<0.01; ns = not significant (P>0.05).

Overall, these results demonstrate that cell density is the primary determinant of carbon sequestration potential, while the influence of growth rate is indirect and species-dependent. The findings suggest that carbon accumulation in microalgae is more strongly associated with biomass production and cell concentration than with intrinsic growth rate alone.

The present study demonstrated that the estimated carbon accumulation potential of live feed microalgae was strongly influenced by maximum cell density and the carbon conversion factor used for each microalgal group, rather than by intrinsic growth rate alone. This finding supports the conceptual

pathway of growth, biomass, and carbon, in which microalgal growth contributes to carbon capture indirectly through biomass production. Microalgae assimilate carbon dioxide via photosynthesis and convert it into cellular biomass; therefore, the total amount of carbon accumulated in a culture system is related to the amount of biomass produced, although growth rate alone does not necessarily reflect the final carbon accumulation. Similar observations have been reported in previous studies, where biomass productivity was identified as the key determinant of carbon fixation efficiency in microalgal systems [5, 6].

The strong and consistent positive correlations observed between cell density-based biomass estimates and carbon-related parameters ($r=0.645$-0.984, $P<0.05$-0.01) across all species further reinforce this mechanism. However, the carbon estimates in the present study were calculated from maximum cell density using literature-derived carbon conversion factors rather than from direct measurements of biomass or cellular carbon. Therefore, differences among species reflect the combined effects of cell abundance and the assumed carbon content per cell. This is consistent with the findings of Menden-Deuer & Lessard [12], who demonstrated that carbon content in phytoplankton is closely linked to cell biovolume and biomass rather than division rate. Consequently, species such as *Chlorella* and *Nannochloropsis*, which exhibited high maximum cell densities, showed relatively high estimated carbon accumulation despite not having the highest growth rates. In contrast, the absence of significant correlations between growth rate and carbon sequestration parameters across all species suggests that rapid cell division alone does not necessarily translate into greater carbon capture. This can be explained by the fact that growth rate reflects the rate of population increase but does not account for the final cell abundance or the carbon content assigned to each cell. In microalgal systems, carbon fixation is fundamentally linked to photosynthetic conversion of CO_2 into biomass; therefore, cell density and biomass accumulation provide important information for evaluating comparative carbon accumulation potential, but should be interpreted together with the carbon conversion factors applied. Similar conclusions have been reported in previous studies, where biomass production and process conditions were identified as key determinants of CO_2 fixation efficiency, rather than growth rate alone [18-20].

A notable result of this study was the perfect correlation ($r = 1.00$) between maximum cell density and estimated carbon content and CO_2 fixation across all species. This relationship arises directly from the estimation procedure, in which carbon content was calculated as maximum cell density multiplied by a constant carbon conversion factor (pg C/cell). Therefore, the observed perfect correlation represents a deterministic mathematical relationship rather than an independent biological correlation. Similar approaches have been widely applied in phytoplankton studies when direct carbon measurements are not feasible [10, 12]. Therefore, the observed perfect correlation should be interpreted as a calculation-dependent relationship rather than an independent biological correlation. Nonetheless, this approach remains useful for comparative analysis across species under standardized assumptions, while the absolute magnitude of the estimates should be interpreted with caution.

From an application perspective, these findings have important implications for both carbon capture, utilization, and storage (CCUS) and sustainable aquaculture systems. Integrating microalgae into carbon management frameworks has been increasingly recognized as a viable strategy due to their high photosynthetic efficiency and capacity for biomass-driven CO_2 fixation [20, 21]. The present results further suggest that incorporating comparative carbon accumulation potential into species selection criteria could enhance the environmental sustainability of hatchery systems. By prioritizing species with high biomass productivity, aquaculture operations may simultaneously improve live feed production efficiency and contribute to carbon mitigation. This integrated approach aligns with emerging concepts of climate-smart aquaculture, which emphasize resource efficiency, emission reduction, and ecosystem-based management [22].

Despite the promising findings, several limitations of this study should be acknowledged. Carbon sequestration was not directly measured; instead, carbon accumulation was estimated from maximum cell density and literature-derived carbon conversion factors and should therefore be

interpreted as comparative rather than absolute estimates. Future studies should incorporate direct carbon measurements and sensitivity or uncertainty analyses using alternative carbon conversion factors, together with larger-scale cultivation and life cycle assessment (LCA), to improve the robustness and practical applicability of these estimates.

4. CONCLUSIONS

Overall, this study demonstrated that the estimated carbon accumulation potential of live feed microalgae was influenced by maximum cell density and the carbon conversion factor applied, rather than by intrinsic growth rate alone. The comparative estimates varied among species, highlighting the importance of considering both biomass accumulation and cellular carbon content when evaluating microalgal performance for carbon capture. Although carbon sequestration was estimated indirectly, the comparative framework provides a practical basis for evaluating relative carbon accumulation potential among live feed microalgae and identifying species that may support both efficient feed production and carbon mitigation in sustainable aquaculture systems.

References

[1] Ildefonso, L.L.H., Renato, N.S., Silva, N.D., Rocha, D.N. & Martins, M.A. (2026). Potential of microalgae cultivation for carbon sequestration and stock associated with biofertilizer production. Biomass and Bioenergy, 209, 108975.
[2] Zhu, C., Hu, C., Wang, J., Chen, Y., Zhao, Y. & Chi, Z. (2023). A precise microalgae farming for CO2 sequestration: A critical review and perspectives. Science of the Total Environment, 901, 166013.
[3] Ramanna, L., Ansari, F.A., Rawat, I. & Bux, F. (2025). Microalgae-driven carbon sequestration and bio-fertiliser: Steps towards a sustainable future. Chemical Engineering Journal, 519, 164892.
[4] Borg-Stoveland, S., Draganovic, V., Spilling, K. & Gabrielsen, T.M. (2024). Successful growth of coastal marine microalgae in wastewater from a salmon recirculating aquaculture system. Journal of Applied Phycology, 36, 2851-2861.
[5] Chisti, Y. (2007). Biodiesel from microalgae. Biotechnology Advances, 25(3), 294-306.
[6] Kumar, K., Dasgupta, C.N., Nayak, B., Lindblad, P., & Das, D. (2011). Development of suitable photobioreactors for CO_2 sequestration addressing global warming using green algae and cyanobacteria. Bioresource Technology, 102, 4945-4953.
[7] Olguín, E.J., Sánchez-Galván, G., Arias-Olguín, I.I., Melo, F.J., González-Portela, R.E., Cruz, L., De Philippis, R., & Adessi, A. (2022). Microalgae-based biorefineries: Challenges and future trends to produce carbohydrate enriched biomass, high-added value products and bioactive compounds. Biology, 11, 1146.
[8] Zhu, C., Zhai, X., Dong, H., Wang, Y., & Liu, X. (2023). Microalgae for carbon sequestration: A review. Science of the Total Environment, 901, 166013.
[9] He, Z., Wang, J., & Li, Y. (2025). Recent advances in microalgae-driven carbon capture, utilization, and storage: Strain engineering through adaptive laboratory evolution and microbiome optimization. Green Carbon, 3, 74-99.
[10] Montagnes D.J.S., Berges, J.A., Harrison, P.J. & Taylor, F.J.R. (1994). Estimating carbon, nitrogen, protein, and chlorophyll a from volume in marine phytoplankton. Limnology and Oceanography, 39(5), 1044-1060.
[11] Xavier, B., Ranjan, R., Megarajan, S., Loka, J., & Kizhakudan, J.K. (2023). Training manual on live feed culture techniques for mariculture applications (CMFRI Training Manual Series No. 36/2023). CMFRI, Andhra Pradesh, India.
[12] Menden-Deuer, S. & Lessard E.J. (2000). Carbon to volume relationships for dinoflagellates, diatoms, and other protist plankton. Limnology and Oceanography, 45(3), 569–579.
[13] Linacre, L., Sánchez-Robles, C., Mirabal-Gómez, U., Lara-Lara, J.R. & Bazán-Guzmán, C. (2021). Cell carbon content and biomass assessments of dinoflagellates and diatoms in the oceanic ecosystem of the Southern Gulf of Mexico. PLoS ONE, 16(2), e0247071.
[14] Yap, B.H.J., Crawford, S.A., Dagastine, R.R., Scales, P.J. & Martin, G.J.O. (2016). Nitrogen deprivation of microalgae: effect on cell size, cell wall thickness, cell strength, and resistance to mechanical disruption. Journal of Industrial Microbiology and Biotechnology, 43(12), 1671-1680.
[15] Reitan, K.I., Øie, G., Jørgensen, H. & Wang, X. (2021). Chemical composition of selected marine microalgae, with emphasis on lipid and carbohydrate production for potential use as feed resources. Journal of Applied Phycology, 33, 3831–3842.
[16] Zhou, L., Ji, N., Sprecher, B.N. & Lin, S. (2025). Estimating carbon biomass using DNA: Phytoplankton as a case study. DNA, 5, 13.
[17] Intergovernmental Panel on Climate Change (IPCC). (2006). 2006 IPCC guidelines for national greenhouse gas inventories. Institute for Global Environmental Strategies (IGES).

[18] Zhao, B., & Su, Y. (2014). Process effect of microalgal-carbon dioxide fixation and biomass production: A review. Renewable and Sustainable Energy Reviews, 31, 121-132.
[19] Morales, M., Sánchez, L., & Revah, S. (2018). The impact of environmental factors on carbon dioxide fixation by microalgae. FEMS Microbiology Letters, 365(3), fnx262.
[20] Li, G., Xiao, W., Yang, T. & Lyu, T. (2023). Optimization and Process Effect for Microalgae Carbon Dioxide Fixation Technology Applications Based on Carbon Capture: A Comprehensive Review. C, 9, 35.
[21] Balasubramaniam, V., Rathi, D.-N.G., Mustar, S., Lee, J.C. (2025). Microalgae as an eco-friendly and functional ingredient for sustainable aquafeed. Aquaculture Journal, 5, 14.
[22] FAO. (2023). Climate-smart fisheries and aquaculture: Guidance for implementation. Food and Agriculture Organization of the United Nations.