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REVIEW ARTICLE

Moult induction methods in soft-shell crab production

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Abstract

Soft-shell crabs are gaining attention internationally as a more lucrative option of selling commercially important portunid species due to their ease of consumption, high nutritional values, and unique and excellent taste. This product, however, is only attainable in captivity as crabs are harvested right after moulting when their exoskeletons are still soft. Among the most crucial factor in soft-shell crab production is the moult induction method. Shorter moult intervals imply more soft-shell crabs could be produced, increasing productivity and profit for farmers. This review describes the moulting event, soft-shell crab production process and production systems, and highlights the currently available and potential moult induction methods, including eyestalk ablation, limb autotomy, the use of ecdysteroid, phytoecdysteroid, biogenic amines and methyl farnesoate, the inhibition of moult-inhibiting hormone (MIH) and the regulation of physical parameters. This review further compares these moult induction methods and their benefits towards soft-shell crab production.

KEYWORDS

aquaculture production, crab aquaculture, moult induction method, moulting, portunid, soft-shell crab

1 | INTRODUCTION

Marine portunid crabs (Decapoda: Crustacea) are sought-after delicacies with high commercial value and of great aquaculture potential (Azra et al., 2020; Azra & Ikhwanuddin, 2015; Fazhan, Waiho, Darin Azri, et al., 2017; Zmora et al., 2005). Capture of marine portunid crabs support the livelihood of many local coastal communities (Stacey et al., 2019; Waiho et al., 2017) and with the increasing global catch trend of crabs, they are among the key players in the economic growth of many countries (FAO, 2018). Some portunid species, such as the mud crab of the genus *Scylla*, are being extensively cultured in the Asia-Pacific region due to their high market price (Fazhan et al., 2017b; Shi et al., 2019; Waiho et al., 2019). In addition to being sold in their hard-shell condition, marine portunid crabs are also being traded in another more profitable form – as soft-shell crabs (Tavares et al., 2018).

In general, soft-shell crabs can be produced from any edible portunid crab species. Focus has been given, however, on species with high commercial value and abundant in their native geographical regions. For example, the Atlantic Blue Crab *Callinectes sapidus* is the primary species used to produce soft-shell crabs in the United States (Chaves & Englestone, 2003); blue swimming crab *Portunus pelagicus* is used to produce soft-shell crabs in India (Maheswarudu et al., 2008); while mud crabs (*Scylla* spp.) are the preferred candidates for soft-shell crab production in many countries around Asia (Fujaya, 2011; Shelley & Lovatelli, 2011; Tobias-Quinitio et al., 2015). Eliminating the necessity of extracting meat from its hard exoskeleton, soft-shell crabs can be consumed whole and this is the primary factor for its higher market price. In addition, soft-shell crabs are also gaining popularity and perceived as a healthy food choice due to its unique and excellent taste, high protein content, and minimal carbohydrates (Dana et al., 2015). In particular, by comparing the

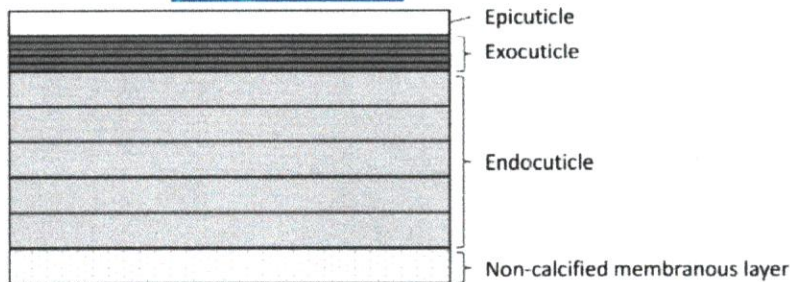


FIGURE 1 Primary layers of crab cuticle

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nutritional value of the edible parts of soft- and hard-shell crabs, He et al., (2016) found that soft-shell crabs were of higher crude protein, moisture, ash and phosphorus contents than hard-shell crabs, whereas the total free amino acids were similar between them.

The production and commercialization of soft-shell crabs started about 150 years ago in the United States and is considered as among the first forms of aquaculture (Roberts, 1905), although it was reported that Native Americans were already consuming soft-shell crabs prior to the arrival of English settlers (Oesterling, 1988). In Asia, the rise in soft-shell crab production occurred during the early 1990s due to an increase in the demand for soft-shell crabs in both domestic and international markets (Tobias-Quinitio et al., 2015). Since then, various studies were conducted to increase the production of soft-shell crabs such as construction of efficient culture systems (Tavares et al., 2018), development of suitable diets (Lwin, 2018), and optimizing physical rearing parameters (Agus et al., 2014). Also, with the advent of technology, a greater understanding on the moulting process of crabs has been achieved by studying their transcriptomic gene expression (Shaymal et al., 2018; Tran et al., 2019). The global status of soft-shell crab production has been reviewed by Hungria et al., (2017). Although the exact production quantity of soft-shell crabs is unknown, most of the soft-shell crab exporting countries are main crab-producing countries, with the Asian continent as the main producer of soft-shell crabs (Hungria et al., 2017; Tobias-Quinitio et al., 2015) and the demand for soft-shell crabs exceeds its supply.

In the production of soft-shell crabs, the main concern of farmers is how to induce moulting in crabs after stocking as shorter moult duration means shorter rearing time, lesser feed cost and other inputs, and therefore, greater profit (Rahman et al., 2020). This review describes the natural moulting process of crabs, the current knowledge on the mechanism behind it, moult induction methods currently used by soft-shell crab farmers and also other potential induction methods that could be used in large-scale culture in the future. Due to the narrative nature of this review, the methodology employed is briefly described (Baethge et al., 2019; Green et al., 2006). Two online databases, Web of Science and Scopus, were searched within the article title using the term "soft-shell crab", "molting" AND "crab", "eyestalk ablation", "limb autotomy", "limb removal", "molt induction" AND "crab", and "ecdysteroid" AND "crab", from 1975 to 2020. Only articles and reviews were included. In addition, snowballing approach based on the reference lists of relevant articles and hand search method were also employed to account for

studies that may have not been indexed in either Web of Science or Scopus databases.

2 | MOULTING

2.1 | Moulting stages and the process

The main process that is involved in the production of soft-shell crabs is moulting. Moulting, also known as ecdysis, is a common phenomenon experienced by many invertebrates with exoskeletons, including crustaceans, to attain growth (Hyde et al., 2018). This process is risky because between moulting and the hardening of their new exoskeletons, crabs are incapacitated and are vulnerable to predators. At the same time, moulting is beneficial because it allows the regeneration of damaged tissues and missing appendages (Hopkins, 2001).

In portunid crabs, the moulting process can be divided into four main stages, that is intermoult, premoult, ecdysis and postmoult (Quinitio & Estepa, 2011; Roer & Dillaman, 2018). The cuticle layers involved during moulting are the epicuticle (outermost), exocuticle, endocuticle and non-calcified membranous layer (innermost) (Figure 1). The outermost epicuticle consists of an organic matrix rich in protein, lipid and calcium salts but without chitin whereas the organic matrix of the inner three cuticle layers is of protein and chitin microfibrils (Roer & Dillaman, 2018). The intermoult stage of portunid crabs is often the longest stage where cuticular formation is completed and the outer exoskeleton is hard - cuticle completely deposited and fully mineralized (Priester et al., 2005) - with minimal sign of epidermis separation from the exoskeleton (Freeman et al., 1987; Mangum, 1985). Most of the crabs stocked for soft-shell crab production are commonly in this moult stage.

The premoult stage can then be further classified into early premoult, mid premoult, and late premoult (Sugumar et al., 2013). Entering premoult stage, a new exoskeleton starts to form underneath and retracts from the cuticle of the old exoskeleton (early premoult stage). This separation is initiated by crustecdysone and caused by a moulting secretion of digestive, chitinolytic enzymes (Priester et al., 2005; Roer et al., 2001). This process is also known as apolysis. Eventually, the inner, non-calcified membranous layer and subsequent calcified layer of the old cuticle - the endocuticle - are partially digested by the enzymes (Compère et al., 1998; Skinner, 1962). When viewed at the propodus of crab's swimming legs, a

clear space between the new and old exoskeleton is visible, with no clear pigmentation. The subsequent mid premoult stage is characterized by the presence of pink pigmentation at the edge of the new exoskeleton as a result of carotenoid mobilization in the epidermis (Mangum, 1985). At the late premoult stage, its coloration changes from pink to dark red as maximum concentration of carotenoid is present (Mangum, 1985). It is also during this stage that the absorption rate of the digested old exoskeleton is at its highest (Priester et al., 2005).

At the beginning of moulting, ecdysial sutures at predictable sites such as underneath and at the rear of the carapace (posterior and lateral margins) are observed as the new exoskeleton expands from within. The dorsal carapace is still attached to the anterior margin of the old exoskeleton similar to a hinge. The new exoskeleton increases in size, along with the ecdysial sutures while the crab backs out from the old exoskeleton. Once completely detached from the old exoskeleton, the crab continues to take up more water in order to maximize the expansion of the new exoskeleton (Mangum, 1985; Waiho et al., 2015). Right after moulting, the crab's new exoskeleton is still uncalcified and soft, thus movement is greatly hindered with very minimal locomotor activity and large chelipeds are not functional, rendering it highly vulnerable to predators (Priester et al., 2005; Waiho et al., 2015). It is during this stage that they are harvested as soft-shell crabs.

The calcification of the epi- and exocuticle (the two outermost cuticle layers) begins in several hours after moulting—postmoult stage (Shafer et al., 1995). Amorphous calcium carbonate, together with α -chitin and β -keratin, are deposited along the epicuticle and the inner and outer edges of the exocuticle, giving early strength and stability to the newly moulted crab (Roer & Dillaman, 2018). The construction and mineralization of endocuticle come after the formation of the first two cuticle layers, that is epi- and exocuticle (Pratoomchat et al., 2002). Cuticle increases in thickness due to the rapid precipitation of calcium carbonate, which gradually change to calcite deposition (Dillaman et al., 2005). Mineralization of the exocuticle and the concurrent calcification of the endocuticle continues until a non-calcified membranous layer is secreted. This marks the end of exoskeleton mineralization and indicates the transition to intermoult stage (Dillaman et al., 2005; Roer & Dillaman, 2018).

2.2 | Hormonal regulation

As in all crustaceans, portunid crabs experience intermittent growth and moulting is a prerequisite for growth and development. The moulting process is regulated by several crucial hormones. Moulting-inhibiting hormone (MIH), a polypeptide neurohormone that negatively regulates moulting from the X-organ sinus gland (XO-SG) complex by reducing the intracellular second messenger cAMP, suppresses the synthesis of moulting hormones known as ecdysteroids, primarily produced in the Y-organ (Nakatsuji et al., 2009; Rodriguez et al., 2007; Techa & Chung, 2015). Ecdysteroids are commonly found in two forms, that is the inactive ecdysone (prohormone) and

the physiologically active form 20-hydroxyecdysone (20E) which is activated in the peripheral tissues (Hyun, 2018). Generally, 20E and ecdysone concentrations are low during intermoult, highest during moult and decrease again during postmoult (Abdullah-Zawawi et al., 2021; Styriehave et al., 2004; Thomson et al., 2006). Apart from 20E, another active form of ecdysteroid, that is ponasterone A (PoA), exists in some crustacean species. For example, PoA is the major type of ecdysteroid rather than 20E in the haemolymph of premoult *C. sapidus* (Chung, 2010) and *C. maenas* (Styriehave et al., 2008). MIH is, in turn, regulated by the extracellular signal-regulated kinases (ERK)/mitogen-activated protein kinases (MAPK) pathway and the moulting process is accelerated when the phosphorylation of ERK is inhibited during early- and mid-postmoult, and intermoult stages (Imayavaramban et al., 2007). In the absence of phosphor ERK, protein kinase C-mediated pathway and subsequently steroidogenic acute regulatory protein (StAR) protein synthesis (an essential ingredient for steroidogenesis, including ecdysteroid biosynthesis) are activated (Imayavaramban et al., 2007; Stocco, 2000).

In addition to ecdysteroids, neuropeptide crustacean cardioactive peptide (CCAP) – produced from the pericardial organs of crab or ventral nerve cord of crayfish – is also shown to be involved in crustacean moulting (Philippen et al., 2000). The haemolymph level of CCAP increases about 30- to 100-fold in crab (*C. maenas*) and crayfish (*Orconectes limosus*), respectively, during moulting and drops a few hours after postmoult, suggesting their potential involvement in successful termination of the moulting process (Philippen et al., 2000).

Methyl farnesoate (MF) is produced by the mandibular organs (MOs) of crustaceans and is chemically similar to insect juvenile hormone III (Laufer et al., 1987; Xie et al., 2016). MF is negatively regulated by mandibular organ inhibiting peptide hormone (MOIH) produced by the XO-SG complex in the eyestalk (Reddy et al., 2004). It was shown *in vitro* that methyl farnesoate stimulated the secretion of ecdysteroid in Dungeness crab *Cancer magister* (Tamone & Chang, 1993). In addition to inducing ecdysis (Reddy et al., 2004; Rotllant et al., 2000), MF is also involved in gonadal maturation (Laufer et al., 1998; Rotllant et al., 2000), morphogenesis (Rotllant et al., 2000) and protein synthesis (Paulson & Skinner, 1988).

3 | SOFT-SHELL CRAB PRODUCTION PROCESS

Soft-shell crab farming starts with securing suitable sub-adult candidates. In most Asian countries where the production of soft-shell crabs is well established and being conducted in large-scale, seedstocks are still sourced from the wild (Fujaya, 2011; Tobias-Quinitio et al., 2015). This put tremendous pressure on the already decreasing wild crab populations and is not sustainable (Fazhan et al., 2017c; Waiho et al., 2018). With the recent advancement in larval rearing and juvenile culture of crabs, Southeast Asian Fisheries Development Center (SEAFDEC) in the Philippines and Gulf Coast Research Laboratory in the United States are spearheading the production of soft-shell mud crabs (*Scylla* spp.) (Tobias-Quinitio et al.,

2015) and blue crabs (*C. sapidus*) (Perry et al., 2010), respectively, using hatchery-reared crablets.

Generally, the common stocking sizes used are 50–80 mm carapace width (CW) (60–100 g) for *Scylla* spp. (Fujaya, 2011; Tobias-Quinitio et al., 2015) and 40–50 mm CW for *C. sapidus* (Perry et al., 2010). Crabs are usually stocked individually in cages throughout the rearing period to facilitate easier identification of moulting and harvesting, and to avoid cannibalism (Fazl et al., 2017c). Feeding is carried out once or twice daily using a wide variety of protein sources such as trash fish, bivalves, and formulated diets at 5%–10% of their initial biomass (Fujaya, 2011; Perry et al., 2010; Shelley & Lovatelli, 2011). Excess feed is often removed an hour after feeding.

Daily visual monitoring is conducted every four to five hours to identify premoult crabs. Newly moulted crabs are retrieved immediately. The identification of premoult period is feasible by visual inspection, that is the visualization of the swimming legs (Freeman et al., 1987; Ostrensky et al., 2015). When a crab is entering the premoult period, new exoskeleton is almost ready and can be seen beneath the old exoskeleton in the form of a white line along the edges of the propodus segment of its swimming legs. When the white line changes to reddish coloration, moulting is expected within 24–48 hr (Kennedy & Cronin, 2007). Since the calcification process of new exoskeleton occurs immediately after moulting, only a short time frame of 1–3 hr is available for soft-shell crab collection before the new exoskeleton starts to exhibit a firm and papery texture, upon which the crab loses its commercial value (Wheatly, 1999) (Figure 2).

After collection, soft-shell crabs are immediately cleaned using freshwater, individually packed and frozen at -20°C while still alive to ensure freshness and quality of the final soft-shell crab products. Storage of frozen soft-shell crabs at -20°C maintains their freshness for at least a year (Shelley & Lovatelli, 2011) and they can be easily stored and transported in the frozen state.

4 | SOFT-SHELL CRAB PRODUCTION SYSTEMS

The high market demand and the scarcity in obtaining soft-shell crabs from wild-caught fisheries drive the need for a continuous

production of soft-shell crabs in captivity. The current available soft-shell crab production systems are adequately reviewed by Tavares et al., (2018). Hence, only a brief introduction to the common soft-shell crab production systems is provided in this review.

4.1 | Open systems

The open systems are considered the most traditional systems where a selected coastal zone with tidal influences is enclosed with wooden fences (Oesterling, 1993). Sub-adult crabs are then stocked within the enclosure and newly moulted crabs are harvested as soft-shell crabs. To enable an easier and more efficient monitoring and harvesting of newly moulted crabs, individual boxes or cages, either made of wood or polyethylene, are placed within the enclosure. However, the open systems have several limitations despite its cost-effectiveness in terms of construction and operation. The uncontrollable fluctuations in environmental parameters (e.g. temperature, salinity, dissolved oxygen) would affect the consistency of the overall production of soft-shell crabs (Tavares et al., 2018). Large-scale production of soft-shell crabs would take up large surface area of the coastal zones. Therefore, this will surely have an impact on the coastal ecosystem in addition to the extensive labour needed for the daily management of the open systems (Gaudé & Anderson, 2011; Oesterling, 1988).

4.2 | Semi-closed systems

In semi-closed systems, the whole production set-up of the open systems, for example the use of individual boxes or cages, are incorporated into inland aquaculture ponds to enable a better monitoring and control over the environmental parameters. Waters are often sourced directly from the adjacent brackish environment and walkway structures are constructed perpendicularly across rows of boxes or cages to facilitate easier feeding and monitoring activities (Tavares et al., 2018; Trino et al., 2001). Although the semi-closed systems allow better protection from weather and predators, and provide some control over the environmental parameters, especially

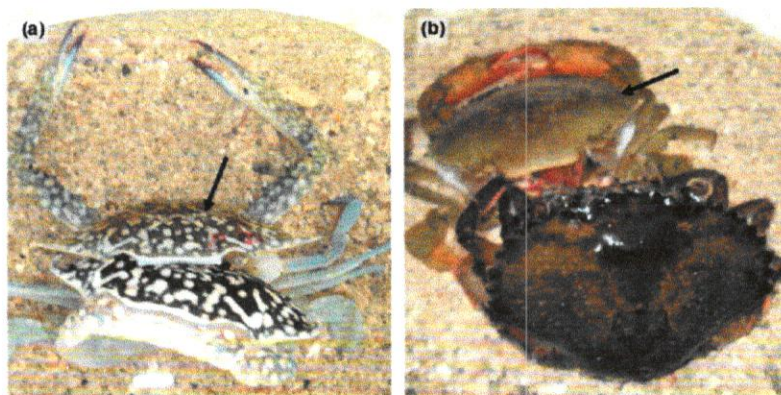


FIGURE 2 Newly moulted *Portunus pelagicus* (a) and *Scylla olivacea* (b). The old exoskeletons are marked with arrows

salinity, they are still very much dependent on the water quality of their source (Kennedy & Cronin, 2007).

4.3 | Closed systems

The closed systems are independent of the natural environment and can be constructed and maintained at any inland indoor facilities, thus giving full control over site selection. In general, closed systems incorporate recirculating systems and crabs are reared in individually connected compartments. The use of stackable individual compartment allows high-density production and enable better monitoring and harvesting. Also, the closed systems allow easy incorporation of other forms of automation, such as the incorporation of monitoring systems to enhance feeding and allow the timely collection of newly moulted crabs. However, the attractive benefits of the closed systems are accompanied by high investment and production costs, and the requirement for skilled labour (Oesterling, 1988; Tavares et al., 2018).

5 | MOULT INDUCTION METHODS

Traditionally, soft-shell crab production involves the rearing of crabs in captivity and retrieve them right after they moult naturally (Oesterling, 1988). However, with the current knowledge on the moulting process of portunid crabs, several methods are commonly practised or potentially useful in soft-shell crab farming.

5.1 | Eyestalk ablation

Eyestalk ablation, the removal of either one (unilateral) or both (bilateral) eyestalks, is among the first methods being applied in crustaceans to induce moulting (Alikunhi et al., 1975; Browdy & Samocha, 1985). Among the common techniques used to perform eyestalk ablation includes (1) direct pinching or cutting of the eyestalk, although this method is prone to leave an open wound (Imavera & Borlongan, 1977); (2) enucleation, that is slicing the distal portion of the eye with a razor and removing the eyestalk contents via the incision (Taylor et al., 2004); (3) cauterizing the eyestalk using electrocautery devices or red-hot forceps (Chu & Chow, 1992); and (4) ligation at the base of the eyestalk using surgical thread (Diarte-Plata et al., 2012). Among these ablation techniques, cauterizing and ligation methods are preferred as they provide immediate wound closure.

Eyestalk ablation essentially removes the XO-SG complex, thus stopping or suppressing the production of MIH and allowing ecdysteroids produced by the Y-organ to act (Stella et al., 2000). Eyestalk ablation successfully reduced the moulting duration of economically important brachyuran species (Table 1). It was found that crabs subjected to eyestalk ablation at intermoult stage exhibited shorter intermoult duration compared with those that had

their eyestalk ablated during postmoult stage or without eyestalk ablation (Rana, 2018; Sukardi et al., 2019). Also, bilateral eyestalk ablation induced faster moulting and resulted in higher moulting rate compared with unilateral ablation (Stella et al., 2000). Evidently, haemolymph ecdysteroid levels increased significantly after eyestalk ablation in crabs (Sudha & Anilkumar, 2007; Tamone et al., 2005) and were found to be even higher than the ecdysteroid levels of normal premoult individuals (Abuhagr et al., 2014; Sudha & Anilkumar, 2007).

However, ablation is known to cause adverse sensory experiences (Diarte-Plata et al., 2012), stress (Elwood et al., 2009) and death in crustaceans (Racotta et al., 1998), and these raised concerns among farmers. Eyestalk ablation also induces internal physiological changes, including disrupting the function of crustacean hyperglycaemic hormone (CHH), a stress-indicating hormone, by elevating haemolymph glucose levels (Loredo-Ranjel et al., 2017). CHH is produced in the X-organ and released from the sinus gland, and eyestalk ablation removes these two completely.

5.2 | Limb autotomy

Unlike eyestalk ablation, limb autotomy, or self-amputation of limb, commonly occurs in crustaceans including brachyuran crabs, in their attempt to escape or in response to injury (Emberts et al., 2017; McVean & Findlay, 1979). There is a pre-formed breakage plane between the coxopodite and basi-ischiopodite of the crustacean appendage where limb autotomy could occur (Cooney et al., 2017; McVean, 1982; Sy & Airriess, 2002). It is believed that two separately innervated muscles, the anterior and posterior levator muscles, that are involved in normal walking movements have autotomy-specific motor neurons to initiate and generate the required force to perform limb autotomy in crabs (Emberts et al., 2017; McVean, 1982; Moffett et al., 1987; Vidal-Gadea & Belanger, 2009). New limbs are then fully regenerated during subsequent moulting(s) (Mykles, 2001). Thus, limb autotomy induces moulting in crustaceans (Cooney et al., 2017; Rahman et al., 2020) and has been documented to trigger precocious moults in many brachyuran species (Table 2).

Limb autotomy is one of the practices used by farmers in Southeast Asia to shorten intermoult duration in the production of soft-shell crabs. It is often done by pinching or applying pressure to the merus segment of the appendage (limb) (Smith & Hines, 1991). Patterson et al., (2009) induced autotomy of the chelipeds by making a small cut near the joint of the merus, distal to the breakage plane. This method, however, does not always produce desirable results, as some crabs may not be able to regenerate back the lost limbs to their original size in one moult (Smith, 1990). Some brachyuran species, such as the commercially important blue crab *C. sapidus* would need up to three moults (Smith, 1990) whereas mud crab *Scylla* juveniles need at least two moults to regenerate the missing limbs to the original size (Quinitio & Estepa, 2011). In addition, the effect of limb autotomy on moult induction also depends greatly on the stage during which limbs were lost and the numbers

TABLE 1 Eystalk ablation in commercially important brachyuran species

Family	Species	Sex	Treatment (n)	Ablation method	Days to moult (Mean ± SD)	Moult rate (%)	Other changes after ablation	References
Portunidae	<i>Callinectes sapidus</i>	N/A	UEA (9) C (9)	Direct pinching	31.5 ± 15.50 ^a 62.6 ± 17.50 ^b	N/A N/A	N/A	Amador del Angel et al., 1999
		MF	BEA (15) C (5)	Cauterization	51.6 ± 0.64 ^a N/A	80.0 N/A	N/A	Havens & McConaughy, 1990 Vega-Villasante et al., 2007
	<i>Callinectes arcuatus</i>	JF (<60 mm)	UEA (18) C (18)	Cauterization	15.0 ± 2.00 ^a 20.0 ± 2.00 ^b	N/A N/A	N/A	Martelli et al., 2019
		JF (>70 mm)	UEA (18) C (18)	Cauterization	15.0 ± 2.00 ^a 30.0 ± 2.00 ^b	N/A N/A	N/A	
Pisidae	<i>Ovalipes trimaculatus</i>	J	UEA (8–10) C (8–10)	Cauterization	No moulting 43–45	N/A N/A	N/A	Hinsch, 1972
		MF IF	BEA (43) BEA (51)	Direct cutting	No moulting 14–35	0 N/A	- increased spawning	
	<i>L. emarginata</i>	IF	BEA (14) C (7)	Cauterization	27.4 ± 2.31 ^a 71.6 ± 0.39 ^b	N/A N/A	- reduced carapace length - increased haemolymph methyl farnesoate level	Laufer et al., 1997
		MM	BEA (68) C (40)	Cauterization	N/A N/A	17.6 0	- increased in weight of mandibular organs and Y-organs	Sainath & Reddy, 2010
Gecarcinidae	<i>Oziotelphusa senex senex</i>	MM	BEA (40) C (40)	Cauterization	N/A N/A	7.5 0	- high mortality (22.5%) in BEA group versus control (0%)	Reddy, 2019
		F	BEA (40) C (40)	Cauterization	N/A N/A	7.5 0	- increased in weight of mandibular organs and methyl farnesoate levels	Nagaraju et al., 2004
	<i>O. senex senex</i>	MM	BEA (34) C (26)	Cauterization	N/A N/A	N/A N/A	- increased in weight of mandibular organs and methyl farnesoate levels	Nagaraju et al., 2004
		MF	BEA (29) C (37)	Cauterization	N/A N/A	N/A N/A	- increased in weight of mandibular organs and methyl farnesoate levels	

Note: Uppercase alphabets or asterick in each experiment indicate significant difference ($p < 0.05$).

MF, mature females; IF, immature females; M, males; F, females; MM, mature males; IM, immature males; n, number of individuals; C, control; UEA, unilateral eystalk ablation; BEA, bilateral eystalk ablation; N/A, not available.

^aIndicates standard error instead of standard deviation (SD).

TABLE 2 Limb autotomy in commercially important brachyuran species.

Family	Species	Stage/sex	Number of appendages autotomized (n)	Days to moult (Mean ± SD)	Mouthing rate (%)	Other changes after limb autotomy	References
Portunidae	<i>Callinectes sapidus</i>	Im	1 - right CH (26)	Intermoult lengths of 1st, 2nd and 3rd moults were not significant among treatments.	N/A	Multiple limb autotomy resulted in smaller size (lesser CW increment)	Smith, 1990
			4 - CHs, right first WL & left SL (26) C (26)				
	<i>Scylla olivacea</i>	Im	1 - right CH (30)	Intermoult length of 1st and 2nd moults were shortened when both CHs and when all appendages were removed.	N/A	60%–90% showed relatively small claws and walking legs	Rahman et al., 2020
			2 - CHs (30)				
			3 - right WLs (30)				
			6 - all WLs (30)				
			4 - right CH and WLs (30)				
8 - all appendages except SLs (30) C (30)							
	<i>Scylla olivacea</i>	IM	6 - WLs (48)	28.07 ± 11.71 ^b	87.50 ± 6.25 ^a	Removal of all appendages except SLs resulted in lowest size and weight increment	Fujaya et al., 2020
			8 - all appendages except SLs (48)	19.81 ± 5.87 ^a	89.58 ± 7.22 ^b		
			C (48)	59.31 ± 12.43 ^c	54.17 ± 7.22 ^b		
			6 - WLs (48)	26.51 ± 8.00 ^b	81.25 ± 16.54 ^{ab}		
			8 - all appendages except SLs (48)	19.58 ± 3.45 ^a	93.75 ± 6.25 ^a		
			C (48)	57.04 ± 15.28 ^c	50.00 ± 12.50 ^b		
	<i>Scylla paramamosain</i>	Stage 2 crablets	1 - CH (75)	6.2 ± 0.1 ^a	98.7 ± 2.3 ^a	N/A	Gong et al., 2015
			C (75)	5.8 ± 0.1 ^b	97.3 ± 2.3 ^a		
			1 - CH	10.3 ± 0.38 ^a	N/A		
	<i>Scylla serrata</i>	Im	2 - CHs	10.3 ± 0.52 ^a	N/A	Specific growth rate of crabs with 2 autotomized chelipeds had the lowest specific growth rate after first moult but was the highest after second moult.	de la Cruz-Huervana et al., 2019
			C	12.5 ± 0.66 ^b			
Varunidae	<i>Eriocheir sinensis</i>	Im	1 (16)	Intermoult length of 1st (but not 2nd) moult decreased with increasing number of autotomized appendages.	>90 (no significant difference for all treatments)	Specific growth rate positively correlated with number of appendages autotomized	He, Wu, et al., 2016
			2 (16)				
			3 (16)				
			4 (16)				
			5 (16)				
C (16)							

Im, immature crabs; IM, immature males; IF, immature females; n, number of individuals; C, control; CH, cheliped; WL, walking leg; SL, swimming leg; CW, carapace width; N/A, not available; uppercase alphabets in each experiment indicate significant difference ($p < 0.05$).

^aIndicates standard error instead of standard deviation (S.D.).

^bIndicates significant when compared to control.

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of limbs autotomized. Moulting is hastened if multiple limb autotomy occurs during intermoult stage but no effect or even longer intermoult duration is observed if limbs were autotomized during premoult, especially mid- to late premoult (McCarthy & Skinner, 1977). Thus, for farmers to apply limb autotomy in soft-shell crab production, knowledge on the accurate determination of moult stage is important. The shorter moult cycle induced by limb autotomy is highlighted in the studies of Fujaya et al., (2020) and Rahman et al., (2020) on a commonly used species for soft-shell crab production, that is mud crab *S. olivacea*.

Limb autotomy comes with enormous costs. Crabs subjected to limb autotomy are at risk of huge loss of haemolymph (Fleming et al., 2007), and a feeding and locomotion handicap depending on the number and types of limb lost (Emberts et al., 2017; Smith & Hines, 1991). Also, crabs subjected to multiple limb autotomy exhibited smaller size (carapace width) increment (Fujaya et al., 2020; Smith, 1990) and body weight (Fujaya et al., 2020; He et al., 2016) compared with intact controls post-autotomy moult. The regeneration of appendages, especially chelipeds, after limb autotomy requires even more energy and time. As soft-shell crabs are also classified based on the presence or size of limbs, crabs with smaller newly regenerated limbs upon moulting will not benefit soft-shell crab farmers from an economic viewpoint.

5.3 | Ecdysteroid application

Ecdysteroids are the main hormones that regulate moulting in crustaceans and their levels are positively related to moult stages (Techa & Chung, 2015). Thus, manipulating ecdysteroid levels in haemolymph theoretically would result in faster moulting. After several successful trials of inducing moulting in other crustacean species using 20E (Krishnakumaran & Schneiderman, 1970; Warner et al., 1969), Raghavan and Avanath (2019) showed that when administered during early premoult and intermoult stages, 20E induced shorter premoult and intermoult intervals in the adults of edible freshwater crab *Travancoriana schinerae*. However, as observed in other crustaceans, *T. schinerae* subjected to 20E injections were less likely to survive (up to 43% mortality rate in 20E treated crabs compared with up to 13% in control) (Raghavan & Ayanath, 2019). Interestingly, in mud crab *Scylla olivacea*, Tamsil and Hasnidar (2018) reported that injection of 1.0 µg/ml caused a significant increase in haemolymph ecdysteroid level, higher moulting percentage and body size and weight increment, shorter moulting duration, and survival rate was not negatively affected, whereas higher 20E dosage (1.3 and 1.6 µg/ml) resulted in a negative feedback effect and crabs exhibited lower moulting and growth performance. Due to the high mortality following ecdysteroid application, this method has not been tested in most species used in soft-shell crab production. The use of ecdysteroids on mud crab genus *Scylla*, however, has high potential as shown by the results of Tamsil and Hasnidar (2018). Future research should focus on optimizing the 20E dosage and trials in other *Scylla* species other than *S. olivacea*.

5.4 | Phytoecdysteroid application

Phytoecdysteroids are plant-based secondary metabolites analogue to insect's ecdysteroids that are responsible for the regulation of moulting, growth and reproduction (Rharrabe et al., 2010). It is suggested that they form a part of a plant's defence system against insects (Schmelz et al., 2002). Although more than 300 different types of phytoecdysteroids were identified, the most common form is similar to that found in insects and crustaceans, that is 20E (Baltaev, 2000). Phytoecdysteroid levels vary greatly among plant species, and while most contain only minimal amounts, some plant families are known to exhibit high levels of ecdysteroids, such as plants of the family Asteraceae (Odinokov et al., 2002) and Lamiaceae (Rharrabe et al., 2010).

Although generally toxic to insects (induce abnormal moulting leading to developmental defect) and exhibit a strong anti-feedant effect (Dinan, 2009; Rharrabe et al., 2010; Schmelz et al., 1998), phytoecdysteroids are known to induce synchronized development and yield in commercially important arthropods (Chandrakala et al., 1998) and have great potential in arthropod culture and aquaculture (Kanazawa et al., 1972). Research on the use of phytoecdysteroid as a moulting inducer of crustaceans is currently being spearheaded by researchers in Indonesia (Aslamyah & Fujaya, 2010; Fujaya, 2011; Nikhlani & Sukarti, 2017) and Thailand (Sorach et al., 2013), with some phytoecdysteroid products already being used commercially in soft-shell crab production farms (Fujaya, 2011). The most common administration method is injection (Fujaya, 2011; Herlinah et al., 2014, 2015; Sorach et al., 2013) although trials incorporating phytoecdysteroids into feed were also being conducted (Aslamyah & Fujaya, 2010; Fujaya et al., 2011). Based on the available literature (Table 3), phytoecdysteroids extracted from the family Amaranthaceae, Lamiaceae and Moraceae induced higher moulting success and moulting percentage, in addition to promoting higher growth increment and survival rate in portunids. Although further research and optimization are needed, the use of phytoecdysteroids to induce moulting in crabs is promising.

5.5 | Control of physical parameters

5.5.1 | Temperature

Aside from directly manipulating moulting hormones and/or their related organs, changes in physical parameters such as temperature could also affect the production of neuropeptides in the Y-organ (Chung & Webster, 2005; Pitts et al., 2017). As the Y-organ is negatively regulated by MIH and CHH, and CHH is known to increase upon exposure to environmental stress (Rajendiran et al., 2016), therefore, moult inhibition or delay may occur upon stress exposure (Pitts et al., 2017). For example, maximum growth after moulting of *C. sapidus* was observed when reared at a temperature of 23°C and salinity of 30 ppt (Cadman & Weinstein, 1988). In a separate experiment, Brylawski and Miller (2006) showed

TABLE 3 Phytoecdysteroid application in brachyurans.

Source of phytoecdysteroid		Tested species		Growth stage (Application method)	Phytoecdysteroid concentration	Effect	Reference
Family	Species	Family	Species				
Amaranthaceae	<i>Amaranthaceae tricolor</i> (leaf)	Portunidae	<i>Portunus pelagicus</i>	Larvae (Feed)	C 1 mg/100 g ³² 2 mg/100 g 4 mg/100 g	- Dose of 4 mg/100 g showed higher survival at crablet stage.	Nikhlani & Sukarti, 2017
	<i>Spinacia oleracea</i>	Portunidae	<i>Scylla</i> sp.	Juvenile (Feed)	C A (Pro.: 46.8%; Carb.: 33.3%) B (Pro.: 41.6%; Carb.: 38.3%) C (Pro.: 35.6%; Carb.: 44.3%) D ((Pro.: 30.6%; Carb.: 49.1%) A-D were enriched with 700 ng/g <i>S. oleracea</i> extract	- Treatment D achieved 100% moulting success within 60 days. - Treatment A and B showed higher growth increment after moulting.	Aslamyah & Fujaya, 2010 ²¹
	<i>Amaranthus</i> spp. (developed into product called Vitomolt)	Portunidae	<i>Scylla</i> spp.	Juvenile (Injection)	C 9 µg/g 15 µg/g 21 µg/g	- 21 µg/g resulted in highest weight increment after moulting. - 15 µg/g resulted in highest moulting percentage after 55 days.	Fujaya, 2011
	<i>Vitomolt</i>	Portunidae	<i>Scylla olivacea</i>	Juvenile (Injection & Feed)	C Injection only (15 µg/g) Injection (15 µg/g) + Feed (32.38 mg/g)	- 'Injection only' resulted in highest moulting percentage. - 'Injection +feed' resulted in fastest moulting response. - Both 'injection only' and 'injection +feed' had lower mortality rate than control.	Fujaya et al., 2011
Lamiaceae	<i>Vitex glabrata</i> (bark)	Portunidae	<i>Portunus pelagicus</i>	Juvenile (Injection)	C 0.1 µg/g ¹⁶ 0.2 µg/g 0.3 µg/g 0.4 µg/g 0.5 µg/g 1.0 µg/g	- Dose of 0.4 µg/g BW injected during postmolt shortened postmolt to premolt stages. - Dose of 0.5 µg/g BW injected during intermolt shortened intermolt to premolt stages. - Survival rates were equal or higher than control when phytoecdysteroids were given at postmolt and intermolt stages.	Sorach et al., 2013
Moraceae	<i>Morus</i> sp. (leaf)	Portunidae	<i>Scylla olivacea</i>	Juvenile (feed)	C 1.1 mg/g ³⁷ 1.9 mg/g 2.7 mg/g 3.5 mg/g	- Doses of 1.9 and 2.7 mg/g resulted in faster moulting.	Fujaya et al., 2018
	<i>Morus</i> sp. (leaf)	Portunidae	<i>Scylla olivacea</i>	Juvenile (Injection)	C 100 mg/l ⁵⁰ 125 mg/l 150 mg/l	- Dose of 100 mg/l resulted in higher (50%) moulting percentage compared with other treatments and control (all at 33.3%).	Herlinah et al., 2014, Herlinah et al., 2015 ⁶¹

C., control; conc., concentration; BW, body weight; Pro., protein; Carb., carbohydrate.

that the intermoult period of *C. sapidus* decreased as temperature increased, although temperature did not affect their growth per moult. *Scylla serrata* juveniles held in a constant temperature of 29°C and 32°C exhibited significant shorter moult interval (32 ± 0.8 days and 28 ± 1.1 days respectively) than those reared at ambient temperature (39 ± 0.9 days) whereas all crabs reared in 35°C died 11 days after stocking due to incomplete moulting (de la Cruz-Huervana et al., 2019). Further, crabs reared in 32°C had significantly higher specific growth rate compared with those reared in 29°C and ambient temperature in both first and second moult, although no difference was observed in weight and body size increment after each moult (de la Cruz-Huervana et al., 2019). Also, Ruscoe et al., (2004) showed that *S. serrata* instar 2 crabs exhibited shorter intermoult duration when held at high temperature (30 and 35°C) compared with at 25°C and had the highest mean weight at harvest at 30°C in salinities of 5–20 ppt. A similar observation of shorter intermoult duration in higher temperature (up to 32–34°C) was also observed in *S. serrata* larvae (Nurdiani & Zeng, 2007) and in stage 1 crabs of other *Scylla* species, that is *Scylla paramamosain* (Gong et al., 2015).

5.5.2 | Salinity

Low salinity (5 ppt) resulted in low moulting success rate ($74.7 \pm 2.3\%$) but shorter moulting interval (4.7 ± 0.1 days) compared with higher salinities (10–40 ppt with moulting success rate >96.0%, moulting intervals >5.0 days) in stage 1 crabs of *S. paramamosain* (Gong et al., 2015). Thus, to a certain extent within the acceptable zone, an increase in salinity induces moulting in brachyurans. Salinity has a lesser effect on moulting compared with temperature and the optimal salinity is mostly species dependent.

5.6 | Other potential moult induction methods

5.6.1 | Biogenic amines application

Biogenic amines are biogenic substances with at least one amine group. They are neuroregulatory molecules involved in various biological functions of crustaceans (Fingerman, 1994). For example, serotonin and melatonin are known regulators of crustaceans' reproduction (Fingerman, 1997; Tinikul et al., 2008), glucose homeostasis (Reddy & Pushpalatha, 2007; Tilden et al., 2001, 2003) and moulting (Reddy, 1990; Sainath & Reddy, 2010; Tilden et al., 1997). By using freshwater edible crab *Oziotelopus senex senex* as a model, Sainath and Reddy (2010) showed that injection of melatonin (10^{-7} mol/crab) into intact crabs ($n = 60$) resulted in faster moulting (42 in premoult stage, 6 in postmoult stage after 28-day experimental period) compared with control ($n = 40$: all in intermoult stage after 28-day experimental period) and induced heavier mandibular organs and Y-organs by 28.8% and 42.6% respectively. The injection of serotonin (10^{-6} mol/crab) into intact crabs ($n = 60$), however, did not cause significant changes in

moulting. Further, no significant variations in moulting duration, and weights of mandibular organs and Y-organs were observed in crabs when serotonin and melatonin were injected after eyestalk ablation compared with crabs subjected to only eyestalk ablation (Sainath & Reddy, 2010). Thus, it was postulated that melatonin induces moulting in crabs by inhibiting the release of MIH and/or MOIH (Sainath & Reddy, 2010). In a separate study on mud crab *Scylla serrata*, injection with 0.4 ng/g body weight of serotonin resulted in significantly higher methyl farnesoate (86.5%) and ecdysteroid (132%) levels in haemolymph (Girish et al., 2017). Therefore, the effect of serotonin in moult induction of crabs appears to be species-specific.

5.6.2 | Methyl farnesoate application

As mentioned in 3.2, the sesquiterpenoid methyl farnesoate is synthesized in the MOs (Laufer et al., 1998). Its role in moulting is tightly linked with its stimulatory effect on the secretion of ecdysteroids (Homola & Chang, 1997). An earlier study showed that the length between moults of white shrimp *Penaeus setiferus* significantly reduced (average days to moult = 32.2 days) when implanted with the MOs of blue crab *C. sapidus* compared with intact controls (average days to moult was 87.6 days), those only jabbed with syringes (average days to moult = 76.5 days) and those implanted with muscle tissues (average days to moult = 70.6 days) (Yudin et al., 1980). Injection of methyl farnesoate into *T. schimurae* (10, 30, 50 ng/10 μ l per injection) during intermoult and early premoult stages significantly shortened their intermoult and premoult intervals, although it also resulted in high mortality rate (up to 47% compared with control of only up to 13%) (Raghavan & Sainath, 2019). The positive effect of methyl farnesoate on moulting was also validated in freshwater crab *O. senex senex* when 64% and 16% of females injected with methyl farnesoate (10 ng/crab) were in premoult stage and moulted respectively. Also, 76% and 24% of methyl farnesoate-injected (10 ng/crab) males were in premoult stage and moulted respectively (Reddy et al., 2004). Comparatively, the controls (intact controls and controls injected with 10% ethanol) of both sexes remained in intermoult stage (Reddy et al., 2004). Administration of methyl farnesoate also resulted in significant increase in ovarian and testicular indexes, and mean oocyte and testicular follicle diameters (Reddy et al., 2004). Based on these results, Reddy (2019) then tested the effect of dietary methyl farnesoate on the growth of female *O. senex senex*. It was found that dietary methyl farnesoate of 10^{-8} mole/crab, 10^{-9} mole/crab and 10^{-7} mole/crab resulted in higher moult percentage (25.0%, 12.5% and 10.0% respectively) and no mortality compared with eyestalk-ablated controls (moult percentage = 7.5%; mortality = 22.5%) (Reddy, 2019).

5.6.3 | Moulting-inhibiting hormone (MIH) inhibition

Moulting-inhibiting hormone essentially inhibits the moulting process by negatively regulating the synthesis of ecdysteroids by the

Y-organs. Thus, theoretically, inhibition of MIH would enhance ecdysteroid synthesis and subsequently promote ecdysis. This is feasible using RNA interference (RNAi) technique. With the aid of double-strand RNA (dsRNA), Techa and Chung (2015) showed that multiple injections of CasMIH-dsRNA (15 µg per injection, approximately 30 times within 60 days) successfully reduced the expression of MIH in *C. sapidus* by about 50 times. However, the significant reduction of MIH levels in *C. sapidus* did not result in shorter moult intervals compared with control (14.5 ± 3.0 days versus 20.0 ± 3.2 days respectively). In contrast, *in vivo* injections of Cq-MIH dsRNA significantly reduced moult interval up to 32% in Australian red claw crayfish *Cherax quadricarinatus* and comparable to treatments injected with ecdysone (Pamuru et al., 2012). Similar significant reduction of moult interval in both sexes was also reported in the oriental river prawn, *Macrobrachium nipponense* after inhibition of MIH by RNAi (Qiao et al., 2018). These suggest that the effect or extent of MIH on ecdysteroid synthesis might be species-specific. In mud crabs (*Scylla serrata*), it has been shown that MIH suppressed ecdysteroidogenesis via the induction of ERK activation through Ras/Raf pathway (Imayavaramban et al., 2007). Therefore, it is highly possible that the inhibition of MIH might promote ecdysteroid synthesis and leads to shorter moulting interval in *Scylla* species.

6 | COMPARISON BETWEEN MOULT INDUCTION METHODS

Although the efficiency of a technique to induce moulting would be the main criterion during the selection of moult induction methods, farmers and aquaculturists would also need to consider other cost- and profit-related factors such as the ease of application, application cost, crab survival rate, effect on size and weight, and limb completeness (Table 4). Among the methods described in this study, manipulation of physical parameters, that is temperature and salinity would be the easiest to apply. Eyestalk ablation, limb autotomy, and the administration of moult inducers such as ecdysteroid, phytoecdysteroid and methyl farnesoate would require some form of prior knowledge and handling practice.

In terms of costing, eyestalk ablation, limb autotomy and salinity manipulation are the cheapest. In comparison to salinity control, heater and chiller are needed to manipulate temperature, and their purchase and maintenance are pricier. The cost of phytoecdysteroids is considered as moderate because these plant-derived moult inducers can be extracted in high quantity and their raw materials (plants) are readily available (Fujaya, 2011). Comparatively, pure synthetic ecdysteroid, biogenic amines, methyl farnesoate and the manipulation of MIH are more expensive and could be a deterring factor for small-scale farmers.

The ability to induce moulting is obvious in most moult induction methods although different methods use different approaches. For example, eyestalk ablation and the inhibition of MIH method suppress MIH production and thus promote the expression of

TABLE 4 Comparative analysis of the characteristics of different moult induction methods for soft-shell crab production

Characteristics	Eyestalk ablation	Limb autotomy	Ecdysteroid	Phytoecdysteroid	Physical parameters		Biogenic amines	Methyl farnesoate	Moult-inhibiting hormone inhibition
					Temperature	Salinity			
Ease of application	●	●	●	●	●	●	○	●	○
Application cost	○	○	●	●	●	○	●	●	●
Moult induction	●	●	●	●	●	○	●	●	●
Survival	●	●	●	●	●	○	NA	○	NA
Weight increment	NA	○	●	●	●	○	NA	○	NA
Size increment	NA	○	●	●	●	○	NA	○	NA
Limb completeness	●	○	●	●	●	○	●	●	●

○, low/difficult; ●, medium; ●, high/easy; NA, no data available.
*Varies between species.

ecdysteroids (Qiau et al., 2018; Stella et al., 2000). The administration of ecdysteroid and phytoecdysteroid into crab directly increase its ecdysteroid level and accelerate the moulting process (Fujaya, 2011; Raghavan & Ayanath, 2019). The increase in methyl farnesoate levels stimulates the production of ecdysteroids (Reddy et al., 2004) whereas different biogenic amines regulate physiological processes such as moulting differently, with melatonin might inhibit the release of **MIH or mandibular organ inhibiting hormone** to promote the production of ecdysteroids and subsequent promote moulting (Sainath & Reddy, 2010).

Among all moulting induction methods, limb autotomy consistently showed no significant effect on crab survival (Table 2) as limb loss and regeneration is common in crabs (Edwards, 1972; Hopkins, 2001) whereas eyestalk ablation moderately affects survival of crabs (Table 1) as the process is stressful and eyestalk-ablated crabs are more prone to infection (Taylor et al., 2004). In comparison, the negative effect of methyl farnesoate on survival has been reported in crabs (Raghavan & Ayanath, 2019) and other commercial crustacean species such as crayfish (Abdu et al., 2001) and shrimps (Alnawafleh et al., 2014). The administration of ecdysteroids and phytoecdysteroids are known to enhance the size and weight of crabs after moulting (Fujaya, 2011; Tamsil & Hasnidar, 2018). The size and weight increments in soft-shell crabs were less obvious, with smaller increments being reported in limb autotomized crabs compared with controls (Table 2).

All moulting induction methods except limb autotomy do not require the removal of limbs, thus have no effect on the aesthetic value of the soft-shell crabs produced. However, crabs subjected to limb autotomy often presented with incomplete or significantly smaller new appendages (Fujaya et al., 2020). This greatly affects the market value of soft-shell crabs, in addition to lighter average body weight. Although aesthetic value could be considered as a secondary factor in selecting moulting induction methods, its effect on grading and final market price makes limb autotomy unsuitable to be promoted as the ideal moulting induction methods for soft-shell crab production.

7 | CONCLUSION AND FUTURE PROSPECTS

With its increasing world market demand, soft-shell crab production is among the promising revenue-generating industry for commercially important crab species aside from them being sold off as it is. Progress has been made in understanding the moulting mechanism of crabs, the production process of soft-shell crabs and moulting induction methods that would effectively shorten moulting intervals and allow more synchronized moulting. Induce moulting via eyestalk ablation for soft-shell crab production should be avoided as it is considered inhumane and causes significant stress towards the animal. Limb autotomy, although occurs naturally, should be used minimally as well as this method produces soft-shell crabs of uneven body size and weight with obvious reduction in size of newly generated limbs,

and increase in risk of infection from the open wound generated if limbs are not autotomized properly.

The main challenge of the current soft-shell crab production industry is the lack of a suitable moulting-inducing method that exert minimal stress towards the animal yet still able to hasten moulting. The various methods that are able to induce faster moulting in crabs reviewed here are promising, although most of them are still in their early experimental stages. Until a mature technique is developed, soft-shell crab farmers are selective in using moulting induction methods and most still rely on traditional rearing and harvesting soft-shell crabs right after moulting. Future research on the mechanism of limb autotomy is warranted as this would allow moulting to be induced without physically removing crab's appendages. Also, the use of ecdysteroid and phytoecdysteroid is promising, although subsequent studies should focus on their optimization of administered dosages and reduction of production costs.

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DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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REFERENCES

- Abdu, U., Barki, A., Karplus, I., Barel, S., Takac, P., Yehezkel, G., Laufer, H., & Dagi, A. (2001). Physiological effects of methyl farnesoate and pyriproxyfen on wintering female crayfish *Cherax quadricarinatus*. *Aquaculture*, 202, 162–175. [https://doi.org/10.1016/S0044-486\(01\)00596-8](https://doi.org/10.1016/S0044-486(01)00596-8).
- Abdullah-Zawawi, M.-R., Afiqah-Aleng, N., Ikhwanuddin, M., Sung, Y. Y., Tola, S., Fazhan, H., & Waiho, K. (2021). Recent development in ecdysone receptor of crustaceans: current knowledge and future applications in crustacean aquaculture. *Reviews in Aquaculture*, <https://doi.org/10.1111/raq.12552>.
- Abuhagr, A. M., Blindert, J. L., Nimitkul, S., Zander, I. A., LaBere, S. M., Chang, S. A., Maclea, K. S., Chang, E. S., & Mykles, D. L. (2014). Molt regulation in green and red color morphs of the crab *Carcinus maenas*: gene expression of molt-inhibiting hormone signaling components. *Journal of Experimental Biology*, 217, 796–808. <https://doi.org/10.1242/jeb.093385>.
- Agus, M., Johanes, H., Darmanto, Y. S., & Prayitno, S. B. (2014). The dynamics of water quality soft-shelled crab aquaculture in Pemalang

- Regency, middle Java, Indonesia. *International Journal of Science and Research*, 5, 1448–1451. <https://doi.org/10.21275/v5i2>.
- Alikunhi, K. H., Poernomo, A., Adisukresno, S., Budiono, M., & Busman, S. (1975). Preliminary observations on the induction of maturity and spawning in *Penaeus monodon* Fabricius and *Penaeus merguensis* de Man by eyestalk extirpation. *Bulletin of Shrimp Culture Research Center*, 1, 1–11.
- Alnawafleh, T., Kim, B.-W., Kang, H.-E., Yoon, T.-H., & Kim, H.-W. (2014). Stimulation on molting and ovarian maturation by methyl farnesoate in the Pacific White Shrimp *Litopenaeus vannamei* (Boone, 1931). *Fisheries and Aquatic Sciences*, 17, 115–121. <https://doi.org/10.5657/FAS.2014.0115>.
- Amador del Ángel, L. E., Moreno, J. L., & Cabrera-Rodríguez, P. (1999). Chelotomy and eyestalk ablation in the production of the soft shell blue crabs *Callinectes sapidus* Rathbun in laboratory conditions. In: Creswell L (ed.), Proceedings of the 45th Annual Session of the Gulf and Caribbean Fisheries Institute, pp. 588–599.
- Aslamyah, S., & Fujaya, Y. (2010). Stimulasi molting dan pertumbuhan kepiting bakau (*Scylla* sp.) melalui aplikasi pakan buatan berbahan dasar limbah pangan yang diperkaya dengan ekstrak bayam. *Ilmu Kelautan* 15: 170–178. [In Indonesian language]. <https://doi.org/10.14710/ikijms.15.3.170-178>
- Azra, M. N., Aaqillah-Amr, M. A., Ikhwanuddin, M., Ma, H., Waiho, K., Ostrensky, A., Tavares, S. C. P., & Abol-Munafi, A. B. (2020). Effects of climate-induced water temperature changes on the life history of brachyuran crabs. *Reviews in Aquaculture*, 12, 1211–1216. <https://doi.org/10.1111/rag.12380>.
- Azra, M. N., & Ikhwanuddin, M. (2015). Larval culture and rearing techniques of commercially important crab, *Portunus pelagicus* (Linnaeus, 1758): present status and future prospects. *Songklanakarin Journal of Science and Technology*, 37, 135–145.
- Baethge, C., Goldbeck-Wood, S., & Mertens, S. (2019). SANRA—a scale for the quality assessment of narrative review articles. *Research Integrity and Peer Review*, 4, 5. <https://doi.org/10.1186/s41073-019-0064-8>.
- Baltaev, U. A. (2000). Phytoecdysteroids: structure, sources, and biosynthesis in plants. *Russian Journal of Bioorganic Chemistry*, 26, 799–831. <https://doi.org/10.1023/A:1026662505403>.
- Browdy, C. L., & Samocha, T. M. (1985). The effect of eyestalk ablation on spawning, molting and mating of *Penaeus semisulcatus* de Haan. *Aquaculture*, 49, 19–29. [https://doi.org/10.1016/0044-8486\(85\)90187-5](https://doi.org/10.1016/0044-8486(85)90187-5).
- Brylawski, B. J., & Miller, T. J. (2006). Temperature-dependent growth of the blue crab (*Callinectes sapidus*): a molt process approach. *Canadian Journal of Fisheries and Aquatic Sciences*, 63, 1298–1308. <https://doi.org/10.1139/f06-011>.
- Cadman, L. R., & Weinstein, M. P. (1988). Effects of temperature and salinity on the growth of laboratory-reared juvenile blue crabs *Callinectes sapidus* Rathbun. *Journal of Experimental Marine Biology and Ecology*, 121, 193–207. [https://doi.org/10.1016/0022-0981\(88\)90088-3](https://doi.org/10.1016/0022-0981(88)90088-3).
- Chandrakala, M. V., Maribashetty, V. G., & Jyothi, H. K. (1998). Application of phytoecdysteroids in sericulture. *Current Science*, 74, 341–346.
- Chaves, J. C., & Eggleston, D. B. (2003). Blue crab mortality in the North Carolina soft shell industry: biological and operational effects. *Journal of Shellfish Research*, 22, 241–250.
- Chu, K. H., & Chow, W. K. (1992). Effects of unilateral versus bilateral eyestalk ablation on molting and growth of the shrimp, *Penaeus chinensis* (Osbeck, 1765) (Decapoda, Penaeidea). *Crustaceana*, 62, 225–233. <https://doi.org/10.1163/156854092X00127>.
- Chung, J. S. (2010). Hemolymph ecdysteroids during the last three molt cycles of the blue crab, *Callinectes sapidus*: quantitative and qualitative analyses and regulation. *Archives of Insect Biochemistry and Physiology*, 73, 1–13. <https://doi.org/10.1002/arch.20327>.
- Chung, J. S., & Webster, S. G. (2005). Dynamics of in vivo release of molt-inhibiting hormone and crustacean hyperglycemic hormone in the shore crab, *Carcinus maenas*. *Endocrinology*, 146, 5545–5551. <https://doi.org/10.1210/en.2005-0859>.
- Compère, P., Thorez, A., & Goffinet, G. (1998). Fine structural survey of the old cuticle degradation during pre-ecdysis in two European Atlantic crabs. *Tissue and Cell*, 30, 41–56. [https://doi.org/10.1016/S0040-8166\(98\)80005-0](https://doi.org/10.1016/S0040-8166(98)80005-0).
- Cooney, P., Korey, C. A., & Hughes, M. (2017). Autotomy and recovery in the snapping shrimp, *Alpheus augulosus* McClure, 2002 (Caridea: Alpheidae). *Journal of Crustacean Biology*, 37, 701–708.
- Dana, S. S., Ghosh, A., & Bandyopadhyay, U. K. (2015). Socio-economic profile and problems of mud-crab farmers of South 24-Parganas, West Bengal: an explorative study. *Journal of Crop and Weed*, 11, 120–123.
- de la Cruz-Huervana, J. J. Y., Quintino, E. T., & Corre, V. L. (2019). Induction of moulting in hatchery-reared mangrove crab *Scylla serrata* juveniles through temperature manipulation or autotomy. *Aquaculture Research*, 50, 3000–3008. <https://doi.org/10.1111/are.14257>.
- Diarte-Plata, G., Sainz-Hernández, J. C., Aguiñaga-Cruz, J. A., Fierro-Coronado, J. A., Polanco-Torres, A., & Puente-Palazuelos, C. (2012). Eyestalk ablation procedures to minimize pain in the freshwater prawn *Macrobrachium americanum*. *Applied Animal Behaviour Science*, 140, 172–178. <https://doi.org/10.1016/j.applanim.2012.06.002>.
- Dillaman, R., Hequembourg, S., & Gay, M. (2005). Early pattern of calcification in the dorsal carapace of the blue crab, *Callinectes sapidus*. *Journal of Morphology*, 263, 356–374. <https://doi.org/10.1002/jmor.10311>.
- Dinan, L. (2009). The Karlson lecture. Phytoecdysteroids: What use are they? *Archives of Insect Biochemistry and Physiology*, 72, 126–141. <https://doi.org/10.1002/arch.20334>.
- Edwards, J. S. (1972). Limb loss and regeneration in two crabs: The king crab *Paralithodes camtschatica* and the Tanner crab *Chionoecetes bairdi*. *Acta Zoologica*, 53, 105–112. <https://doi.org/10.1111/j.1463-6395.1972.tb00577.x>.
- Elwood, R. W., Barr, S., & Patterson, L. (2009). Pain and stress in crustaceans? *Applied Animal Behaviour Science*, 118, 128–136. <https://doi.org/10.1016/j.applanim.2009.02.018>.
- Emberts, Z., Miller, C. W., Kiehl, D., & St. Mary, C. M. (2017). Cut your losses: self-amputation of injured limbs increases survival. *Behavioural Ecology*, 28, 1047–1054. <https://doi.org/10.1093/beheco/axx063>.
- FAO (2018). *The State of World Fisheries and Aquaculture 2018 - Meeting the sustainable development goals*. Food and Agriculture Organization of the United Nations.
- Fazhan, H., Waiho, K., Darin Azri, M. F., Al-Hafiz, I., Norfaizza, W. I. W., Megat, F. H., Jasmani, S., Ma, H., & Ikhwanuddin, M. (2017). Sympatric occurrence and population dynamics of *Scylla* spp. in equatorial climate: Effects of rainfall, temperature and lunar phase. *Estuarine, Coastal and Shelf Science*, 198, 299–310. <https://doi.org/10.1016/j.ecss.2017.09.022>.
- Fazhan, H., Waiho, K., Wan-Norfaizza, W. I., Megat, F. H., & Ikhwanuddin, M. (2017b). Inter-species mating among mud crab genus *Scylla* in captivity. *Aquaculture*, 471, 49–54. <https://doi.org/10.1016/j.aquaculture.2017.01.005>.
- Fazhan, H., Waiho, K., Wan-Norfaizza, W. I., Megat, F. H., & Ikhwanuddin, M. (2017c). Assortative mating by size in three species of mud crabs, genus *Scylla* (Brachyura: Portunidae). *Journal of Crustacean Biology*, 37, 654–660. <https://doi.org/10.1093/jcbr/rux063>.
- Fingerman, M. (1994). Biogenic amines in crustaceans: identification, localization, and roles. *Journal of Crustacean Biology*, 14, 413–437. <https://doi.org/10.1163/193724094X00010>.
- Fingerman, M. (1997). Roles of neurotransmitters in regulating reproductive hormone release and gonadal maturation in decapod crustacean. *Invertebrate Reproduction and Development*, 31, 47–54. <https://doi.org/10.1080/07924259.1997.9672562>.

- Fleming, P. A., Muller, D., & Bateman, P. W. (2007). Leave it all behind: a taxonomic perspective of autotomy in invertebrates. *Biological Reviews*, 82, 481–510. <https://doi.org/10.1111/j.1469-18X.2007.00020.x>.
- Freeman, J. A., Kilgus, G., Laurendeau, D., & Perry, H. M. (1987). Postmolt and intermolt molt cycle stages of *Callinectes sapidus*. *Aquaculture*, 61, 201–209. [https://doi.org/10.1016/0044-8486\(87\)90149-9](https://doi.org/10.1016/0044-8486(87)90149-9).
- Fujaya, Y. (2011). Growth and molting of mud crab administered by different doses of vitomolt. *Jurnal Akuakultur Indonesia*, 10, 24–28. [In Indonesian language] <https://doi.org/10.19027/jai.10.24-28>
- Fujaya, Y., Aslamyah, S., & Usman, Z. (2011). Respon molting, pertumbuhan, dan mortalitas kepiting bakau (*Scylla olivacea*) yang disuplementasi Vitomolt melalui injeksi dan pakan buatan. *Ilmu Kelautan* 16: 211–218. [In Indonesian language] <https://doi.org/10.14710/ik.ijms.16.4.211-218>
- Fujaya, Y., Rukminasari, N., Alam, N., Rusdi, M., Fazhan, H., & Waiho, K. (2020). Is limb autotomy really efficient compared to traditional rearing in soft-shell crab (*Scylla olivacea*) production? *Aquaculture Reports*, 18, 100432.
- Fujaya, Y., Trijuno, D. D., Haryati, H., Hasnidar, H., Rusdi, M., & Usman, Z. (2018). Effectivity of mulberry leaf extract on stimulating ecdysteroid hemolymph content and molting of mud crab (*Scylla olivacea*). *Journal of Fisheries and Marine Science* 2: 32–43. [In Indonesian language]. <https://doi.org/10.1016/j.aqrep.2020.100432>
- Gaudé, A., & Anderson, J. A. (2011). *Soft Shell Crab Shedding Systems*, Vol. 4306, pp. 6. SRAC Publication.
- Girish, B. P., Swetha, C., & Reddy, P. S. (2017). Serotonin induces ecdysteroidogenesis and methyl farnesoate synthesis in the mud crab, *Scylla serrata*. *Biochemical and Biophysical Research Communications*, 490, 1340–1345. <https://doi.org/10.1016/j.bbrc.2017.07.025>.
- Gong, J., Yu, K., Shu, L., Ye, H., Li, S., & Zeng, C. (2015). Evaluating the effects of temperature, salinity, starvation and autotomy on molting success, molting interval and expression of ecdysone receptor in early juvenile mud crabs, *Scylla paramamosain*. *Journal of Experimental Marine Biology and Ecology*, 464, 11–17. <https://doi.org/10.1016/j.jembe.2014.12.008>.
- Green, B. N., Johnson, C. D., & Adams, A. (2006). Writing narrative literature reviews for peer-reviewed journals: secrets of the trade. *Journal of Chiropractic Medicine*, 5, 101–117. [https://doi.org/10.1016/S0899-3467\(07\)60142-6](https://doi.org/10.1016/S0899-3467(07)60142-6).
- Havens, K. J., & McConaughy, J. R. (1990). Molting in the mature female blue crab, *Callinectes sapidus* Rathbun. *Bulletin of Marine Science*, 46, 37–47.
- He, J., Chen, J. X., & Cai, C. F. (2016). Comparison of soft and hard shell crab in nutritional value. *Food Research and Development*, 37, 100–103.
- He, J., Wu, X., & Cheng, Y. (2016). Effects of limb autotomy on growth, feeding and regeneration in the juvenile *Eriocheir sinensis*. *Aquaculture*, 457, 79–84. <https://doi.org/10.1016/j.aquaculture.2016.02.004>.
- Herlinah, H., Tenriulo, A., Septiningsih, E., & Suwoyo, H. S. (2015). Survival and response molting of mud crab (*Scylla olivacea*) injected with mureby (*Morus* spp.) leave extract. *Jurnal Ilmu Dan Teknologi Kelautan Tropis*, 7, 247–258. <https://doi.org/10.29244/jitkt.v7i1.9810>.
- Herlinah, H., Tenriulo, A., & Suryati, E. (2014). Hormone ecdysterone of mulberry leaves extract, *Morus* spp. as moulting stimulant on mangrove crabs. *Jurnal Riset Akuakultur*, 9, 387–397. [In Indonesian language].
- Hinsch, G. W. (1972). Some factors controlling reproduction in the spider crab, *Libinia emarginata*. *The Biological Bulletin*, 143, 358–366. <https://doi.org/10.2307/1540059>.
- Homola, E., & Chang, E. S. (1997). Methyl farnesoate: Crustacean juvenile hormone in search of functions. *Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology*, 117, 347–356. [https://doi.org/10.1016/S0305-0491\(96\)00337-9](https://doi.org/10.1016/S0305-0491(96)00337-9).
- Hopkins, P. M. (2001). Limb regeneration in the fiddler crab, *Uca pugi-lator*: hormonal and growth factor control. *American Zoologist*, 41, 389–398. <https://doi.org/10.1093/icb/41.3.389>.
- Hungria, D. B., Tavares, C. P. S., Pereira, L. A., da Silva, U. A. T., & Ostrensky, A. (2017). Global status of production and commercialization of soft-shell crabs. *Aquaculture International*, 25, 2213–2226. <https://doi.org/10.1007/s10499-017-0183-5>.
- Hyde, C. J., Elizur, A., & Ventura, T. (2018). The crustacean ecdysone cassette: a gatekeeper for molt and metamorphosis. *Journal of Steroid Biochemistry and Molecular Biology*, 185, 172–183. <https://doi.org/10.1016/j.jsbmb.2018.08.012>.
- Hyun, S. (2018). Body size regulation by maturation steroid hormones: a *Drosophila* perspective. *Frontiers in Zoology*, 15, 44. <https://doi.org/10.1186/s12983-018-0290-9>.
- Imayavaramban, L., Dhayaparan, D., & Devaraj, H. (2007). Molecular mechanism of molt-inhibiting hormone (MIH) induced suppression of ecdysteroidogenesis in the Y-organ of mud crab: *Scylla serrata*. *FEBS Letters*, 581, 5167–5172. <https://doi.org/10.1016/j.febslet.2007.09.029>.
- Kanazawa, A., Tanaka, N., & Kashiwada, K. (1972). Nutritional requirements of prawns-IV. The dietary effect of ecdysones. *Bulletin of the Japanese Society of Scientific Fisheries*, 38, 1067–1071. <https://doi.org/10.2331/suisan.38.1067>.
- Kennedy, V. S., & Cronin, L. E. (2007). *The Blue Crab: Callinectes sapidus*, pp. 774. Maryland Sea Grant College, University of Maryland, College Park, MD.
- Krishnakumaran, A., & Schneiderman, H. A. (1970). Control of molting in mandibulate and chelicerate arthropods by ecdysones. *The Biological Bulletin*, 139, 520–538. <https://doi.org/10.2307/1540371>.
- Laufer, H., Biggers, W. J., & Ahl, J. S. N. (1998). Stimulation of ovarian maturation in the crayfish *Procambarus clarkii* by methyl farnesoate. *General and Comparative Endocrinology*, 111, 113–118. <https://doi.org/10.1006/gcen.1998.7109>.
- Laufer, H., Borst, D. W., Baker, F. C., Carrasco, C., Sinkus, M., Reuter, C. C., Tsai, L. W., & Sinkus, M. (1987). Identification of a juvenile hormone-like compound in crustacean. *Science*, 235, 202–205. <https://doi.org/10.1126/science.235.4785.202>.
- Laufer, H., Takac, P., Ahl, J. S. B., & Laufer, M. R. (1997). Methyl farnesoate and the effect of eyestalk ablation on the morphogenesis of the juvenile female spider crab *Libinia emarginata*. *Invertebrate Reproduction and Development*, 31, 63–68. <https://doi.org/10.1080/07924259.1997.9672564>.
- Loredo-Ranjel, R., Fanjul-Moles, M. L., & Escamilla-Chimal, E. G. (2017). Crustacean hyperglycemic hormone is synthesized in the eyestalk and the brain of the crayfish *Procambarus clarkii*. *PLoS One*, 12, e0175046. <https://doi.org/10.1371/journal.pone.0175046>.
- Lwin, M. M. N. (2018). *Development of diets for soft-shell mangrove crabs (Scylla spp.)*. PhD Thesis. Auburn University, Alabama, United States.
- Maheswarudu, G., Jose, J., Nair, K. R. M., Arputharaj, M. R., Ramakrishna, A., Vairamani, A., & Ramamoorthy, N. (2008). Evaluation of the seed production and grow out culture of blue swimming crab *Portunus pelagicus* (Linnaeus, 1758) in India. *Indian Journal of Marine Sciences*, 37, 313–321.
- Mangum, C. P. (1985). Molting in the blue crab *Callinectes sapidus*: a collaborative study of intermediary metabolism, respiration and cardiovascular function, and ion transport. Preface. *Journal of Crustacean Biology*, 5, 185–187. <https://doi.org/10.2307/1547865>.
- Martelli, A., Hernandez-Moresino, R. D., Barki, L., & Barón, P. J. (2019). The effect of temperature, salinity, eyestalk ablation, and limb removal on growth and survival of juvenile paddle crab, *Ovalipes trimaculatus* (Brachyura: Portunidae). *Bulletin of Marine Science*, 95, 69–82. <https://doi.org/10.5343/bms.2018.0015>.
- McCarthy, J. F., & Skinner, D. M. (1977). Interruption of proecdysis by autotomy of partially regenerated limbs in the land crab,

- Gecarcinus lateralis*. *Developmental Biology*, 61, 299–310. [https://doi.org/10.1016/0012-1606\(77\)90300-1](https://doi.org/10.1016/0012-1606(77)90300-1).
- McVean, A. (1982). Autotomy. In D. E. Bliss (Ed.), *The Biology of Crustacea*, Vol. 4 (pp. 107–132). Academic Press.
- McVean, A., & Findlay, I. (1979). The incidence of autotomy in an estuarine population of the crab *Carcinus maenas*. *Journal of the Marine Biological Association of the United Kingdom*, 59, 341–354. <https://doi.org/10.1017/S0025315400042648>.
- Moffett, S., Yox, D. P., Kahan, L. B., & Ridgway, R. L. (1987). Innervation of the anterior and posterior levator muscles of the fifth leg of the crab *Carcinus maenas*. *Journal of Experimental Biology*, 127, 229–248.
- Mykles, D. L. (2001). Interactions between limb regeneration and molting in decapod crustaceans. *American Zoologist*, 41, 399–406. <https://doi.org/10.1093/icb/41.3.399>.
- Nagaraju, G. P. C., Reddy, P. R., & Reddy, P. S. (2004). Mandibular organ: It's relation to body weight, sex, molt and reproduction in the crab, *Oziotelphusa senex senex* Fabricius (1791). *Aquaculture*, 232, 603–612. [https://doi.org/10.1016/S0044-8486\(03\)00519-2](https://doi.org/10.1016/S0044-8486(03)00519-2).
- Nakatsujii, T., Lee, C. Y., & Watson, R. D. (2009). Crustacean molt-inhibiting hormone: structure, function, and cellular mode of action. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, 152, 139–148. <https://doi.org/10.1016/j.cbpa.2008.10.012>.
- Nikhilani, A., & Sukarti, K. (2017). Survival and metamorphosis rate of swimming crab *Portunus pelagicus* larvae with the use of phytoecdysteroid in the artificial feed. *Jurnal Akuakultur Indonesia*, 16, 261–267. <https://doi.org/10.19027/jai.16.2.261-267>.
- Nurdiani, R., & Zeng, C. (2007). Effects of temperature and salinity on the survival and development of mud crab, *Scylla serrata* (Forsskål), larvae. *Aquaculture Research*, 38, 1529–1538. <https://doi.org/10.1111/j.1365-2109.2007.01111.x>.
- Odinokov, V. N., Galyautdinov, I. V., Nedopekin, D. V., Khalilov, L. M., Shashkov, A. S., Kachala, V. V., Dinan, L., & Lafont, R. (2002). Phytoecdysteroids from the juice of *Serratula coronata* L. (Asteraceae). *Insect Biochemistry and Molecular Biology*, 32, 161–165. [https://doi.org/10.1016/S0965-1748\(01\)00106-0](https://doi.org/10.1016/S0965-1748(01)00106-0).
- Oesterling, M. J. (1988). *Manual for Handling and Shedding Blue Crabs (Callinectes sapidus)* (p. 94). Virginia Institute of Marine Science.
- Oesterling, M. (1993). Marine aquaculture in the Commonwealth of Virginia, in VIMS Educational Series. *Virginia Sea Grant's Marine Advisory Program, School of Marine Science* (p. 23). Gloucester Point, VA: Virginia Institute of Marine Science.
- Ostrensky, A., Ventura, R., Correa, A. M. A., Santos, G. V., & Castilho-Westphal, G. G. (2015). Improving production of soft-shelled swimming crabs: Macroscopic signs of molting as a tool for selection and management of *Callinectes danae* and *Callinectes exasperatus* (Portunidae, Decapoda, Crustacea). *Archives of Veterinary Science*, 20, 122–131. <https://doi.org/10.5380/avs.v20i2.39855>.
- Pamuru, R. R., Rosen, O., Manor, R., Chung, J. S., Zmora, N., Glazer, L., Affalo, E. D., Weil, S., Tamone, S. L., & Sagi, A. (2012). Stimulation of molt by RNA interference of the molt-inhibiting hormone in the crayfish *Cherax quadricarinatus*. *General and Comparative Endocrinology*, 178, 227–236. <https://doi.org/10.1016/j.ygcen.2012.05.007>.
- Patterson, L., Dick, J. T. A., & Elwood, R. W. (2009). Claw loss and feeding ability in the edible crab, *Cancer pagurus*: implications of fishery practice. *Applied Animal Behaviour Science*, 116, 302–305. <https://doi.org/10.1016/j.applanim.2008.08.007>.
- Paulson, C. R., & Skinner, D. M. (1988). Molecular action of 20-hydroxyecdysone, methyl farnesoate and juvenile hormone on crab tissues. *American Zoologist*, 28, 83A.
- Perry, H., Graham, D., Trigg, C., Crochet, G., & GCRL/MDMR Aquaculture Team (2010). *Expansion of the soft crab fishery in Mississippi using cultured blue crabs*. Proceedings of the 63rd Gulf and Caribbean Fisheries Institute, November 1–5, 2010, San Juan, Puerto Rico.
- Philppen, M. K., Webster, S. G., Chung, J. S., & Dirksen, H. (2000). Ecdysis of decapod crustaceans is associated with a dramatic release of crustacean cardioactive peptide into the haemolymph. *Journal of Experimental Biology*, 203, 521–536.
- Pitts, N. L., Schulz, H. M., Oatman, S. R., & Mykles, D. L. (2017). Elevated expression of neuropeptide signalling genes in the eyestalk ganglia and Y-organ of *Gecarcinus lateralis* individuals that are refractory to molt induction. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, 214, 66–78. <https://doi.org/10.1016/j.cbpa.2017.09.011>.
- Pratoomchat, B., Sawangwong, P., Guedes, R., Reis, M. D. L., & Machado, J. (2002). Cuticle ultrastructure changes in the crab *Scylla serrata* over the molt cycle. *Journal of Experimental Zoology*, 293, 414–426. <https://doi.org/10.1002/jez.90002>.
- Priester, C., Dillaman, R. M., & Gay, D. M. (2005). Ultrastructure, histochemistry, and mineralization patterns in the ecdysial suture of the blue crab, *Callinectes sapidus*. *Microscopy and Microanalysis*, 11, 479–499. <https://doi.org/10.1017/S1431927605050555>.
- Primavera, J. H., & Borlongan, E. (1977). Notes on the induced maturation and spawning in four-month-old *Penaeus monodon* Fabricius by eyestalk ablation. *SEAFDEC Aquaculture Department Quarterly Research Report*, 1, 27–29. <http://aquaticcommons.org/id/eprint/18600>.
- Qiao, H., Jiang, F., Xiong, Y., Jiang, S., Fu, H., Li, F., Zhang, W., Sun, S., Jin, S., Gong, Y., & Wu, Y. (2018). Characterization, expression patterns of molt-inhibiting hormone gene of *Macrobrachium nipponense* and its roles in molting and growth. *PLoS One*, 13, e0198861. <https://doi.org/10.1371/journal.pone.0198861>.
- Quinitio, E. T., & Estepa, F. D. P. (2011). Survival and growth of mud crab, *Scylla serrata*, juveniles subjected to removal or trimming of chelipeds. *Aquaculture*, 318, 229–234. <https://doi.org/10.1016/j.aquaculture.2011.05.034>.
- Racotta, I., Palacios, E., & Carreño, D. (1998). *Effect of ablation on reproductive performance and biochemical composition of eggs, nauplii, and spawner tissues in Penaeus vannamei*. In: Proceedings of the Symposium held in Brest, 19–20 November 1998, vol. 27, Ifremer, Plouzane, France, p. 184.
- Raghavan, S. D. A., & Ayanath, A. (2019). Effect of 20-OH ecdysone and methyl farnesoate on moulting in the freshwater crab *Travancoriana schirnerae*. *Invertebrate Reproduction and Development*, 63, 309–318. <https://doi.org/10.1080/07924259.2019.1653387>.
- Rahman, M. R., Asaduzzaman, M., Zahangir, M. M., Islam, S. R., Nahid, S.-A.-A., Jahan, D. A., Mahmud, Y., & Khan, M. N. A. (2020). Evaluation of limb autotomy as a promising strategy to improve production performances of mud crab (*Scylla olivacea*) in the soft-shell farming system. *Aquaculture Research*, 51, 2555–2572. <https://doi.org/10.1111/are.14598>.
- Rajendiran, S., Iqbal, B. M. M., & Vasudevan, S. (2016). Induced thermal stress on serotonin levels in blue swimmer crab, *Portunus pelagicus*. *Biochemistry and Biophysics Reports*, 5, 425–429. <https://doi.org/10.1016/j.bbrep.2015.11.005>.
- Rana, S. (2018). Eyestalk ablation of freshwater crab, *Barytelphusa lugubris*: an alternative approach of hormonal induced breeding. *International Journal of Pure and Applied Zoology*, 6, 30–34.
- Reddy, P. S. (1990). Neuroendocrine control of molting in the freshwater field crab, *Oziotelphusa senex senex* Fabricius. *Tropical Freshwater Biology*, 2, 213–222. <https://doi.org/10.2307/1548403>.
- Reddy, P. R. (2019). Methyl farnesoate through feed: a growth manipulator in female crab *Oziotelphusa senex senex*. *Journal of Fisheries Sciences.com*, 13, 1–6. <https://doi.org/10.36638/1307-234X.13.1.155>.
- Reddy, P. R., Nagaraju, G. P. C., & Reddy, P. S. (2004). Involvement of methyl farnesoate in the regulation of molting and reproduction in the freshwater crab *Oziotelphusa senex senex*. *Journal of Crustacean Biology*, 24, 511–515. <https://doi.org/10.1651/C-2478>.

- Reddy, P. S., & Pushpalatha, T. (2007). Effect of serotonin on hemolymph glucose regulation in the fresh water edible crab, *Oziotelphusa senex senex*. *Aquaculture*, 266, 274–278. <https://doi.org/10.1016/j.aquaculture.2007.02.023>.
- Rharrabe, K., Sayan, F., & LaFont, R. (2010). Dietary effects of four phytoecdysteroids on growth and development of the Indian Meal Moth, *Plodia interpunctella*. *Journal of Insect Science*, 10, 13. <https://doi.org/10.1673/031.010.1301>.
- Roberts, W. A. (1905). *The Crab Industry of Maryland*. The Govt. Print. Off., Washington, DC.
- Rodriguez, E. M., Medesani, D. A., & Fingerman, M. (2007). Endocrine disruption in crustaceans due to pollutants: A review. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, 146, 661–671. <https://doi.org/10.1016/j.cbpa.2006.04.030>.
- Roer, R. D., & Dillaman, R. M. (2018). The initiation and early stages of postmolt mineralization in the blue Crab, *Callinectes sapidus*. *Frontiers in Marine Science*, 5, 151. <https://doi.org/10.3389/fmars.2018.00151>.
- Roer, R. D., Halbrook, K. E., & Shafer, T. H. (2001). Glycosidase activity in the post-ecdysial cuticle of the blue crab, *Callinectes sapidus*. *Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology*, 128, 683–690. [https://doi.org/10.1016/S1096-4959\(00\)00363-8](https://doi.org/10.1016/S1096-4959(00)00363-8).
- Rotllant, G., Takac, P., Liu, L., Scott, G. L., & Laufer, H. (2000). Role of ecdysteroids and methyl farnesoate in morphogenesis and terminal moult in polymorphic males of the spider crab *Libinia emarginata*. *Aquaculture*, 190, 103–118. [https://doi.org/10.1016/S0044-8486\(00\)00388-4](https://doi.org/10.1016/S0044-8486(00)00388-4).
- Ruscoe, I. M., Shelley, C. C., & Williams, G. R. (2004). The combined effects of temperature and salinity on growth and survival of juvenile mud crabs (*Scylla serrata* Forskål). *Aquaculture*, 238, 239–247. <https://doi.org/10.1016/j.aquaculture.2004.05.030>.
- Sainath, S. B., & Reddy, P. S. (2010). Evidence for the involvement of selected biogenic amines (serotonin and melatonin) in the regulation of molting of the edible crab, *Oziotelphusa senex senex* Fabricius. *Aquaculture*, 302, 261–264. <https://doi.org/10.1016/j.aquaculture.2010.02.025>.
- Schmelz, E. A., Grebenok, R. J., Galbraith, D. W., & Bowers, W. S. (1998). Damage-induced accumulation of phytoecdysteroids in spinach: a rapid root response involving the octadecanoic acid pathway. *Journal of Chemical Ecology*, 24, 339–360. <https://doi.org/10.1023/A:1022588610232>.
- Schmelz, E. A., Grebenok, R. J., Ohnmeiss, T. E., & Bowers, W. S. (2002). Interactions between *Spinacia oleracea* and *Bradysia impatiens*: a role for phytoecdysteroids. *Archives of Insect Biochemistry and Physiology*, 51, 204–221. <https://doi.org/10.1002/arch.10062>.
- Shafer, T. H., Roer, R. D., Midgette-Luther, C., & Brookins, T. A. (1995). Postecdysial cuticle alteration in the blue crab, *Callinectes sapidus*: synchronous changes in glycoproteins and mineral nucleation. *Journal of Experimental Zoology*, 271, 171–182. <https://doi.org/10.1002/jez.1402710303>.
- Shaymal, S., Das, S., Guruacharya, A., Mykles, D. L., & Durica, D. S. (2018). Transcriptomic analysis of crustacean molting gland (Y-organ) regulation via the mTOR signaling pathway. *Scientific Reports*, 8, 7307. <https://doi.org/10.1038/s41598-018-25368-x>.
- Shelley, C., & Lovatelli, A. (2011). *Mud crab aquaculture – A practical manual*. FAO Fisheries and Aquaculture Technical Paper. No. 567 Rome, FAO.
- Shi, X., Lu, J., Wu, Q., Waiho, K., Aweya, J. J., Fazhan, H., Zhang, Y., Li, S., Zheng, H., Lin, F., You, C., Ikhwanuddin, M., & Ma, H. (2019). Comparative analysis of growth performance between female and male mud crab *Scylla paramamosain* crablets: Evidences from a four-month successive growth experiment. *Aquaculture*, 505, 351–362. <https://doi.org/10.1016/j.aquaculture.2019.02.062>.
- Skinner, D. M. (1962). The structure and metabolism of a crustacean integumentary tissue during a molt cycle. *The Biological Bulletin*, 123, 635–647.
- Smith, L. D. (1990). Patterns of limb loss in the blue crab, *Callinectes sapidus* Rathbun, and the effects of autotomy on growth. *Bulletin of Marine Science*, 46, 23–36.
- Smith, L. D., & Hines, A. H. (1991). The effect of cheliped loss on blue crab *Callinectes sapidus* Rathbun foraging rate on soft-shell clams *Mya arenaria* L. *Journal of Experimental Marine Biology and Ecology*, 151, 245–256. [https://doi.org/10.1016/0022-0981\(91\)90127-1](https://doi.org/10.1016/0022-0981(91)90127-1).
- Sorach, K., Pratoomchat, B., Hanna, P. J., & Suksamrarn, A. (2013). Effects of phytoecdysone on the molting period and survival rate of the blue swimming crab, *Portunus pelagicus*. *Journal of Science, Technology, and Humanities*, 11, 87–94.
- Stacey, N., Gibson, E., Loneragen, N. R., Warren, C., Wiryawan, B., Adhuri, D., & Fitriana, R. (2019). Enhancing coastal livelihoods in Indonesia: an evaluation of recent initiatives on gender, women and sustainable livelihoods in small-scale fisheries. *Maritime Studies*, 18, 359–371. <https://doi.org/10.1007/s40152-019-00142-5>.
- Stella, V. S., López Greco, L. S., & Rodríguez, E. M. (2000). Effects of eyestalk ablation at different times of the year on molting and reproduction of the estuarine grapsid crab *Chasmagnathus granulata* (Decapoda, Brachyura). *Journal of Crustacean Biology*, 20, 239–244. <https://doi.org/10.1163/20021975-99990036>.
- Stocco, D. M. (2000). The role of StAR protein in steroidogenesis: challenges for the future. *Journal of Endocrinology*, 164, 247–253. <https://doi.org/10.1677/joe.0.1640247>.
- Styrishave, B., Lund, T., & Andersen, O. (2008). Ecdysteroids in female shore crabs *Carcinus maenas* during the moulting cycle and oocyte development. *Journal of the Marine Biological Association of the United Kingdom*, 88, 575–581. <https://doi.org/10.1017/S0025315408000878>.
- Styrishave, B., Rewitz, K., Lund, T., & Andersen, O. (2004). Variations in ecdysteroid levels and cytochrome *p₄₅₀* expression during moult and reproduction in male shore crabs *Carcinus maenas*. *Marine Ecology Progress Series*, 274, 215–224. <https://doi.org/10.3354/meps274215>.
- Sudha, K., & Anilkumar, G. (2007). Elevated ecdysteroid titer and precocious molt and vitellogenesis induced by eyestalk ablation in the estuarine crab, *Metopograpsus messor* (Brachyura: Decapoda). *Journal of Crustacean Biology*, 27, 304–308. <https://doi.org/10.1651/S-2750.1>.
- Sugumar, V., Vijayalakshmi, G., & Saranya, K. (2013). Molt cycle related changes and effect of short term starvation on the biochemical constituents of the blue swimmer crab *Portunus pelagicus*. *Saudi Journal of Biological Sciences*, 20, 93–103. <https://doi.org/10.1016/j.sjbs.2012.10.003>.
- Sukardi, P., Prayogo, N. A., Harisam, T., & Sudaryono, A. (2019). Effect of eyestalk-ablation and differences salinity in rearing pond and molting speed of *Scylla serrata*. *AIP Conference Proceedings*, 2094, 020029. <https://doi.org/10.1063/1.5097498>.
- Sy, C., & Airriess, C. N. (2002). Dopamine-stimulated limb autotomy in the Dungeness crab, *Cancer magister*. *Journal of Crustacean Biology*, 22, 697–703. <https://doi.org/10.1163/20021975-99990283>.
- Tamone, S. L., Adams, M. M., & Dutton, J. M. (2005). Effects of eyestalk-ablation on circulating ecdysteroids in hemolymph of snow crabs, *Chionoectes opilio*: physiological evidence for a terminal molt. *Integrative and Comparative Biology*, 45, 166–171. <https://doi.org/10.1093/icb/45.1.166>.
- Tamone, S. L., & Chang, E. S. (1993). Methyl farnesoate stimulates ecdysteroid secretion from crab Y-organs in vitro. *General and Comparative Endocrinology*, 89, 425–432. <https://doi.org/10.1006/gcen.1993.1050>.
- Tamsil, A., & Hasnidar, H. (2018). The effect of molting hormone (20-hydroxyecdysone) on molting of mud crab (*Scylla olivacea* Herbst, 1976). *Ecology, Environment and Conservation*, 24, 960–967.

- Tavares, C. P. S., Silva, U. T., Pereira, L. A., & Ostrensky, A. (2018). Systems and techniques used in the culture of soft-shell swimming crabs. *Reviews in Aquaculture*, 10, 913–923. <https://doi.org/10.1111/raq.12207>.
- Taylor, J., Vinatea, L., Ozorio, R., Schuweitzer, R., & Andreatta, E. R. (2004). Minimizing the effects of stress during eyestalk ablation of *Litopenaeus vannamei* females with topical anesthetic and a coagulating agent. *Aquaculture*, 233, 173–179. <https://doi.org/10.1016/j.aquaculture.2003.09.034>.
- Techa, S., & Chung, J. S. (2015). Ecdysteroids regulate the levels of molt-inhibiting hormone (MH) expression in the blue crab, *Callinectes sapidus*. *PLoS One*, 10, e0117278. <https://doi.org/10.1371/journal.pone.0117278>.
- Thomton, J. D., Tamone, S. L., & Atkinson, S. (2006). Circulating ecdysteroid concentrations in Alaskan Dungeness crab (*Cancer magister*). *Journal of Crustacean Biology*, 26, 176–181. <https://doi.org/10.1651/C-2625.1>.
- Tilden, A. R., Brauch, R., Ball, R., Janze, A. M., Ghaffari, A. H., Sweeney, C. T., Yurek, J., & Cooper, R. L. (2003). Modulatory effects of melatonin on behavior, hemolymph metabolites, and neurotransmitter release in crayfish. *Brain Research*, 992, 252–262. <https://doi.org/10.1016/j.brainres.2003.08.053>.
- Tilden, A., McGann, L., Schwartz, J., Bowe, A., & Salazar, C. (2001). Effect of melatonin on hemolymph glucose and lactate levels in the fiddler crab, *Uca pugilator*. *Journal of Experimental Zoology*, 290, 379–383. <https://doi.org/10.1002/jez.1078>.
- Tilden, A. R., Rasmussen, P., Awantang, R. M., Fulran, S., Goldstein, J., Palsgrove, M., & Sauer, A. (1997). Melatonin cycle in the fiddler crab, *Uca pugilator* and influence of melatonin on limb regeneration. *Journal of Pineal Research*, 23, 142–147. <https://doi.org/10.1111/j.1600-079X.1997.tb00347.x>.
- Tinikul, Y., Mercier, A., Soonklang, N., & Sobhon, P. (2008). Changes in the levels of serotonin and dopamine in the central nervous system and ovary, and their possible roles in the ovarian development in the giant freshwater prawn, *Macrobrachium rosenbergii*. *Comparative Endocrinology*, 158, 250–258. <https://doi.org/10.1016/j.ygcen.2008.07.009>.
- Tobias-Quinitio, E. J., Libunao, G. X. S., Parado-Esteva, F. D., & Calpe, A. T. (2015). *Soft-shell crab production using hatchery-reared mud crab*. Tigbauan, Iloilo, Philippines: Aquaculture Department, Southeast Asian Fisheries Development Center; Los Baños, Laguna: Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development.
- Tran, N. M., Mykles, D. L., Elizur, A., & Ventura, T. (2019). Characterization of G-protein coupled receptors from the blackback land crab *Gecarcinus lateralis* Y organ transcriptome over the molt cycle. *BMC Genomics*, 20, 74. <https://doi.org/10.1186/s12864-018-5363-9>.
- Trino, A. T., Millamena, O. M., & Keenan, C. P. (2001). Pond culture of the mud crab *Scylla serrata* (Forsk.) fed formulated diet with or without vitamin and mineral supplements. *Asian Fisheries Science*, 14, 191–200. <http://hdl.handle.net/10862/1914>.
- Vega-Villasante, F., Cortés-Jacinto, E., & García-Guerrero, M. (2007). Contribution to the knowledge of moulting and growth of *Callinectes arcuatus* Ordway, 1863 (Brachyura, Portunidae) in Baja California Sur, Mexico. *Crustaceana*, 80, 769–778. <https://doi.org/10.1163/156854007781363132>.
- Vidal-Gadea, A. G., & Belanger, J. H. (2009). Muscular anatomy of the legs of the forward walking crab, *Libinia emarginata* (Decapoda, Brachyura, Majoidea). *Arthropod Structure and Development*, 38, 179–194. <https://doi.org/10.1016/j.asd.2008.12.002>.
- Waiho, K., Fazhan, H., Quinitio, E. T., Baylon, J. C., Fujaya, Y., Azmie, G., Wu, Q., Shi, X., Ikhwanuddin, M., & Ma, H. (2018). Larval rearing of mud crab (*Scylla*): What lies ahead. *Aquaculture*, 493, 37–50. <https://doi.org/10.1016/j.aquaculture.2018.04.047>.
- Waiho, K., Fazhan, H., Shahreza, M. D., Moh, J. H. Z., Noorbaiduri, S., Wong, L. L., Sinnasamy, S., & Ikhwanuddin, M. (2017). Transcriptome analysis and differential gene expression on the testis of orange mud crab, *Scylla olivacea* during sexual maturation. *PLoS One*, 12, e0171095. <https://doi.org/10.1371/journal.pone.0171095>.
- Waiho, K., Mustaqim, M., Fazhan, H., Wan-Norfaiza, W. I., Megat, F. H., & Ikhwanuddin, M. (2015). Mating behavior of the orange mud crab, *Scylla olivacea*: The effect of sex ratio and stocking density on mating success. *Aquaculture Reports*, 2, 50–57. <https://doi.org/10.1016/j.aqrep.2015.08.004>.
- Waiho, K., Shi, X., Fazhan, H., Li, S., Zhang, Y., Zheng, H., Liu, W., Fang, S., Ikhwanuddin, M., & Ma, H. (2019). High-density genetic linkage maps provide novel insights into ZW/ZZ sex determination system and growth performance in mud crab (*Scylla paramamosain*). *Frontiers in Genetics*, 10, 298. <https://doi.org/10.3389/fgene.2019.00298>.
- Warner, A. C., Stevenson, J. R., & Church, C. (1969). The initiation of precocious premolt in *Orconectes obscurus* with injections of α -ecdysone and crustecdysone. *American Zoologist*, 9, 1085. <https://doi.org/10.1007/BF00303233>.
- Wheatly, M. G. (1999). Calcium homeostasis in crustacea: the evolving role of branchial, renal, digestive and hypodermal epithelia. *Journal of Experimental Zoology*, 283, 620–640. [https://doi.org/10.1002/\(sici\)1097-010x\(1999060\)283:7<620::aid-jez>3.3.co;2-v](https://doi.org/10.1002/(sici)1097-010x(1999060)283:7<620::aid-jez>3.3.co;2-v).
- Xie, X., Tao, T., Liu, M., Zhou, Y., Liu, Z., & Zhu, D. (2016). The potential role of juvenile hormone and methyltransferase in methyl farnesoate (MF) biosynthesis in the swimming crab, *Portunus trituberculatus*. *Animal Reproduction Science*, 169, 40–49. <https://doi.org/10.1016/j.anireprosci.2016.02.024>.
- Yudin, A. I., Diener, R. A., Clark, W. H., & Chang, E. S. (1980). Mandibular gland of the blue crab, *Callinectes sapidus*. *The Biological Bulletin*, 159, 760–772. <https://doi.org/10.2307/1540840>.
- Zmora, O., Findiesen, A., Stubblefield, J., Frenkel, V., & Zohar, Y. (2005). Large-scale juvenile production of the blue crab *Callinectes sapidus*. *Aquaculture*, 244, 129–139. <https://doi.org/10.1016/j.aquaculture.2004.11.012>.

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crabs", Anais da Academia Brasileira de Ciências, 2021

Publication

77

G. Purna Chandra Nagaraju, P. Sreenivasula Reddy, P. Ramachandra Reddy. "Involvement of Methyl Farnesoate in the Regulation of Molting and Reproduction in the Freshwater Crab *Oziotelphusa Senex Senex*", Journal of Crustacean Biology, 2004

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