Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 28(4): 1883 – 1894 (2024)
www.ejabf.journals.ekb.eg

Comparing the Effectiveness of Bamboo Floats and Plastic Bottles in Vertical Cultivation of *Kappaphycus alvarezii* for Mitigating Marine Debris Pathways: An Insight into Eco-Friendly Seaweed Aquaculture

Nursidi[1*], Nur Fajriani Nursida[1], Heriansah[2], Imran Lapong[2], Zaenal Saputra[2], Arpin Hardiana[3]

[1]Pangkep State Agricultural Polytechnic, Mandalle-90655, Indonesia
[2]Balik Diwa Institute of Maritime Technology and Business, Makassar-90245, Indonesia
[3]Master's program student, Fisheries Science Study Program, Faculty of Marine Science and Fisheries, Hasanuddin University, Makassar-90245, Indonesia

[*]**Corresponding Author: nursidilatif@gmail.com**

ARTICLE INFO

Article History:
Received: Feb. 15, 2024
Accepted: Aug. 15, 2024
Online: Aug. 21, 2024

Keywords:
Floats,
Bamboo,
Plastic bottles.
Vertical method seaweed,
Marine debris

ABSTRACT

The cultivation of seaweed is a subject of an ongoing debate due to its potential to provide ecosystem services and, concurrently, to serve as an entry point for marine debris, notably through the use of plastic bottle floats. This study aimed to compare the efficacy of bamboo floats against plastic bottles in the cultivation of *Kappahycus alvarezii*, with the objective of discerning their potential in mitigating marine debris pathways. Two types of float materials, each comprising three construction units, were devised for the vertical cultivation method over a 42-day period. Each construction unit, measuring 2 × 5m, incorporated three stretching ropes, fifteen hanging ropes, and 45 propagules planted vertically (at the top, middle, and bottom). The floats were constructed using either 330mL mineral water plastic bottles and 10cm long segments of used building construction bamboo, with 18 units of each type employed. The construction unit was designed to adopt a zigzag pattern between the bamboo float unit and the plastic bottle. Biomass production and semi-refined carrageenan (SRC) content of *K. alvarezii* were employed as indicators for evaluating float performance. The results indicated that there was no statistically significant difference in biomass production and SRC between the two float types ($P > 0.05$). The findings of this study suggested that bamboo holds the potential to replace plastic bottles as floats in seaweed cultivation, offering a promising avenue to mitigate marine debris pathways in sustainable mariculture.

INTRODUCTION

Macroalgae, commonly known as seaweed, encompasses a wide array of applications and advantages. Owing to their ecosystem services, these photosynthetic organisms emerge as pivotal entities in the present and forthcoming blue-green economy **(Cotas *et al.*, 2023)**. In addressing concerns related to climate change and dependence on fossil fuels, seaweed serves as an alternative feedstock for biofuel **(Hessami *et al.*, 2020)**,

Indexed in Scopus ELSEVIER DOAJ IUCAT

and demonstrating potential in mitigating emissions **(Ross *et al*., 2023)** . The red algae, in particular, represent a valuable reservoir of hydrocolloids such as carrageenan, essential in the production of both food and non-food ingredients **(Lomartire & Goncalves, 2023)**. Furthermore, seaweed have gained recognition for their pharmaceutical properties**(Rupert *et al*., 2022)**, showcasing antiviral activity against SARS-CoV-2, the causative agent of COVID-19 **(Oliyaei *et al*., 2022)**. Additionally, the cultivation of seaweed has the potential to generate employment and income opportunities for coastal communities **(Sultana *et al*., 2023)**. Given their multifaceted properties and applications, the demand for seaweed products is anticipated to rise in the future.

Kappaphycus alvarezii, formerly identified as *Eucheuma cottonii*, is a seaweed variety distinguished by its elevated carrageenan content, specifically kappa-carrageenan **(Tabacof *et al*., 2023)**. Alongside other *Eucheuma* species, *K. alvarezii* constitutes over 90% of the worldwide carrageenan production and is predominantly farmed in Asian nations, including Indonesia, the Philippines, Vietnam, and Malaysia **(Rupert *et al*., 2022)**. Indonesia stands as the foremost global producer of carrageenan seaweed, exporting 65% of its production in raw dry form, while the remaining 35% undergoes domestic processing **(Zhang *et al*., 2023)**. Of the domestically processed seaweed, 55% is exported, with approximately 58% in the form of semi-refined carrageenan (SRC), 28% as refined carrageenan (RC), and 14% as alkali-treated cottonii (ATC). The cultivation of *K. alvarezii* in Indonesia boasts a long history dating back to the late 1970s, now extending extensively along the Indonesian coast, offering a vital source of income for local communities **(Waldron *et al*., 2024)**. Consequently, cultivation activities, predominantly conducted by small-scale farmers, hold economic and social significance in Indonesia **(Rimmer *et al*., 2021)**.

Seaweed cultivation in Indonesia typically employs the long-line method **(Simatupang *et al*., 2021)**. In South Sulawesi, the primary region for *K. alvarezii* production in Indonesia, cultivation plots generally consist of a 20 to 25 meter length of nylon rope, tethered to thalli at 20 to 25 centimeter intervals along a 25-meter stretch. Plastic bottles serve as floats and are setted every 5 meters **(Nurdin *et al*., 2023)**. It is noteworthy that the practice of using used plastic bottles as floats is a traditional method handed down through generations of cultivators in Indonesia. A spatial study by **Nurdin *et al*. (2020)** in Takalar and Pangkep Regencies, South Sulawesi, estimated that approximately 3.6 million used plastic bottles were employed as floats to elevate *K. alvarezii* on 360.7 hectares of land. These plastic bottles are utilized for only 3-4 cycles in a year before being discarded into the sea by farmers. **Kasim *et al*. (2020)** also observed that floats crafted from used plastic bottles have a lifespan of only one year, after which they tend to leak and are subsequently discarded into the sea. The plastic bottles disposed of into the sea may contribute to Indonesia's status as the world's second-largest producer of marine debris **(Nurhati & Cordova, 2020)**.

Plastic bottles are commonly employed as floats in seaweed cultivation due to their affordability and widespread availability; however, their environmental impact is a concern. Therefore, it is crucial to explore alternative options. Bamboo, a non-plastic material, possesses potential as a float owing to its natural hollow structure **(Archila *et al*., 2018)**. Moreover, bamboo is prevalent in Asian countries **(Hao *et al*., 2022)**, including Indonesia, which is documented to host 176 species from 24 bamboo genera **(Ervianti *et al*., 2019)**. Empirical evidence suggests the use of bamboo in constructing seaweed media through the raft method due to its buoyancy **(Kasim *et al*., 2020)**. Despite this, there is limited published research on the use of bamboo as floats in seaweed cultivation. To comprehend the potential of bamboo as a float in seaweed cultivation, this study aimed to compare bamboo floats with plastic bottles in the vertical cultivation of the seaweed *K. alvarezii*. The outcomes of this investigation can contribute to environmentally friendly and sustainable seaweed cultivation practices and aid in mitigating marine debris.

MATERIALS AND METHODS

Experimental design

The research was conducted at the cultivation site of *K. alvarezii* farmers in Manyampa Village, Ujung Loe District, Bulukumba Regency, South Sulawesi, Indonesia (Fig. 1). Bamboo floats were compared with identically designed plastic bottle floats for vertical cultivation methods. The performance of the floats in this method is crucial as they need to support the weight of the seaweed, guiding it vertically into the water column. The vertical cultivation method of *K. alvarezii* has been previously studied, demonstrating a good production performance **(Nursidi *et al.*, 2017; Pong-Masak & Sarira, 2020; Heriansah *et al*., 2022)**.

A construction unit measuring 2 × 5m was designed to have three stretch ropes made of 4mm diameter polyethylene, each 1m apart. Floats were installed on each span rope at a distance of 1m. Anchors were used at each corner to secure the construction. Additionally, five hanging ropes made of 2mm diameter polyethylene, each measuring 1m long and equipped with weights, were installed on each span rope. Furthermore, three *K. alvarezii* propagules (seedlings) weighing 50± 0.5g each were tied to hanging ropes vertically at a distance of 25cm (top, middle, and bottom). The propagules were obtained from previous *K. alvarezii* harvests by local farmers at the same source. The design of one construction unit is illustrated in Fig. (2).

The plastic bottle floats used in this study were 330mL plastic water bottle waste. The bamboo floats were obtained from used building construction and cut into 10cm pieces (species: *Bambusa vulgaris*). Bamboo with proper treatment has a service-life up to 3-5 years **(Wahab *et al*., 2008)**. These two types of floats were collected from local locations and prepared with farmers in the research location. The construction unit for each type of float is designed in a zigzag pattern, with a 2-meter distance between the bamboo float units and the plastic bottles. This design reduces bias from the influence of nutrients and sunlight (Fig. 3)

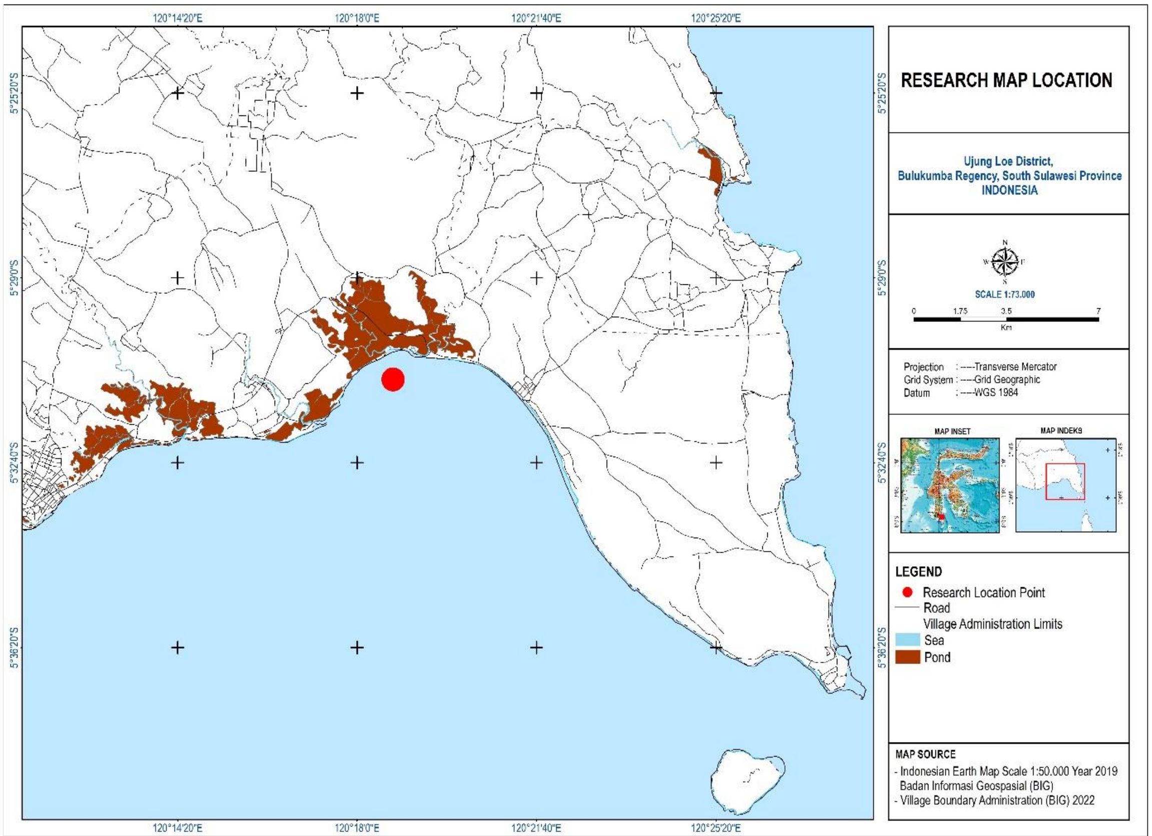

Fig. 1. Research location (Map drawn using QGIS 3.16.6-1 Program)

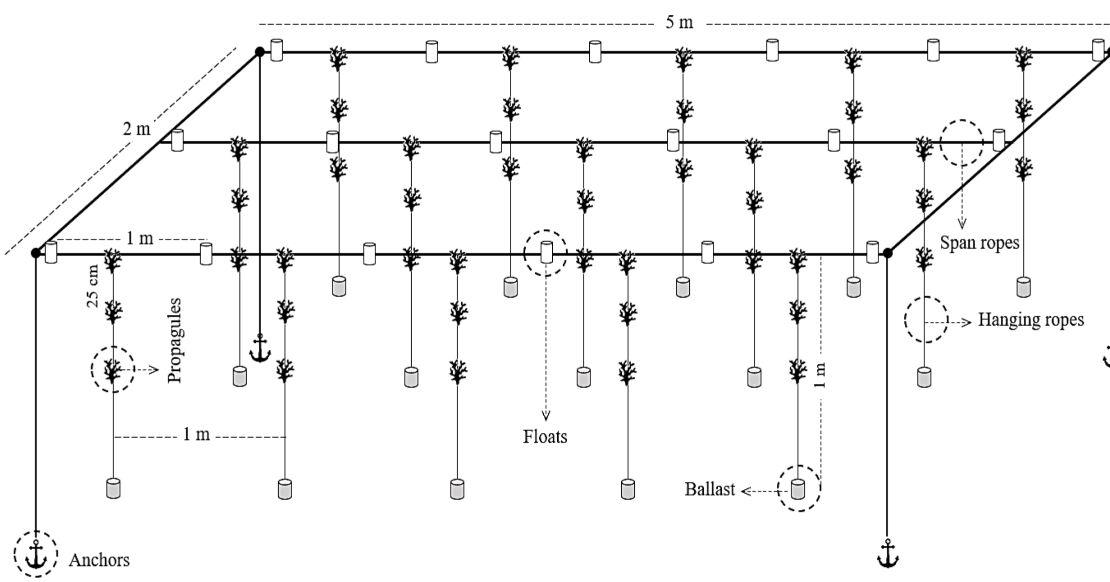

Fig. 2. Design of the *Kappahycus alvarezii* vertical cultivation experimental unit

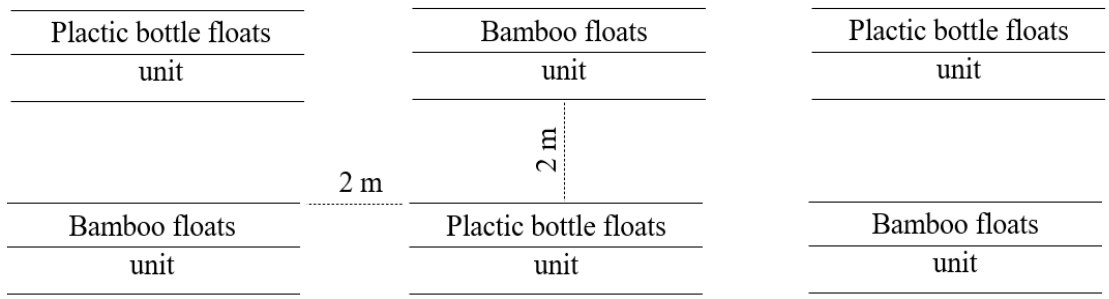

Fig. 3. Design of placement of experimental units for each floats

Rearing management

For 42 days, we conducted weekly maintenance, control, and cleaning of the mud in collaboration with local farmers. Concurrently, we measured water quality parameters, including temperature and dissolved oxygen (DO meter Lutron-5509), salinity (Refractometer Atago 53T), pH (pH meter Lutron pH-201), and brightness (Secchidisk). All *in situ* measurements were conducted around the experimental unit in the morning and evening, respectively. Additionally, water samples were collected at the beginning, middle, and end of the study using 250mL polypropylene (PP) sample bottles for the analysis of nitrate and phosphate parameters. These samples were analyzed in the laboratory of Pangkep State Agricultural Polytechnic using the colorimetric method.

In this study, we compared the performance of plastic bottles and bamboo floats by assessing two seaweed production variables: biomass production and semi-refined carrageenan (SRC) content. Biomass production was determined by weighing the total *K. alvarezii* for each experimental unit upon the conclusion of the study. SRC content was measured using the potassium hydroxide (KOH) extraction method, following the procedures outlined by **Uju *et al*. (2019)** and **Simatupang *et al*. (2021)**. Seaweed samples from the top, middle, and bottom planting points for each experimental unit were collected, washed with running water to remove dirt, sun-dried, and subsequently cut into small pieces. Approximately 50g of each sample was then heated at 80°C in a 10% KOH solution (1:10) for 30 minutes. The resulting SRC was soaked in distilled water until a pH of around 7 was achieved, then sun-dried, and further processed into carrageenan flour using a blender. SRC content was calculated as a percentage of the dry sample weight using the following equation:

SRC content (%) = (Weight of SRC (g) / Dry weight of sample (g)) x 100)

Statistical analysis

The data on biomass production and carrageenan content were subjected to statistical analysis using IBM SPSS Statistics 25 software. Independent sample t-tests were employed to compare the two types of floats concerning biomass production parameters and *K. alvarezii* carrageenan content. The significance level for these statistical tests was set at 95% (P<0.05).

RESULTS

Growth performance

During a 42-day study conducted in the dry season, water quality data from both bamboo float and plastic bottle locations were observed to be relatively similar. Additionally, the recorded data fell within the optimal range for cultivating *K. alvarezii*, as displayed in Table (1). The favorable conditions of various water quality parameters observed during this study contribute to the biomass production and carrageenan content of *K. alvarezii*.

Table 1. Range of water quality parameter values during 42 days of *K. alvarezii* rearing

Parameter	Bamboo floats	Bottles plastic floats	Optimal range [1]
Temperature (˚C)	26.1 – 30.2	26.1 – 30.4	25 – 35
Dissolved oxygen (mg L^{-1})	5.3 – 5.8	5.3 – 5.7	4 – 8
Salinity (ppt)	30 – 31	30 – 31	25 – 35
pH	7.8 – 8.1	7.8 – 8.1	7 – 9
Brightness (m)	1.1 – 1.8	1.2 – 1.7	> 1
Nitrate (mg L^{-1})	0.05 – 0.13	0.05 – 0.15	0.01 – 3.50
Phosphate (mg/L)	0.04 – 0.07	0.04 – 0.07	0.02 – 2.00

[1]**Aris and Labenua (2020)**.

The average biomass production and SRC content of *K. alvarezii*, cultivated for 42 days using a vertical system with different types of floats, are illustrated in Fig. (4). Employing bamboo floats yielded higher biomass and SRC content compared to plastic bottle floats. However, no statistically significant difference was observed between the two types of floats (*P*>0.05).

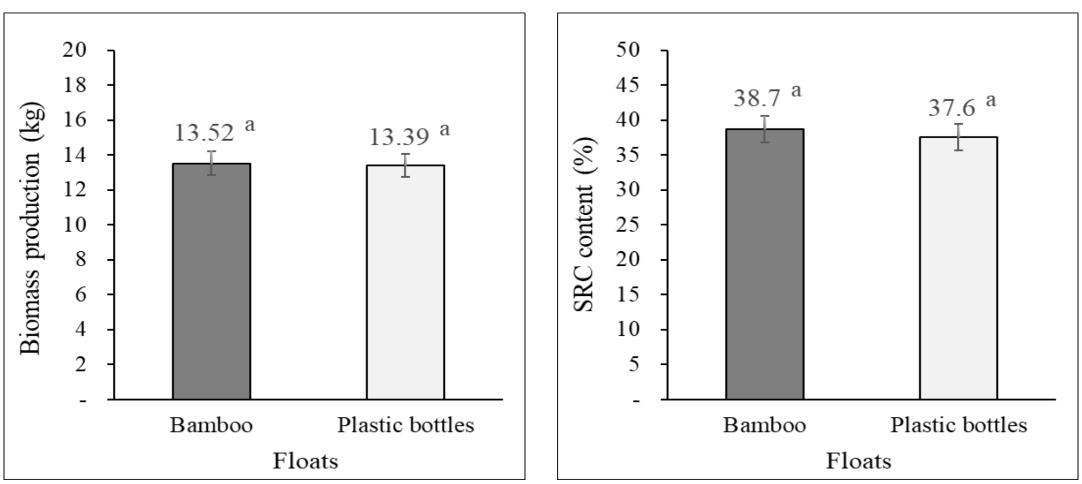

Fig. 4. The average biomass production and content of semi-refined carrageenan (SRC) of *K. alvarezii*. The same superscript letter indicates no significant difference between float types (*P*> 0.05)

DISCUSSION

Growth performance

Seaweed aquaculture in Indonesia presents a paradox. On one hand, seaweed provides ecosystem services **(Cotas *et al*., 2023; Ross *et al*., 2023)**. Moreover, it has the potential for bioplastic production **(Chia *et al*., 2020)**. On the other hand, aquaculture practices contribute to marine debris. The utilization of plastic bottles in seaweed aquaculture in Indonesia, as discussed in the introduction, supports **Skirtun *et al*. (2022)** assertion that mariculture practices contribute to plastic pollution. This study compares bamboo floats with plastic bottles for the vertical cultivation of *K. alvarezii*, based on biomass production and SRC content.

In this study on vertical seaweed cultivation, the biomass production of *K. alvarezii* in bamboo floats and plastic bottles ranged from 13.32 to 13.68kg (average 13.52kg) and 13.25 to 13.56kg (average 13.39kg), respectively (Fig. 4). These results are challenging to compare objectively with previous studies due to differences in system designs. Many factors, such as stocking density, seed quality, environmental conditions, and cultivation methods, can influence biomass production **(Kambey *et al*., 2020; Simatupang *et al*., 2021)**. However, **Nursidi *et al*. (2017)** and **Heriansah *et al*. (2022)** reported that the vertical method can increase productivity because more seaweed are produced on the same land.

The results of the SRC content of *K. alvarezii* in bamboo floats and plastic bottles ranged from 37.1 to 39.9% (average 38.7%) and 36.5 to 38.3% (average 37.6%), respectively (Fig. 4). These results are higher than the findings of **Pong-Masak and Sarira (2020)**, who obtained an SRC content of between 27.6 to 34.0% using the same cultivation and extraction method for carrageenan. However, the results in this study were lower compared to the findings of **Nursidi *et al*. (2017)**, who obtained an SRC content of between 56.3 to 57.7%, also with a relatively similar research design, such as cultivation methods and length of cultivation, including carrageenan extraction. Yield variations may be caused by cultivation environmental factors and seed quality **(Simatupang *et al*., 2021; Rupert *et al*., 2022)**.

Indonesia boasts a mariculture land area of approximately 12.1 million hectares, of which only 1.1 million hectares (9%) are allocated for seaweed cultivation **(Waters *et al.*, 2019)**. Based on calculations from the study by **Nurdin *et al.* (2020)**, we can estimate that the number of plastic bottle floats used on this land could reach 5.5 billion, assuming only 50% of the area utilizes plastic bottle floats. If it is further assumed that only 10% of these floats are damaged, it implies that 550 million plastic bottles are discarded each year, exacerbating the growing plastic waste problem. While these calculations are contingent on assumptions and uncertainties, the practice of farmers discarding used plastic bottle floats into the sea raises significant concerns.

Plastic bottles, in the form of macro, micro, and nanoplastics, have detrimental effects on marine ecosystems and aquatic animals, as underscored by environmental activists **(Gopal *et al*., 2022)**. For instance, they can diminish light penetration and create artificial habitats conducive to the spread of non-native (invasive) species **(Abalansa *et al*., 2020)**. Microplastics or nanoplastics can be inadvertently ingested by various sea organisms during respiration or mistaken recognition as food, leading to disruptions in metabolic processes **(Wu *et al*., 2022)**. Furthermore, microplastics can induce behavioral abnormalities, histological changes, and deoxyribonucleic acid (DNA) damage in organisms **(Wang *et al*., 2019; Parker *et al*., 2021)**. The adverse effects of marine debris can detrimentally impact food production and marine health.

This study, although limited to one maintenance cycle with a simple design, it reveals a positive indication of bamboo's potential as a float, with production performance meeting expectations. These results are pertinent as bamboo has long been utilized as a flotation material in aquaculture due to its affordability, accessibility, and minimal environmental impact **(Wahab *et al*., 2009)**. The floating raft method constructed from bamboo has been successfully employed for pilot-scale and commercial-scale cultivation of various seaweed species in different countries **(Kasim *et al*., 2020; Behera *et al*., 2022; Sobuj *et al*., 2023)**.

Research findings suggest that utilizing bamboo as a float does not adversely affect *K. alvarezii*. In fact, this material yields comparable biomass production and SRC content to that of plastic bottles. The low cost and widespread availability of bamboo in Indonesia further enhance its potential for use as a float in seaweed cultivation. Additionally, bamboo's resistance to marine environmental stress makes it a suitable material for deployment in the sea **(Mulyadi *et al*., 2018)**.

CONCLUSION

Bamboo floats offer a simple and cost-effective method for floating seaweed ropes, akin to the use of plastic bottles. However, bamboo is environmentally friendly and supports the development of sustainable seaweed cultivation. This study suggests that bamboo can serve as a substitute for plastic floats, potentially mitigating the current contribution of seaweed cultivation to marine waste. Further investigation into the technical, economic, and ecological implications of bamboo floats is necessary to build upon these promising results.

ACKNOWLEDGMENTS

The author expresses gratitude to the seaweed farmers in Manyampa Village, Ujung Loe District, Bulukumba Regency, South Sulawesi, Indonesia, for their invaluable assistance throughout the study. Additionally, the author extends appreciation to the editors and reviewers of the Egyptian Journal of Aquatic Biology & Fisheries for their dedicated editorial services.

REFERENCES

Abalansa, S.; Mahrad, B.El; Vondolia, G.K., Icely, J. and **Newton, A. (2020)**. The Marine Plastic Litter Sssue : A Social-Economic Analysis. Sustainability, **12**(8667). https://doi.org/DOI:10.3390/su12208677

Archila, H.; Kaminski, S.; Trujillo, D.; Zea E.E. and **Harries, K.A**. **(2018)**. Bamboo Reinforced Concrete: A Critical Review. Materials And Structures/Materiaux et Constructions, **51**(4), 1–18. https://doi.org/10.1617/s11527-018-1228-6

Aris, M. and **Labenua, R. (2020)**. Evaluation of Land Suitability of *Kappaphycus alvarezii* Cultivation in the Dry And Rainy Season. IOP Conference Series: Earth and Environmental Science, **584**(1). https://doi.org/10.1088/1755-1315/584/1/012025

Behera, D.P.; Vadodariya, V.; Veeragurunathan, V.; Sigamani, S.; Moovendhan, M.; Srinivasan, R.; Kolandhasamy, P. and **Ingle, K.N. (2022)**. Seaweeds Cultivation Methods and their Role in Climate Mitigation and Environmental Cleanup. Total Environment Research Themes, **3–4**(July), 100016. https://doi.org/10.1016/j.totert.2022.100016

Chia, W.Y.; Ying T.D.Y.; Khoo, K.S.; Kay L.A.N. and **Chew, K.W. (2020)**. Nature's Fight Against Plastic Pollution: Algae for Plastic Biodegradation and Bioplastics Production. Environmental Science and Ecotechnology, **4**, 100065. https://doi.org/10.1016/j.ese.2020.100065

Cotas, J.; Gomes, L.; Pacheco, D. and **Pereira, L. (2023)**. Ecosystem Services Provided by Seaweeds. Hydrobiology, **2**, 75–96. https://doi.org/10.3390/hydrobiology2010006

Ervianti, D.; Widjaja, E A. and **Sedayu, A. (2019)**. Bamboo Diversity of Sulawesi, Indonesia. Biodiversitas, **20**(1), 91–109. https://doi.org/10.13057/biodiv/d200112

Gopal, J.; Sivanesan, I.; Muthu, M. and **Oh, J.W. (2022)**. Overviewing the Ground Reality of Microplastic Effects on Seafoods, Including Fish, Shrimps and Crabs: Future Research Directions. Foods, **11**(24). https://doi.org/10.3390/foods11243976

Hao, A.; Su, M.; Kobayashi, S.; Zhao, M. and **Iseri, Y. (2022)**. Multiple Roles of bamboo as a Regulator of Cyanobacterial Bloom in Aquatic Systems. Scientific Reports, 1–12. https://doi.org/10.1038/s41598-022-05506-2

Heriansah; Syamsuddin, R.; Najamuddin and **Syafiuddin. (2022)**. Growth of *Kappaphcus alvarezii* in Vertical Method of Multi-trophic System Based on Feeding

Rate. Egyptian Journal of Aquatic Biology and Fisheries, **26**(5), 1197–1210. https://doi.org/10.21608/ejabf.2022.267643

Hessami, M.J.; Salleh, A. and **Phang, S.M. (2020)**. Bioethanol a by-Product of Agar and Carrageenan Production Industry from the Tropical Red Seaweeds, *Gracilaria manilaensis* and *Kappaphycus alvarezii*. Iranian Journal of Fisheries Sciences, **19**(2), 942–960. https://doi.org/10.22092/ijfs.2018.117104

Kambey, C.S.B.; Sondak, C.F.A. and **Chung, I.K. (2020)**. Potential Growth and Nutrient Removal of *Kappaphycus alvarezii* in A Fish Floating-Net Cage System in Sekotong Bay, Lombok, Indonesia. Journal of the World Aquaculture Society, **51**(4), 944–959. https://doi.org/10.1111/jwas.12683

Kasim, M.; Balubi, A.M.; Mustafa, A.; Nurdin, R.; Patadjai, R.S. and **Jalil, W. (2020)**. Floating Cage : A New Innovation of Seaweed Culture. In Emerging Technologies, Environment and Research for Sustainable Aquaculture (pp. 1–16). IntechOpen. https://doi.org/http://dx.doi.org/10.5772/intechopen.90035

Lomartire, S. and **Goncalves, A.M.M. (2023)**. Algal Phycocolloids : Bioactivities and Pharmaceutical Applications. Marine Drugs, **21**(384), 1–30. https://doi.org/10.3390/md21070384

Mulyadi, Y.; Sambodho, K.; Syahroni, N.; Zikra, M. and **Herdianti, W.A. (2018)**. Development of Eco-Friendly Aquaculture Design for Lobster Cultivation in Indonesia. Journal of Aquaculture Research & Development, **09**(03). https://doi.org/10.4172/2155-9546.1000527

Nurdin, N.; Alevizos, E.; Syamsuddin, R.; Asis, H.; Zainuddin, E.N.; Aris, A;, Oiry, S.; Brunier, G.; Komatsu, T. and **Barill, L. (2023)**. Precision Aquaculture Drone Mapping of the Spatial Distribution of *Kappaphycus alvarezii* biomass. Remote Sensing, **15**(3674), 1–21. https://doi.org/10.3390/rs15143674

Nurdin, N.; Setiawan, R.Y.; Helmi, M.; Maslukah, L.; Agus, A.; Akbar, M.A., Anas, A.; Nurfitrah, M. and **Komatsu, T. (2020)**. Spatial Water Quality and Plastic Buoy of Seaweed Culture in Coastal Area, Indonesia. Proc. SPIE 11525, SPIE Future Sensing Technologies, **1152515**(November), 1–13. https://doi.org/10.1117/12.2576385

Nurhati, I.S. and **Cordova, M.R. (2020)**. Marine Plastic Debris in Indonesia: Baseline Estimates (2010-2019) and Monitoring Strategies (2021-2025). Marine Research Indonesia, **45**(2), 97–102. https://doi.org/10.14203/mri.v45i2.581

Nursidi, Mauli and **Heriansah. (2017)**. Development of seaweed *Kappaphycus alvarezii* Cultivation through Vertical Method in the Water of Small Islands in South Sulawesi, Indonesia. AACL Bioflux, **10**(6), 1428–1435.

Oliyaei, N.; Moosavi-Nasab, M. and **Mazloomi, S.M. (2022)**. Therapeutic activity of

Fucoidan and Carrageenan as Marine Algal Polysaccharides Against Viruses. 3 Biotech, **12**(7), 1–15. https://doi.org/10.1007/s13205-022-03210-6

Parker, B.; Andreou, D.; Green, I.D. and **Britton, J.R. (2021)**. Microplastics in Freshwater Fishes: Occurrence, Impacts and Future Perspectives. Fish and Fisheries, **22**, 467–488. https://doi.org/10.1111/faf.12528

Pong-Masak, P.R. and. **Sarira, N.H. (2020)**. Effect of Depth on the Growth and Carrageenan Content of Seaweed *Kappaphycus alvarezii* Cultivated Using Verticulture Method. E3S Web of Conferences, **147**. https://doi.org/10.1051/e3sconf/202014701011

Rimmer, M.A.; Larson, S.; Lapong, I.; Purnomo, A.H.; Pong-masak, P.R., Swanepoel, L. and **Paul, N.A. (2021)**. Seaweed Aquaculture in Indonesia Contributes to Social and Economic Aspects of Livelihoods and Community Wellbeing. Sustainability (Switzerland), **13**(19), 1–22. https://doi.org/10.3390/su131910946

Ross, F.W.R.; Boyd, P.W.; Filbee-Dexter, K.; Watanabe, K.; Ortega, A.; Krause-Jensen, D.; Lovelock, C.; Sondak, C.F.A.; Bach, L.T.; Duarte, C.M.; Serrano, O.; Beardall, J.; Tarbuck, P. and **Macreadie, P.I. (2023)**. Potential Role of Seaweeds in Climate Change Mitigation. Science of the Total Environment, **885**(December 2022), 163699. https://doi.org/10.1016/j.scitotenv.2023.163699

Rupert, R.; Rodrigues, K.F.; Thien, V.Y. and **Yong, W.T.L. (2022)**. Carrageenan from *Kappaphycus alvarezii* (Rhodophyta, Solieriaceae): Metabolism, Structure, Production, and Application. Frontiers in Plant Science, **13**(May), 1–16. https://doi.org/10.3389/fpls.2022.859635

Simatupang, N.F.; Pong-Masak, P.R.; Ratnawati, P.; Agusman; Paul, N.A. and **Rimmer, M.A. (2021)**. Growth and Product Quality of the Seaweed *Kappaphycus alvarezii* from Different Farming Locations in Indonesia. Aquaculture Reports, **20**(April), 100685. https://doi.org/10.1016/j.aqrep.2021.100685

Skirtun, M.; Sandra, M.; Strietman, W.J.; van den Burg, S.W.K.; De Raedemaecker, F. and **Devriese, L.I. (2022)**. Plastic Pollution Pathways from Marine Aquaculture Practices and Potential Solutions for the North-East Atlantic Region. Marine Pollution Bulletin, **174**, 113178. https://doi.org/10.1016/j.marpolbul.2021.113178

Sobuj, M.K.A.; Mostofa, G.; Islam, Z.; Rabby, A.F.; Rahman, T.; Sonia, S.S.; Hasan, S.J. and **Rahman, S. (2023)**. Floating Raft Culture of *Gracilariopsis longissima* for Optimum Biomass Yield Performance on the coast of Cox’s Bazar, Bangladesh. Scientific Reports, **13**(2308), 1–10. https://doi.org/10.1038/s41598-023-28675-0

Uju; Prasetyaningsih, E.; Santoso, J.; Kamiya, N. and **Oshima, T. (2019)**. Preparation and Characterization of Semi-Refined Carrageenan from *Kappaphycus alvarezii* Seaweed Bleached by Peracetic Acid. IOP Conference Series: Earth and Environmental Science, **278**(1). https://doi.org/10.1088/1755-1315/278/1/012077

Wahab, R.; Sulaiman, O.; Mohamad, A.; Samsi, H. and**& Khalid, I. (2008)**. Bamboo as An Eco-friendly Material for Use in Aquaculture Industry in Malaysia. Journal of Sustainable Development, **1**(2), 49–54. https://doi.org/10.5539/jsd.v1n2p49

Waldron, S.; Langford, Z.; Pasaribu, S.H. and **Nuryartono, N. (2024)**. The Indonesian Seaweed Industry. In Globalisation and Livelihood Transformations in the Indonesian Seaweed Industry (Issue December 2023, pp. 52–76). https://doi.org/10.4324/9781003183860-4

Wang, W.; Ge, J. and **Yu, X. (2019)**. Ecotoxicology and Environmental Safety Bioavailability and Toxicity of Microplastics to Fish Species : A Review. Ecotoxicology and Environmental Safety, March, **109913**. https://doi.org/10.1016/j.ecoenv.2019.109913

Waters, T.; Jones, R.; Theuerkauf, S.; Lionata, H.; Prasetyo, T.; Subhan, W.; Muhammad, U.; Amin, I. and **Muhammad, I. (2019)**. Coastal Conservation and Sustainable Livelihoods through Seaweed Aquaculture in Indonesia: A Guide for Buyers, Conservation Practitioners, and Farmers. In The Nature Conservancy. Arlington VA, USA and Jakarta, Indonesia. (Issue V1).

Wu, C.; Xiong, X.; Hossein, A.; Zhang, Y. and **Xu, X. (2022)**. A review on Source , Occurrence, and Impacts of Microplastics in Freshwater Aquaculture Systems in China. Water Biology and Security, **1**(3), 100040. https://doi.org/10.1016/j.watbs.2022.100040

Zhang, J.; Waldron, S.; Langford, Z.; Julianto, B. and **Martin, A. (2023)**. China's Growing Influence in the Global Carrageenan Industry and Implications for Indonesia. Journal of Applied Phycology, **0123456789**. https://doi.org/10.1007/s10811-023-03004-0