

Evaluation of Alginate Use as an Immunostimulant in *Litopenaeus vannamei* Shrimp Aquaculture (Review)

Nuri Muahiddah^{1,2*}, Irzal Effendi¹, Eddy Supriyono¹, Rangga Idris Affandi²

¹Aquaculture, Faculty of Fisheries and Marine Sciences, IPB University
 Rasamala Street, IPB Darmaga Campus, Bogor, West Java, 16680, Indonesia

²Aquaculture Study Program, Faculty of Agriculture, University of Mataram
 37 Pendidikan Street, Mataram City, West Nusa Tenggara, 83114, Indonesia

Correspondence:

nurimuahiddah@unram.ac.id

ABSTRACT

Received:

October 8th, 2025

Accepted:

October 27th, 2025

Published:

November 11th, 2025

Keywords:

Alginate, Aquaculture,
 Evaluation,
 Immunostimulant,
Litopenaeus vannamei

The Pacific white shrimp (*Litopenaeus vannamei*) is one of the most important species in global aquaculture but remains highly vulnerable to bacterial, viral, and environmental stressors. Conventional reliance on antibiotics and chemicals has raised concerns over resistance and sustainability, underscoring the need for eco-friendly alternatives. Alginate, a natural polysaccharide extracted from brown seaweeds such as *Sargassum*, has emerged as a promising immunostimulant and functional feed additive. Experimental studies show that alginate supplementation enhances non-specific immune responses, including total haemocyte count, phenoloxidase, superoxide dismutase, phagocytic activity, and total plasma protein. At the molecular level, alginate upregulates immune-related genes (e.g., Toll, LGBP, proPO), resulting in higher resistance against *Vibrio* spp. and White Spot Syndrome Virus (WSSV). In addition, low molecular weight sodium alginate improves antioxidant activity and stress tolerance under cadmium exposure, while dietary supplementation supports growth performance and feed utilization. From a sustainability perspective, converting *Sargassum* biomass into alginate aligns with circular economy principles by transforming an abundant, underutilized seaweed into high-value aquafeed additives. This reduces dependency on antibiotics and synthetic chemicals while generating added value for coastal communities. Overall, alginate represents a multifunctional and cost-effective strategy to strengthen shrimp immunity, enhance resilience to pathogens and stressors, and promote environmentally responsible aquaculture production.

INTRODUCTION

The Pacific white shrimp (*Litopenaeus vannamei*) is one of the most economically important aquaculture species worldwide due to its rapid growth, high market demand, and adaptability to diverse culture conditions (Darmawan *et al.*, 2023). However, the expansion of intensive shrimp farming has been consistently challenged by disease outbreaks, particularly those caused by bacterial and viral pathogens, which can lead to significant economic losses (Yudiati *et al.*, 2016). Traditional approaches to disease management, such as antibiotics and chemical treatments, have raised concerns regarding antimicrobial resistance, environmental impact, and food safety (Muahiddah & Diamahesa, 2022; Muahiddah & Dwiyantri, 2024). As a result, there is growing interest in sustainable and eco-friendly strategies to enhance shrimp health and resilience.

One promising approach is the application of immunostimulants—substances that can modulate and strengthen the innate immune system of shrimp, thereby improving their ability to resist pathogenic infections. Among these, alginate, a natural polysaccharide derived from brown seaweeds (*Sargassum* sp., *Laminaria* sp., and others), has attracted considerable attention. Alginate and its derivatives are recognized for their biocompatibility, biodegradability, and immunomodulatory properties. In shrimp aquaculture, alginate has been investigated for its potential roles in enhancing non-specific immune responses, improving disease resistance, and supporting overall growth performance (Araujo & Jasmanindar, 2022; Muahiddah & Rahmadani 2024; Muahiddah & Diamahesa, 2022; Muahiddah & Dwiyantri, 2024).

This review aims to provide a comprehensive evaluation of alginate use as an immunostimulant in *L. vannamei* culture. It summarizes current knowledge on the mechanisms by which alginate influences shrimp immunity, highlights experimental findings on its effectiveness under various culture conditions, and discusses its potential application in sustainable aquaculture practices. By synthesizing available evidence, this review seeks to clarify the benefits and limitations of alginate supplementation, and to identify future research directions for its practical implementation in shrimp farming systems.

METHODS

This review was conducted to evaluate the use of alginate as an immunostimulant in *Litopenaeus vannamei* shrimp aquaculture. The study was carried out in Bogor, Indonesia, during September to October 2025. A total of 26 relevant scientific articles were collected and analyzed.

The literature search was performed using online databases, including Google Scholar, ScienceDirect, and PubMed. Keywords such as “alginate,” “immunostimulant,” “shrimp aquaculture,” and *Litopenaeus vannamei* were applied either individually or in combination. Articles were selected based on their relevance to the topic, particularly those addressing the effects of alginate on shrimp immunity, growth performance, and disease resistance.

All selected publications were reviewed and synthesized to provide a comprehensive overview of current knowledge and to identify potential applications and future research directions regarding alginate use as an immunostimulant in shrimp aquaculture.

RESULTS AND DISCUSSION

Diseases are the greatest challenge in the shrimp industry because they cause major economic losses, reduced production, and lower product quality. Their impact is not only felt at the farm level but also influences global prices, given the international nature of the shrimp market. Many countries have responded to outbreaks by relocating production areas or switching species, such as the transition from *P. monodon* to *P. vannamei*, driven by the availability of pathogen-free stocks. Breeding programs, biosecurity, and closed production systems are important strategies to mitigate disease, while experiences in various countries highlight that governance both formal and private plays a crucial role in successful disease management. Although there are positive signs such as the development of disease-resistant breeding programs, intensive research, and closed production cycles, the shrimp industry still faces the risk of new crises due to short-term profit orientation. High profitability often leads farmers to overlook sustainability, allowing outbreaks to re-emerge. Therefore, a combination of technological innovation, strict biosecurity, selective breeding, and effective governance is essential to build a more sustainable shrimp industry capable of managing diseases (Asche *et al.*, 2021).

The use of alginate as an immunostimulant in *Litopenaeus vannamei* culture has been widely explored in recent years due to its potential to improve shrimp health and reduce dependency on antibiotics (Adella *et al.*, 2023; Yudiati *et al.*, 2016). Findings from various studies consistently show that alginate enhances several non-specific immune responses, such as total hemocyte count, phenoloxidase activity, respiratory burst, and lysozyme activity (Mohan *et al.*, 2019; Pakidi & Suwoyo, 2017). These immune indicators play central roles in crustacean defense systems, indicating that alginate supplementation can strengthen shrimp resistance against a broad range of pathogens (Adella *et al.*, 2023; Darmawan *et al.*, 2023; Mulyadi *et al.*, 2020; Setyawan *et al.*, 2021).

Another important outcome of alginate administration is the improvement of shrimp survival following bacterial challenges, particularly with *Vibrio* spp., which remain among the most threatening pathogens in shrimp farming (Adella *et al.*, 2023; Yeh *et al.*, 2006; Yudiati *et al.*, 2016). The consistent increase in survival rates demonstrates that alginate is effective in activating the shrimp's innate immune system, providing a natural defense mechanism that could help mitigate disease outbreaks in intensive aquaculture systems (Adella *et al.*, 2023; Mohan *et al.*, 2019; Yudiati *et al.*, 2016).

In addition to immunological benefits, alginate supplementation has been reported to enhance growth performance and feed efficiency when provided at moderate levels (Muahiddah & Dwiyantri, 2024; Santos *et al.*, 2019). This effect is possibly linked to better gut health, improved nutrient absorption, and reduced energy allocation to stress responses. However, excessive inclusion of alginate does not necessarily yield proportional benefits and, in some cases, may result in neutral or negative effects. This highlights the importance of optimizing dosage and delivery methods for practical applications.

At the molecular level, the immunostimulatory properties of alginate are associated with its unique polysaccharide structure, which interacts with shrimp pattern recognition receptors (PRRs) (Santos *et al.*, 2019; Yudiati *et al.*, 2019). Such interactions stimulate signaling cascades that activate antimicrobial peptide synthesis and the prophenoloxidase system. Moreover, alginate has been investigated as an encapsulation matrix for probiotics, vaccines, or other bioactive agents, suggesting its multifunctional potential beyond direct immune stimulation (Li *et al.*, 2021).

Nevertheless, several limitations remain. Variations in alginate source (e.g., *Sargassum* sp., *Laminaria* sp.), extraction techniques, and purity levels can result in inconsistent findings across studies. Long-term impacts of continuous alginate use on shrimp physiology, water quality, and microbial ecology are also not fully understood. Furthermore, economic considerations such as production cost and scalability need to be addressed before alginate can be widely applied in commercial aquaculture.

Taken together, the evidence indicates that alginate is a valuable candidate for promoting shrimp immunity and health management in *L. vannamei* aquaculture. Future studies should aim to standardize alginate preparation, determine optimal dosages, and explore synergistic applications with other health-promoting strategies, such as probiotics and vaccination. Such efforts will be critical in translating alginate research into practical, sustainable, and cost-effective solutions for the shrimp farming industry. Effects of Alginate on Immune Parameters.

Several studies have demonstrated that dietary supplementation or immersion treatment with alginate significantly enhances the non-specific immune responses of *Litopenaeus vannamei*. Key indicators such as total hemocyte count (THC), phenoloxidase (PO) activity, respiratory burst activity, and lysozyme levels were elevated in shrimp receiving alginate treatments compared to controls. These findings suggest that alginate stimulates cellular and humoral defense mechanisms, which are crucial for crustacean innate immunity (Cokrowati *et al.*, 2024). Moreover, alginate has been reported to upregulate the expression of immune-related genes, including prophenoloxidase, crustin, and penaeidin, further supporting its role as an immunomodulator (Darmawan *et al.*, 2023; Husni *et al.*, 2012; Santos *et al.*, 2019; Suryati *et al.*, 2023; Yeh *et al.*, 2006).

Disease Resistance and Survival

Alginate-treated shrimp exhibited improved resistance against bacterial infections, particularly those caused by *Vibrio* spp., which are among the most significant pathogens in shrimp aquaculture (Aranguren *et al.*, 2017; Ghaednia *et al.*, 2011; Yeh *et al.*, 2006). Enhanced survival rates were consistently observed in challenge tests following alginate administration. In addition, some studies highlighted the synergistic effect of alginate when combined with probiotics or other immunostimulants, indicating potential for integrated health management strategies in aquaculture.

Growth Performance and Feed Utilization

Beyond immune enhancement, several investigations have assessed the influence of alginate supplementation on growth parameters. Results indicate that moderate inclusion levels of alginate in diets can improve feed conversion ratio (FCR) and weight gain, possibly due to better intestinal health and nutrient absorption (Mudiarti *et al.*, 2023; Yudiati *et al.*, 2019). However, excessively high levels may have neutral or even adverse effects, suggesting the importance of optimizing dosage for practical use.

Mechanisms of Action

The immunostimulatory effects of alginate are attributed to its structural properties, including its β -1,4-glycosidic linkage and the presence of guluronic and mannuronic acid residues, which may interact with pattern recognition receptors (PRRs) in shrimp hemocytes (Cheng *et al.*, 2004; Yudiati *et al.*, 2016). These interactions can trigger signaling pathways involved in immune activation, such as the prophenoloxidase system and antimicrobial peptide synthesis. Furthermore, alginate's ability to act as an encapsulating agent for bioactive compounds or probiotics enhances its versatility in shrimp aquaculture applications.

Limitations and Considerations

Despite promising results, some limitations have been identified. Variability in alginate source, extraction method, molecular weight, and purity can lead to inconsistent outcomes across studies. Additionally, long-term impacts of continuous alginate supplementation on shrimp physiology and pond ecosystems remain insufficiently explored. Cost-effectiveness and scalability of alginate application in commercial settings also require further evaluation.

Future Perspectives

Future research should focus on standardizing alginate formulations, determining optimal dosage and delivery methods, and investigating synergistic applications with probiotics, prebiotics, or vaccines. Understanding the molecular mechanisms underlying alginate-mediated immune responses will also be crucial for advancing its practical use. Ultimately, alginate shows strong potential as a sustainable immunostimulant that can reduce reliance on antibiotics and improve disease resilience in *L. vannamei* aquaculture.

Table 1. Use of Alginate as an Immunostimulant in *L. vannamei* Aquaculture

No	Source	Type of Alginate	Results Improve	Against Disease	References
1	Sodium alginate from Sigma Chemical Co	Sodium alginate injected with sodium alginate at 20 $\mu\text{g g}^{-1}$	Increased its phenoloxidase activity and respiratory burst	<i>Vibrio alginolyticus</i>	(Cheng <i>et al.</i> , 2004)
2	<i>Sargassum siliquosum</i>	Sodium Alginate; Acid alginate; Calcium Alginate; Best Dose (oral) The 2.0 g kg^{-1}	Increase The Total Haemocyte Count (THC), phenoloxidase (PO), Superoxide Dismutase (SOD) activity, Phagocytic Activity/Index and Total Protein Plasma (TPP); Four immune related genes expression i.e. LGBP, Toll, Lectin, proPO were up regulated.	-	(Yudiati <i>et al.</i> , 2016)
3	<i>Sargassum siliquosum</i>	Sodium Alginate Best Dose (oral) 2.0 g kg^{-1}	Increase Total Haemocyte Count, PA (Phagocytic Activity), and PI (Phagocytic Index), Phenoloxidase Activity, the lectin gene and Toll gene were upregulated Survival Rate	White spot syndrome virus (WSSV)	(Yudiati <i>et al.</i> , 2019)
4	Sodium Alginate	Sodium Alginate	Enhances growth and performance	<i>Vibrio alginolyticus</i>	(Santos <i>et al.</i> , 2019)

No	Source	Type of Alginate	Results Improve	Against Disease	References
	from Sigma Chemical Co	Best Dose (oral): 0.2 and 0.4 g kg ⁻¹	induces LvToll2 and LvToll3 gene expressions; 100% percent survival		
5	<i>Sargassum</i> sp.	Sodium Alginate Best Dose (oral): 2.0 g kg ⁻¹	Increase total haemocyte count (THC), phagocytocyte activity (PA), and total plasma protein (TPP)	-	(Setyawan <i>et al.</i> , 2021)
6	Low Molecular Weight Sodium alginate was provided from Thailand	Low Molecular Weight Sodium alginate (LMWSA) Best Dose 2.0 LMWSA g kg ⁻¹	Enhances antioxidant response, serological enzymes, and survival rate	Cadmium Stress	(Bagheri <i>et al.</i> , 2023)

The evaluation of various forms of sodium alginate and its derivatives demonstrates their potential as immunostimulants and functional feed additives in aquaculture (Table 1). Across the reviewed studies, sodium alginate—whether commercially sourced or extracted from *Sargassum* species—consistently enhanced immune responses, antioxidant activities, and survival rates in shrimp when challenged with pathogens or environmental stressors.

From a systematic perspective, sodium alginate supplementation improves both cellular and humoral immune parameters. Cheng *et al.* (2004) reported that injected sodium alginate from Sigma Chemical Co. significantly increased phenoloxidase activity and respiratory burst, providing protection against *Vibrio alginolyticus*. Similarly, oral administration proved effective in later studies, where optimal dosages (ranging from 0.2 to 2.0 g kg⁻¹) enhanced total haemocyte count (THC), phenoloxidase (PO), phagocytic activity (PA), and total plasma protein (TPP). These immune markers are critical indicators of disease resistance in shrimp aquaculture.

From a molecular standpoint, sodium alginate supplementation was shown to regulate the expression of immune-related genes. Yudiati *et al.* (2016; 2019) demonstrated upregulation of genes such as LGBP, Toll, Lectin, and proPO, while Santos *et al.* (2019) confirmed the induction of LvToll2 and LvToll3, resulting in improved survival against *V. alginolyticus*. This genetic modulation indicates that sodium alginate does not merely act as a nutrient supplement but also as a functional immunostimulant capable of triggering specific innate immune pathways.

In addition to disease resistance, sodium alginate supports stress tolerance and growth performance. Bagheri *et al.* (2023) showed that low molecular weight sodium alginate (LMWSA) improved antioxidant responses and survival under cadmium stress, highlighting its potential role in mitigating environmental toxicity. Meanwhile, Santos *et al.* (2019) observed improved growth performance in shrimp, linking sodium alginate to not only immunity but also production efficiency—an essential factor for sustainable aquaculture.

From an aquaculture management viewpoint, the incorporation of sodium alginate into feeding regimes offers a sustainable strategy to reduce dependency on antibiotics and chemicals, which are often associated with resistance development and environmental concerns. By enhancing innate immunity and stress resistance, sodium alginate provides a natural, cost-effective means to improve shrimp health and survival, thus contributing to more resilient production systems.

However, it is important to note that effectiveness depends on form, dosage, and administration method. For example, while oral administration of 2.0 g kg^{-1} appears optimal in several studies (Yudiati *et al.*, 2016; Setyawan *et al.*, 2021), lower doses ($0.2\text{--}0.4 \text{ g kg}^{-1}$) were sufficient to achieve full survival in certain contexts (Santos *et al.*, 2019). This suggests the necessity for species-specific and condition-specific optimization before large-scale application.

The evaluation of alginate application in shrimp aquaculture reveals consistent benefits in enhancing immunity, disease resistance, growth, and stress tolerance. Viewed through the framework of systematic aquaculture management and circular economy principles, alginate emerges not only as a functional immunostimulant but also as a sustainable bioproduct that supports both production efficiency and environmental responsibility.

From a systematic aquaculture perspective, commercial sodium alginate has demonstrated substantial improvements in shrimp health and survival. Cheng *et al.* (2004) showed that injected sodium alginate increased phenoloxidase activity and respiratory burst, enhancing resistance against *Vibrio alginolyticus*. Similarly, Santos *et al.* (2019) found that dietary supplementation with $0.2\text{--}0.4 \text{ g kg}^{-1}$ of sodium alginate not only promoted growth performance but also upregulated Toll-like receptor genes (LvToll2 and LvToll3), achieving 100% survival under bacterial challenge. These findings underscore alginate's role in reducing mortality, boosting productivity, and strengthening innate immunity—key goals in efficient aquaculture systems.

Equally important is the application of Sargassum-derived alginates, which provide a sustainable, circular alternative to synthetic additives. Studies by Yudiati *et al.* (2016; 2019) and Setyawan *et al.* (2021) reported that supplementation at 2.0 g kg^{-1} significantly enhanced immune parameters such as total haemocyte count (THC), phenoloxidase (PO), superoxide dismutase (SOD), phagocytic activity, and total plasma protein (TPP). Moreover, immune-related genes (LGBP, Toll, Lectin, proPO) were upregulated, leading to greater survival against White Spot Syndrome Virus (WSSV). This highlights the potential of underutilized *Sargassum* biomass to be converted into high-value feed additives that directly improve shrimp health and farm profitability.

Beyond pathogen resistance, alginate also plays a critical role in stress mitigation. Bagheri *et al.* (2023) demonstrated that low molecular weight sodium alginate (LMWSA) enhanced antioxidant capacity, improved serological enzyme responses, and increased survival under cadmium-induced stress. These results emphasize alginate's multifunctional role—not only as an immune booster but also as a resilience enhancer against environmental challenges in intensive aquaculture.

From a circular economy perspective, valorizing seaweed biomass into aquaculture feed inputs exemplifies a closed-loop resource use model. Seaweeds such as *Sargassum* are abundant, renewable, and often problematic when left unmanaged in coastal ecosystems. Transforming them into alginate reduces ecological burdens such as coastal overgrowth, while simultaneously generating economic opportunities for coastal communities. At the production level, alginate supplementation reduces dependence on antibiotics and synthetic

chemicals, lowering farming risks, environmental impacts, and long-term costs. This integration aligns with sustainable aquaculture objectives—enhancing productivity, safeguarding animal welfare, and minimizing ecological footprints.

CONCLUSION

The collective evidence demonstrates that alginate, whether derived from commercial sources or seaweed biomass such as *Sargassum* spp., is a promising immunostimulant and functional feed additive for *Litopenaeus vannamei* aquaculture. Its supplementation enhances key immune parameters, improves survival against major pathogens like *Vibrio* spp. and WSSV, supports growth performance, and increases tolerance to environmental stressors. At the molecular level, alginate stimulates innate immune pathways and upregulates immune-related genes, confirming its role as a potent immunomodulator rather than a simple dietary supplement. Beyond its biological benefits, alginate contributes to sustainable aquaculture by reducing reliance on antibiotics and synthetic chemicals, while the use of seaweed-derived alginates aligns with circular economy principles by converting underutilized coastal biomass into high-value aquafeed inputs. However, variations in alginate type, dosage, and administration methods highlight the need for further research to standardize formulations and optimize applications for commercial use. Taken together, alginate offers a multifunctional solution for improving shrimp health, productivity, and resilience, while also promoting environmental responsibility and economic sustainability. Future directions should emphasize integrated strategies—combining alginate with probiotics, vaccines, and selective breeding programs—to strengthen disease management and secure long-term stability in the global shrimp industry.

ACKNOWLEDGEMENT

The authors would like to express their profound gratitude to IPB University. The University has generously provided the necessary research facilities that made this study possible. In addition, the authors sincerely appreciate the invaluable assistance and support given by Mr. Rangga Idris Affandi.

REFERENCES

- Adella, A. S., Yudiati, E., & Sedjati, S. (2023). Suplementasi Alginat dan Spirulina Meningkatkan Ketahanan Udang *Litopenaeus vannamei* Terhadap Paparan Salinitas. *Journal of Marine Research*, 12(4), 655–662. <https://doi.org/10.14710/jmr.v12i4.37937>
- Aranguren, L. F., Han, J. E., & Tang, K. F. J. (2017). Enterocytozoon Hepatopenaei (EHP) is a Risk Factor for Acute Hepatopancreatic Necrosis Disease (AHPND) and Septic Hepatopancreatic Necrosis (SHPN) in the Pacific White Shrimp *Penaeus vannamei*. *Aquaculture*, 471, 37–42. <https://doi.org/10.1016/j.aquaculture.2016.12.038>
- Araujo, F. B. De, & Jasmanindar, Y. (2022). Pemanfaatan Ekstrak *Sargassum* sp. Untuk Menghambat Pertumbuhan Bakteri *Vibrio* sp. pada Ikan Bandeng (*Chanos chanos*). 178–190.
- Asche, F., Anderson, J. L., Botta, R., Kumar, G., Abrahamsen, E. B., Nguyen, L. T., & Valderrama, D. (2021). The Economics of Shrimp Disease. *Journal of Invertebrate Pathology*, 186, 107397. <https://doi.org/10.1016/j.jip.2020.107397>

- Bagheri, D., Moradi, R., Zare, M., Sotoudeh, E., Hoseinifar, S. H., Oujifard, A., & Esmaeili, N. (2023). Does Dietary Sodium Alginate with Low Molecular Weight Affect Growth, Antioxidant System, and Haemolymph Parameters and Alleviate Cadmium Stress in Whiteleg Shrimp (*Litopenaeus vannamei*)? *Animals*, 13(11), 1–15. <https://doi.org/10.3390/ani13111805>
- Cheng, W., Liu, C. H., Yeh, S. T., & Chen, J. C. (2004). The Immune Stimulatory Effect of Sodium Alginate on the White Shrimp *Litopenaeus vannamei* and Its Resistance Against *Vibrio alginolyticus*. *Fish and Shellfish Immunology*, 17(1), 41–51. <https://doi.org/10.1016/j.fsi.2003.11.004>
- Cokrowati, N., Junaidi, M., Affandi, R. I., Sumsanto, M., Muahiddah, N., Anggraini, I. D., Marno, S., Asri, Y., Dwiyantri, S., Lumbessy, S. Y., Latifah, W., & Fikri, R. A. (2024). The Distribution, Habitat Characteristics, and Bioenergy Potential of *Sargassum* sp. in Indonesia. *International Journal of Design and Nature and Ecodynamics*, 19(6), 2049–2062. <https://doi.org/10.18280/ij dne.190621>
- Darmawan, M., Setiawan, A., Juliasih, N. L. G. R., & Fidyandini, H. P. (2023). Efektivitas Perlindungan Udang Vaname (*Litopenaeus vannamei*) terhadap Infeksi White Spot Syndrome Virus (WSSV) dengan Suplementasi Natrium Alginat *Sargassum* sp. Dari Perairan Lampung dan Kombinasi dengan Vitamin C. *Journal of Tropical Marine Science*, 6(1), 11–22. <https://doi.org/10.33019/jour.trop.mar.sci.v6i1.3819>
- Ghaednia, B., Mehrabi, M. R., Mirbakhsh, M., Yeganeh, V., Hoseinkhezri, P., Garibi, G., & Ghaffar, J. A. (2011). Effect of Hot-water Extract of Brown Seaweed *Sargassum glaucescens* via Immersion Route on Immune Responses of *Fenneropenaeus indicus*. *Iranian Journal of Fisheries Sciences*, 10(4), 616–630.
- Husni, A., Subaryono, S., Pranoto, Y., Taswir, T., & Ustadi, U. (2012). Pengembangan Metode Ekstraksi Alginat dari Rumpun Laut *Sargassum* sp. sebagai Bahan Pengental. *AgriTECH*, 32(1), 1–8. <https://doi.org/10.22146/agritech.9649>
- Li, D., Wei, Z., & Xue, C. (2021). Alginate-based Delivery Systems for Food Bioactive Ingredients: An Overview of Recent Advances and Future Trends. *Comprehensive Reviews in Food Science and Food Safety*, 20(6), 5345–5369. <https://doi.org/10.1111/1541-4337.12840>
- Mohan, K., Ravichandran, S., Muralisankar, T., Uthayakumar, V., Chandirasekar, R., Seedevi, P., Abirami, R. G., & Rajan, D. K. (2019). Application of Marine-Derived Polysaccharides as Immunostimulants in Aquaculture: A review of Current Knowledge and Further Perspectives. *Fish and Shellfish Immunology*, 86 (December 2018), 1177–1193. <https://doi.org/10.1016/j.fsi.2018.12.072>
- Muahiddah, N. & Rahmadani, T. B. C. (2024). *sp . yang diambil dari Pantai Pantai Sundak , Gunung Kidul*. 10(2), 332–340.
- Muahiddah, N., & Diamahesa, W. A. (2022). Potential Use of Brown Algae As an Immunostimulant Material in the Aquaculture Field To Increase Non-Specific Immunity and Fight Disease. *Journal of Fish Health*, 2(2), 109–115. <https://doi.org/10.29303/jfh.v2i2.2075>
- Muahiddah, N., & Dwiyantri, S. (2024). Potensi *Sargassum* Sebagai Imunostimulan Pada Bidang Akuakultur (Review). *Ganec Swara*, 18(1), 553. <https://doi.org/10.35327/gara.v18i1.794>
- Mudiarti, L., Setiowati, D., Kursistiyanto, N., & Alimin, N. (2023). Pengaruh Penambahan Alginat Dalam Pakan Terhadap Performa Pertumbuhan dan Efisiensi Pemanfaatan Pakan Udang Vannamei (*Litopenaeus vannamei*). *Jurnal Media Akuatika*, 8(1), 13. <https://doi.org/10.33772/jma.v8i1.28413>

-
- Mulyadi, T., Sarjito, S., & Rachmawati, D. (2020). Penambahan Ekstrak *Sargassum* sp. Hasil Ekstraksi Enzimatis Pada Pakan Terhadap Performa Pertumbuhan Udang Vaname (*Litopenaeus vannamei*). *Sains Akuakultur Tropis*, 4(1), 13–18. <https://doi.org/10.14710/sat.v4i1.5615>
- Pakidi, C. S., & Suwoyo, H. S. (2017). Potensi dan Pemanfaatan Bahan Aktif Alga Cokelat *Sargassum* sp. *Jurnal Octopus*, 6(1), 551–562.
- Santos, H. M., Tsai, C. Y., Yanuaria, C. A. S., Tayo, L. L., Vo, D. D., Mariatulqabtiah, A. R., & Chuang, K. P. (2019). Effects of Sodium Alginate-fed Pacific White Shrimps, *Litopenaeus vannamei*, on Toll-like Receptors and *Vibrio alginolyticus* Infection. *Aquaculture Research*, 50(4), 1384–1392. <https://doi.org/10.1111/are.13989>
- Setyawan, A., Riana, Supono, Hudaidah, S., & Fidyandini, H. P. (2021). Non-specific Immune Response of Pacific White Shrimp *Litopenaeus vannamei* by Supplementation of Sodium Alginate of *Sargassum* Collected from Lampung Indonesia. *IOP Conference Series: Earth and Environmental Science*, 890(1). <https://doi.org/10.1088/1755-1315/890/1/012015>
- Suryati, Mulyati, Arma, N. R., & Rusli. (2023). Antibacterial and Immunostimulatory Activities of Sodium Alginate Isolated from Brown Seaweed, *Sargassum* sp. *AACL Bioflux*, 16(3), 1757–1768.
- Yeh, S. T., Lee, C. S., & Chen, J. C. (2006). Administration of Hot-water Extract of Brown Seaweed *Sargassum duplicatum* via Immersion and Injection Enhances the Immune Resistance of White Shrimp *Litopenaeus vannamei*. *Fish and Shellfish Immunology*, 20(3), 332–345. <https://doi.org/10.1016/j.fsi.2005.05.008>
- Yudiati, E., Isnansetyo, A., Murwantoko, Ayuningtyas, Triyanto, & Handayani, C. R. (2016). Innate Immune-stimulating and Immune Genes up-regulating Activities of Three Types of Alginate from *Sargassum siliquosum* in Pacific White Shrimp, *Litopenaeus vannamei*. *Fish and Shellfish Immunology*, 54, 46–53. <https://doi.org/10.1016/j.fsi.2016.03.022>
- Yudiati, E., Isnansetyo, A., Murwantoko, Triyanto, & Handayani, C. R. (2019). Alginate from *Sargassum siliquosum* Simultaneously Stimulates Innate Immunity, Upregulates Immune Genes, and Enhances Resistance of Pacific White Shrimp (*Litopenaeus vannamei*) Against White Spot Syndrome Virus (WSSV). *Marine Biotechnology*, 21(4), 503–514. <https://doi.org/10.1007/s10126-019-09898-7>