JURNAL BIOSENSE
Jurnal Penelitian Biologi dan Terapannya
Volume 9 No. 4, Oktober 2026, Hal 1027 - 1032 E-ISSN: 2622 - 6286

POTENTIAL OF COMBINING SEAWEED EXTRACT AND FUNGAL MYCELIUM IN ECO-FRIENDLY BIOPLASTICS: A NARRATIVE REVIEW

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Abstract
Petroleum based plastic waste causes serious ecological damage, particularly in marine environments, thereby increasing interest in biodegradable alternatives. Seaweed polysaccharides and fungal mycelium are renewable raw materials, each of which has limitations in terms of film-forming properties. This narrative review summarizes the characteristics of seaweed-based and mycelium-based bioplastics, compares their reported mechanical and biodegradation properties, and evaluates the prospects for combining them into a single biocomposite. A literature search was conducted on ScienceDirect, PubMed, Google Scholar, and ResearchGate, and 47 publications (20 core studies, including one preprint, and 27 supporting publications) were selected for thematic synthesis. Reported tensile strengths ranged from 0.54 to 45.07 MPa for seaweed films and from 0.7 to 12.3 MPa for mycelium-based materials (24.21 MPa for one engineered material), while seaweed films modified with chitosan reached 25 MPa. Biodegradation results were obtained under different testing conditions and cannot be directly compared. No studies have yet reported on seaweed bioplastic films combined with mycelium; however, compositions such as mycelium with alginate and seaweed with chitosan suggest that these two polysaccharide-rich materials may be compatible. Standardized testing, formulation studies, and life-cycle assessments are needed to validate this concept.
Keywords: *bioplastics, seaweed, fungal mycelium, biodegradation, biocomposites*

1. INTRODUCTION

Plastic waste derived from petroleum poses a serious threat to global ecosystems, particularly in marine environments. Global plastic production has reached billions of metric tons, and most of this waste accumulates in landfills or in the environment (Geyer et al., 2017), while millions of metric tons enter the ocean from land each year (Jambeck et al., 2015). Conventional plastics also contribute to greenhouse gas emissions and perpetuate dependence on fossil resources (Zheng & Suh, 2019), and the amount of plastic in the oceans could exceed the number of fish by 2050 if current trends continue (Khan et al., 2024). Therefore, bioplastics materials derived from

biological resources that can degrade naturally are considered a promising option for achieving a circular and low carbon economy (Karan et al., 2019; Kumar et al., 2024). However, their biodegradability does not occur automatically, it is highly dependent on the receiving environment, as degradation in both seawater and freshwater is not guaranteed and can proceed slowly (Bagheri et al., 2017; Haider et al., 2019; Narancic et al., 2018). Therefore, their benefits depend on the choice of raw materials and end-of-life management, as well as on the properties of the materials (Rosenboom et al., 2022).

Seaweed is a rapidly growing renewable biomass resource that does not require fertile land, fresh water, or fertilizer, and absorbs CO_2 through photosynthesis, which can help mitigate the impacts of climate change (Ayala et al., 2024; Duarte et al., 2017). Indonesia is the world's second-largest producer of seaweed, with production of approximately 9.66 million metric tons in 2019, and seaweed-based biodegradable plastics have become one of the country's national development initiatives (Basyuni et al., 2024). Hydrocolloids primarily alginate, agar, and carrageenan are biodegradable polysaccharides with good film-forming properties (Jayakody et al., 2022; Santana et al., 2024). Alginate forms a gel with divalent cations such as calcium (Lee & Mooney, 2012), while carrageenan is a sulfated galactan (Campo et al., 2009).

Fungal mycelium the filamentous vegetative body of fungi grows rapidly on organic substrates and produces lightweight, flexible, and biodegradable materials at low cost, making it an attractive candidate for environmentally friendly bioplastics (Shao et al., 2024). A review of mycelium composites describes their growth on lignocellulosic substrates as well as their applications in design, architecture, and construction (Attias et al., 2020; Girometta et al., 2019; Jones et al., 2020), and fungus-based materials have also been studied in the patent literature (Cerimi et al., 2019).

However, every material has its limitations. Seaweed-based bioplastics are

generally brittle when dry (Hanry & Surugau, 2023), and calcium cross linking of alginate has been used to enhance strength and reduce water solubility (Ridlo et al., 2022). Unmodified mycelium films exhibit low tensile strength and an uneven texture (Shao et al., 2024), although they are hydrophobic, with a water contact angle above 120° (Haneef et al., 2017). These contrasting profiles have prompted the combination of the two in a single formulation.

To date, only a few studies have explicitly explored seaweed-derived polymers and mycelium in a single bioplastic formulation. The closest examples are an alginate-mycelium paste developed for additive manufacturing (Chen et al., 2021) and an alginate-chitosan film combining seaweed-derived polysaccharides and filamentous fungi (Gomaa et al., 2018). Therefore, data on optimal formulations and life cycle assessments (LCA) are still unavailable (Bordeos et al., 2024).

This narrative review aims to (1) summarize research on bioplastics derived from seaweed; (2) review bioplastics based on fungal mycelium; (3) compare reported mechanical properties and biodegradability, taking data consistency into account; and (4) discuss the prospects, hypothesized mechanisms, and research needs for combining seaweed extracts and mycelium.

2. METHODS

2.1 Literature Search and Selection

This study is a narrative review that presents a thematic and critical synthesis of representative studies; it is not a comprehensive systematic review. The literature search was conducted on ScienceDirect, PubMed, Google Scholar, and ResearchGate, beginning in July 2025 and supplemented with targeted searches using keywords that combined seaweed extracts (including *Eucheuma cottonii, Kappaphycus sp., and Sargassum sp.*), fungal mycelium (including *Ganoderma lucidum* and *Pleurotus ostreatus*), and bioplastics. Publications from 2015 to 2026 were considered. Papers were included if they discussed bioplastic or biopolymer materials relevant to seaweed, fungal mycelium, or chitosan, whether as original studies or reviews; others

were excluded. In total, 47 publications were included: 20 core studies, which form the basis for the synthesis of materials and properties, and 27 supporting publications that provide background, mechanisms, and standards.

Twelve of the core studies reported tensile strength data, which are summarized in Tables 1–3. The supporting publications covered plastic pollution, polysaccharide chemistry, fungal cell walls, biodegradation, and related systems (Chen et al., 2021; Zaghbib et al., 2024) and were not used for numerical comparisons.

2.2 Data extraction and synthesis

For each study, the material, extraction or cultivation method, additives, tensile strength, elongation, thickness and biodegradation result were extracted as reported, compiled in tables and synthesized thematically, without formal quality appraisal. Values were not pooled or statistically compared because formulation, sample form and test method differ, and the non exhaustive search means that the findings may be affected by selection bias.

3. RESULTS AND DISCUSSION

3.1 Bioplastics from seaweed extract

Seaweed extract is a biopolymer fraction consisting mainly of polysaccharides such as alginate, carrageenan and agar. Extraction generally involves washing, drying, softening with acid or base, heating and separation of the solution (Santana et al., 2024); for example, semi-refined carrageenan from *Gracilaria sp*. was obtained by pressurized hot water extraction (PHWE) (Khan et al., 2024), and alginate from the residual biomass of cultivated brown seaweed (Ayala et al., 2024).

Several studies illustrate the potential of different seaweeds for bioplastic production (Table 1). *Ulva reticulata* films were prepared by solvent casting with glycerol, gelatin and polyvinyl alcohol (PVA) (Bordeos et al., 2024). In *Kappaphycus alvarezii*, tensile strength fell as glycerol content and water ratio increased, reaching

7.2 MPa at 1% glycerol and a 1:50 biomass to water ratio (Hanry & Surugau, 2023), although this preprint should be interpreted with caution. In *Sargassum sp.*, carboxymethyl cellulose (CMC) improved flexibility and CaCl2 crosslinked the alginate chains, enhancing strength and reducing water solubility (Ridlo et al., 2022). *Gracilaria sp.* plasticized with polyethylene glycol (PEG) 1540 reached up to 20.17 MPa and 44% elongation, with over 90% biodegradation in 16 days (Khan et al., 2024). Without plasticizer, sodium alginate alone reached 45.07 MPa, and the alginate–κ-carrageenan blend selected as optimal 22.97 MPa (Putri et al., 2025).

Table 1. Characteristics of bioplastics from various seaweed species

Seaweed	Extraction method	Plasticizer / additives	Tensile strength (MPa)	Thickness (mm)	Biodegradability	Reference
Ulva reticulata	Natural extract	Glycerol (with gelatin and PVA)	0.54	0.30	82.05% in 21 days	Bordeos et al. (2024)
Kappaphycus alvarezii	Whole seaweed	Glycerol (1%)	7.2	0.071	Complete in 14 days	Hanry & Surugau (2023) †
Sargassum sp.	Alginate	Glycerol (with $CaCl_2$ and CMC)	11.61	0.16	57.54% in 6 days	Ridlo et al. (2022)
Gracilaria sp.	Pressurized hot water extraction (PHWE)	PEG 1540	20.17	0.10–0.13	>90% in 16 days	Khan et al. (2024)
Alginate + κ-carrageenan (optimal blend)	Commercial sodium alginate and κ-carrageenan	None	22.97	0.138	16.6% (1 week, soil)	Putri et al. (2025)
Alginate only	Commercial sodium alginate	None	45.07	0.057	15.5% (1 week, soil)	Putri et al. (2025)

PVA, polyvinyl alcohol; CMC, carboxymethyl cellulose; PEG, polyethylene glycol; n.r., not reported. †Preprint (not peer reviewed).

There are two interesting findings from these studies. First, the tensile strength spans nearly two orders of magnitude (0.54–45.07 MPa); however, the extraction methods, plasticizers, film thicknesses (0.057–0.30 mm), and testing protocols varied, so these differences cannot be attributed solely to the seaweed species. Second, plasticizers were added to address the brittleness of the biopolymers (Vieira et al., 2021) , and their effect depends on the type and amount: the strongest *K. alvarezii*

film used only 1% glycerol (Hanry & Surugau, 2023), and in Schizophyllum commune mycelium films, 1–4% glycerol increased tensile strength, whereas 32% actually reduced it and increased the elongation at break (Appels et al., 2020). Blending alginate with kappa-carrageenan (Putri et al., 2025) and reinforcing carrageenan with nanocellulose (Adam et al., 2022) are other strategies for tailoring the properties of seaweed based bioplastics.

3.2 Fungal Mycelium-Based Bioplastics

Mycelium biocomposites are based on fungal hyphal networks grown on organic substrates and can be molded and dried into solid materials or bioplastic films (Shao et al., 2024). Hyphal walls are layered nanocomposites in which crystalline chitin fibers form a structural framework embedded in a matrix of glucans and cell wall proteins (Fredricks et al., 2023; Gow et al., 2017). The composition is not fixed: Ganoderma lucidum and Pleurotus ostreatus films grown on cellulose contained more chitin and showed a higher Young's modulus and lower elongation than films grown on dextrose-containing substrates, and all films were hydrophobic (water contact angle above 120°) (Haneef et al., 2017). Substrate and fabrication conditions likewise influence the mechanical and moisture-related properties of mycelium composites (Appels et al., 2019; Elsacker et al., 2019).

Mycelium of *G. lucidum*, *P. ostreatus* and *Auricularia polytricha* can be processed into films or composites (Table 2). Adding glycerol to G. lucidum films increased tensile strength by 207% and elongation by 84.83% relative to films without glycerol (1.14 MPa and 19.05%) (Shao et al., 2024); in S. commune films post-treated with glycerol, 2% raised tensile strength from 5.0 to 12.3 MPa, whereas 32% lowered it to 1.8 MPa and raised strain at failure from 1.5% to 29.6% (Appels et al., 2020). Tween-20 added to liquid cultures of *G. lucidum*, together with a glycerol-based plasticizer, gave a tensile strength of 24.21 MPa (Cui et al., 2026). Hot pressing has been used for oyster mushroom composites (Kohphaisansombat et al., 2023), and films grown on cellulose-based substrates showed a stress at break of 0.7–1.1 MPa

and elongation of 4–33% (Haneef et al., 2017).

Two caveats apply to Table 2: the *P. ostreatus* value comes from a substrate-grown composite rather than a pure mycelium film, and the *G. lucidum* value of Shao et al. (2024) is the baseline before glycerol addition. Most mycelium materials in Table 2 show low to moderate tensile strength (0.7–12.3 MPa) and elongation of 1.5–33%, and plasticizers, reinforcement or culture engineering can change these properties substantially, as in the Tween-20-engineered *G. lucidum* material (24.21 MPa) (Appels et al., 2020; Cui et al., 2026; Kohphaisansombat et al., 2023; Shao et al., 2024; Vandelook et al., 2021).

Table 2. Characteristics of fungal mycelium bioplastics

Fungus	Cultivation / processing	Tensile strength (MPa)	Elongation (%)	Biodegradation	Application	Reference
Ganoderma lucidum	PDB culture + hot pressing	1.14[a]	19.05	<4 weeks	Packaging	Shao et al. (2024)
Pleurotus ostreatus	Spent coffee grounds (SCG) composite[b]	1.21	11	>80% in 30 days	Composite	Kohphaisansombat et al. (2023)
Auricularia polytricha	PDB culture + hot pressing	0.75	15	Fast (28 days)	Flexible film	Shao et al. (2024)
G. lucidum	Liquid culture + Tween-20, glycerol-based plasticizer	24.21	n.r.	Biodegradable (reported)	Packaging, consumer goods	Cui et al. (2026)
S. commune film	Shaken liquid culture; post-treatment with 0–32% glycerol	1.8–12.3[c]	1.5–29.6[c]	n.r.	Material classification	Appels et al. (2020)
G. lucidum, P. ostreatus	Cellulose or cellulose–PDB substrate, 20-day films	0.7–1.1	4–33	n.r.	Fibrous films	Haneef et al. (2017)

PDB, potato dextrose broth. [a]Baseline value before glycerol addition. [b]Composite grown on spent coffee grounds with pineapple fibre reinforcement, not a pure mycelium film. [c]Untreated films: 5.0 MPa, 1.5%; 2% glycerol: 12.3 MPa (maximum); 32% glycerol: 1.8 MPa, 29.6%. n.r., not reported.

3.3 Seaweed with chitosan films as an analogue

Combining seaweed extract with chitosan has been widely studied to improve the properties of natural polymer films. Chitosan has antimicrobial activity and biocompatibility and is commonly used as an additive in polymer matrices (Elsabee

& Abdou, 2013; Sinaga et al., 2021). Because it is derived from chitin, the structural polymer of fungal hyphae, seaweed with chitosan films offer an indirect model of how a chitin-related polysaccharide interacts with seaweed polysaccharides, although chitin in mycelium is embedded in a glucanprotein cell-wall matrix. Chitin glucan nanofibers isolated from mushroom tissue have been processed into nanopapers with tensile strength above 200 MPa (Fazli Wan Nawawi et al., 2019), and mycelium has been proposed as a source of chitin and chitosan (Yang et al., 2021)

Marsa et al. (2023) combined *K. alvarezii* carrageenan with carboxymethyl chitosan (CMK) and glycerol; higher CMK content increased tensile strength, attributed to hydrogen bonding, and the best film degraded within 373 minutes in an effective microorganism (EM) solution (Table 3). Sinaga et al. (2021) added chitosan and glycerol to *Gracilaria sp.* films; 3% chitosan gave the highest tensile strength compiled here (25 MPa), better elongation and homogeneity, and antibacterial activity against Escherichia coli and Staphylococcus aureus. Chitosan thus improved strength and antibacterial properties, but concentrations above the optimum can reduce flexibility. Adding *Ulva lactuca* powder (0.5–2.5%) to chitosan films likewise increased tensile strength and elongation, and the films decomposed within 12 days in soil (Zaghbib et al., 2024).

Table 3. Tensile strength and degradation of seaweed–chitosan bioplastics

Main composition	Tensile strength (MPa)	Degradation / thermal test	Result	Reference
Carrageenan (3 g), glycerol (1.7 mL), carboxymethyl chitosan (5 g)	1.61	Biodegradation in effective microorganism (EM) solution	Degraded in 373 min	Marsa et al. (2023)
Gracilaria sp. (2.5 g), glycerol (0.2%), chitosan (3%)	25	Thermogravimetric analysis (TGA)	Stage 1 (35–105 °C): 8–15% mass loss; stage 2 (175–340 °C): 47–55% mass loss	Sinaga et al. (2021)

Film thickness of the carrageenan–CMK formulation: 0.82 mm.

3.4 Comparison of Mechanical Properties and Biodegradation

Figure 1 shows a comparison of the tensile strength values listed in Tables 1–3. Among the seaweed films, pure alginate (45.07 MPa; Putri et al. (2025)) is the

JURNAL BIOSENSE
Jurnal Penelitian Biologi dan Terapannya
Volume 9 No. 4, Oktober 2026, Hal 1027 - 1032 E-ISSN: 2622 - 6286

strongest, followed by the *Gracilaria* film with chitosan (25 MPa), the alginate-κ-carrageenan blend (22.97 MPa), and *Gracilaria sp.* with PEG 1540 (20.17 MPa). Most mycelium-based materials have tensile strengths ranging from 0.7 to 12.3 MPa, and one modified *G. lucidum* material reached 24.21 MPa (Cui et al., 2026). Mycelium strength is highly dependent on the species, strain, and processing method.

Because formulations, thicknesses, and testing conditions vary, Figure 1 provides a general descriptive overview rather than a ranking; ASTM D882 does not specify a minimum tensile strength value, so strength claims require benchmarks specific to a given application.

The biodegradation results in Tables 1–3 cannot be ranked due to differences in media, sample forms, and endpoints (seaweed films, 6–21 days; mycelium-based materials, 28–30 days; carrageenan film with CMK, 373 minutes in EM solution), making testing under identical conditions necessary (Bagheri et al., 2017; Narancic et al., 2018).

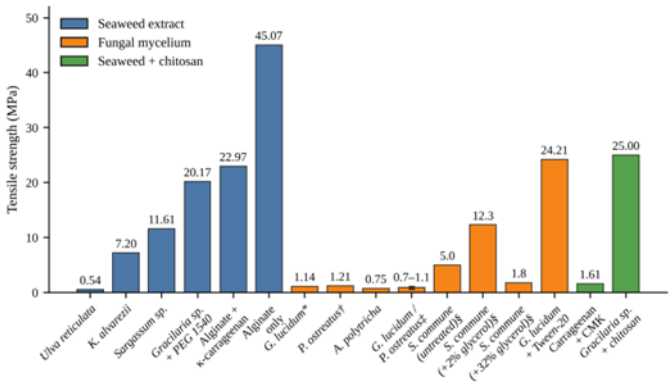


Figure 1. Tensile strength of bioplastics from seaweed extract, fungal mycelium and seaweed with chitosan combinations, as reported in the original studies (Tables 1–3). Values come from different formulations, thicknesses and test conditions and are not directly comparable. *Baseline value before glycerol addition; †value for a substrate grown composite, not a pure mycelium film; ‡midpoint of the reported 0.7–1.1 MPa range (bar marks the range); §untreated and post-treated with 2% or 32% glycerol. CMK, carboxymethyl chitosan; PEG, polyethylene glycol.

3.5 Prospects for combining seaweed extract and mycelium

The reviewed studies suggest that seaweed polysaccharides and mycelium have complementary profiles (Table 4): seaweed extracts provide film-forming

polysaccharides that can reach high tensile strength when plasticized or crosslinked but are brittle and water-sensitive, whereas mycelium provides a hydrophobic, chitin-rich fibrous network but forms weak, heterogeneous films on its own.

No study identified in this review has reported a bioplastic film that combines seaweed extract and mycelium; indirect evidence comes from related systems. Chen et al. (2021) prepared extrudable pastes from inactive Fomes fomentarius mycelium and alginate; Ca2+ crosslinking and freeze-drying gave porous objects stable in water, whereas uncrosslinked ones fell apart overnight. The products were foams rather than films, and tensile properties were not reported. Alginate with chitosan films combining seaweed and fungus derived polysaccharides (Gomaa et al., 2018) and the seaweed–chitosan films in Section 3.3 point the same way.

Table 4. Complementary characteristics of seaweed extract and fungal mycelium and the hypothesized benefits of combining them

Characteristic	Seaweed extract	Fungal mycelium	Hypothesized benefit of the combination
Film formation	Good film-forming polysaccharides (alginate, carrageenan, agar)	Films from unmodified mycelium are heterogeneous	A polysaccharide matrix may improve film homogeneity
Tensile strength	0.54–45.07 MPa, depending on species and formulation	0.7–12.3 MPa (24.21 MPa in one engineered material)	The hyphal network may reinforce the polysaccharide matrix
Flexibility	Brittle under dry conditions unless plasticized	Elongation 1.5–33%; glycerol effect depends on the system	Better balance between strength and flexibility
Water behavior	Hydrophilic; Ca^{2+} crosslinking reduces solubility	Hydrophobic (contact angle >120°); low water uptake	Reduced water sensitivity of the composite
Biodegradation	Substantial degradation within 6–21 days (various tests)	Degradation within 28–30 days (various tests)	To be determined under identical test conditions

Compiled from Tables 1–3 and the studies cited in Sections 3.1–3.5. The right-hand column is hypothetical and has not been tested experimentally.

Based on these studies, several mechanisms can be hypothesized. (i) The hyphal network, with chitin fibers in the glucan matrix, may act as a fibrous reinforcement within the seaweed polysaccharide matrix. (ii) The hydroxyl and acetamido groups of chitin and glucan may form hydrogen bonds with alginate, carrageenan, or agar, as described in seaweed films reinforced by carboxymethyl chitosan (Marsa et al.,

2023). (iii) Calcium cross-linking in alginate (Lee & Mooney, 2012), which reduces water solubility in seaweed films (Ridlo et al., 2022) and stabilizes mycelium with alginate assemblies (Chen et al., 2021), may also stabilize the composite. (iv) The hydrophobic nature of the mycelium (Haneef et al., 2017) may reduce sensitivity to water. These mechanisms have not yet been tested in films (see also Sarkar et al. (2024)).

Marine resources and agricultural waste can serve as raw materials and mycelium substrates, thereby supporting the use of local biomass (Khan et al., 2024); food contact applications will require safety assessments.

3.6 Limitations of the evidence and research gaps

Several limitations constrain the current evidence. First, the central hypothesis that seaweed extract and mycelium act synergistically has no direct experimental support in the literature reviewed; the seaweed to mycelium ratio, plasticizer, crosslinker, mycelium inactivation and forming method need systematic examination.

Second, the available data are not comparable because formulation, thickness and test method differ. Tensile properties should follow a recognized method such as ASTM D882, and biodegradation should be assessed under defined soil or controlled composting conditions (e.g., ASTM D5988, ASTM D5338).

Third, conformity with biodegradability standards cannot be claimed. ASTM D6400 and EN 13432 require at least 90% biodegradation within 180 days under controlled composting, and Indonesia's ecolabel standard SNI 7188-7:2022 likewise addresses compostable products (BSN, 2022). The degradation times in Tables 1–3 were obtained under other conditions and do not demonstrate compliance.

Fourth, evidence on long-term stability, water resistance, food-contact safety, scale-up and environmental impact is limited. Life cycle assessment is needed to determine whether a seaweed with mycelium composite offers a net benefit, because biological origin alone does not guarantee lower impact (Hottle et al., 2013; Rosenboom et al., 2022); supply chain analyses of cultivated seaweed provide a

starting point (Ayala et al., 2024).

4. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

This narrative review shows that seaweed extract and fungal mycelium are natural materials with potential as sustainable raw materials for environmentally friendly bioplastics. Seaweed-based films reached tensile strengths of 0.54–45.07 MPa depending on the species, plasticizer and crosslinker, mycelium-based materials mostly 0.7–12.3 MPa (24.21 MPa in one engineered material), and a chitosan containing *Gracilaria* film 25 MPa. Biodegradation methods differ too much to rank the materials.

No study has yet reported a seaweed with mycelium bioplastic film. Related mycelium with alginate and seaweed with chitosan systems nevertheless suggest that the combination is plausible and merits experimental study.

4.2 Recommendations

Future work should define formulations and processing conditions, test the materials with standardized tensile and biodegradation methods, assess water resistance and safety, and include life cycle assessment and scale up analysis.

5. REFERENCES

Adam, F., Othman, N. A., Yasin, N. H. M., Cheng, C. K., & Azman, N. A. M. (2022). Evaluation of Reinforced and Green Bioplastic from Carrageenan Seaweed with Nanocellulose. *Fibers and Polymers*, *23*(10), 2885–2896. https://doi.org/10.1007/s12221-022-4006-6

Appels, F. V. W., Camere, S., Montalti, M., Karana, E., Jansen, K. M. B., Dijksterhuis, J., Krijgsheld, P., & Wösten, H. A. B. (2019). Fabrication factors influencing mechanical, moisture- and water-related properties of mycelium-based composites. *Materials & Design*, *161*, 64–71. https://doi.org/10.1016/j.matdes.2018.11.027

Appels, F. V. W., van den Brandhof, J. G., Dijksterhuis, J., de Kort, G. W., & Wösten, H. A. B. (2020). Fungal mycelium classified in different material families based on glycerol treatment. *Communications Biology*, *3*(1), 334. https://doi.org/10.1038/s42003-020-1064-4

Attias, N., Danai, O., Abitbol, T., Tarazi, E., Ezov, N., Pereman, I., & Grobman, Y. J. (2020). Mycelium bio-composites in industrial design and architecture: Comparative review and experimental analysis. *Journal of Cleaner Production*, *246*, 119037. https://doi.org/10.1016/j.jclepro.2019.119037

Ayala, M., Arlov, Ø., Nøkling-Eide, K., Sœther, M., Dore, C., Vidal, J., Zhou, Q., Wang, S., Michalak, L., Kyvik, A., Jolain, B., Aubel, L., Strand Jacobsen, S., & Pizzol, M. (2024). A supply-chain perspective on producing and upscaling bioplastic from cultivated

brown seaweed. *Journal of Cleaner Production*, *444*, 1–14. https://doi.org/10.1016/j.jclepro.2024.141248

Bagheri, A. R., Laforsch, C., Greiner, A., & Agarwal, S. (2017). Fate of So-Called Biodegradable Polymers in Seawater and Freshwater. *Global Challenges*, *1*(4). https://doi.org/10.1002/gch2.201700048

Basyuni, M., Puspita, M., Rahmania, R., Albasri, H., Pratama, I., Purbani, D., Aznawi, A. A., Mubaraq, A., Al Mustaniroh, S. S., Menne, F., Rahmila, Y. I., Salmo III, S. G., Susilowati, A., Larekeng, S. H., Ardli, E., & Kajita, T. (2024). Current biodiversity status, distribution, and prospects of seaweed in Indonesia: A systematic review. *Heliyon*, *10*(10), e31073. https://doi.org/10.1016/j.heliyon.2024.e31073

Bordeos, M. E. R., Dagalea, F. M. S., & Vicencio, M. C. G. (2024). Characterization of a Bioplastic Product from the Ulva reticulata (Ribbon Sea Lettuce) Extract. *Asian Journal of Chemical Sciences*, *14*(2), 161–168. https://doi.org/10.9734/ajocs/2024/v14i2301

BSN. (2022). *SNI 7188-7:2022: Kriteria ekolabel – Bagian 7: Kategori produk, kemasan produk dan wadah bioplastik yang dapat dikomposkan*.

Campo, V. L., Kawano, D. F., Silva, D. B. da, & Carvalho, I. (2009). Carrageenans: Biological properties, chemical modifications and structural analysis – A review. *Carbohydrate Polymers*, *77*(2), 167–180. https://doi.org/10.1016/j.carbpol.2009.01.020

Cerimi, K., Akkaya, K. C., Pohl, C., Schmidt, B., & Neubauer, P. (2019). Fungi as source for new bio-based materials: a patent review. *Fungal Biology and Biotechnology*, *6*(1), 17. https://doi.org/10.1186/s40694-019-0080-y

Chen, H., Abdullayev, A., Bekheet, M. F., Schmidt, B., Regler, I., Pohl, C., Vakifahmetoglu, C., Czasny, M., Kamm, P. H., Meyer, V., Gurlo, A., & Simon, U. (2021). Extrusion-based additive manufacturing of fungal-based composite materials using the tinder fungus Fomes fomentarius. *Fungal Biology and Biotechnology*, *8*(1), 21. https://doi.org/10.1186/s40694-021-00129-0

Cui, J., Xu, M., Li, T., Hao, Y., Wang, Q., Zhao, L., Chen, L., Shi, G., & Ding, Z. (2026). Bottom-up fabrication of high-strength mycelium-based materials: Tween as a bioregulator of mycelium growth. *Materials Horizons*, *13*(18), 9321–9338. https://doi.org/10.1039/D6MH01176D

Duarte, C. M., Wu, J., Xiao, X., Bruhn, A., & Krause-Jensen, D. (2017). Can Seaweed Farming Play a Role in Climate Change Mitigation and Adaptation? *Frontiers in Marine Science*, *4*. https://doi.org/10.3389/fmars.2017.00100

Elsabee, M. Z., & Abdou, E. S. (2013). Chitosan based edible films and coatings: A review. *Materials Science and Engineering: C*, *33*(4), 1819–1841. https://doi.org/10.1016/j.msec.2013.01.010

Elsacker, E., Vandelook, S., Brancart, J., Peeters, E., & De Laet, L. (2019). Mechanical, physical and chemical characterisation of mycelium-based composites with different types of lignocellulosic substrates. *PLOS ONE*, *14*(7), e0213954. https://doi.org/10.1371/journal.pone.0213954

Fazli Wan Nawawi, W. M., Lee, K.-Y., Kontturi, E., Murphy, R. J., & Bismarck, A. (2019). Chitin Nanopaper from Mushroom Extract: Natural Composite of Nanofibers and

Glucan from a Single Biobased Source. *ACS Sustainable Chemistry & Engineering*, *7*(7), 6492–6496. https://doi.org/10.1021/acssuschemeng.9b00721

Fredricks, J. L., Jimenez, A. M., Grandgeorge, P., Meidl, R., Law, E., Fan, J., & Roumeli, E. (2023). Hierarchical biopolymer-based materials and composites. *Journal of Polymer Science*, *61*(21), 2585–2632. https://doi.org/10.1002/pol.20230126

Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science Advances*, *3*(7). https://doi.org/10.1126/sciadv.1700782

Girometta, C., Picco, A. M., Baiguera, R. M., Dondi, D., Babbini, S., Cartabia, M., Pellegrini, M., & Savino, E. (2019). Physico-Mechanical and Thermodynamic Properties of Mycelium-Based Biocomposites: A Review. *Sustainability*, *11*(1), 281. https://doi.org/10.3390/su11010281

Gomaa, M., Hifney, A. F., Fawzy, M. A., & Abdel-Gawad, K. M. (2018). Use of seaweed and filamentous fungus derived polysaccharides in the development of alginate-chitosan edible films containing fucoidan: Study of moisture sorption, polyphenol release and antioxidant properties. *Food Hydrocolloids*, *82*, 1–35. https://doi.org/10.1016/j.foodhyd.2018.03.056

Gow, N. A. R., Latge, J.-P., & Munro, C. A. (2017). The Fungal Cell Wall: Structure, Biosynthesis, and Function. *Microbiology Spectrum*, *5*(3). https://doi.org/10.1128/microbiolspec.FUNK-0035-2016

Haider, T. P., Völker, C., Kramm, J., Landfester, K., & Wurm, F. R. (2019). Plastics of the Future? The Impact of Biodegradable Polymers on the Environment and on Society. *Angewandte Chemie International Edition*, *58*(1), 50–62. https://doi.org/10.1002/anie.201805766

Haneef, M., Ceseracciu, L., Canale, C., Bayer, I. S., Heredia-Guerrero, J. A., & Athanassiou, A. (2017). Advanced Materials From Fungal Mycelium: Fabrication and Tuning of Physical Properties. *Scientific Reports*, *7*(1), 41292. https://doi.org/10.1038/srep41292

Hanry, E. L., & Surugau, N. (2023). Optimization of biomass-to-water ratio and glycerol content to develop bioplastics from whole seaweed, Kappaphycus alvarezii. *Research Square*, 1–17. https://doi.org/10.21203/rs.3.rs-2757261/v1

Hottle, T. A., Bilec, M. M., & Landis, A. E. (2013). Sustainability assessments of bio-based polymers. *Polymer Degradation and Stability*, *98*(9), 1898–1907. https://doi.org/10.1016/j.polymdegradstab.2013.06.016

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., Narayan, R., & Law, K. L. (2015). Plastic waste inputs from land into the ocean. *Science*, *347*(6223), 768–771. https://doi.org/10.1126/science.1260352

Jayakody, M. M., Vanniarachchy, M. P. G., & Wijesekara, I. (2022). Seaweed derived alginate, agar, and carrageenan based edible coatings and films for the food industry: a review. *Journal of Food Measurement and Characterization*, *16*(2), 1195–1227. https://doi.org/10.1007/s11694-021-01277-y

Jones, M., Mautner, A., Luenco, S., Bismarck, A., & John, S. (2020). Engineered mycelium composite construction materials from fungal biorefineries: A critical review. *Materials & Design*, *187*, 108397. https://doi.org/10.1016/j.matdes.2019.108397

Karan, H., Funk, C., Grabert, M., Oey, M., & Hankamer, B. (2019). Green Bioplastics as Part of a Circular Bioeconomy. *Trends in Plant Science*, *24*(3), 237–249. https://doi.org/10.1016/j.tplants.2018.11.010

Khan, N. M., Chakma, P., Uddin, M. S., & Monirul Hasan, C. M. (2024). Preparation and Characterization of Biodegradable Plastic from Red Seaweed (Gracilaria sp.) from Coastal Areas in Bangladesh. *ChemistrySelect*, *9*(34). https://doi.org/10.1002/slct.202401990

Kohphaisansombat, C., Jongpipitaporn, Y., Laoratanakul, P., Tantipaibulvut, S., Euanorasetr, J., Rungjindamai, N., Chuaseeharonnachai, C., Kwantong, P., Somrithipol, S., & Boonyuen, N. (2023). Fabrication of mycelium (oyster mushroom)-based composites derived from spent coffee grounds with pineapple fibre reinforcement. *Mycology*, *15*(4), 665–682. https://doi.org/10.1080/21501203.2023.2273355

Kumar, R., Lalnundiki, V., Shelare, S. D., Abhishek, G. J., Sharma, S., Sharma, D., Kumar, A., & Abbas, M. (2024). An investigation of the environmental implications of bioplastics: Recent advancements on the development of environmentally friendly bioplastics solutions. *Environmental Research*, *244*, 1. https://doi.org/10.1016/j.envres.2023.117707

Lee, K. Y., & Mooney, D. J. (2012). Alginate: Properties and biomedical applications. *Progress in Polymer Science*, *37*(1), 106–126. https://doi.org/10.1016/j.progpolymsci.2011.06.003

Marsa, Y., Susanto, A. B., & Pramesti, R. (2023). Bioplastik dari Karagenan Kappaphycus alvarezii dengan Penambahan Carboxymethyl Chitosan dan Gliserol. *Buletin Oseanografi Marina*, *12*(1), 1–8. https://doi.org/10.14710/buloma.v12i1.42859

Narancic, T., Verstichel, S., Reddy Chaganti, S., Morales-Gamez, L., Kenny, S. T., De Wilde, B., Babu Padamati, R., & O'Connor, K. E. (2018). Biodegradable Plastic Blends Create New Possibilities for End-of-Life Management of Plastics but They Are Not a Panacea for Plastic Pollution. *Environmental Science & Technology*, *52*(18), 10441–10452. https://doi.org/10.1021/acs.est.8b02963

Putri, D. A. L., Ridlo, A., & Hartati, R. (2025). The Characteristics of Bioplastic Made from Sodium Alginate and Kappa Carrageenan. *Jurnal Kelautan Tropis*, *28*(1), 97–106. https://doi.org/10.14710/jkt.v28i1.25887

Ridlo, A., Sedjati, S., Supriyantini, E., & Putri, O. K. (2022). Karakteristik Biofilm Komposit CMC- Gliserol-Alginat dari Sargassum sp pada Perlakuan dengan Kalsium Klorida. *Jurnal Kelautan Tropis*, *25*(2), 257–265. https://doi.org/10.14710/jkt.v25i2.13773

Rosenboom, J.-G., Langer, R., & Traverso, G. (2022). Bioplastics for a circular economy. *Nature Reviews Materials*, *7*(2), 117–137. https://doi.org/10.1038/s41578-021-00407-8

Santana, I., Felix, M., & Bengoechea, C. (2024). Seaweed as Basis of Eco-Sustainable Plastic Materials: Focus on Alginate. In *Polymers* (Vol. 16, Number 12). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/polym16121662

Sarkar, A. K., Yang, Z., Astruc, T., & Amdursky, N. (2024). Aqueous-Based Assembly of Plant-Derived Proteins Yields a Crosslinker-Free Biodegradable Bioplastic Consistent with Green Chemistry Principles. *ChemSusChem*, 1.

https://doi.org/10.1002/cssc.202401567

Shao, G., Xu, D., Xu, Z., Jin, Y., Wu, F., Yang, N., & Xu, X. (2024). Green and sustainable biomaterials: Edible bioplastic films from mushroom mycelium. *Food Hydrocolloids*, *146*, 1–9. https://doi.org/10.1016/j.foodhyd.2023.109289

Sinaga, M. Z. E., Gea, S., Zuhra, C. F., Sihombing, Y. A., Zaidar, E., Sebayang, F., & Ningsih, T. U. (2021). The effect of plasticizers and chitosan concentration on the structure and properties of Gracilaria sp.-based thin films for food packaging purpose. *Polimery/Polymers*, *66*(2), 119–126. https://doi.org/10.14314/POLIMERY.2021.2.5

Vandelook, S., Elsacker, E., Van Wylick, A., De Laet, L., & Peeters, E. (2021). Current state and future prospects of pure mycelium materials. *Fungal Biology and Biotechnology*, *8*(1), 20. https://doi.org/10.1186/s40694-021-00128-1

Vieira, T. M., Moldão-Martins, M., & Alves, V. D. (2021). Design of Chitosan and Alginate Emulsion-Based Formulations for the Production of Monolayer Crosslinked Edible Films and Coatings. *Foods*, *10*(7), 1654. https://doi.org/10.3390/foods10071654

Yang, L., Park, D., & Qin, Z. (2021). Material Function of Mycelium-Based Bio-Composite: A Review. *Frontiers in Materials*, *8*. https://doi.org/10.3389/fmats.2021.737377

Zaghbib, I., Abdullah, J. A. A., & Romero, A. (2024). Development of a Multifunctional Chitosan-Based Composite Film from Crab Shell (Portunus segnis) and Algae (Ulva lactuca) with Enhanced Antioxidant and Antimicrobial Properties for Active Food Packaging. *Foods*, *14*(1), 53. https://doi.org/10.3390/foods14010053

Zheng, J., & Suh, S. (2019). Strategies to reduce the global carbon footprint of plastics. *Nature Climate Change*, *9*(5), 374–378. https://doi.org/10.1038/s41558-019-0459-z