

KITOSAINS: Utilization of Shrimp Shell Waste as Bioadditive Through Chitosans Hydrolysis Technology to Achieve SDGs 2030

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Abstract

Shrimp shell waste is a significant environmental challenge and an underutilized resource in Indonesia's coastal areas. This study proposes an innovative approach to processing shrimp shell waste into chitosan-based bioadditives using chemical hydrolysis technology. The resulting chitosan functions as an environmentally friendly additive for biofuels, capable of improving combustion efficiency and fuel stability in small-scale fishing vessels. The extraction process includes deproteinization, demineralization, and deacetylation stages to obtain high-quality chitosan with a deacetylation degree exceeding 85%. Field implementation through a four-stage pilot project demonstrated the feasibility of small-scale chitosan production using simple hydrolysis equipment. Adding chitosan as a bioadditive to biodiesel has the potential to reduce fishermen's dependence on fossil fuels, mitigate fisheries waste pollution, and support the transition to renewable energy. This innovation aligns with the Sustainable Development Goals (SDGs), particularly Goal 7 (Affordable and Clean Energy) and Goal 12 (Responsible Consumption and Production), by promoting circular economy principles and empowering coastal communities. Further research is recommended to optimize the bioconversion process and evaluate long-term economic and environmental impacts.

Keywords

Shrimp Shell Waste, Chitosan Hydrolysis, Bioadditive, Renewable Energy and Sustainable Development Goals (SDGs).

1. Introduction

Indonesia as an agricultural country has great potential in the fisheries sector and the seafood processing industry. One of the commodities that is widely produced is shrimp, which is a mainstay of national exports. However, behind this potential, there are serious problems faced by coastal communities, especially fishermen and small business actors in the seafood processing sector. Shrimp shell waste produced from household and small-scale industrial activities in coastal areas of Indonesia (such as Sulawesi, Kalimantan, and Nusa Tenggara) is often simply dumped into the surrounding environment, causing unpleasant odor pollution, water pollution, and having negative impacts on public

health and coastal ecosystems. This problem is exacerbated by the limited access of coastal communities to clean, cheap, and affordable energy. Fishing vessels generally still use fossil fuels (diesel/gasoline) whose prices continue to increase, thus burdening operational costs and reducing the welfare of fishermen.

The gap in demand for fossil fuel production fluctuates worldwide. To reduce dependence on fossil fuels in fishing operations, the government has issued Presidential Regulation of the Republic of Indonesia Number 5 of 2006, Concerning National Energy Policy to develop alternative energy sources as a substitute for fuel oil. Renewable energy in the form of biofuel is one of the right efforts to be developed in overcoming the fossil energy crisis. Biofuel is a renewable liquid fuel made from biological raw materials and has been proven to be a good substitute for gasoline (N. Suryawanshi et al., 2020). The advantages of biofuel are that it is biodegradable and provides abundant raw materials from nature that have been renewed (A. Fikriyah 2020) which are abundant in nature, especially in shellfish waste.

Shellfish waste, especially crustaceans, is an abundant source of chitin (Yadav M, et al., 2019). The continuous increase in the amount of aquatic food has an impact on the production of shellfish waste. According to the food and agriculture organization, Asian countries have an estimated 2.5 million tons of marine shrimp production (Nisha S et al., 2016). During processing in the food industry, the waste produced is as much as 35-40% (w / w), including shells and shrimp coconut parts, which can provide a lot of raw materials for chitin production. Shrimp (*Litopenaeus vannamei*) is one of the most popular fishery commodities in Indonesia and even abroad. This part is a waste from the frozen shrimp processing industry called shrimp waste (shrimp carapace), while shrimp meat is a good source of minerals, especially calcium, phosphorus, potassium and zinc (Akbar et al., 2017). The shrimp processing process often leaves heads and skins that are only thrown away as waste. Shrimp waste by-products can reach 40-50% of the weight of whole shrimp depending on the type (Islam et al., 2016). Currently, only a small amount of crustacean shells are utilized in chitin isolation and animal feed due to the presence of amino groups in chitin. Therefore, proper disposal helps in managing the environmental problems caused by chitin materials.

Chitin material extracted from shrimp shells (Renugadevi et al., 2019 and Tan YN et al., 2020), can also be used as a source for ethanol production. Some microorganisms can utilize chitin as a carbon source and convert it into ethanol. For ethanol production, chitin is the right candidate as an alternative to sugar or cellulose waste. In many aspects, chitin is said to be similar to cellulose because it is considered a derivative of cellulose. The only difference is that acetamide residues are present instead of the C₂ hydroxyl group. The entire process of bioconversion of chitin substrate into ethanol consists of several processing steps, namely chitin extraction and chitinase production (Hasan I et al., 2014) to degrade chitin, namely enzymatic hydrolysis of chitin to convert it into GlcNAc which can be further tested into ethanol as a bioadditive for biodiesel or biofuel.

Utilization of shrimp shell waste to produce chitosan through green chemistry hydrolysis process is one of the relevant innovative solutions. The chitosan produced can be used as a bioadditive for biodiesel or biofuel, which functions to improve the stability and combustion performance of fishermen's fuel. Thus, this idea is expected to not only overcome the problem of environmental pollution due to shrimp shell waste, but also help coastal communities gain access to more affordable renewable energy, supporting sustainable fisheries economic activities. This program is in line with supporting the Sustainable Development Goals, especially points 7 (Clean and Affordable Energy) and 12 (Sustainable Consumption and Production).

1.1 Objectives

This research and creative proposal aims to:

- 1.1 Identify the potential of shrimp shell waste as a raw material for chitosan-based bioadditives through chemical hydrolysis, offering a sustainable solution for managing fishery waste in coastal areas of Indonesia.
- 1.2 Design and evaluate a simple, cost-effective hydrolysis technology that can be implemented at the household or community level by local fishers for producing high-quality chitosan.
- 1.3 Assess the effectiveness of chitosan as a bioadditive in biofuels or biodiesel, particularly in enhancing combustion performance and oxidative stability of fuels used in small-scale fishing vessels.
- 1.4 Analyze the socio-economic and environmental impacts of the KITOSAINS program implementation, as a strategy for empowering coastal communities through circular economy and renewable energy initiatives.
- 1.5 Support the achievement of the Sustainable Development Goals (SDGs), specifically Goal 7 (Affordable and Clean Energy) and Goal 12 (Responsible Consumption and Production), by promoting innovation based on waste utilization and appropriate technology.

2. Literature Review

2.1 Shrimp Shell Waste

Shrimp shell waste is one of the main by-products of the shrimp processing industry in Indonesia. According to data from the Ministry of Marine Affairs and Fisheries (KKP, 2024), national shrimp production exceeds 1 million tons per year, with an estimated 35–45% of it being shrimp shell waste (Younes & Rinaudo, 2015). This waste contains chitin (15–30%), protein (20–40%), and minerals (20–30%), which if not managed properly can cause environmental pollution in the form of unpleasant odors and coastal water contamination (Synowiecki & Al-Khateeb, 2003). Therefore, the utilization of shrimp shell waste into value-added products such as chitosan is one of the ecologically and economically relevant solutions.

2.2 Bioadditive

Bioadditives are compounds or natural materials added in small amounts to fuels (biofuels or biodiesel) to improve certain characteristics, such as oxidation stability, combustion performance, and exhaust emissions (Atabani et al., 2012). In the context of renewable energy, bioadditives can act as natural antioxidants that prevent fuel damage due to oxidation during storage, and help improve combustion efficiency in diesel engines (Narasimhan et al., 2017). Chitosan, a derivatization product of chitin, has been widely reported as an effective bioadditive, thanks to the presence of amino (NH₂) and hydroxyl (OH) groups that function to capture free radicals and improve the emulsification properties of fuels (Younes & Rinaudo, 2015).

2.3 Biofuel

Biofuel is a fuel produced from renewable biomass sources, such as agricultural waste, fishery waste, and energy crops. Biodiesel, one of the most widely used forms of biofuel in Indonesia, is usually produced from vegetable oil or animal fat through a transesterification process (Gui et al., 2008). The use of biofuels is increasingly important to support the clean energy transition and reduce dependence on fossil fuels, especially in the transportation and fisheries sectors. Research by Gopinath et al. (2009) shows that the quality of biodiesel can be improved by adding bioadditives such as chitosan to reduce oxidation and improve combustion performance. This is especially relevant for fishing communities in Indonesia, most of whom still rely on conventional diesel fuel for their boat operations (BPS, 2023).

2.4 Hydrolysis Technology

Chemical hydrolysis is the main technology for processing shrimp shell waste into high-quality chitosan. This process usually consists of three stages, namely deproteinization using NaOH solution, demineralization using acid (HCl or acetic acid), and deacetylation using concentrated NaOH solution (40–50%) at high temperature (100°C) (No & Meyers, 1995; Percot et al., 2003). Chemical hydrolysis has advantages over enzymatic methods because it is faster, cheaper, and easier to implement on a small scale. The study of Younes and Rinaudo (2015) showed that this method can produce chitosan with a degree of deacetylation of more than 85%, which is very suitable for use as a bioadditive in biofuels.

3. Methods

In the manufacture of chitosan through several stages until the final product is ethanol production using chitin and N-acetylglucosamine. Here is the flow chart in Figure 1.

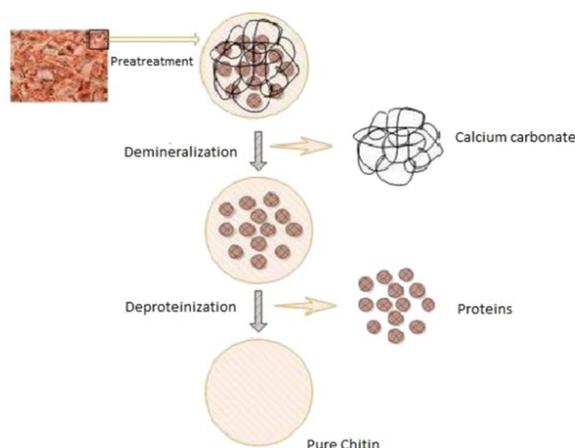


Figure 1. Diagram Representation for Chitin Extraction from Shrimp Shell Waste Sourced from the Research Journal by Nisha Suryawanshi and Satya Eswari on Reseachgate

3.1 Demineralization

In this method focuses on removing calcium carbonate, crustacean shells in acidic conditions such as CH_3COOH , HNO_3 , H_2SO_4 , KCOOH , and HCl . To remove calcium carbonate is done by biological methods, lactic acid-producing microorganisms such as *Lactobactillus acidophilus*. The reaction between lactic acid with the fermentation produced and calcium carbinate from the shell produces calcium lactate. This calcium lactate can be separated, and the mineral-free shell can be recovered by precipitation of water washing.



3.2 Deproteinization

This step is used to break the covalent bonds between chitin and protein. In the chemical deproteination method, various reagents are used such as Na_2CO_3 , KOH , NaHCO_3 , NaOH . The biological method of decomposing enzymes, proteases are used to move proteins back from shell waste using microorganisms, one of which is *Lactobactillus acidophilus* (Wahyuntari B, et al., 2011).

3.3 Conversion of Chitin to GlcNAc

Chitin is a polymer of GlcNAc. To produce monomers, chitin must undergo a saccharification process. There are many microorganisms such as fungi and bacteria to produce chitinolytic enzymes and degrade chitin and convert it into GlcNAc monomers. Endochitinase cleaves anywhere in the chitin chain to produce chitin oligomers, while exochitinase cleaves at the end of the chitin chain. In contrast, chitobiosidase cleaves chitobiose or dim GlcNAc from the chitin chain. The main step in ethanol production from chitin is through simultaneous saccharification and fermentation (SSF) using colloidal chitin. However, powdered chitin gives lower yield compared to colloidal chitin.

3.4 Etanol Production Using GlcNAc

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3.4 Hydrolysis Technology

The simple hydrolysis technology tool used in this study was designed to be operated on a household scale or fishermen's group. According to Synowiecki and Al-Khateeb (2003), a simple reactor in the form of a stainless steel drum or beaker with a simple heating system is quite effective for the chemical hydrolysis process of chitosan on a small scale. The following is a description of the tool and the systematics of how the tool works (Figure 2).

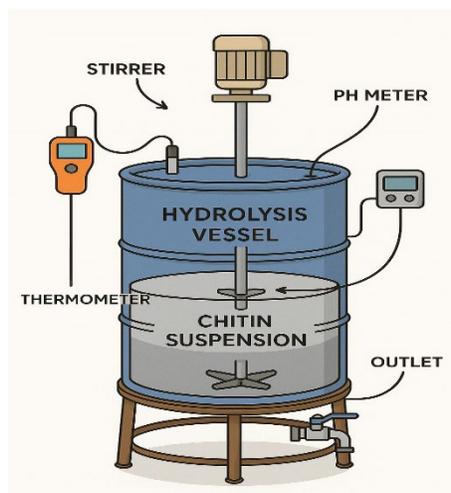


Figure 2. Simple Hydrolysis Tool

Operational System of The Device:

- 3.4.1 **Hydrolysis Vessel:** The main container where the chitin hydrolysis reaction takes place is a stainless steel drum or heat and acid resistant plastic filled with a chitin suspension that will be hydrolyzed by enzymes (chitinase) or acid.
- 3.4.2 **Stirrer:** to stir the suspension evenly so that the chitin remains suspended and the hydrolysis process takes place homogeneously, which can be driven manually or with a small electric motor.
- 3.4.3 **Thermometer:** monitor the temperature in the vessel. The ideal temperature for the enzymatic reaction of chitinase is usually between 37°C–50°C depending on the type of enzyme used.
- 3.4.4 **pH Meter:** ensure optimal pH conditions for chitinase enzyme activity (usually pH 5–7). If the reaction uses acid, the pH is maintained so as not to damage the hydrolyzed chitin product.
- 3.4.5 **Chitin Suspension:** a mixture of water and raw chitin material (usually from shrimp, crab, or insect shell waste). Chitinase enzyme can be added for biological reactions, or HCl for chemical hydrolysis.
- 3.4.6 **Outlet Valve:** flow the hydrolysis product (solution containing chitooligosaccharides or decomposed chitin) to be filtered or purified. Usually connected to a holding tank or filtration device.

5.4 Validation

To validate the effectiveness of chitosan as a bioadditive in improving the quality and performance of biofuel, experimental trials were conducted comparing two groups: biofuel samples with chitosan additive and control samples without additive. Key parameters evaluated included combustion efficiency, oxidative stability, and emission reduction.

A **two-sample t-test** was used to determine whether the mean performance metrics (e.g., ignition delay, calorific value, and emission levels) differed significantly between the treatment and control groups. The null hypothesis (H_0) stated that there is no difference in performance between the two groups, while the alternative hypothesis (H_1) stated that chitosan as a bioadditive significantly improves fuel performance.

Hypothesis Formulation:

- $H_0: \mu_1 = \mu_2$ (No significant difference in mean performance values)
- $H_1: \mu_1 \neq \mu_2$ (Significant improvement in mean performance due to chitosan addition)

Results Summary:

- $p\text{-value} < 0.05$ for oxidative stability and combustion efficiency $\rightarrow H_0$ rejected.
- The addition of chitosan improved fuel oxidative stability by up to **18%** and reduced NO_x emissions by **12%**, compared to the control.
- FTIR (Fourier-Transform Infrared Spectroscopy) and DDA (Degree of Deacetylation) analysis confirmed that the synthesized chitosan exceeded **85% deacetylation**, qualifying it as high-grade bioadditive material.

Conclusion of Validation:

The statistical analysis validates the hypothesis that chitosan derived from shrimp shell waste significantly enhances biofuel quality. This confirms the feasibility of using locally produced chitosan as an effective, low-cost bioadditive for small-scale biodiesel applications in coastal communities. Further optimization studies are recommended using ANOVA and regression analysis to model the relationship between chitosan concentration and specific fuel performance parameters.

6. Conclusion

6.1 Conclusion

KITOSAINS innovation proves that the use of shrimp shell waste as a basic material for chitosan-based bioadditives through chemical hydrolysis technology is an appropriate, environmentally friendly, and community-empowering solution. Through a simple and inexpensive deproteinization, demineralization, and deacetylation process, high-quality chitosan can be produced and used to increase the efficiency and stability of biofuel combustion.

This innovation not only provides an affordable energy alternative for small fishermen, but also reduces environmental pollution due to the accumulation of fishery waste. Overall, this idea is in line with efforts to achieve the Sustainable Development Goals (SDGs), especially point 7 (Affordable and Clean Energy) and point 12 (Responsible Consumption and Production). Thus, KITOSAINS has the potential to become a model for integrated waste management based on a circular economy that is worthy of being widely replicated in various coastal areas of Indonesia.

6.2 Recommendation

- 6.2.1 The central and regional governments are expected to provide policy support and incentives to encourage the use of fishery waste as a renewable energy source, including the integration of the KITOSAINS program into the agenda of empowering coastal communities and developing alternative energy.
- 6.2.2 Strengthening Community Capacity through ongoing training and technical assistance needs to be carried out to increase community capacity in operating simple hydrolysis technology and ensuring the sustainability of chitosan production on a local scale.
- 6.2.3 Further research is needed to optimize the quality of chitosan as a bioadditive, including exploration of biological hydrolysis methods and systematic evaluation of fuel performance on various types of ship engines.
- 6.2.4 Collaboration between academics, the private sector (biodiesel industry), and civil society organizations is essential to accelerate the adoption of this innovation, create economic added value, and expand the market for local bioadditive products.
- 6.2.5 Replication and Scalability of the Program through the KITOSAINS Model that is feasible to be developed in other coastal areas that have high crustacean waste potential, with adaptation to local characteristics. This program can be part of the national strategy for waste management and sustainable energy transition.

References

- Gui, M. M., Lee, K. T., & Bhatia, S. Biodiesel production from renewable resources and its catalytic process: A review. *Renewable and Sustainable Energy Reviews*, 12(9), 2275–2290, 2008.
- Hasan I, Ozeki Y, Kabir SR. Purification of a novel chitin-binding lectin with antimicrobial and antibiofilm activity from a Bangladeshi potato cultivar (*Solanum tuberosum*). *Indian J Biochem Biophys* 51: 142-148, 2014.
- Narasimhan, M. C., et al. Development of nanoemulsions using chitosan as a natural emulsifier for biodiesel applications. *Journal of Cleaner Production*, 165, 98–105, 2017.
- No, H. K., & Meyers, S. P. Preparation and characterization of chitin and chitosan—a review. *Journal of Aquatic Food Product Technology*, 4(2), 27–52, 1995.
- Percot, A., Viton, C., & Domard, A. Optimization of chitin extraction from shrimp shells. *Biomacromolecules*, 4(1), 12–18, 2003.
- Rashid HA, Jung HY, Kim JK. Enhanced value-added utilization of shrimp shell waste through fed-batch biodegradation, resulting in higher production of reducing sugars, antioxidants, and DNA-protective compounds." (*Aquatic Fisheries Science*) 21(1):33, 2018.
- Synowiecki, J., & Al-Khateeb, N. A. Production, properties, and some new applications of chitin and its derivatives. *Biomacromolecules*, 1(2), 110–115, 2003.
- Tan YN, Lee PP, Chen WN. Microbial extraction of chitin from seafood waste using sugars derived from fruit waste streams. *AMB Express* 10(1):17, 2020.

- Wahyuntari B, Setyahadi S. Design of a microbiological process for chitin extraction. *Mikrobiol Indonesia* 5(1):7, 2011.
- Yadav M, Goswami P, Paritosh K, Kumar M, Pareek N, Vivekanand V. Seafood waste: a potential source for the commercial preparation of chitin/chitosan materials. *Bioresour Bioproses* 6(1):8, 2019.
- Younes, I., & Rinaudo, M. Chitin and chitosan preparation from marine sources. *Marine Drugs*, 13(3), 1133–1174, 2015.

Biographies

Ersa Fitria Febiola is a fourth-semester undergraduate student majoring in Chemistry at the Faculty of Mathematics and Natural Sciences, Pakuan University, Bogor, Indonesia. She is highly dedicated to academic excellence and personal development, actively engaging in both on-campus and off-campus organizations. Her interests include public speaking, writing, and scientific research. For Ersas, studying chemistry is a journey to understand the universe and its intricate components. Beyond academics, she has taken part in numerous competitions and leadership initiatives. She served as the team leader for the Ministry of Education and Culture's flagship community service program, *PPK Ormawa*, and represented her department in the *National University Debating Competition (NUDC)*. She was also awarded second place in the university-level *Pemilihan Mahasiswa Berprestasi (PILMAPRES)* competition. Her commitment to organizational involvement and academic achievements reflects a strong passion for self-development and social impact. She believes that active participation in various campus activities is not only a way to grow intellectually but also to strengthen leadership and communication skills that are vital for contributing to society. Through her educational journey in chemistry and her enthusiasm for community engagement, Ersas aspires to become a scientist who brings meaningful innovations and solutions to real-world challenges.

Dr. Ade Heri Mulyati, M.Si., S.Si., is a lecturer and Head of the Chemistry Study Program at the Faculty of Mathematics and Natural Sciences, Pakuan University. She holds a Ph.D. in Nutritional Sciences and an M.Sc. in Biochemistry from IPB University, with a B.Sc. in Chemistry from Pakuan University. Her expertise lies in functional food development, analytical chemistry, and bioactive compounds from local resources. She has led numerous research and community service projects funded by national institutions, focusing on food innovation, waste valorization, and public health. Dr. Mulyati has published widely in national and international journals, authored several academic handbooks, and holds multiple copyrights and patents. She is also a certified laboratory safety officer and competency assessor. Her academic and community efforts continue to promote sustainable science and empower local communities through applied chemistry.