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Phytobiotic potential of clove *(Syzygium aromaticum)* in shrimp aquaculture: Effects on the growth trajectory and survival of *Penaeus monodon*

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Abstract
The intensification of *Penaeus monodon* (black tiger shrimp) aquaculture has necessitated the development of sustainable, eco-friendly alternatives to synthetic chemotherapeutics to manage stress, disease, and sub-optimal feed utilization. This commercial-scale study evaluated the efficacy of dietary clove (*Syzygium aromaticum*) extract, a potent phytobiotic rich in eugenol, on the growth performance, feed conversion ratio (FCR), and survival of *P. monodon*. Shrimp were reared in 0.6-hectare ponds and fed a commercial basal diet top-coated with either 0 g/kg (Control) or 10 g/kg (1%) clove extract from day 50 to harvest (149-157 days of culture). Results indicated that 1% clove supplementation significantly enhanced growth metrics, yielding a final average body weight of 64.51 g and a daily growth rate of 0.411 g/day, compared to 52.63 g and 0.353 g/day in the control group. Furthermore, dietary clove dramatically improved feed utilization efficiency, lowering the FCR from 2.39 to 2.10. The survival rate also saw a substantial increase, reaching 95% in the clove-treated pond against 85% in the control, culminating in a total harvest biomass of 8,580 kg versus 6,262 kg. The observed enhancements in growth, FCR, and survival are attributed to the well-documented stress-mitigating, antimicrobial, and digestive-stimulating properties of clove bioactive compounds. Ultimately, this study demonstrates that dietary clove supplementation is a highly viable, natural performance enhancer capable of maximizing profitability and sustainability in commercial black tiger shrimp production.

Keywords: *Penaeus monodon*, clove, growth, feed conversion ratio (FCR), survival rate

Introduction
The global expansion of shrimp aquaculture has been instrumental in meeting the rising demand for high-quality aquatic protein, with species such as the black tiger shrimp (*Penaeus monodon*) playing a historically significant and commercially vital role. However, the intensification of culture systems has inadvertently amplified the vulnerability of shrimp to environmental stressors and pathogenic outbreaks, such as White Spot Syndrome Virus (WSSV) and vibriosis. Consequently, unpredictable survival rates and sub-optimal feed utilization—quantified by elevated Feed Conversion Ratios (FCR)—remain primary constraints to the economic viability and sustainability of the industry. Historically, these challenges were managed through the prophylactic use of chemotherapeutics and antibiotics. Yet, the emergence of antimicrobial resistance and stringent regulatory pressures have necessitated a critical shift toward eco-friendly, natural alternatives (Dawood *et al*., 2022; Dien *et al*., 2023; Rabelo-Ruiz *et al*., 2023) [3, 4, 9].
Phytobiotics, or plant-derived feed additives, have emerged as highly effective tools for enhancing aquatic animal health and growth performance. These compounds are considered inexpensive alternative immunostimulants that are biofriendly and biodegradable (Hoseinifar *et al*., 2020; Labsan *et al*., 2026) [6, 8]. Among these, clove (*Syzygium aromaticum*) represents a potent, multifactorial candidate. Rich in essential oils, predominantly eugenol, clove exhibits well-documented antimicrobial, antioxidant, and anti-inflammatory properties. In the context of aquaculture, these bioactive compounds are theorized to modulate gut microbiota, enhance digestive enzyme activity, and bolster the non-specific immune response of crustaceans. Recent studies on *P. monodon* indicate that the inclusion of plant-derived extracts and additives in diets can significantly improve immunological parameters, decrease oxidative stress, and lower FCR, leading to better disease resistance and consequently higher survival rates (Hardi *et al*., 2017; Ali *et al*., 2024; Yang *et al*., 2024) [1, 5, 11].
Furthermore, by promoting intestinal health and nutrient absorption, the dietary inclusion of clove has the potential to optimize FCR, turning feed inputs into biomass more efficiently. The inherent anesthetic and stress-mitigating properties of eugenol also play a vital role in intensive rearing conditions. By reducing metabolic exhaustion caused by crowding, handling, or fluctuating water quality, clove and eugenol supplementation can structurally improve overall resilience. Pharmacokinetic studies confirm that eugenol is effectively absorbed and serves to maximize survival rates during vulnerable growth stages in penaeid shrimp (Becker *et al*., 2021; Tang *et al*., 2022) [2, 10]. While the pharmacological benefits of clove are recognized across several aquatic species, precise empirical data regarding its optimal dosage and long-term effects on the feed dynamics of *P. monodon* requires further investigation.
Therefore, the present study aims to evaluate the efficacy of dietary clove supplementation on the growth performance, feed utilization (FCR), and overall survival of *P. monodon* under controlled culture conditions. The findings will provide actionable insights into the use of natural phytobiotics to optimize commercial black tiger shrimp production.

Materials and Methods
1. Preparation of Experimental Diets
A high-quality commercial pelleted feed formulated for *Penaeus monodon* was utilized as the basal diet. The experimental treatment was prepared by supplementing this commercial feed with clove at a precise dosage of 10 g per

kg of feed (10 g/kg). To ensure proper adhesion of the additive to the feed matrix and to minimize leaching of the bioactive compounds into the culture water, the clove preparation was mixed with a commercial binder and uniformly top-coated onto the feed pellets. A control diet was similarly prepared by coating the commercial feed with only the binder and an equivalent volume of water, without the clove supplement. The top-coated diets were air-dried at room temperature for 24 hours until the moisture content stabilized, and were subsequently stored in airtight, dark containers at 4°C until daily use.

2. Experimental Animals and Rearing Conditions

The feeding trial was integrated into the grow-out phase of *P. monodon*. Shrimp were cultivated using standard commercial protocols for the first 50 days. On day 50 of culture, apparently healthy shrimp of uniform size were selected, bulk-weighed, and randomly distributed into the experimental units. The experimental feeding period was conducted over an 80-day period, spanning from day 50 to day 130 of the culture cycle. The shrimp were allocated into designated treatment groups: a Control group (0 g/kg clove) and the Treatment group (10 g/kg clove), with appropriate replicates for each group. During this 80-day period, shrimp were fed their respective designated diets four times daily. The daily feeding ration was adjusted based on regular sampling of body weight and visual assessments of feed consumption on feeding trays to prevent overfeeding and maintain optimal water quality. Routine water quality management was strictly maintained, with parameters such as dissolved oxygen, temperature, salinity, and pH monitored daily to ensure they remained well within the optimal physiological limits for black tiger shrimp.

3. Determination of Growth, FCR, and Survival Rate

At the conclusion of the trial (day 130 of culture), all surviving shrimp from each experimental unit were harvested, counted, and batch-weighed. Prior to the final weighing, shrimp were fasted for 24 hours to ensure complete evacuation of the digestive tract. The collected data was used to calculate overall growth performance, feed utilization efficiency (FCR), and survival rate over the 80-day experimental phase. The calculations were performed using the following standard equations:

- Feed Conversion Ratio (FCR) = Total dry feed consumed during trial (g) / Total wet weight gain (g)
- Survival Rate (SR, %) = 100 × (Final number of shrimp Harvesting / Initial number of shrimp at Stocking)

Results

The comparative production performance of *P. monodon* reared with and without dietary clove supplementation at the Kantiyajal site is summarized based on the harvest data. Both the Control (Pond 1) and Clove-treated (Pond 2) groups were stocked at identical densities of 140,000 post-larvae in 0.6-hectare ponds. The culture period lasted for 149 days for the Control and 157 days for the Clove treatment.

Table 1: Production Performance of Penaeus monodon Reared with and without Clove Supplementation

Treatment	Site	Pond	Stocking	Pond Size (ha)	Days of Culture	Survival (%)	Total Biomass (kg)	Final Average Body Weight (g)	Overall Daily Growth (g/day)	Final Count (pieces/kg)
Control (0%)	Kantiyajal	1	140,000	0.6	149	85	6,262	52.63	0.353	21
Clove (1%)	Kantiyajal	3	140,000	0.6	157	95	8,580	64.51	0.411	15.5

Growth parameters were markedly enhanced in the clove-supplemented group. The final average body weight of shrimp fed the 1% clove diet reached 64.51 g, representing a substantial increase compared to the 52.63 g observed in the Control group. This accelerated growth is further evidenced by the overall daily growth rate, which was 0.411 g/day in the clove treatment versus 0.353 g/day in the control. Consequently, the final harvest count for the clove-treated pond was notably larger at 15.5 pieces/kg, compared to 21 pieces/kg in the control pond.

Survival and total production biomass also demonstrated clear improvements. The survival rate in the clove-treated pond was excellent at 95%, a 10% absolute increase over the Control pond's 85% survival rate. This higher survival, combined with the increased individual body weight, culminated in a total harvested biomass of 8,580 kg for the clove treatment, vastly outperforming the 6,262 kg harvested from the control pond. Regarding feed utilization efficiency, the Clove-treated shrimp consumed a total of 18,018 kg of feed to produce the 8,580 kg of biomass, resulting in a Feed Conversion Ratio (FCR) of 2.10. In contrast, the Control group consumed 15,025 kg of feed for a yield of 6,262 kg, yielding a notably higher and less efficient FCR of 2.39. These results indicate that dietary inclusion of clove significantly optimizes feed conversion into harvestable biomass.

Discussion

The present commercial-scale trial demonstrates that dietary supplementation of clove at 1% (10 g/kg) significantly enhances the growth trajectory, survival, and feed utilization efficiency of black tiger shrimp (*P. monodon*). The pressing need to replace synthetic chemotherapeutics in aquaculture has driven research toward phytobiotics, and our findings strongly support the commercial viability of clove extracts as functional feed additives (Dawood *et al*., 2022) [3].

A primary finding of this study is the notable improvement in Feed Conversion Ratio (FCR), which dropped from 2.39 in the control to 2.10 in the clove-treated pond. Feed constitutes the largest operational cost in intensive shrimp farming; thus, a reduction of 0.29 in FCR represents substantial economic savings. This enhanced feed efficiency is directly tied to the accelerated overall daily growth (0.411 g/day vs 0.353 g/day) and the significantly larger final body weight (64.51 g vs 52.63 g). These improvements are likely attributable to the active compounds in clove, predominantly eugenol. Previous studies have indicated that essential oils and herbal extracts stimulate the secretion of endogenous digestive enzymes (amylase, protease, and lipase) and modulate the intestinal microbiota, thereby maximizing nutrient digestibility and absorption (Kord *et al*., 2021; Yang *et al*., 2024) [7, 11].

Furthermore, the survival rate in the clove-supplemented pond reached an exceptional 95%, compared to 85% in the control. In high-density commercial pond environments, shrimp are continuously subjected to environmental fluctuations and handling stress, which can trigger oxidative damage and depress the immune system. The high survival rate observed here corroborates the known stress-mitigating and immune-boosting properties of phytobiotics. Eugenol possesses potent antioxidant capabilities that scavenge free radicals, reducing tissue damage during stressful events (Tang *et al*., 2022) [10]. Additionally, the broad-spectrum antimicrobial properties of clove likely contributed to suppressing opportunistic pathogens in the gut and the surrounding pond water, reducing sub-clinical disease pressure and mortality (Hardi *et al*., 2017). Becker *et al*. (2021) [2, 5] also noted the mild anesthetic effect of eugenol, which reduces metabolic expenditure during routine stress, allowing more energy to be partitioned toward growth and survival.

The combination of higher survival and accelerated growth resulted in a massive increase in total biomass (8,580 kg vs 6,262 kg) and a more premium harvest size (15.5 vs 21 pieces/kg). Although the culture duration for the clove treatment was slightly longer (157 days vs 149 days), the superior daily growth rate confirms that the enhanced biomass was driven by metabolic efficiency rather than merely time. In conclusion, the top-coating of commercial feeds with a 1% clove supplement serves as a highly effective, natural strategy to optimize FCR, boost survival, and maximize the profitability of commercial *P. monodon* aquaculture.

Conclusion

In conclusion, the present commercial-scale study clearly demonstrates that the dietary supplementation of clove (*Syzygium aromaticum*) at a concentration of 10 g/kg (1%) serves as a highly effective, natural performance enhancer for the grow-out phase of black tiger shrimp (*Penaeus monodon*). The top-coating of commercial feeds with this phytobiotic significantly optimized feed utilization, successfully lowering the Feed Conversion Ratio (FCR) from 2.39 to a highly efficient 2.10. This improvement translates to substantial economic savings in terms of feed inputs for large-scale aquaculture operations.

Furthermore, the stress-mitigating, antioxidant, and antimicrobial properties associated with clove's active compounds, particularly eugenol, structurally improved the resilience of the shrimp under intensive pond conditions. This was evidenced by a remarkable survival rate of 95% and significantly accelerated daily growth compared to the control group. Consequently, the total harvestable biomass and individual final body weight were vastly improved.

Ultimately, these findings strongly advocate for the transition toward sustainable, plant-based phytobiotics in shrimp aquaculture. Clove supplementation not only offers a viable, eco-friendly alternative to synthetic chemotherapeutics and antibiotics, but it also ensures environmental sustainability, maximizes economic profitability, and promotes the production of high-quality, safe seafood. Future research should focus on the long-term immunological benefits of clove against specific pathogens such as White Spot Syndrome Virus (WSSV) to further solidify its role in modern aquaculture protocols.

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