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Original Research Paper

Effectiveness of Different Binders in Improving Feed Stability and Survival Rate of Mud Crab (*Scylla sp.*) Fed Trash Fish-Based Diet

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Abstract: Feed stability is crucial in aquaculture to minimize nutrient loss and ensure optimal growth of cultured species. This study evaluated the effects of different binders (carboxymethyl cellulose/CMC, wheat gluten, tapioca flour, and Gracilaria sp. flour) at 3% and 5% concentrations, processed via hot and cold mixing methods, on feed stability and survival of mud crab (*Scylla spp.).* Conducted over 45 days, the research involved feed formulation, stability testing in seawater (30 ppt salinity), and a 30-day feeding trial in a recirculating aquaculture system. Results showed that binder type and processing method significantly influenced feed integrity, with CMC 5% + hot mixing exhibiting the highest stability (96.99% retention after 240 minutes), while tapioca 5% + hot mixing degraded fastest. All formulations met the ≥70% stability threshold after 120 minutes, confirming suitability for aquaculture. The feeding trial revealed 100% survival across all treatments, indicating that binder selection can prioritize physical stability without compromising crab health. Hot processing consistently enhanced binder performance, particularly for polysaccharide-based CMC and Gracilaria sp. flour. These findings suggest CMC 5% (hot) as the optimal binder for durable mud crab feed, whereas tapioca requires careful concentration control. The study provides practical insights for feed development, though further replicated trials under varied farming conditions are recommended to validate commercial applicability. This research contributes to sustainable aquaculture by improving feed efficiency and reducing waste in mud crab production.

Keywords: Feed binder; Feed Stability; Mud crab (*Scylla sp.*); Trash Fish; Survival Rate

Introduction

Aquaculture feed stability is a critical factor in ensuring optimal nutrient delivery and minimizing waste in aquatic farming systems (Amirkolaie, 2011; Hlaváč et al., 2014; Zaabwe et al., 2020). Feed that disintegrates rapidly in water leads to nutrient leaching, poor feed conversion ratios, and water pollution, ultimately affecting aquatic species' growth and survival (Bhambri & Karn, 2020; Mente et al., 2006). Mud crabs (*Scylla spp.*), an economically important species, require feed with high water stability to accommodate their slow feeding habits (Jaya-Ram et al., 2021; Viswanathan & Raffi, 2015). However, conventional binders such as carboxymethyl cellulose (CMC), wheat gluten, and tapioca flour exhibit varying degrees of effectiveness (Agustiyana et al., 2024; Ahamad Ali et al., 2010; Gao et al., 2020). Thus, evaluating different binder types and processing methods is essential to develop cost-effective and durable feed formulations for mud crab aquaculture.

The selection of appropriate binders and processing techniques significantly influences feed stability. Previous studies have

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demonstrated that binder concentration and mixing methods (hot vs. cold) affect feed integrity in water. For instance, polysaccharide-based binders like CMC form stable gels when heated, while protein-based binders such as wheat gluten provide structural reinforcement (Aksoy et al., 2022; Lopez & Richtering, 2021; Mediha et al., 2025; Megone et al., 2021; Ruscoe et al., 2005). However, comparative studies on their performance in mud crab feed remain limited. This study investigates the effects of different binders (CMC, wheat gluten, tapioca flour, and *Gracilaria* sp. flour) at varying concentrations (3% and 5%) and processing methods (hot and cold mixing) on feed stability and crab survival rates.

Feed formulation and processing techniques also play a crucial role in ensuring consistency and durability (Hardy & Brezas, 2022; Lapierre, 2005). In this study, trash fish meal was processed into a fine powder and mixed with other ingredients to produce a homogeneous dough. The feed was then shaped, dried, and subjected to stability testing in seawater to evaluate disintegration rates over time. The study followed established criteria, where feed with ≥70% stability after 120 minutes was considered acceptable for aquaculture use. By comparing different binder formulations, this research aims to identify the most effective combination for mud crab feed production. Beyond feed stability, the study also assessed the impact of different binder formulations on mud crab survival in a controlled recirculating aquaculture system. A 30-day feeding trial was conducted using the best-performing binders from the stability tests (CMC and wheat gluten at 3% and 5% concentrations).

Given the increasing demand for sustainable aquaculture practices, optimizing feed formulations is essential to enhance productivity and reduce environmental impact (Gencer, 2025; Hoerterer et al., 2022) This study contributes to the growing body of knowledge on mud crab nutrition by providing empirical data on binder efficacy and processing methods. The findings highlight the superiority of CMC (5%) with hot mixing in maintaining feed stability, while also demonstrating that alternative binders like wheat gluten and *Gracilaria sp*. flour are viable options. Further research with replication under different farming conditions, growth performance and feed efficiency are recommended to validate these preliminary findings and refine feed formulations for commercial mud crab aquaculture.

Materials and Methods

Research Time and Location

This study was conducted over 45 days, from August 16 to September 30, 2024, in Empol Hamlet, Empol Preparatory Village, Sekotong District, West Lombok Regency, and at the Fish Nutrition Laboratory, Faculty of Agriculture, University of Mataram.

Research Method

This study employed an experimental and preliminary exploratory design without replication. The independent variables (treatments) consisted of different binder types (carboxymethyl cellulose/CMC, wheat gluten, tapioca flour, and *Gracilaria sp*. flour) at concentrations of 3% and 5%, processed using hot and cold mixing methods (Bonilla et al., 2020; He et al., 2020). The dependent variable was feed stability (%) at different immersion times (30, 60, 120, and 240 minutes).

Follow-Up Feeding Trial

Based on the best feed stability results, wheat gluten and CMC (3% and 5%) were selected as binders for crab feed in a subsequent 30-day apartment culture system trial.

Equipment and Materials

The study utilized aquaculture and feed production equipment. For crab culture, a recirculating crab apartment system equipped with water pumps, aerators, water filters, tubing, and airstones was employed (Agustiyana et al., 2024; Sukardi et al., 2024; Usman et al., 2024). Feed preparation involved sieves, mixing bowls, steamers, stoves, ovens, meat grinders, choppers, and feed storage containers. Water quality parameters were monitored using a DO meter, pH meter, thermometer, and refractometer, while digital scales, buckets, and ladles were used for practical purposes.

Research materials comprised feed ingredients and supplementary materials. Feed binders included CMC, wheat gluten, and tapioca flour, while feed ingredients consisted of trash fish, shrimp head meal, and fish oil (Agustiyana et al., 2024; Ahamad Ali et al., 2010; Gao et al., 2020; Johny et al., 2020; Liu, Cao, et al., 2022; Yusoff et al., 2021). A vitamin-mineral mix was supplemented, with supporting materials including seawater, food-grade silica gel, plastic, and latex for experimental purposes. All materials and equipment were selected to support successful mud crab aquaculture research.

Research Procedure

Fishmeal Preparation

Trash fish processing began with sun-drying for approximately three days. Filleting was performed manually using knives, sectioning from below the head to near the tail. Whole fish were rinsed with freshwater, drained, and sun-dried on plastic trays. The dried product was ground and sieved through an 80-mesh screen to produce uniform fishmeal (Brooks MS, 2013; Diamahesa et al., 2024; Fu et al., 2024; Kousoulaki et al., 2022; P et al., 2024; Yao et al., 2024). Other flour ingredients underwent identical sieving to ensure consistency

Feed Formulation

Feed production commenced with ingredient preparation. Dry materials (fishmeal, wheat flour, sago flour, wheat gluten, and seaweed flour) were sieved through an 80-mesh screen. Precisely weighed ingredients were mixed uniformly before adding binders (CMC) and functional additives (vitamin mix, mineral mix, lecithin). Fish oil and water were incorporated gradually to achieve a homogeneous, kneadable dough. The mixture was molded into cubes using a cookie cutter. The formulated feed was oven-dried at 50-60°C to <10% moisture content, then stored in airtight containers with silica gel to prevent mold growth. Feed quality was verified through water stability testing, evaluating disintegration rates after 0, 30, 60, 120, and 240 minutes of seawater immersion (Aksoy et al., 2022; Cheng & Sørensen, 2025; Zaabwe et al., 2020).

Feed Stability Test

This study evaluated the stability of formulated mud crab feed using two binder types (wheat gluten and CMC) at concentrations of 3% and 5%. The key distinction between hot and cold mixing methods lay in water temperature during binder incorporation. The hot method utilized boiling water to create a homogeneous gel binder prior to mixing with feed ingredients, whereas the cold method employed room-temperature water for binder dissolution. Feed pellets were immersed in seawater (30 ppt salinity, 28-30°C) to assess stability. Samples were retrieved at 0, 30, 60, 120, and 240-minute intervals, then drained and weighed to determine mass loss percentage through disintegration. Feed stability criteria required ≥70% weight retention after 120 minutes (Dominy et al., 2004; Ferreira et al., 2020). Comparative analysis of binder performance across concentrations identified optimal formulations.

Survival Rate Assessment

Ten Mud crabs (*Scylla spp.)* were selected for each treatment based on uniform size and physical condition. Following initial weighing, specimens underwent 7-day acclimation in controlled recirculating systems, with 3-day fasting prior to treatment initiation to purge digestive tracts. Experimental groups (CMC/wheat gluten at 3% and 5% concentrations) were maintained in separate apartment tanks with aeration and shelter to minimize stress. Over 30 days, crabs were fed experimental diets once daily ad satiation. Daily 80-100% water exchange via siphoning maintained water quality while monitoring mortality and physical condition. Survival rate was calculated as the percentage of crabs surviving to trial completion relative to initial stock.

Data Analysis

The feed stability and mud crab (*Scylla spp.*) survival rate data obtained during the trial period were analyzed descriptively using Microsoft Excel and presented graphically to visualize treatment performance trends. Comparative analysis focused on identifying optimal binder formulations through temporal stability patterns and survival outcomes.

Results and Discussion

Cold Water Method

The study revealed significant variations in feed stability across binder types, concentrations, and processing methods. All treatments exhibited progressive stability decline during 30 – 240 minute immersion periods. Under cold processing: Tapioca 3% demonstrated peak initial stability (99.45%). Wheat Gluten 5% and CMC 5% showed comparable performance (99.43% and 98.71% respectively).

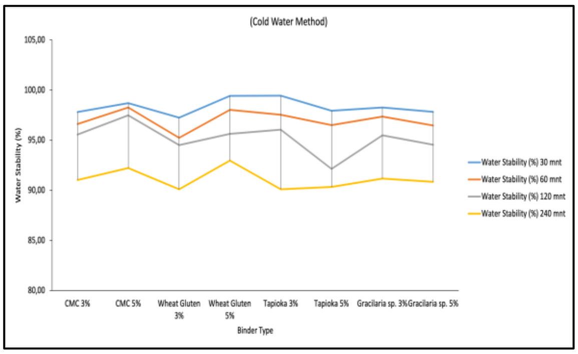

Figure 1. Water Stability of Feed (Cold Method) at Different Immersion Times

However, after 240 minutes, stability values decreased to 90.10-92.98% (Figure 1), indicating: Concentration-dependent degradation patterns, time-sensitive binder efficacy, and critical threshold of ≥70% stability maintenance.

Hot Water Method

The hot mixing method demonstrated a distinct and superior performance pattern. CMC 5% with hot processing maintained consistently high stability throughout the immersion period, ranging from 99.45% (30 minutes) to 96.99% (240 minutes). In contrast, Tapioca 5% with hot processing showed the most significant stability decline, decreasing from 92.04% to 88.87% over the same duration (Figure 2).

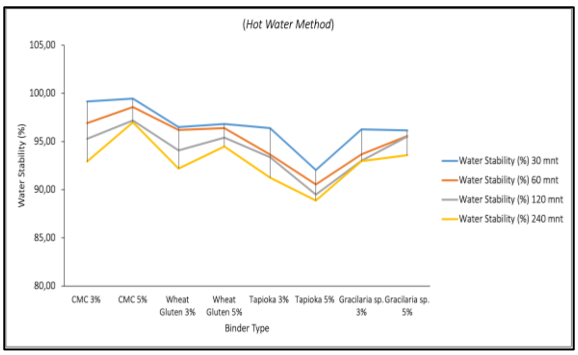

Figure 2. Water Stability of Feed (Hot Method) at Different Immersion Times

The results demonstrate that the interaction between processing method and binder type significantly influences feed stability. Hot mixing proved more effective in maintaining feed integrity, particularly when combined with CMC 5% (Figure 2), which showed the highest stability retention (96.99%) after 240 minutes of immersion.

Survival Rate

The analysis revealed that the survival rate of mud crabs (Scylla spp.) remained optimal across all feed formulations containing different binder types (Figure 3).

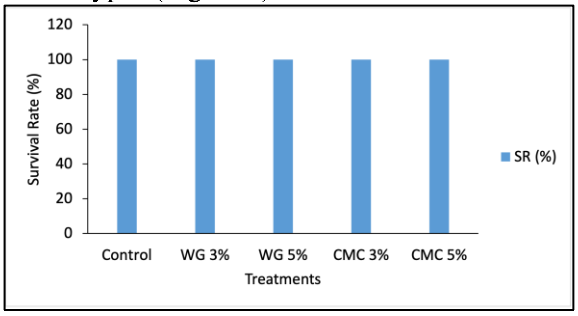

Figure 3. Survival Rate of Mud Crabs Fed Different Binder Formulations (30-Day Trial)

The consistent 100% survival rate indicates that binder selection for mud crab feed can be primarily based on physical stability parameters, as all tested formulations proved equally effective in supporting crab survival under the given experimental conditions. This finding is particularly significant for feed development, as it allows for binder selection to focus on optimizing feed stability without compromising animal health outcomes.

Discussion

Cold Water Method

This study demonstrates that cold processing methods significantly influence feed stability, with variations depending on binder type and concentration. Tapioca at 3% exhibited the highest initial stability (99.45%), followed by wheat gluten at 5% (99.43%) and CMC at 5% (98.71%). These findings align with (Kaveh et al., 2021), who reported tapioca's effectiveness as a cold-condition binder due to its stable gel-forming properties. However, the decline in stability after 240 minutes (90.10–92.98%) indicates that binder selection must account for long-term durability, particularly for aquaculture applications requiring ≥70% stability (Dominy et al., 2004).

The performance differences among binders can be attributed to their functional properties. Wheat gluten, for instance, demonstrated high stability due to its ability to form robust protein networks (Aksoy et al., 2022), while CMC relies on its hydrocolloid properties to maintain feed integrity (Liu, Fan, et al., 2022). Yet, the progressive stability loss across all treatments confirms that environmental factors (e.g., water temperature and salinity) also play critical roles. This reinforces (du Pontavice, 2019)'s conclusion that binder-aquatic environment interactions require optimization for practical applications.

Hot Water Method

The results demonstrate that binder type and heating method significantly influence feed water stability. CMC 5% with hot mixing exhibited optimal stability, attributed to its enhanced viscosity at elevated temperatures. This characteristic enabled superior structural integrity during water immersion, establishing it as the preferred choice for aquaculture feed formulations. Conversely, tapioca 5% (hot) showed the most pronounced stability decline, likely due to its gelatinization properties accelerating feed disintegration under prolonged heat and water exposure (Russ et al., 2016). While tapioca is commonly used as a binder, these findings suggest its application in high concentrations with hot processing requires careful evaluation to prevent feed fragility.

Comparative analysis revealed hot mixing consistently improved feed stability, particularly for CMC and wheat gluten binders. The optimal gelatinization achieved through hot processing appears crucial, especially for polysaccharide-based binders like CMC and *Gracilaria sp.* (maintaining 93.58% stability after 4 hours). All formulations met the minimum stability threshold (>70%), confirming hot mixing as a viable strategy for high-durability feeds (Dominy et al., 2004; Ferreira et al., 2020). Although this study lacked replicates, the consistent patterns provide valuable preliminary data for crab feed development. The findings emphasize that binder selection and processing methods must align with stability targets. CMC 5% (hot) and *Gracilaria* sp. 5% (hot) emerge as prime candidates, whereas tapioca requires concentration limitations or modifications to prevent rapid disintegration. Further studies with replication under varied aquaculture conditions are recommended to validate these results.

Survival Rate

The 30-day culture trial investigating various binder formulations for mud crab (*Scylla spp.*) feed yielded consistently positive results, with all treatment groups maintaining a 100% survival rate and showing no mortality throughout the experimental period. Both CMC and wheat gluten binders, tested at 3% and 5% concentrations, demonstrated excellent capacity to support crab viability, indicating that all formulated feeds adequately met the nutritional requirements of the mud crabs without adversely affecting their health or survival (Liu, Cao, et al., 2022; Liu, Fan, et al., 2022).

These findings confirm that the different binder types and concentrations tested maintained sufficient feed palatability while fulfilling the crabs' dietary needs. Importantly, the results suggest that binder selection for mud crab feed formulations can be primarily guided by stability performance parameters, as the tested binders showed equivalent effectiveness in supporting survival outcomes. This provides feed developers with valuable flexibility in optimizing feed physical properties through binder choice without compromising the nutritional quality or zootechnical performance of the feed. The consistent survival rates across all experimental groups underscore the robustness of these binder options for mud crab aquaculture applications.

Conclusion

This study concludes that carboxymethyl cellulose (CMC) at 5% concentration with hot mixing is the most effective binder for mud crab feed, demonstrating superior water stability (96.99% retention after 240 minutes) while maintaining a 100% survival rate in crabs. While wheat gluten and Gracilaria sp. flour also performed well, tapioca flour showed limitations at higher concentrations under heated conditions. The findings highlight that hot processing enhances binder performance, and feed formulations can prioritize physical stability without compromising nutritional adequacy.

Further research should validate these results under commercial-scale conditions and assess growth performance to optimize sustainable mud crab aquaculture feed production

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References

Agustiyana, C., Hadiroseyani, Y., Diatin, I., & Effendi, I. (2024). Optimization of the production of soft shell crab (Scylla sp.) cultivation using the apartment system. *Egyptian Journal of Aquatic Research*, *50*(4), 552–557. https://doi.org/10.1016/j.ejar.2024.05.003

Ahamad Ali, S., Gopal, C., Ramana, J. V., Sampoornam, B., Vasu, C. A., Vaitheeswaran, T., & Selvakumar, P. (2010). Evaluation of selected binders in a ring-die pellet mill for processing shrimp feed pellets. *Indian Journal of Fisheries*, *57*(1), 103–106.

Aksoy, B., Yildirim-Aksoy, M., Jiang, Z., & Beck, B. (2022). Novel animal feed binder from soybean hulls -evaluation of binding properties. *Animal Feed Science and Technology*, *288*, 115292. https://doi.org/10.1016/j.anifeedsci.2022.115292

Amirkolaie, A. K. (2011). Reduction in the environmental impact of waste discharged by fish farms through feed and feeding. *Reviews in Aquaculture*, *3*(1), 19–26. https://doi.org/10.1111/j.1753-5131.2010.01040.x

Bhambri, A., & Karn, S. K. (2020). Biotechnique for nitrogen and phosphorus removal: a possible insight. *Chemistry and Ecology*, *36*(8), 785–809. https://doi.org/10.1080/02757540.2020.1777991

Bonilla, J. C., Erturk, M. Y., Schaber, J. A., & Kokini, J. L. (2020). Distribution and function of LMW glutenins, HMW glutenins, and gliadins in wheat doughs analyzed with 'in situ' detection and quantitative imaging techniques. *Journal of Cereal Science*, *93*, 102931. https://doi.org/10.1016/j.jcs.2020.102931

Brooks MS, R. V. (2013). Fish Processing Wastes as a Potential Source of Proteins, Amino Acids and Oils: A Critical Review. *Journal of Microbial & Biochemical Technology*, *05*(04). https://doi.org/10.4172/1948-5948.1000110

Cheng, H., & Sørensen, M. (2025). Feed manufacturing technology. In *Feed and Feeding for Fish and Shellfish* (pp. 279–307). Elsevier. https://doi.org/10.1016/B978-0-443-21556-8.00008-9

Diamahesa, W. A., Setyono, B. D. H., Affandi, R. I., & Diniariwisan, D. (2024). Potensi dan Kadar Nutrisi Ikan Rucah yang Didaratkan di pantai Ampenan, Nusa Tenggara Barat. *Jurnal Perikanan Unram*, *13*(4), 971–978. https://doi.org/10.29303/jp.v13i4.718

Dominy, W. G., Cody, J. J., Terpstra, J. H., Obaldo, L. G., Chai, M. K., Takamori, T. I., Larsen, B., & Forster, I. P. (2004). A Comparative Study of the Physical and Biological Properties of Commercially-Available Binders for Shrimp Feeds. *Journal of Applied Aquaculture*, *14*(3–4), 81–99. https://doi.org/10.1300/J028v14n03_07

du Pontavice, H. (2019). Changing biomass flows in marine ecosystems: from the past to the future. In *Predicting Future Oceans* (pp. 121–128). Elsevier. https://doi.org/10.1016/B978-0-12-817945-1.00012-5

Ferreira, M. L. S., da Silva, F. M., dos Santos, M. C., Lucena, J. E. C., Sado, R. Y., & Bicudo, Á. J. de A. (2020). Heat-treated bean (Phaseolus vulgaris) residue meal as an alternative protein source in pelleted diets for Nile tilapia fingerlings: growth, body composition, and physical characteristics of diets. *Tropical Animal Health and*

Production, *52*(5), 2443–2450. https://doi.org/10.1007/s11250-020-02266-x

Fu, J., He, Y., & Cheng, F. (2024). Intelligent Cutting in Fish Processing: Efficient, High-quality, and Safe Production of Fish Products. *Food and Bioprocess Technology*, *17*(4), 828–849. https://doi.org/10.1007/s11947-023-03163-5

Gao, S., Han, D., Zhu, X., Yang, Y., Liu, H., Xie, S., & Jin, J. (2020). Effects of gelatin or carboxymethyl cellulose supplementation during pelleting processing on feed quality, intestinal ultrastructure and growth performance in gibel carp (Carassius gibelio). *Aquaculture Nutrition*, *26*(4), 1244–1254. https://doi.org/10.1111/anu.13080

Gencer, Ö. (2025). Dietary ınnovation in blue crab aquaculture: effects on performance and product quality. *Aquaculture International*, *33*(3), 1–12. https://doi.org/10.1007/s10499-025-01899-9

Hardy, R. W., & Brezas, A. (2022). Diet formulation and manufacture. In *Fish Nutrition* (pp. 643–708). Elsevier. https://doi.org/10.1016/B978-0-12-819587-1.00002-1

He, Y., Liu, S., Ji, T., Kong, Y., & Shui, L. (2020). Effects of Organosilane-modified PCE on the Fluidity and Hydration Properties of Cement-Fly Ash Composite Binder. *Journal of Wuhan University of Technology-Mater. Sci. Ed.*, *35*(6), 1081–1089. https://doi.org/10.1007/s11595-020-2358-6

Hlaváč, D., Adámek, Z., Hartman, P., & Másílko, J. (2014). Effects of supplementary feeding in carp ponds on discharge water quality: a review. *Aquaculture International*, *22*(1), 299–320. https://doi.org/10.1007/s10499-013-9718-6

Hoerterer, C., Petereit, J., Lannig, G., Johansen, J., Conceição, L. E. C., & Buck, B. H. (2022). Effects of dietary plant and animal protein sources and replacement levels on growth and feed performance and nutritional status of market-sized turbot (Scophthalmus maximus) in RAS. *Frontiers in Marine Science*, *9*. https://doi.org/10.3389/fmars.2022.1023001

Jaya-Ram, A., Wong, S. C., & Shahirah, E. S. N. (2021). Feeding preference of juvenile mud crab (Scylla olivacea, Herbst, 1896) in captivity. *Journal of Survey in Fisheries Sciences*, *7*(2), 189–198. https://doi.org/10.18331/SFS2021.7.2.16

Johny, A., Berge, G. M., Bogevik, A. S., Krasnov, A., Ruyter, B., Fæste, C. K., & Østbye, T.-K. K. (2020). Sensitivity to Dietary Wheat Gluten in Atlantic Salmon Indicated by Gene Expression Changes in Liver and Intestine. *Genes*, *11*(11), 1339. https://doi.org/10.3390/genes11111339

Kaveh, Z., Azadmard-Damirchi, S., Yousefi, G., & Hashem Hosseini, S. M. (2021). A new approach in improving granular cold water swelling starch properties using xanthan gum and β-lactoglobulin/xanthan gum electrostatic coupled gel. *Food Hydrocolloids*, *113*, 106438. https://doi.org/10.1016/j.foodhyd.2020.106438

Kousoulaki, K., Sveen, L., Norén, F., & Espmark, Å. (2022). Atlantic Salmon (Salmo salar) Performance Fed Low Trophic Ingredients in a Fish Meal and Fish Oil Free Diet. *Frontiers in Physiology*, *13*. https://doi.org/10.3389/fphys.2022.884740

Lapierre, O. (2005). Système des acteurs et stratégie de formulation. *Oléagineux, Corps Gras, Lipides*, *12*(3), 217–223. https://doi.org/10.1051/ocl.2005.0217

Liu, Y., Cao, Y., Zhang, Y., Fan, J., Zhou, H., Huang, H., Jiang, W., Zhang, W., Deng, J., & Tan, B. (2022). Intestinal flora and immunity response to different viscous diets in juvenile largemouth bass, Micropterus salmoides. *Fish & Shellfish Immunology*, *127*, 1012–1023. https://doi.org/10.1016/j.fsi.2022.06.054

Liu, Y., Fan, J., Zhou, H., Zhang, Y., Huang, H., Cao, Y., Zhang, W., Deng, J., & Tan, B. (2022). Feeding juvenile largemouth bass (Micropterus salmoides) with carboxymethyl cellulose with different viscous: Impacts on nutrient digestibility, growth, and hepatic and gut morphology. *Frontiers in Marine Science*, *9*. https://doi.org/10.3389/fmars.2022.1023872

Lopez, C. G., & Richtering, W. (2021). Oscillatory rheology of carboxymethyl cellulose gels: Influence of concentration and pH. *Carbohydrate Polymers*, *267*, 118117. https://doi.org/10.1016/j.carbpol.2021.118117

Mediha, Y.-A., Aksoy, B., Ozdemir, Y. E., Beck, B. H., Aksoy, J., & Iglesias, M. C. (2025). Full utilization of liberated and modified fibers from plant biomass as feed binders. *Journal of Agriculture and Food Research*, *21*, 101909. https://doi.org/10.1016/j.jafr.2025.101909

Megone, W., Tang, P., Roohpour, N., & Gautrot, J. E. (2021). Impact of the molecular structure of cationic binders on the rheological and adhesive properties of carboxymethyl cellulose-based coacervate hydrogels. *Arkivoc*, *2021*(6), 101–119. https://doi.org/10.24820/ark.5550190.p011.516

Mente, E., Pierce, G. J., Santos, M. B., & Neofitou, C. (2006). Effect of feed and feeding in the culture of salmonids on the marine aquatic environment: a synthesis for European aquaculture. *Aquaculture International*, *14*(5), 499–522. https://doi.org/10.1007/s10499-006-9051-4

P, J., Machavaram, R., Jana, P., Paradkar, V., & Sahu, G. (2024). Development and Testing of a Small-Scale Fish Filleting Machine for an Indian Major Carp, Rohu (Labeo rohita). *Journal of Aquatic Food Product Technology*, *33*(9), 747–764. https://doi.org/10.1080/10498850.2024.2430236

Ruscoe, I. M., Jones, C. M., Jones, P. L., & Caley, P. (2005). The effects of various binders and moisture content on pellet stability of research diets for freshwater crayfish. *Aquaculture Nutrition*, *11*(2), 87–93. https://doi.org/10.1111/j.1365-2095.2004.00324.x

Russ, N., Zielbauer, B. I., Ghebremedhin, M., & Vilgis, T. A. (2016). Pre-gelatinized tapioca starch and its mixtures with xanthan gum and ι-carrageenan. *Food Hydrocolloids*, *56*, 180–188. https://doi.org/10.1016/j.foodhyd.2015.12.021

Sukardi, R. W., Saade, E., Zainuddin, & Abustang. (2024). Utilization of gutter in fattening Mangrove Crabs, Scylla olivacea consuming GEL feed containing various shrimp paste origins as attractant with vertical crab house systems and RAS. *IOP Conference Series: Earth and Environmental Science*, *1410*(1), 012022. https://doi.org/10.1088/1755-1315/1410/1/012022

Usman, Z., Alauddin, M. H. R., Anton, Yunarty, Ihwan, Syahrir, M., Budiyati, Supryady, Leilani, A., Saridu, S. A., Wahid, E., Renitasari, D. P., Rasnijal, M., Hardianto, T., Regan, Y., & Kurniaji, A. (2024). Mud crabs (Scylla olivacea) fattening in recirculating aquaculture system (RAS) using vertical gallons crab house with different feed types. *IOP Conference Series: Earth and Environmental Science*, *1410*(1), 012020. https://doi.org/10.1088/1755-1315/1410/1/012020

Viswanathan, C., & Raffi, S. M. (2015). The natural diet of the mud crab Scylla olivacea (Herbst, 1896) in Pichavaram mangroves, India. *Saudi Journal of Biological Sciences*, *22*(6), 698–705. https://doi.org/10.1016/j.sjbs.2015.08.005

Yao, T., Jing, Y., Lu, Y., Liu, W., Lyu, J., Zhang, X., & Chang, S. (2024). Recognition of catfish fillets using computer vision toward automated singulation. *Journal of Food Process Engineering*, *47*(9). https://doi.org/10.1111/jfpe.14726

Yusoff, N. A. H., Zakariah, M. I., Mohamad, J., Rahmah, S., & Hassan, M. (2021). Evaluation of Carboxymethyl Cellulose (CMC) Binder and Squid Oil Attractant in the Formulation of Litopenaeus vannamei Diet. *Jurnal Ilmiah Perikanan Dan Kelautan*, *13*(2), 279–287. https://doi.org/10.20473/jipk.v13i2.24428

Zaabwe, T., Singini, W., Kang'ombe, J., Kapute, F., & Mbamba, D. (2020). An Evaluation of Water Pellet Stability of two Iso-proteineous Floating and Sinking Diets. *Egyptian Journal of Aquatic Biology and Fisheries*, *24*(7), 211–318. https://doi.org/10.21608/ejabf.2020.120615