DEPIK
Jurnal Ilmu-Ilmu Perairan, Pesisir dan Perikanan
Journal homepage: www.jurnal.usk.ac.id/depik

Utilization of natural stimulants on crab survival and molting acceleration: progresses and challenges

Said Ali Akbar[1,*], Cut Nuzlia[1], Sari Afriani[1], Ilham Zulfahmi[2]

[1]*Department of Aquaculture, Faculty of Marine and Fisheries, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia*
[2]*Department of Fisheries Resources Utilization, Faculty of Marine and Fisheries, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia*

ARTICLE INFO

Keywords:
Molting
Mangrove Crab
Ecdysteroids
Natural Stimulant
Sustainable Cultivation

DOI: 10.13170/depik.13.2.39271

ABSTRACT

This study investigates the potential of natural stimulants, specifically ecdysteroids, in accelerating the molting process in mangrove crabs. The research analyzed various plants containing ecdysterone and their effects on the crabs. The results indicate that forest fern leaves and mulberry leaves are effective sources of ecdysterone in stimulating molting and growth in crabs. The use of such natural stimulants has the potential to enhance productivity and reduce reliance on synthetic hormones in crab cultivation. However, further research is needed to determine the optimal dosage and to understand the mechanisms of ecdysterone action in crabs in more detail. The main challenge in implementation is adjusting the dosage and frequency of natural stimulant administration to achieve optimal results without disrupting the balance of the cultivation ecosystem. This approach offers an environmentally friendly alternative for the sustainable development of crab farming.

Introduction

Mangrove crabs have significant economic value in the Indo-Pacific region due to their exquisite flavor and high nutritional content. Some species of mangrove crabs, known as *Scylla* spp., are members of the family Portunidae and can be found in practically all coastal areas. They are particularly prevalent in shorelines with mangroves, shallow waters near mangrove forests, estuaries, and muddy beaches, all of which play various significant ecological roles (Sharifian *et al*., 2021; Zulfahmi *et al*., 2021; Rianjuanda *et al*., 2020).

Farmers have engaged in various activities related to cultivating mangrove crabs. These operations include breeding, growing, fattening, egg production, and the production of soft-shell crabs. Soft-shell crab cultivation is a high-value mangrove crab product. Soka crabs, also known as soft-shell mangrove crabs, are in the process of molting and are found in mangroves. Crabs in this phase have the advantage of having a soft shell, making them entirely edible (Yousefi & Naderloo, 2022; So *et al*., 2023). This type of crab is known as a soft-shell mud crab. There is a significant market opportunity for soka crab farming, notably in markets in Singapore, Hong Kong, Taiwan, the European Union, the United States, China, and Japan, where the price of soka crabs has reached Rp. 110,000 per kilogram (Adhawati *et al*., 2023). The soka crab sector is becoming increasingly popular and promising due to the rising demand for soka crabs from domestic markets and countries like Japan, Singapore, Taiwan, and China. Additionally, the pricing of soka crabs is becoming more competitive (Himawan, 2023).

Ablation, mutilation, and supplementing with spinach extract are methods devised to hasten the molting process in mangrove crabs. During ablation, the right eyestalk is removed. Within twelve to fourteen days, crabs that have undergone ablation will molt (Asmat-Ullah *et al*., 2023). The mutilation procedure involves cutting the crab's claws and six walking legs at the base with pliers, leaving the two

* Corresponding author.
Email address: saidaliakbar@usk.ac.id

p-ISSN 2089-7790; e-ISSN 2502-6194
Received 19 June 2024; Received in revised form 1 July 2024; Accepted 11 July 2024
Available online 2 August 2024

swimming legs intact, and keeping the crab in the pond for fifteen days or until molting occurs (Waiho *et al.*, 2021). The third method, supplementation with spinach extract, can be administered via injection or feed. Injections of spinach extract containing ecdysteroid hormones are given to hard-shelled mangrove crabs (Akbar *et al.*, 2023). Among Crustacea, the molting hormone is called ecdysteroid. The molting process, or ecdysis, in mangrove crabs, is comparable to that in other Crustacea genera (Akbar *et al.*, 2023). Molting occurs regularly when the old cuticle separates from the new one. The crab's length, width, and weight increase proportionately with each molt. The amount of ecdysteroid hormone in a crab's body is quite low, approximately 500 nanograms per kilogram of body weight, which is why molting takes a long time (Xiong *et al.*, 2023). By injecting spinach extract at a concentration of 1/10 mg per kg of body weight, crabs are ready to molt by the fourth day. By the sixteenth day, approximately seventy percent of the crabs have completely molted (Lumbantoruan *et al.*, 2021). The most successful method for inducing molting in mangrove crabs was feeding them a combination of fish, coconut meal, cornmeal, soybean meal, and carapace meal that contained 30.62% protein and 49.13% carbohydrates, plus spinach extract at a concentration of 700 ng/g of crab body weight (Lumbantoruan *et al.*, 2021).

This research demonstrates that the physiological effects of bioactive chemicals derived from plants are comparable to those of hormones in animals. If a plant contains ecdysteroid hormones, it has the potential to serve as a molting stimulant for crabs. Researchers have reported that the molting process can be accelerated by utilizing plant bioactive substances. In addition to spinach, the use of mulberry leaves as a molting stimulant in crabs has shown that administering mulberry leaf extract at a concentration of 100 µg/L resulted in fifty percent molting, compared to the control treatment and concentrations of 125 µg/L and 150 µg/L, which only resulted in thirty-three point three percent molting (Herlinah *et al.*, 2014).

There are currently no review articles summarizing natural molting stimulants for crabs, highlighting a gap in the existing body of research. This article aims to provide pertinent information on natural sources of ecdysteroid hormones, the molting mechanism in crabs, the progress made with natural ecdysteroids adopted for crab molting, and the challenges that future research will face.

Materials and Methods

For this study, we collected articles from various sources, including Google Scholar and Google Search. This was because research on the utilization of natural plants as a source of ecdysteroids is scarce, with the majority of studies conducted in Indonesia. Recent references published between 2013 and 2023 were retrieved using the keyword "crab molting stimulant." Following a thorough evaluation, the gathered data was systematically organized and imported into Microsoft Excel for detailed analysis.

Results

Many natural plants possess active compounds that stimulate crabs' molting process. For instance, extracts from mulberry leaves, spinach, ferns, and Melastoma malabathricum have been proven effective in accelerating crab molting. These plants contain compounds like ecdysteroids that can influence the crab's hormonal system, stimulating the growth and shedding of the skin required during molting. With further research, discovering new potential from other plants and a deeper understanding of their mechanisms could pave the way for more sustainable alternatives in crab cultivation. The summary of the research progress to date regarding natural stimulants for accelerating crab molting is presented in Table 1.

Table 1. Summary of Natural Stimulants Implemented to Accelerate Crab Molting

No.	Stimulants Source	Crab Species	Initial Weight of Crab (g)	Best Dose	Moulting Percentage (%)	SR (%)	Molting Speed	Reference
1	Forest fern leaves (*Diplazium caudatum*)	*Scylla serrata*	100	125 mg/L	-	100	0,50±0,57 Mass/Day	Romadhon *et al.*, 2022
2	Spinach King (*Amaranthus hybridus*) and lime	*Scylla serrata*	80-100	4 mL lime water and 40 g spinach	-	-	36 Day	Andika *et al.*, 2013
3	Mulberry leaves (*Morus alba* L.)	*Scylla serrata*	50 - 83	100 mg/L	50	-	3,44 Mass/Day	Herlinah *et al.*, 2014

4	Spinach King (*Amaranthus hybridus*)	*Scylla olivacea*	50-51	10 g	56-63	61-68	-	Hasnidar *et al.*, 2021
5	Vegetable fern leaves (*Diplazium esculentum Swartz*)	*Scylla serrata*	-	50 mg/kg	90	-	16-30 Day	Koniyo *et al.*, 2022
6	Fingerroot (*Boesenbergia pandurata*)	*Scylla serrata*	200 -280	20 mL/kg	44	78	20 Day	Jolpano *et al.*, 2023
7	Silver Brake Fern (*Nephrolepis Biserrata*)	*Scylla serrata*	75 – 150	150 ppm	50	100	-	Iswan, 2019
8	*Vitex glabrata*	*Portunus pelagicus*	50±5	-	-	-	-	Sorach & Pratoomchat, 2017
9	Mulberry leaves (*Morus alba* L.)	*Scylla olivacea*	45-55	2.4 mg/g	60	-	-	Fujaya *et al.*, 2018
10	Karamunting Leaves (*Melastoma malabathricum* L)	*Scylla serrata*	75	5 µg/g	100	100	13-32 Day	Almaliki, 2021
11	Batik Spinach (*Amaranthus bicolor*)	*Scylla serrata*	100	150 ppm	-	100	12,5 Day	Lumbantoruan *et al.*, 2021
12	Betel leaves (*Piper betle*)	*Scylla serrata*	90-120	75%	66,67	100	-	Deru *et al.*, 2019
13	Tea Seeds (*Camellia oleifera*)	*Scylla serrata*	50	45 ppm	-	100	18 Day	Burhanuddin, 2013
14	Garlic (*Alium Sativum*)	*Scylla serrata*	-	10%	-	100	-	Deru *et al.*, 2018
15	Vitomolt (Composition *Morus alba*, *Curcuma xanthorrhiza*, *Boesenbergia rotunda*)	*Scylla olivacea*	100-110	100 mL kg-1 /3 hari	16.67±14.43	100	-	Kanna *et al.*, 2021
16	Mulberry leaves (*Morus alba* L.)	*Scylla serrata*	80-100	25%	41	100	10 Day	Dewi *et al.*, 2023

Discussion

Natural Sources of Ecdysteroid Hormones

The principal steroid hormone in arthropods, including crustaceans and insects, is called ecdysteroid. Its primary function is to regulate molting, which involves developing a new exoskeleton to replace the old one. This hormone regulates physiological processes such as growth, metamorphosis, and reproduction. According to research conducted by Andika *et al.* (2013), molting can occur naturally in cultivated crabs or be induced through stimulation and injecting this hormone.

There are several plants known to produce ecdysterone. These include spinach, which contains ecdysteroids in every part of the plant, as well as asparagus, mulberry, purslane, and various ferns typically found in highland regions, such as the king fern, also known as Cycas revoluta (Table 1). Mulberry, belonging to the Morus genus, is sometimes referred to as the silk plant because it provides a habitat and food source for silkworms, Bombyx mori (Dewi *et al.*, 2023). According to Fujaya *et al.* (2018), mulberry contains a wide range of chemical components, including ecdysterone, inokosterone, lupeol, β-sitosterol, rutin, moracetin, scopoletin, benzaldehyde, eugenol, linalool, benzyl alcohol, butylamine, acetone, choline, and quercetin. Mulberry has been shown to accelerate insect molting (silkworms). Since crabs and silkworms belong to the same phylum, Arthropoda, the ecdysterone from mulberry leaves that aids in the silkworm molting phase could also be effective during the molting phase of mangrove crabs. Traditionally, ecdysterone is obtained through isolation from various crustacean species, which is relatively costly and difficult to acquire. Therefore, it is necessary to look for alternative sources, such as plant-derived ecdysterone (Jolpano *et al.*, 2023).

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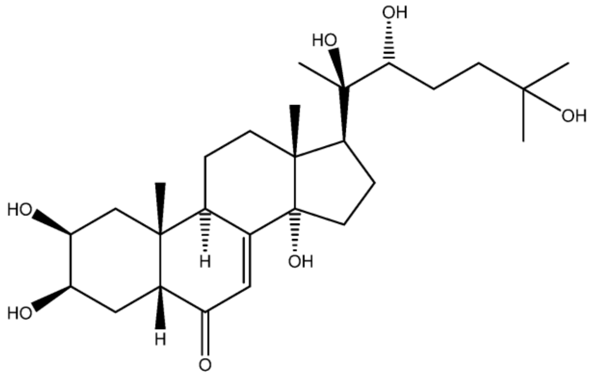

Figure 1. Chemical Structure of Ecdysterone

Molting, or ecdysis, is an important event in the life cycle of arthropods, including decapods, because the exoskeleton must be shed for the organism to grow and undergo metamorphosis (Almaliki, 2021). Figure 1 depicts the molecular structure of ecdysterone. Since the molting process is critical to crabs' growth and productivity, technical innovation in the physiological engineering of molting (ecdysterone hormone) is required. Physiological engineering is necessary to attain coordinated molting timings and speed up the molting phase.

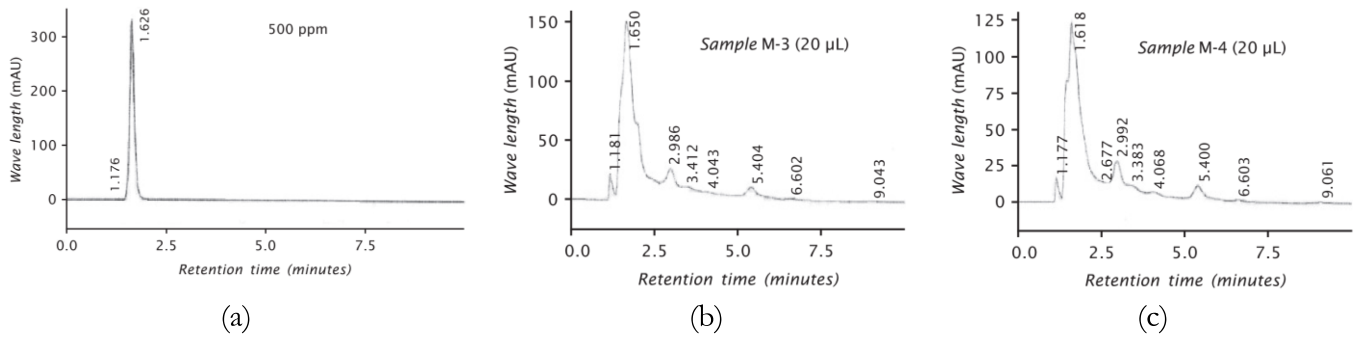

Figure 2. Chromatogram of (a) ecdysteroid standard, (b) fraction-3 (M-3), (c) fraction-4 (M-4) (Herlinah *et al.*, 2014) Copyright 2014 Jurnal Riset Akuakultur.

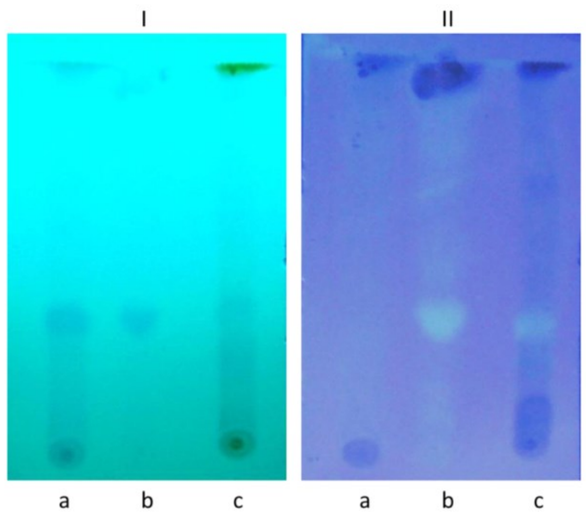

Figure 3. Chromatogram of compound groups from Spinach (a), Mulberry (b), and 20-hydroxyecdysone (c) using Silica Gel 60 F254 for the stationary phase and Dichloromethane : Ethanol = 5 : 1 for the mobile phase. I, observation under UV 254 and II under UV 366 (Fujaya *et al.*, 2018) Copyright 2021 Torani Journal of Fisheries and Marine Science.

Crabs can consume any plant that produces ecdysteroids. Although derived from plants, this class of ecdysteroid compounds shares similarities with spinach, mulberries, ferns, betel leaves, and crabs. Phytoecdysteroids are chemicals plants produce to defend against herbivorous insects (Herlinah *et al.*, 2014; Romadhon *et al.*, 2022).

These substances are the same as ecdysteroids, which are hormones that crustaceans and other arthropods use during ecdysis, the molting process. Various ecdysteroids are found in animals; for example, the silkworm (Bombyx mori) has at least 19 different kinds. More than 1000 ecdysteroid structures may exist naturally, and over 250 ecdysteroid analogs have been found in plants (Romadhon *et al.*, 2022). Among these ecdysteroids, 20-hydroxyecdysone (20-HE) is the most commonly present in plants and animals. Fujaya *et al.* (2018) observed ecdysteroid compounds in spinach and mulberry plants using thin-layer chromatography and found a set of molecules similar to 20-HE. This suggests that phylum-specific constraints do not limit the hormone signaling system. For instance, exogenous thyroid hormones have been shown to promote larval development and metamorphosis in certain echinoderm species. Recent studies indicate that the phytoplankton consumed by larvae strongly influences endogenous thyroid hormone synthesis in sea urchins. Furthermore, synthesizing ecdysteroids requires plant sterols (Koniyo *et al.*, 2022). Although the exact structure of ecdysteroids derived from mulberries and spinach has not been confirmed, the TLC chromatogram results show spots with Rf

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values of 0.25 and 0.67, corresponding to the leaf and spinach fractions, respectively. When these spots are exposed to UV light at 254 and 366 nm and sprayed with 10% H_2SO_4, they exhibit the same color, indicating that the spots are identical (Figure 3).

The presence of ecdysteroid compounds can also be analyzed using HPLC, as demonstrated in a study by Herlinah *et al.* (2014) on ecdysteroid hormones from mulberry leaf extract, Morus spp., as a molting stimulant for mangrove crabs. The purity of the obtained ecdysterone and the ECD standard was tested using HPLC with a mobile phase mixture of methanol and water (80:20). The ecdysterone standard had a retention time of 1.6 minutes, while plant samples F-1 to F-4 had retention times of 1.823 minutes, 1.763 minutes, 1.650 minutes, and 1.618 minutes, respectively (Figure 2). The results showed that fraction-3 and fraction-4 (samples M-3 and M-4) were closest to the standard. This indicates that the ecdysteroid hormone was successfully isolated from mulberry leaves.

Molting Mechanism in Crabs

Molting is a central and continuous process occurring throughout the life of crabs (Koniyo *et al.*, 2022). During studies, molting in mangrove crabs ranged from 21 to 68 days. According to Hasnidar *et al.* (2021), the fastest molting was achieved by the treatment involving mutilation of all walking legs and claws, with an average molting time of 20 days. The larval development of mangrove crabs from zoea-1 to subsequent zoea stages takes about 3 to 4 days after passing through five zoea stages via five molting events, resulting in the megalopa stage (Herlinah *et al.*, 2014). In juvenile crabs, molting occurs more than six times with 30-35 days intervals between each molt (Deru *et al.*, 2019). This molting process leads to a discontinuous and periodic increase in body size. During molting, the crab absorbs water and increases in size, followed by the hardening of the new exoskeleton. Once the outer shell hardens, the crab's size remains unchanged until the next molting cycle (Koniyo *et al.*, 2022) (Figure 4).

Kanna *et al.* (2021) stated that molting stimulates and accelerates growth. Additionally, molting plays a role in gonad maturation, enabling females to produce eggs and males to produce sperm. They also noted that molting helps regenerate damaged organs. Male crabs are preferred to avoid using female crabs as broodstock because it is feared that female crabs around 150 grams might already have developed eggs, and egg-bearing females do not molt (Lumbantoruan *et al.*, 2021). Numerous studies have been conducted to accelerate molting in crabs, such as through feed manipulation (Dewi *et al.*, 2023), environmental manipulation (Sharifian *et al., 2021), and leg-cutting* or mutilation techniques (Deru *et al.*, 2019).

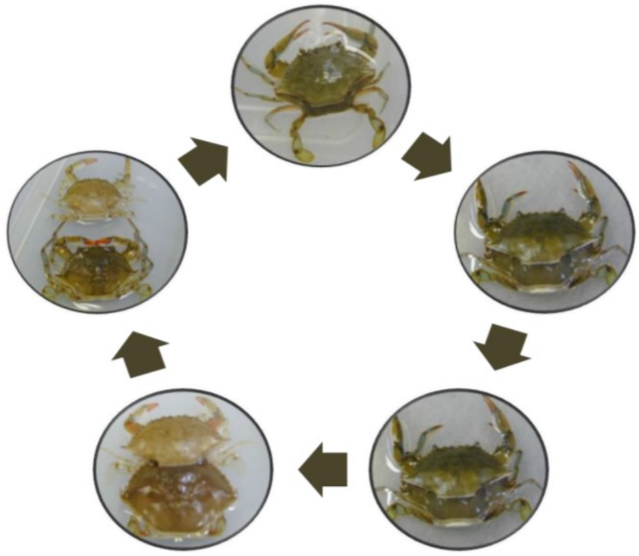

Figure 4. Molting step"s of crab (Islam, 2019) Copyright 2019 Chattogram Veterinary and Animal Sciences University

The average molting period of the test crabs was shorter in the treatment group with lime water alone compared to the control group. Lime water added to the feed serves as a source of Ca^{2+}, which is crucial for increasing ecdysteroid synthesis within cells by inhibiting the action of Molt-Inhibiting Hormone (MIH) on cytoplasmic organs. The calcium-binding protein calmodulin binds to Ca^{2+}, forming a complex that activates the cAMP-phosphodiesterase enzyme, converting cAMP into inactive 5' AMP (Yang *et al.*, 2021). This decrease in cAMP allows the Y-organ to resume ecdysteroid production by neutralizing the effect of MIH. Additionally, Ca^{2+} triggers ATP synthesis, essential for molting energy (Khalifa *et al.*, 2022).

The Y-organ secretes ecdysone, which is converted by the enzyme 20-hydroxylase in the epidermis into the active hormone 20-hydroxyecdysone. Epidermal cells respond to hormonal changes by increasing protein synthesis rates, initiating molting. The molting hormone accelerates protein synthesis, leading to apolysis—the separation of the epidermis from the endocuticle (Xiong *et al.*, 2023). Epidermal cells then release a lipoprotein layer called cuticulin, part of the new epicuticle, while filling the gap with inactive molting fluid. When the cuticulin layer forms, the molting fluid activates, breaking down the old exoskeleton's endocuticle. Beneath the soft and wrinkled cuticulin

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layer, epidermal cells recycle amino acids and microfibrils produced by the cuticulin layer to secrete the new procuticle. Muscle contractions and air intake cause the body to expand once the new exoskeleton is ready, breaking the old exoskeleton along ecdysial sutures and allowing the new exoskeleton to separate. After absorbing water, the crab's newly formed, soft exoskeleton swells, resulting in its larger post-molting (Khalifi *et al*., 2022).

Utilization of Natural Ecdysterone on the Molting Speed of Crabs

Wild fern leaf extract has been utilized to determine mangrove crabs' growth rate and molting speed (Scylla spp.) at an optimal dose of 125 mg/L. This treatment resulted in the highest molting speed value of 0.50±0.57, absolute length growth of 0.37±0.1, absolute weight growth of 20±5.47, specific growth rate of 0.54±0.13, and relative growth of 0.64±0.18 (Romadhon *et al*., 2022). Furthermore, the utilization of Ca^{2+} as a trigger in utilizing spinach in feed on the molting duration of male mud crabs (*Scylla serrata*) showed that the shortest molting duration occurred in the formula using 4 mL of lime water and 40 g of spinach (Andika *et al*., 2013).

Table 2. The growth performance, molting, and survival rate of crabs treated with different frequencies of Vitomolt feeding Treatment (Kanna *et al*., 2021) Copyright 2021 AQUACULTURA INDONESIANA.

Treatment	Molting (%)	SGR (g day^{-1})	AG (g)	SR (%)
A (Control)	0,00±0,00^{a}	3,88±2,06^{a}	3,83±2,59^{a}	83,33±14,43^{a}
B (one time FV/weeks)	8,33±11,78^{a}	7,78±2,12^{b}	12,68±10,79^{b}	50,00±25,00^{b}
C (two time FV/weeks)	16,67±14,43^{a}	7,06±3,39^{b}	14,99±20,47^{ab}	100,00±0,00^{a}
D (three-time FV/weeks)	16,67±28,87^{a}	13,62±17,15^{b}	19,93±22,20^{b}	75,00±0,00^{a}
E (four-time FV/weeks)	8,33±14,43^{a}	6,68±2,66^{b}	11,42±16,49^{ab}	83,33±14,43^{a}

Another study by Kanna *et al.* (2021), the research that focused on evaluating the effects of administering herbal extracts to mud crabs (*Scylla olivacea*) on their growth and molting, specifically considering the frequency of administration of the herbal extract. The herbal extract (Vitomolt®) was a combination of mulberry leaf extract (*Morus alba*), turmeric (*Curcuma xanthorrhiza*), and fingerroot (*Boesenbergia rotunda*), fermented with *Lactobacillus casei*. Sixty crabs, ranging in carapace width from 7.1 cm to 7.7 cm and weighing between 100 and 110 g, were used in the study. Results showed that both absolute growth ($P<0.05$) and specific growth rate ($P<0.05$) were significantly influenced by the frequency of Vitomolt® treatment (Table 2). While ANOVA analysis indicated no apparent effect of Vitomolt® administration frequency on molting, only crabs receiving the PV therapy underwent molting. At the same time, those in the control group did not molt. Administering Vitomolt® two to three days per week was the optimal frequency. These findings suggest that utilizing herbal extracts could offer a different approach to promoting growth and molting in soft-shell crab aquaculture, which is both animal- and environmentally friendly.

Based on research conducted by Herlinah *et al.* (2014), administering ecdysteroids from mulberry leaves to crabs as a molting stimulant showed that a concentration of 100 mg/L resulted in 50% molting, while in the control group and concentrations of 125 mg/L and 150 mg/L, only 33.3% molting was observed. Ecdysterone is a steroid closely related to the molting or ecdysis process. In addition to acting as a molting hormone, ecdysterone can enhance survival rates because it positively affects carbohydrate, lipid, protein, and bone metabolism (Lumbantoruan *et al*., 2021). Naturally, crabs already have ecdysteroid hormones, so hormone administration via injection is based on the ecdysteroid content and hormone requirements at specific phases. However, administering hormones in incorrect doses or concentrations can inhibit molting and growth processes. Therefore, it is important to determine the appropriate dose for optimal molting processes. Excessive hormone administration will not provide optimal benefits. After mulberry ecdysterone administration, the still low molting percentage in mangrove crabs is suspected to be due to an inappropriate hormone dose.

The molting process is a crucial phenomenon for crustaceans, including mangrove crabs. However, this process does not always occur simultaneously and frequently for every individual. Factors such as the environment, nutrition, and body condition can influence molting (Kanna *et al*., 2021). Internal and external factors influence differences in physiological mechanisms in each species. Under normal conditions, young crabs have a greater and more

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frequent likelihood of molting than larger crabs or those that have reached maturity. However, this is not separate from the hormonal cycles and physiological processes within the crab's body.

The potential of karamunting as a substitute source of plant hormones to stimulate molting processes in mud crabs (Scylla serrata) has also been investigated (Almaliki, 2021). The research findings indicate that injection at the optimal dose of 5 µg/g body weight yielded the best molting percentage with a survival rate of 100%. This study suggests administering karamunting leaf extract (Melastoma malabthricum L) can be a molting stimulant in mud crabs. Furthermore, injecting batik spinach extract (Amaranthus bicolor) into mud crabs has a significant dose-dependent effect (Lumbantoruan *et al*., 2021). Using batik spinach extract significantly affects molting speed, specific growth rate, and survival rate of mud crabs. The best treatment for accelerating molting time was P3 (150 ppm/mud crab), with an average of 12.50 days. The highest carapace width growth occurred in P3, reaching 22.50 mm, with a specific growth rate of 0.76% in that treatment. The highest survival rate was achieved in P0, reaching 100%.

Challenges and Future Perspectives

The challenges in utilizing plants containing ecdysteroids to accelerate crab molting include identifying and standardizing plant sources rich in this compound. Not all plants contain sufficient levels, and variations in species, growth conditions, and extraction methods can affect the strength and consistency of extracts. Determining the optimal dose and method of administering ecdysteroids from plants also poses challenges. Excessive dosing can lead to side effects, while insufficient doses may not provide the desired molting acceleration. Striking the right balance is crucial to maximize effectiveness and minimize risks. Furthermore, ensuring the efficacy and reliability of ecdysteroids from plants in accelerating molting in various crab species and developmental stages is also challenging. Factors such as species-specific responses, individual variability, and environmental conditions can affect the effectiveness of this compound. Moreover, meeting regulatory requirements and ensuring the safety of plant-derived ecdysteroids, both for crabs and consumers, is critical. Comprehensive studies on potential side effects, residue levels, and long-term health impacts on crab health and product quality are needed for regulatory approval and consumer trust. There are promising prospects for further developing advanced extraction and purification techniques to enhance efficiency and scalability in obtaining plant extracts rich in ecdysteroids. Adjusting plant-derived ecdysteroid formulations to meet different crab species' physiological needs and developmental stages can enhance their effectiveness. Integrating plant-derived ecdysteroids into sustainable crab farming practices also holds great potential for increasing efficiency and productivity. Through a combination approach by harnessing the synergistic effects between plant-derived ecdysteroids and other bioactive compounds and complementary management strategies, new possibilities can be explored to optimize molting acceleration in crabs. Consumer knowledge about the benefits of plant-derived ecdysteroids in promoting sustainable crab farming practices can drive market demand for products enriched with this compound. Educational efforts highlighting environmental and health benefits can encourage adoption and investment in this innovative approach.

Conclusion

This study highlights the potential of natural stimulants, such as plant extracts, particularly ecdysteroids, in accelerating the molting process in crabs. The research findings indicate that various plants containing ecdysterone can stimulate crab molting. The administration of natural stimulants, such as bracken fern and mulberry leaves, has been shown to enhance crabs' molting speed and growth. However, further research is needed to determine the optimal dosage and understand the mechanism of action of ecdysterone in crabs. Using these natural stimulants could be an environmentally friendly alternative in crab farming, potentially increasing productivity and reducing reliance on synthetic hormones. Nevertheless, the main challenge to address is adjusting the dosage and frequency of natural stimulant administration to achieve optimal results without disrupting the balance of the farming ecosystem.

Acknowledgments

This study is a part of the university's internal research, supported by the Institute for Research and Community Service (LPPM) and the Faculty of Marine and Fisheries, Universitas Syiah Kuala.

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How to cite this paper:
Akbar, S.A., C. Nuzlia, S.Afriani, I. Zulfahmi. 2024. Utilization of Natural Stimulants on Crab Survival and Molting Acceleration: Progresses and Challenges. Depik Jurnal Ilmu-Ilmu Perairan, Pesisir dan Perikanan, 13(2): 256-263.