



PRODUCTION PERFORMANCE AND ECONOMIC ASPECTS OF SOFT-SHELL CRAB *Scylla* spp. CULTURE IN RAS VERTICAL CRAB BOXES WITH HERBAL APPLICATIONS

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ABSTRACT

Mud crabs (*Scylla* spp.) are being cultured in vertical crab boxes using a recirculating aquaculture system. One approach to accelerate and increase the frequency of mud crab molting is to provide plants containing the molting hormone ecdysteroid through feed. This research aims to analyze the production and business performance of soft-shelled crab culture in vertical crab boxes fed diets supplemented with purslane *Portulaca oleracea*, mulberry *Morus alba*, and spinach *Amaranthus hybridus*. Purslane was given to mud crabs at doses of 0 (control), 40, 50, and 60 g/kg, while mulberry was given at doses of 0, 30, 40, and 50 g/kg, and spinach was given at 60 g/kg of feed compared to autotomy and control treatments. Purslane and mulberry, related to the molting percentage and business performance in this mangrove crab culture, were 60 and 50 g/kg of feed, respectively. Purslane and mulberry improved the molting percentage and business performance of mangrove crab culture, although they did not compete with the autotomy treatment. This research contributes to the development of productive, efficient, environmentally friendly, and sustainable soft-shell crab culture by using herbal ingredients to increase the molting percentage.

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INTRODUCTION

Mud crabs *Scylla* spp. are crustaceans commonly found in brackish waters and mangrove forest areas. Four species of mud crabs are commercially traded, namely *Scylla serrata* (giant crab or king crab), *S. paramamosain* (green mud crab), *S. olivacea* (orange mud crab), and *S. tranquebarica* (purple mud crab) (Shelley and Lovatelli, 2011; Khaksari et al., 2023). This aquatic animal is one of the primary export commodities of Indonesian fisheries. Along with India, Pakistan, Vietnam, and China, Indonesia is among the world's leading producers of mud crabs, with major export destinations including the United States, China, and Canada (Muhaemin et al., 2024). The expansion of the upper-middle class, regional growth centers, urbanization, increasing community incomes, expanding knowledge of healthy cuisine, rising per capita seafood intake, and the growth of the food service industry all contribute to increased global demand for crabs. The majority of traded mud crabs come from wild harvests, which are progressively reducing. This is evident in Indonesia's soft-shell crab exports, which decreased from 669,666 tons in 2022 to 503,913 tons in 2023 and are predicted to fall further (BPS, 2023). As a result, the mud crab industry is shifting toward aquaculture (Khasanah et al., 2019; Apine et al., 2023).

Mud crab production has been conducted in many countries utilizing diverse systems such as ponds, cages, and pens, with crabs reared either in mass or individually (cell systems) (Mirera and Moksnes, 2015). Mud crabs are kept individually in the cell system to avoid interaction and cannibalism, which occurs frequently during molting. Vertical crab boxes are a version of the cell system in which boxes are stacked vertically and linked to a recirculating aquaculture system (RAS) (Hayati et al., 2025). In this system, rearing water is recycled after going through physical, chemical, and biological filtration, saving water and improving water quality management (Martins et al., 2010; Badiola et al., 2012). The use of RAS in mud crab and other closed aquaculture systems allows for greater control of water quality and mineral balance, as well as enhanced disease management and product quality, but it comes at a higher cost and demands more technical competence (Astari et al., 2025).

One of the most valuable mud crab aquaculture products is soft-shell crab, which is harvested shortly after molting while the shell is still soft. Molting is closely related to growth in crustaceans and is controlled by the interaction of molt-inhibiting hormone (MIH) and ecdysteroid hormones (Nguyen et al., 2014). MIH, produced by the X-organ in the crustacean brain, inhibits the production of ecdysteroids, limiting molting. In contrast, the Y-organ in the thorax produces ecdysteroids, which encourage molting. The interaction of these two hormones controls the timing and frequency of molting in mud crabs (Benrabaa et al., 2024). Soft-shell crabs are more profitable than live crabs of comparable size, with market prices in

Indonesia ranging from USD 7.32-11.59/kg in 2024, as opposed to only USD 3.05-4.27/kg for live crabs weighing 100-150 g. As a result, increasing the rate and frequency of molting is critical to enhancing soft-shell crab output, productivity, and profitability (Agustiyan et al., 2024).

Efforts to enhance molting in mud crab culture include the use of smaller crabs (40–100 g/ind.), which tend to molt more frequently, and the application of autotomy techniques involving the removal of claws and walking legs to induce the molting process. Additional strategies to stimulate molting include using herbal ingredients containing ecdysteroids or phytoecdysteroids.

Phytoecdysteroids are plant-derived hormones structurally similar to endogenous ecdysteroids found in arthropods, particularly insects and crustaceans, which regulate molting and metamorphosis. These compounds have been identified in plants belonging to more than 100 families across the divisions Polypodiophyta (ferns), Pinophyta, and Magnoliophyta. Several phytoecdysteroid-containing plants have been tested in crustacean aquaculture, including spinach (*Amaranthus* spp.), mulberry (*Morus* spp.), forest fern (*Diplazium* spp.), gray fern (*Nephrolepis biserrata*), kara munting (*Melastoma malabathricum*), purslane (*Portulaca oleracea*), jarong (*Achyranthes aspera*), dayak eggplant (*Solanum ferox*), lempuyang (*Zingiber zerumbet*), temu kunci (*Boesenbergia* spp.), and temu lawak (*Curcuma xanthorrhiza*) (Fujaya, 2018; Romadhon et al., 2022; Hardi et al., 2025). Ecdysteroids can be administered via feed supplementation or direct injection. For example, injection of purslane extract in mud crabs has been reported to improve survival and molting rates. Therefore, the use of herbal ingredients containing phytoecdysteroids shows considerable potential to enhance the production, productivity, and efficiency of soft-shell crab culture systems. However, several limitations and potential disadvantages are associated with current molting stimulation methods, particularly autotomy and injection techniques.

Autotomy, which involves the deliberate removal of claws and walking legs, is an invasive procedure that can cause significant physiological stress and energy loss in crabs (Romano and Zeng, 2020). The removal of appendages may also increase the risk of secondary infections, as open wounds provide entry points for opportunistic pathogens such as *Vibrio* spp. and other bacteria commonly present in aquaculture environments (Gao et al., 2021). In addition, the regenerative process following limb loss requires substantial metabolic energy, which may negatively affect growth performance and overall health if environmental conditions or nutritional support are inadequate (Liu et al., 2022). From an ethical perspective, autotomy techniques have also raised concerns related to animal welfare because they intentionally induce physical injury to stimulate molting (FAO, 2023). Similarly, the injection of phytoecdysteroid extracts, although effective in some studies, is labor-intensive and impractical for large-scale commercial farming because it requires individual

handling of crabs (Wang et al., 2021).

The injection process can cause additional stress and physical damage to tissues, potentially leading to mortality or infection if not performed under strict hygienic conditions (Romano and Zeng, 2020). Moreover, variability in phytoecdysteroid concentration and bioavailability in plant extracts can lead to inconsistent molting responses among treated individuals. These limitations highlight the need for alternative, non-invasive approaches to deliver molting stimulants in crustacean aquaculture (Liu et al., 2022). Dietary administration of phytoecdysteroid-containing plants offers a promising strategy as it can reduce handling stress, minimize the risk of injury-related infections, and improve the practicality of application in intensive soft-shell crab culture systems (Zhang et al., 2021). Therefore, this research aims to evaluate the dietary administration of purslane *Portulaca oleracea*, mulberry *Morus* spp., and spinach *Amaranthus* spp. in soft-shell crab culture using vertical crab boxes integrated with a recirculating aquaculture system (RAS), and to assess their effects on system productivity and profitability.

MATERIALS AND METHODS

Time and place of research

The research was conducted from October 2023 to September 2024. It included the preparation of vertical crab boxes and recirculating aquaculture system (RAS) facilities, procurement and transportation of seeds, acclimatization, distribution, rearing mud crabs *Scylla serrata*, data collection and processing. The research was carried out at the IPB Fisheries and Marine Observation Station (IFMOS), Ancol, Jakarta. Analysis of water samples for physicochemical parameters, including alkalinity, nitrite, nitrate, and total ammonia nitrogen (TAN), was conducted at the Aquaculture Environmental Laboratory, Department of Aquaculture, Faculty of Fisheries and Marine Sciences, IPB University, Dramaga Campus, Bogor, West Java.

Experimental design

This research consisted of three series of treatments: the administration of purslane, mulberry, and spinach, each incorporated into the diet at specific doses. Purslane leaves were added at 0 (control), 40, 50, and 60 g/kg of feed; mulberry leaves at 0 (control), 30, 40, and 50 g/kg; and spinach leaves at 60 g/kg, compared with a control and autotomy treatment. In the control treatment, mud crabs were given only trash fish, specifically yellow scad (*Selaroides leptolepis*). Each treatment consisted of three replications, except for the spinach treatment, which included four replications for both control and autotomy comparisons. Each replicate comprised 30 mud crabs (one crab per vertical box). Thus, 120 mud crabs were used per series and 360 mud crabs in total for the entire research.

Preparation of research containers and mud crabs

The rearing containers were vertical crab boxes (30 × 33 × 15 cm), with a total of 360 units arranged vertically and integrated into a recirculating aquaculture system (RAS) (Figure 1).

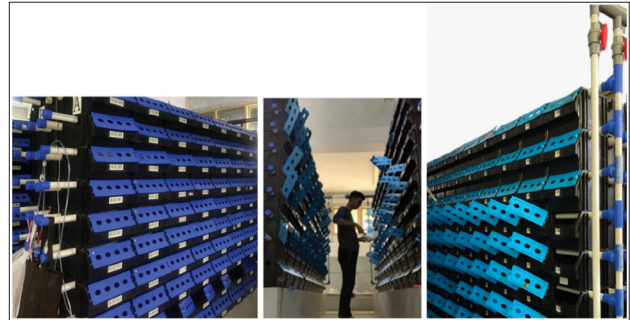


Fig 1. Vertical crab boxes with a recirculating aquaculture system (RAS) for rearing mud crabs *Scylla serrata*

The boxes were cleaned and filled with 25 g/L brackish water to a depth of 7 cm, regulated by a standing outlet pipe. The RAS had a filtration system consisting of physical filters (synthetic cotton or dacron, coral fragments, polyester japmat, biofoam sponge, and UV light), and biological filters (bio-ball and kaldnes) spread across four tanks (Figure 2). After passing through a sand filter tank, wastewater from the vertical crab boxes was pumped into the first tank, which contained coral, dacron, and japmat. It then flowed into the second tank, which contained biofoam and bio-ball, the third tank, which contained kaldnes, and the fourth tank, which acted as a reservoir before being returned to the vertical crab boxes via an ultraviolet sterilizer. Nitrifying bacteria used biofoam, bio-ball, and kaldnes as substrates to produce nitrite and nitrate from organic matter and ammonia. Strong aeration was installed in these tanks.

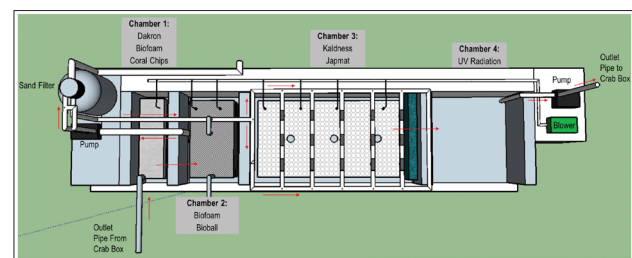


Fig 2. Filter system of the recirculating aquaculture system for rearing mud crabs *Scylla serrata* in vertical crab boxes

Mud crabs *S. serrata* weighing 87.4 ± 6.5 g were obtained from Pakuhaji District, Tangerang Regency, Banten, and Muara Gembong District, Bekasi Regency, West Java. Local fishermen caught these crabs from traditional milkfish ponds and mangroves. The crabs were shipped dry to IFMOS Ancol in plastic baskets covered with damp cloths, their walking legs and claws fastened. The crabs were acclimated by showering them with brackish water

(25 ppt salinity) for 15 minutes, followed by immersing in fiber tanks containing brackish water (25 ppt salinity) at a depth of approximately 8 cm with continuous aeration for 1.5 hours. The crabs were placed in vertical crab boxes once they had acclimated.

Preparation of test feed and culture techniques

The primary feed component was yellow scad *S. leptolepis*. The fish were cleaned, eviscerated, and ground into a paste using a blender. This paste was then combined in the appropriate amounts with pulverized purslane (stems and leaves), mulberry (young leaves), and spinach leaves. Purslane leaves were added at 0 (control), 40, 50, and 60 g/kg of feed; mulberry leaves at 0 (control), 30, 40, and 50 g/kg; and spinach leaves at 60 g/kg, compared with a control and autotomy treatment. In the control treatment, mud crabs were given only trash fish, specifically yellow scad *Selaroides leptolepis*. The mixtures were formed into 2 cm feed balls and frozen until use. Spinach diets included tapioca flour (15 g/kg of fish paste) to improve texture, and feed balls were steamed for 10–15 min before storage. Feed balls containing purslane, mulberry, or spinach were fed to mud crabs once daily (17:00–18:00) at 5% of body weight.

Water quality was managed by daily cleaning of the inlet/outlet pipes and filters. Residual feed and feces were removed daily by siphoning at 07:00–08:00. Temperature, pH, salinity, and dissolved oxygen were measured twice daily (08:00 and 17:00) in situ. In contrast, TAN, nitrite, nitrate, and alkalinity were measured weekly in the laboratory. Water quality parameters remained within optimal ranges for mud crab culture (Shelley and Lovatelli, 2011): temperature 28.0–29.4 °C; pH 7.0–7.9; dissolved oxygen 5.1–6.8 mg/L; salinity 24–27 g/L; alkalinity 44–192 mg/L; TAN 0.04–0.68 mg/L; nitrite 0.01–0.18 mg/L; nitrate 0.24–2.72 mg/L.

Observation, measurement, calculation, and test parameters

Mud crabs were reared for 30 days in individual boxes. Crab condition, feed intake, mortality, and molting were recorded every 4 hours. Feed and crabs were weighed with a digital scale (accuracy ± 0.01 g). Carapace dimensions were measured with callipers (accuracy ± 0.1 mm). Length, width, and weight were recorded every 14 days. Measurements included both live and dead crabs, as well as soft-shell (molting) crabs.

The test parameters in this research included production performance and business performance of soft-shell crab culture. Production performance tested included survival rate (SR), daily growth rate (DGR), weight gain rate (WGR), absolute length growth of the carapace or shell (ALG), feed conversion ratio (FCR), and molting performance, which included the number, time, and percentage of molting. SR (in percentage) was calculated using the formula $= (N_t / N_0) \times 100$, where N_t and N_0 are the number of crabs at the end and beginning of rearing (ind.). DGR (in g/day)

was calculated using the DGR formula $= (W_t \times W_0) / t$, where W_t and W_0 are the average weights at the end and beginning of rearing (g), respectively, and t is the rearing time (in days). WGR (in percentage) was calculated using the WGR formula $= ((W_t - W_0) / W_0) \times 100$, where W_t and W_0 are the average weights of the standard crab at the end and beginning of rearing (g), respectively. ALG (in cm) was calculated as $ALG = L_t - L_0$, where L_t and L_0 are the carapace widths at the end and beginning of rearing (cm), respectively. FCR was calculated using the FCR formula $= (F / ((B_t - B_0) + D))$, where F is the amount of feed given (g), B_t and B_0 are the biomass of crabs on day t and day 0 (g), and D is the weight of dead crabs (g). Observation of molting crabs was carried out every 4 h, molting crabs were recorded, and molting performance was calculated. The first molting time was determined by the number of rearing days when the crabs were molting. The molting percentage (M) was calculated using the formula $M = (N_t / N_0) \times 100$, where N_t and N_0 are the number of molts at the end and beginning of the rearing period (ind.), respectively.

Molting time was defined as the number of days from the beginning of the experiment (stocking) until the crab molted and became a soft-shell crab, expressed as days after stocking (DAS). Crabs that successfully molted during the experimental period were categorized as molting crabs, while those that did not molt were categorized as non-molting crabs. Several molting-related parameters were evaluated. The molting rate (%) was calculated as the proportion of crabs that molted relative to the total number of crabs stocked in each treatment. The time of molting (DAS) was calculated for each crab and averaged across treatments.

The performance of the soft-shell crab farming business is calculated annually using several assumptions, including total cost, revenue, profit, revenue-cost ratio (R/C), break-even point (BEP), cost of goods sold (CGS), and payback period (PP) (Astari et al., 2025). Total cost was calculated as the sum of fixed and variable costs. Fixed costs included depreciation of infrastructure (vertical crab boxes, tanks, pumps, aeration systems, and RAS components), while variable costs included feed, seed crabs, electricity, labor, and other operational expenses. Annual revenue was estimated based on the potential production from the culture system over one year, consisting of 9–12 production cycles, using the formula: $R = \text{Production amount} \times \text{Selling price}$. Annual profit was calculated using the formula $\text{Profit (USD)} = \text{Income} - \text{total cost}$. R/C was calculated using the formula $R/C = (\text{Revenue per year}) / (\text{Total cost})$. BEP is the break-even point of a business, calculated using the BEP formula $\text{(USD)} = (\text{Fixed cost}) / (1 - (\text{Variable cost}) / (\text{Total production}))$, and $\text{BEP (unit)} = \text{production sales mix} \times \text{BEP (USD)}$. CGS in USD/ind. was calculated by $\text{CGS} = (\text{Total cost}) / (\text{Total production})$. PP was calculated using the formula $\text{PP} = (\text{Investation cost per year}) / (\text{Profit per year})$ (Ismi and Budi, 2020).

The production amount used in the economic analysis was derived from the biological performance of each treatment, including survival rate (SR), molting rate, final biomass, and total feed consumption. The potential production of soft-shell crabs was calculated using the molting data obtained during the experiment, as only crabs that successfully molted were harvested as soft-shell crabs. Therefore, the number of marketable soft-shell crabs in each treatment was estimated based on the observed molting success and survival rate during the culture period. Final biomass and total feed consumption for each treatment were also recorded and are presented in the Results section. These parameters were used to estimate feed requirements and operational costs in the economic analysis. Several assumptions were used to standardize the economic evaluation. Feed costs were calculated based on the market price of yellow scad and herbal ingredients at the time of the study. The selling price of soft-shell crabs was based on the average market price in the local seafood market during the study period. The scaling scenario assumed a commercial production unit operating continuously with 9–12 production cycles per year using vertical crab boxes integrated with a recirculating aquaculture system (RAS).

Data analysis

Data were analyzed using Microsoft Excel 2020 and IBM SPSS version 29.0. Growth and survival parameters were analyzed by one-way analysis of variance (ANOVA) at the 95% confidence level, followed by Duncan's multiple range test when significant differences were detected. Polynomial regression analysis was performed using Microsoft Excel 2020. Water quality and profitability data were analyzed descriptively and presented in tables.

RESULTS

Production performance

Purslane administration did not significantly affect survival rate, daily growth rate, weight gain rate, absolute carapace width growth of non-molting crabs, or feed conversion ratio, except for the absolute carapace width growth of molting crabs (Table 1). However, purslane supplementation influenced the molting performance of mud crabs; the frequency of molting increased, and the molting process occurred faster and more synchronously with increasing purslane dosage. The administration of purslane at 60 g/kg feed resulted in the highest molting percentage of mud crabs ($P < 0.05$).

Table 1. Production performance of soft-shell crab *Scylla serrata* culture in RAS vertical crab boxes fed purslane at doses of 0 (control), 40, 50, and 60 g/kg feed during a 30-day rearing period

Parameter (unit)*	Purslane dosage (g/kg of feed)			
	0	40	50	60
SR (%)	66.67 ± 15.28 ^a	70.00 ± 10.00 ^a	73.33 ± 15.28 ^a	80.00 ± 10.00 ^a
DGR m (g/day)	1.27 ± 0.14 ^a	1.25 ± 0.08 ^a	1.33 ± 0.12 ^a	1.43 ± 0.15 ^a
DGR n (g/day)	0.21 ± 0.04 ^a	0.22 ± 0.01 ^a	0.23 ± 0.04 ^a	0.28 ± 0.02 ^a
WGR m (%)	42.37 ± 4.72 ^a	41.37 ± 2.04 ^a	43.11 ± 5.11 ^a	48.16 ± 4.74 ^a
WGR n (%)	7.37 ± 1.24 ^a	7.63 ± 0.17 ^a	8.02 ± 2.08 ^a	9.53 ± 0.20 ^a
ALG m (cm)	0.50 ± 0.18 ^a	0.79 ± 0.04 ^{ab}	0.70 ± 0.16 ^b	1.07 ± 0.08 ^c
ALG n (cm)	0.08 ± 0.02 ^a	0.05 ± 0.03 ^a	0.11 ± 0.05 ^a	0.24 ± 0.15 ^a
FCR m	3.02 ± 0.27 ^b	1.48 ± 0.36 ^a	1.46 ± 0.23 ^a	1.16 ± 0.21 ^a
FCR n	13.11 ± 0.95 ^a	10.88 ± 1.46 ^a	11.45 ± 0.95 ^a	10.24 ± 4.55 ^a
Number of molting (ind.)	7	9	11	19
Time of molting (das)	9	7	8	5
Max. simultaneous molting number (ind./day)	1	2	2	4
Molting percentage (%)	23.33 ± 15.28 ^a	30.00 ± 10.00 ^a	36.67 ± 15.28 ^a	63.33 ± 15.28 ^b

* SR, survival rate; DGR, daily growth rate; WGR, weight gain rate; ALG, absolute length growth; AWG, absolute width growth; FCR, feed conversion ratio; m, molting; n, non-molting; das, day after stocking

Moreover, increasing purslane dosage was positively correlated with molting percentage, following the equation $y = 0.1333x^2 - 11.333x + 270$ (Figure 3).

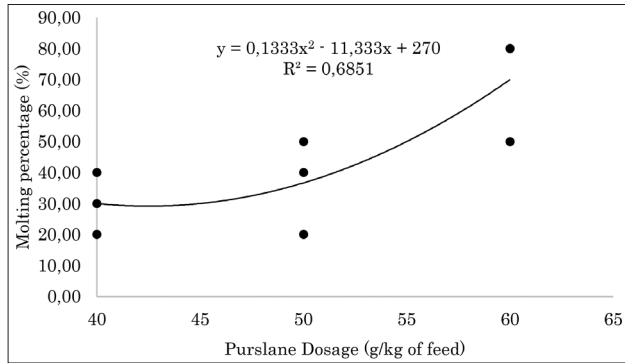


Fig 3. Relationship between administration of purslane at doses of 40, 50, and 60 g/kg feed and the percentage of molting in mud crab *Scylla serrata* culture in RAS vertical crab boxes

Mulberry supplementation did not significantly affect production performance, except for a higher weight gain rate (WGR) in molting crabs at a dosage of 40 g/kg feed ($P < 0.05$) (Table 2). Mulberry feeding affected the mud crabs' ability to molt, much like purslane supplements did. In comparison to the control group that did not receive mulberry supplementation, increasing the mulberry dosage in the feed led to more frequent molting, a shorter molting period, and a higher molting percentage.

Similar to purslane and mulberry supplementation, spinach feeding produced results comparable to garbage fish (control) and autotomy treatment (Table 3). However, autotomy therapy outperformed spinach and trash fish in terms of molting performance, including frequency, duration, synchrony, and percentage. This research, together with the previous series, aimed to identify a herbal-based approach to replace the autotomy method without compromising animal welfare. Nonetheless, compared to purslane (63.33%), mulberry (43.33%), and spinach, autotomy therapy resulted in the highest molting percentage (96.67%).

Business performance

The following assumptions were made to assess the efficacy of soft-shell crab culture in RAS vertical crab boxes with purslane-supplemented feed: (1) The business scale was 3,000 mud crabs or 3,000 box units; (2) the rearing period was 30 days (one month), allowing for 12 production cycles per year; (3) the products were soft-shell crabs, live mud crabs, and fresh crabs, priced at USD 9.15, USD 4.27, and USD 2.13 per kilogram, respectively; and (4) the addition of purslane increased the feed price per kilogram from USD 0.43 to USD 0.52, 0.55, and 0.57 for 0, 40, 50, and 60 g/kg feed, respectively. Production performance statistics (survival rate, mortality rate, weight increase rate, molting percentage, and feed conversion ratio) for molting and non-molting crabs are presented in

Table 2. Production performance of mud crab *Scylla serrata* culture fed mulberry at doses of 0, 30, 40, and 50/kg feed for 30 rearing days in RAS vertical crab boxes

Parameter (unit)*	Mulberry dosage (g/kg of feed)			
	0	40	50	60
SR (%)	63.33 ± 11.55 ^a	73.33 ± 15.28 ^a	83.33 ± 5.77 ^a	80.00 ± 17.32 ^a
DGR m (g/day)	0.95 ± 0.84 ^a	1.78 ± 0.17 ^a	2.08 ± 0.72 ^a	1.69 ± 0.49 ^a
DGR n (g/day)	0.18 ± 0.01 ^a	0.26 ± 0.09 ^a	0.22 ± 0.05 ^a	0.20 ± 0.02 ^a
WGR m (%)	29.59 ± 26.40 ^a	56.92 ± 4.90 ^{ab}	71.29 ± 18.80 ^b	55.47 ± 14.17 ^{ab}
WGR n (%)	0.96 ± 0.21 ^a	6.02 ± 1.05 ^a	7.17 ± 1.18 ^a	6.7 ± 0.54 ^a
ALG m (cm)	0.80 ± 0.46 ^a	1.26 ± 0.13 ^{ab}	1.43 ± 0.50 ^b	1.21 ± 0.44 ^{ab}
ALG n (cm)	0.06 ± 0.05 ^a	0.09 ± 0.04 ^a	0.13 ± 0.09 ^a	0.11 ± 0.08 ^a
FCR m	1.49 ± 0.25 ^a	1.29 ± 0.11 ^a	1.16 ± 0.32 ^a	1.59 ± 0.18 ^a
FCR n	16.75 ± 2.16 ^a	15.93 ± 2.09 ^a	12.27 ± 2.96 ^a	15.62 ± 1.54 ^a
Number of molting (ind.)	4	8	6	12
Time of molting (das)	12	16	7	5
Max. simultaneous molting number (ind./day)	1	2	1	2
Molting percentage (%)	13.33 ± 15.28 ^a	26.67 ± 11.55 ^{ab}	20.00 ± 0.00 ^{ab}	43.33 ± 11.55 ^b

*SR, survival rate; DGR, daily growth rate; WGR, weight gain rate; ALG, absolute length growth; AWG, absolute width growth; FCR, feed conversion ratio; m, molting; n, non-molting; das, day after stocking

Table 1. Table 4 shows the business performance analysis of soft-shell crab culture with purslane supplementation based on the calculations and assumptions mentioned above.

The investment and fixed costs of soft-shell crab culture with purslane supplementation were comparable, with only minor changes in variable costs affecting overall expenditure. The purslane dose of 60 g/kg feed resulted in the highest business income while also improving other business characteristics such as profit, break-even

point (BEP), cost of production (HPP), revenue-cost (R/C) ratio, and payback period (PP). Overall, purslane supplementation improved business performance compared to the control group, with the 60 g/kg dose being the most effective. Table 5 shows the business performance analysis of mulberry supplementation under the same assumptions as for purslane supplementation, with the exception of feed price. Feed costs were influenced by the price of mulberry, which reached USD 6.89/kg.

Table 3. Production performance of mud crab *Scylla serrata* culture in RAS vertical crab boxes fed yellow trevally trash fish, autotomy treatment, and provision of 60 g/kg spinach feed for 30 days of rearing

Parameter (unit)*	Treatments		
	Trash fish	Autotomy	Trash fish + spinach
SR (%)	83.33 ± 5.77 ^a	96.67 ± 5.77 ^a	86.67 ± 5.77 ^a
DGR m (g/day)	1.01 ± 0.09 ^a	0.32 ± 0.06 ^a	1.05 ± 0.12 ^a
DGR n (g/day)	0.02 ± 0.01 ^a	0.00 ± 0.00 ^a	0.05 ± 0.03 ^a
FCR m	1.03 ± 0.29 ^a	6.71 ± 0.92 ^a	1.03 ± 0.46 ^a
FCR n	4.17 ± 0.87 ^a	0.00 ± 0.00 ^a	5.91 ± 1.69 ^a
Number of molting (ind.)	10	36	7
Time of molting (das)	4	12	4
Max. simultaneous molting number (ind./day)	2	9	2
Molting percentage (%)	40.00 ± 20 ^a	96.67 ± 11.55 ^b	30.00 ± 17.32 ^a

^{a)} SR, survival rate; DGR, daily growth rate; WGR, weight gain rate; ALG, absolute length growth; AWG, absolute width growth; FCR, feed conversion ratio; m, molting; n, non-molting; das, day after stocking

Table 4. Analysis of the annual business of cultivating soft-shell crab *Scylla serrata* in RAS vertical crab boxes on a scale of 3,000 units given purslane at 0, 40, 50, and 60 g/kg feed for one year

Parameter (unit)*	Purslane dosage (g/kg of feed)			
	0	40	50	60
Investment cost (USD)	19,887.7	19,887.7	19,887.7	19,887.7
Fixed cost (USD)	10,558.9	10,558.9	10,558.9	10,558.9
Variable cost (USD)	9,371.4	9,366.1	9,563.6	9,392.0
Total cost (USD)	19,930.2	19,924.9	20,122.4	19,950.9
Total revenue (USD)	18,712.0	20,367.6	22,842.4	31,138.6
Profit (USD)	-1,218.2	442.7	2,720.0	11,187.7
BEP price (USD/year)	21,152.4	19,548.1	18,163.5	15,119.1
CGS (USD)	5.4	5.4	5.2	4.7
R/C ratio	0.94	1.02	1.14	1.56
PP (year)	-	44.92	7.31	1.78

¹⁾ BEP, break event point; CGS, cost of goods sold; R/C ratio, revenue cost ratio; PP, payback period

Table 5. Analysis of the annual business of cultivating soft-shell crab *Scylla serrata* in RAS vertical crab boxes fed 0, 40, 50, and 60 g/kg of mulberry feed

Parameter (unit)*	Mulberry dosage (g/kg of feed)			
	0	40	50	60
Investment cost (USD)	26,631.8	26,631.8	26,631.8	26,631.8
Fixed cost (USD)	11,039.8	11,039.8	11,039.8	11,039.8
Variable cost (USD)	10,732.1	10,864.6	10,577.9	10,724.3
Total cost (USD)	21,771.9	21,904.5	21,617.7	21,764.1
Total revenue (USD)	18,038.4	26,139.8	23,445.0	33,925.9
Profit (USD)	-3,733.5	4,235.3	1,827.3	12,161.8
BEP price (USD/year)	53,040.6	44,499.2	21,844.5	31,823.9
CGS (USD)	5.2	4.4	4.8	3.8
R/C ratio	0.83	1.19	1.08	1.56
PP (year)	-	6.28	14.57	2.19

*¹) BEP, break event point; CGS, cost of goods sold; R/C ratio, revenue cost ratio; PP, payback period

Production for each product type was determined based on performance data, including survival rate, mortality rate, weight increase rate, molting percentage, and feed conversion ratio (Table 4).

Several assumptions were made when conducting the business analysis of soft-shell crab culture with spinach supplementation compared to autotomy therapy and feeding with garbage fish. The company size was 600 mud crabs (600 boxes), with 200 boxes allocated to each treatment. One production cycle lasted 45 days, including 15 days of preparation and 30 days of rearing, yielding nine production cycles per year. The original crab weight was approximately 75 g/ind, acquired at USD 2.44/kg, and one person performed the work for a monthly wage of USD

182.97. The prices of production factors were assumed to remain constant during the rearing period, and land and building rent were excluded from the calculation. The harvest biomass of soft-shell crabs in the trash fish, autotomy, and spinach treatments was 88.59 kg, 185.12 kg, and 61.07 kg, respectively, based on survival rate, mortality rate, daily growth rate, and molting percentage. In addition to soft-shell crabs, live, unmolted crabs were also produced and sold for USD 9.15 and USD 3.96/kg. When compared to autotomy therapy, the results in Table 6 indicate that spinach supplementation did not enhance the business performance of the soft-shell crab culture. Instead, with an R/C ratio less than 1, feeding spinach through prepared meals led to financial losses.

Table 6. Analysis of the annual business of cultivating soft-shell crab *Scylla serrata* in RAS vertical crab boxes with the provision of trash fish, autotomy treatment, and spinach in the feed

Parameter (unit)*	Treatments		
	Trash fish	Autotomy	Trash fish + spinach
Investment cost (USD)	1,746.2	1,747.1	1,755.3
Fixed cost (USD)	362.3	362.7	364.1
Variable cost (USD)	650.7	643.2	659.6
Total cost (USD)	1,013.0	1,005.9	1,023.7
Total revenue (USD)	1,172.5	1,693.6	999.4
Profit (USD)	159.5	687.6	-24.2
BEP price (USD/year)	814.1	584.9	1,070.6
R/C ratio	1.16	1.68	0.98
PP (year)	11.00	3.00	-

*¹) BEP, break event point; CGS, cost of goods sold; R/C ratio, revenue cost ratio; PP, payback period

DISCUSSION

The results of this research indicate that dietary supplementation with phytoecdysteroid-containing plants significantly affected molting performance and production efficiency in soft-shell crab culture using vertical crab boxes integrated with a recirculating aquaculture system (RAS). Improvements in molting success directly increased the number of marketable soft-shell crabs, thereby influencing system productivity and economic returns. These findings suggest that using herbal ingredients such as purslane, mulberry, and spinach is a practical strategy to enhance both biological performance and commercial viability in intensive soft-shell crab farming systems.

Purslane increased only the absolute width development of molting crabs, whereas mulberry influenced the weight gain rate. In contrast, none of the production performance metrics in the spinach treatment surpassed those in the autotomy or control treatments. However, in soft-shell crab culture, molting performance is more important than growth performance in terms of production and productivity (Waiho et al., 2021). This is because soft-shell crab farming often uses small crabs (60-100 g/ind), which are less expensive and less marketable, while still meeting consumer demand for whole-crab goods that can be served without cutting. Therefore, growth performance is less significant than molting performance. Molting remains a serious challenge in soft-shell crab culture, along with seed availability (which is still dependent on wild capture) and a lack of defined production techniques (Lovatelli et al., 2025). Molting in mangrove and swimming crabs is regulated by endocrine mechanisms, with ecdysteroid hormones acting as key regulators (Zhao et al., 2022). Ecdysteroids, notably ecdysone, increase the expression of molting-related genes, allowing mud crabs to finish the premolt stage faster (Zhao et al., 2020). Although mud crabs naturally make ecdysteroids, supplementing with external ecdysteroids can speed up internal hormone production and cause molting. According to Herlinah et al. (2015), the premolt stage requires the maximum concentration of ecdysteroids (up to 175.2 mg/L) to commence molting.

In this context, the administration of herbal substances is intended to improve molting performance, such as frequency, synchronization, and overall molting percentage (Aslamyah et al., 2022). Our data revealed that purslane and mulberry supplementation considerably improved molting performance compared to the control. The molting percentage of mud crabs increased with larger dosages of these herbal components, demonstrating a dose-dependent effect. The best molting performance was achieved with 60 g/kg feed for purslane and 50 g/kg feed for mulberry. Purslane consistently outperformed mulberry *Morus* sp. and palm *Cycas revoluta* in terms of molting percentages.

In contrast, spinach supplementation did not increase molting performance and, in fact, resulted in a lower molting frequency than the control. Despite concerns about animal welfare, the autotomy method provided the highest molting percentage (96.67%), followed by purslane (63.33%), mulberry (43.33%), and spinach, confirming previous findings by Rahman et al. (2020) and Fujaya et al. (2021). The poor efficiency of spinach in this study may be due to the meal preparation procedures. Spinach-based feed was treated with 15 g/kg tapioca flour and steamed for 10-15 minutes, which may have affected palatability by affecting the scent, taste, and nutritional content of the scad fish base. Reduced palatability in carnivorous species frequently reduces feed intake, which impairs development and molting performance. Although soft-shell crab cultivation has been commercially performed for over two decades, the development of artificial feed technology as a replacement for waste fish is still limited (Tamsil et al., 2024).

Previous research on herbal supplementation to accelerate molting in mud crabs (Hasnidar et al., 2021; Akbar et al., 2024) focused on production performance measures such as survival, growth, feed efficiency, and molting. The current study improves this topic by analyzing business performance, namely profitability, through the valuation of all cultured goods, including soft-shell crabs, live crabs, and frozen crabs. As expected, soft-shell crab (soka) products command the highest market value, followed by live and frozen crabs.

A clear association was found between molting percentage and company performance: higher molting percentages obtained through purslane and mulberry supplements were associated with better profitability and R/C ratios. This confirms that molting percentage is a key determinant of the success of soft-shell crab culture in vertical crab box systems. At a scale of 1,000 boxes, the highest molting percentage achieved in this research was with 60 g/kg of purslane feed (63.33%), though this still fell short of the autotomy treatment (96.67%). By contrast, spinach supplementation resulted in reduced production and business performance, yielding a negative annual profit and an R/C ratio below one at the 600-box scale (Lovatelli et al., 2025).

The results of this study suggest that improving molting performance using phytoecdysteroid-containing plants has important practical applications for soft-shell crab production. Soft-shell crabs, commonly known as soka crabs, generally have higher market value than hard-shell crabs because they can be consumed whole and are widely used in restaurants and export markets. In many markets, the price of soft-shell crabs can be 1.5–3 times higher than that of hard-shell crabs of similar size. Increasing the molting rate, therefore, directly increases the number of marketable soft-shell crabs produced. In intensive systems such as vertical crab boxes integrated with recirculating aquaculture systems (RAS), production can reach several cycles per year, allowing farmers or

companies to achieve profits multiple times a year. This makes soft-shell crab farming a promising aquaculture business with high economic potential (Hasnidar et al., 2021; Akbar et al., 2024).

CONCLUSION

Efforts to improve production performance and soft-shell crab culture must continue to meet market demand, which tends to increase and is expected to continue to increase. In addition to increasing the percentage of molting, including by using herbal ingredients, other efforts involve the availability of seeds, artificial feed, culture systems, added value products, standardization of production processes, environmentally friendly technology, and business sustainability. This research is one of the efforts toward productive, efficient, environmentally friendly, and sustainable soft-shell crab culture.

PROIZVODNI UČINAK I EKONOMSKI ASPEKTI UZGOJA MANGROVIH RAKOVA (*Scylla* spp.) U VERTIKALNIM RAS KUTIJAMA ZA RAKOVE S PRIMJENOM BILJNIH EKSTRAKTA

SAŽETAK

Mangrovi rakovi uzgajaju se u vertikalnim posudama za rakove s recirkulacijskim sustavom akvakulture. Jedan od pokušaja za ubrzanje i povećanje učestalosti mitarenja mangrovih rakova je dodavanje putem hrane biljaka koje sadrže hormon mitarenja ekdisteroid. Cilj ovog istraživanja je analizirati proizvodne i poslovne rezultate uzgoja mangrovih rakova u vertikalnim posudama za rakove koji se hrane hranom koja sadrži povrtni tušanj (*Portulaca oleracea*), bijelu murvu (*Morus alba*) i zeleni amarant (*Amaranthus hybridus*). Povrtni tušanj je rakovima u blatu davan u dozama od 0 (kontrola), 40, 50 i 60 g/kg, dok je bijela murva davana u dozama od 0, 30, 40 i 50 g/kg, a zeleni amarant je davan u dozi od 60 g/kg hrane u usporedbi s autotomijom i kontrolnim tretmanima. Povrtni tušanj i bijela murva, povezani s postotkom mitarenja i poslovnim rezultatima u ovoj kulturi mangrovih rakova, iznosili su 60, odnosno 50 g/kg hrane. Povrtni tušanj i bijela murva dali su bolji postotak mitarenja i poboljšali poslovne rezultate kulture mangrovih rakova. Međutim, i dalje nisu konkurirali tretmanu autotomijom. Ovo istraživanje je jedan od pokušaja prema produktivnom, učinkovitom, ekološki prihvatljivom i održivom uzgoju mangrovih rakova korištenjem biljnih sastojaka za povećanje postotka mitarenja.

Cljučne riječi: poslovanje, mangrov rak, povrtni tušanj, bijela murva, zeleni amarant

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

The datasets generated and/or analysed during the current study are not publicly available but are available from the corresponding author upon reasonable request.

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