Reproductive and growth performances in female giant freshwater prawn following inhibition of gonadal maturation using dopamine and medroxyprogesterone hormone

Performa reproduksi dan pertumbuhan pascaphambatan pematangan gonad udang galah betina secara hormonal menggunakan dopamin dan medroxyprogesteron

Megawati Wijaya1*, Agus Oman Sudrajat1, Imron2

1Department of Aquaculture, Faculty of Fisheries and Marine Sciences, IPB University, Dramaga, Bogor, West Java, Indonesia 16680
2Fish Breeding Research Center, Subang, West Java, Indonesia
*Corresponding author : Megawatiwijaya20@gmail.com

(Received December 20, 2016; Accepted July 18, 2019)

ABSTRACT

One of the main problem in giant river prawn (GFP) culture is early gonadal maturation in female resulting a reduced growth performance. This problem cause economic losses. When GFP at gonadal maturation, somatic growth will be inhibited because energy is used for reproduction. A factorial experimental design using two factors, namely dopamine and medroxyprogesterone, with each factor consist of three levels was applied. Three dopamine levels were 0, 10⁻⁵ mol/shrimp, and 10⁻¹⁰ mol/shrimp, while the medroxyprogesterone levels were 0, 75 mg/1.5 mL/bobot udang, and 150 mg/3 mL/bobot udang with a density 15 individual/tank. The utilization of dopamine and medroxyprogesterone in GFP (initial bodyweight : 11.27 ± 0.97 g) through injection at the third periopod was done three times at week 0, 2nd, and 4th with two weeks interval. The results showed that hormone inhibitor treatments affected both growth and reproductive performances in female GFP. The treated individuals showed a lower gonadal maturity indicator values and faster growth rate than control. Gonadal maturity, as shown by gonad histology, in all treatments were lower (previtelogenic and vitellogenic stages) than that in control which is in mature stage. Estradiol concentration premix dopamine 10⁻¹⁰ mol/shrimp and medroxyprogesterone 150 mg/3 mL/bobot udang treatments are lower than control. In conclusion, dopamine and medroxyprogesterone administration could suppres GSI and gonad development, and also increase growth rate.

Keywords: Macrobrachium rosenbergii, dopamine, medroxyprogesterone, gonad development, growth.

ABSTRAK

Kematangan gonad dini induk udang galah Macrobrachium rosenbergii betina dapat merugikan. Saat udang matang gonad, pertumbuhan somatik terhambat disebabkan energi untuk pertumbuhan akan digunakan untuk reproduksi. Penelitian ini bertujuan mengevaluasi penggunaan hormon dopamin dan medroxyprogesterone sebagai penghambat pematangan gonad. Penelitian ini menggunakan rancangan acak lengkap faktorial dengan dua perlakuan yaitu pemberian dopamin dan medroxyprogesterone. Dosis dopamin yang digunakan yaitu 0, 10⁻⁴ mol/udang, dan 10⁻⁹ mol/udang, sedangkan medroxyprogesterone dengan dosis 0, 75 mg/1.5 mL/bobot udang, dan 150 mg/3 mL/bobot udang dengan kepadatan 15 ekor/bak. Udang galah betina (bobot awal:11.27 ± 0.97 g) diberi perlakuan berupa dopamin dan medroxyprogesterone sebanyak tiga kali pada minggu ke-0, 2, dan 4 dengan interval waktu dua minggu sekali. Hasil penelitian ini menunjukan perlakuan dopamin dan medroxyprogesterone memiliki nilai indeks kematangan gonad (IKG) yang rendah dan laju pertumbuhan yang lebih cepat dibandingkan kontrol. Histologi gonad pada semua perlakuan berada pada tahap previtelogenic dan vitellogenic dibandingkan kontrol yang berada pada tahap mature. Konsentrasi estradiol pada perlakuan premix dopamin 10⁻¹⁰ mol/udang dan medroxyprogesterone 150 mg/3 mL/bobot udang lebih rendah dibandingkan kontrol. Pemberian dopamin dan medroxyprogesterone dapat menekan IKG, perkembangan gonad, dan meningkatkan laju pertumbuhan.

Kata kunci: Macrobrachium rosenbergii, dopamin, medroxyprogesterone, pertumbuhan, perkembangan gonad.
INTRODUCTION

Giant freshwater prawn *Macrobrachium rosenbergii* is freshwater species with high economic value. A rapid gonad maturation on the female broodstock becomes constraint in giant freshwater prawn production. Ra’an an et al. (1991) stated that a female giant freshwater prawn reached the first gonad maturation in 18–26 g. It disrupts the giant prawn production because of the low energy allocation for growth when the gonad is matured. The somatic growth is disrupted since the major energy allocation will be on the reproduction process (Cavalli et al., 2001).

The gonad development of female giant freshwater prawn is naturally affected by several hormone mechanisms (Swetha et al., 2011). Gonad stimulating hormone (GSH) and methyl farnesoate (MF) are the gonadotropin hormones which essentially work in the reproduction glands activity and progesterone in female giant freshwater prawn. The production of GSH and MF are naturally inhibited by the gonad inhibiting hormone (GIH) activity and mandibular organ inhibiting hormone (MOIH) which is produced by X-organ located in the eyestalk (Thongbuakaew et al., 2019).

The crustaceans growth is controlled by the ecdysteroid hormones (molting hormone) located in the Y-organ. The Y-organ will synthesize and secrete ecdysteroids to the growth cells, such as eyestalk and hepatopancreas (Nagaraju, 2011). According to Chang and Mykles (2011), the function of molt-inhibiting hormone (MIH) is to regulate molting process in crustaceans, whereas the crustacea hyperglemic hormone (CHH) provides the carbohydrates and lipids to fulfill the energy requirement of crustaceans (Vingare & Chung, 2016). The methyl farnesoate stimulates growth in crustaceans. It is supported by Allayie et al. (2010) who stated that the provision of mandibular organ extract was able to rise weight gain in yellowish brown crab *Charybdis lucifera*.

Hormonal engineering is one of the solution to inhibit gonad maturation and increase growth rate. Accordingly, this study used the hormonal engineering through dopamine and medroxyprogesterone injection as gonad maturation inhibitor in female broodstock. Dopamine is a hydrophilic neurotransmitter located in central nerve system and crustaceans ovary (Tinikul et al., 2009). O’Connell et al. (2013) mentioned that dopamine in vertebrates acts as neurotransmitter which contributes in hypothalamus and pituitary function and also inhibits gonad development. Fingerman (1997) stated that dopamine performs to inhibit gonad maturation in prawn through X-organ neuroendocrine cell in terminal medulla in eyestalk to synthesize gonad inhibiting hormone (GIH).

Medroxyprogesterone acetate is a steroid hormone produced by the ovary, adrenal cortex, and placenta in human pregnancy (Suherman, 2008). Medroxyprogesterone is lipophilic (Steele et al., 2013). Daido et al. (2014) mentioned that medroxyprogesterone depressed ovulation in inhibiting hypophysis to secrete luteinizing hormone (LH) and follicle stimulating hormone (FSH). This study aimed to evaluate dopamine and medroxyprogesterone utilization as gonad maturation inhibitor in female broodstock of giant freshwater prawn.

MATERIALS AND METHODS

Experimental prawn

The experimental prawn was giant freshwater prawn Asahan strain. The average weight was 11.27 ± 0.97 g. The prawn was four-month old, healthy, no defect, complete body organ, and pathogen-free. Dopamine hydrochloride powder (Sigma Aldrich), medroxyprogesterone, and Estradiol kit (USA) were utilized in laboratory analysis.

Experimental treatment

The gonad maturation inhibition was conducted through dopamine and medroxyprogesterone injection on the female broodstock. This study applied factorial completely randomized design because it consisted of two factors, i.e. dosage 0, 10^{-5} mol/ind, and 10^{-10} mol/ind, also medroxyprogesterone in dosage 0, 75 mg/1.5 mL/ body weight, and 150 mg/3 mL/ body weight. Thus, nine treatments were applied, i.e. control (NaCl 0.1 mL), D1 (dopamine 10^{-5} mol), D2 (dopamine 10^{-10} mol), M1 (medroxyprogesterone 1.5 mL), M2 (medroxyprogesterone 3 mL), D1M1 (dopamine 10^{-5} mol + medroxyprogesterone 1.5 mL), D2M1 (dopamine 10^{-10} + medroxyprogesterone 1.5 mL), D1M2 (dopamine 10^{-5} mol + medroxyprogesterone 3 mL), and D2M2 (dopamine 10^{-10} + medroxyprogesterone 3 mL).

The female giant freshwater prawn (initial weight: 11.27 ± 0.97 g) were treated using
dopamine and medroxyprogesterone three times on week-0, week-2, and week-4. The dopamine and medroxyprogesterone were injected on the third walking leg. The rearing was managed for three months in a concrete tank sized in 1.5×1×1 m$^3$ with 15 ind/tank of stocking density. The hormone injection was done in the morning at 7 a.m. During the rearing, the experimental prawn was fed using commercial feed with 35% of protein content. The feeding rate was 5% of biomass and it was delivered three times a day.

**Parameters observation and sample collection**

**Estradiol analysis**

Estradiol analysis was managed by collecting 0.3 mL hemolymph sample on the third walking leg using syringe 0.1 mL rinsed using coagulant. The sample was centrifuged and stored in -20°C storage. The estradiol measurement calculation was conducted using ELISA (enzyme-linked immunosorbent assay) method (kit DRG® Estradiol ELISA (EIA–2693)). The estradiol analysis was done at the beginning and at the end of the study.

**Gonado somatic index (GSI)**

Gonado somatic index (GSI) was observed at the beginning and the end of the study using the following formula (Effendie, 2002):

$$\text{GSI} (%) = \frac{\text{Gonad weight}}{\text{Body weight}} \times 100$$

**Gonad histology**

Gonad histology was monitored to observe the gonad microscopic. The method was hematoxyline and eosin staining. It was examined at the beginning and end of the study.

**Specific growth rate**

The specific growth rate was measured at the end of the study using the following formula (Effendi, 2004):

$$\text{SGR (%/day) = } \left[ \frac{\sqrt{\frac{\text{Wt}}{\text{Wo}}} - 1}{n} \right] \times 100$$

Note:
- Wo = Initial weight (g)
- Wt = Final weight (g)
- n = rearing period (day)

**Survival rate (SR)**

Survival rate is a percentage of final population compared with initial population. The calculation was done using this following formula (Effendie, 2002):

$$\text{SR} (%) = \frac{\text{Nt}}{\text{No}} \times 100$$

Note:
- SR = Survival rate (%)
- Nt = Final population (individual)
- No = Initial population (individual)

### Table 1. Production and reproduction performance post-gonad maturation inhibition.

| Treatments | Estradiol concentration (ng/mL) (n=3) | GSI (%) (n = 2) | Gonad histology (n = 2) | SGR (%/day) (n = 3) | SR (%) (n=15) |
|------------|-------------------------------------|----------------|-------------------------|---------------------|---------------|
| Control    | 1.52 ± 0.04$^{ab}$                  | 3.97$^a$       | Mature                  | 0.90 ± 0.20$^a$    | 46.67         |
| D1         | 1.66 ± 0.03$^b$                     | 0.25$^b$       | Previtellogenic         | 1.11 ± 0.09$^{bc}$ | 20            |
| D2         | 1.38 ± 0.14$^{bc}$                  | 0.24$^b$       | previtellogenic         | 1.55 ± 0.06$^a$    | 60            |
| M1         | 1.36 ± 0.11$^{bc}$                  | 0.71$^b$       | previtellogenic         | 1.12 ± 0.36$^{bc}$ | 33.33         |
| M2         | 1.26 ± 0.11$^{bc}$                  | 0.42$^b$       | previtellogenic         | 1.50 ± 0.23$^a$    | 33.33         |
| D1M1       | 1.30 ± 0.10$^{bc}$                  | 0.58$^b$       | previtellogenic         | 1.39 ± 0.10$^{bc}$ | 20            |
| D2M1       | 1.61 ± 0.18$^{bc}$                  | 1.74$^b$       | vitellogenic            | 1.02 ± 0.14$^{bc}$ | 26.67         |
| D1M2       | 1.71 ± 0.22$^a$                     | 0.39$^b$       | previtellogenic         | 1.18 ± 0.04$^{bc}$ | 33.33         |
| D2M2       | 1.06 ± 0.06$^b$                     | 0.33$^b$       | previtellogenic         | 1.16 ± 0.18$^{bc}$ | 46.67         |

Note: Different superscript in the same column indicates significant difference amongst treatments (P<0.05). D1 (dopamine 10$^{-5}$ mol); D2 (dopamine 10$^{-6}$ mol); M1 (medroxyprogesterone 1.5 mL); M2 (medroxyprogesterone 3 mL); D1M1 (dopamine 10$^{-4}$ mol + medroxyprogesterone 1.5 mL); D2M1 (dopamine 10$^{-5}$ mol + medroxyprogesterone 1.5 mL); D1M2 (dopamine 10$^{-4}$ mol + medroxyprogesterone 3 mL); D2M2 (dopamine 10$^{-5}$ mol + medroxyprogesterone 3 mL). GSI : gonado somatic index; SGR : specific growth rate; SR : survival rate.
Data analysis
The data were analyzed using factorial completely randomized design with two factors, i.e. dopamine and medroxyprogesterone. Data were tabulated using Ms. Excel 2010 and analysis of variance was done using Minitab 16. A significant result would be analyzed further with Tukey test. Gonad histology, survival rate, maturation period, and water quality parameters were described descriptively.

RESULTS AND DISCUSSIONS

Result
Production and growth performance of post-induction inhibitory
The parameters consisted of estradiol concentration, gonado somatic index, gonad histology, daily growth rate, and survival rate. The result of gonad maturation inhibition using dopamine and medroxyprogesterone presented that D2, M2, and D2M2 were prominent compared with the other treatments (Table 1). It is described by the estradiol concentration and gonado somatic index result. The three particular treatments showed previtellogenic phase and the growth rate was significantly higher than the other treatments.

Estradiol concentration
Particularly, Figure 1 shows that the D2M2 treatment (dopamine $10^{-10}$ mol + medroxyprogesterone 3 mL) presented a lower concentration of estradiol (1.06 ng/mL) compared with control (1.52 ng/mL) ($P<0.05$). It indicated that dopamine and medroxyprogesterone significantly affected estradiol-17β concentration.

Gonado somatic index (GSI)
The initial GSI level was 0.26%. At the end of the study, the GSI level of dopamine and medroxyprogesterone treatments were

---

![Figure 1](image1.png)

**Figure 1.** Concentration of estradiol-17β. Different superscript indicates significant difference amongst treatments ($P<0.05$). D1 (dopamine $10^{-5}$ mol); D2 (dopamine $10^{-10}$ mol); M1 (medroxyprogesterone 1.5 mL); M2 (medroxyprogesterone 3 mL); D1M1 (dopamine $10^{-5}$ mol + medroxyprogesterone 1.5 mL); D2M1 (dopamine $10^{-10}$ mol + medroxyprogesterone 1.5 mL); D1M2 (dopamine $10^{-5}$ mol + medroxyprogesterone 3 mL); D2M2 (dopamine $10^{-10}$ mol + medroxyprogesterone 3 mL).

![Figure 2](image2.png)

**Figure 2.** Gonado somatic index at the end of the study. Different superscript indicates significant difference amongst treatments ($P<0.05$). D1 (dopamine $10^{-5}$ mol); D2 (dopamine $10^{-10}$ mol); M1 (medroxyprogesterone 1.5 mL); M2 (medroxyprogesterone 3 mL); D1M1 (dopamine $10^{-5}$ mol + medroxyprogesterone 1.5 mL); D2M1 (dopamine $10^{-10}$ mol + medroxyprogesterone 1.5 mL); D1M2 (dopamine $10^{-5}$ mol + medroxyprogesterone 3 mL); D2M2 (dopamine $10^{-10}$ mol + medroxyprogesterone 3 mL).
Figure 3. The gonad histology of giant freshwater prawn before treated (magnification 400×). Note: 1, 2, 3, 4, 5; the initial gonad histology in the previtellogenic phase, n = nucleus; Tra = trabecular; Fc = follicular cell type 1 and 2; li = lipid droplet; Oog = oogonia; Oc1 = late previtellogenic oocyte; Oc2 = early previtellogenic oocyte.

Figure 4. Gonad histology of giant freshwater prawn after treated using dopamine and medroxyprogesterone (magnification 100×). A ; control , B ; D1 (dopamine 10^{-5} mol + medroxyprogesterone 0), C ; D2 (dopamine 10^{-10} mol + medroxyprogesterone 0 mL), D ; M1 (dopamine 0 mol + medroxyprogesterone 1.5 mL), E ; M2 (dopamine 0 + medroxyprogesterone 3 mL), F ; D1M1 (dopamine 10^{-5} mol + medroxyprogesterone 1.5 mL), G ; D2M1 (dopamine 10^{-10} mol + medroxyprogesterone 1.5 mL), H ; D1M2 (dopamine 0 mol + medroxyprogesterone 3 mL), I ; D2M2 (dopamine 10^{-10} mol + medroxyprogesterone 3 mL), n; nucleus, Tra; trabecula, Fc; follicular cell type 1 and 2, Li; lipid droplet, Oog; oogonia, Oc1; late previtellogenic oocyte, Oc2; early previtellogenic oocyte, Oc3; late vitellogenic oocyte, Oc4; early vitellogenic oocyte, mOc; mature oocyte.

significantly lower than the control (P<0.05). The overall result ranged from 0.24−1.74% and the highest was the control (3.97%).

Gonad histology

Gonad histology was observed in the initial and final period of the study. In the beginning of the study, the gonad histology showed previtellogenic phase (Figure 3), i.e. oval oocyte, nucleolus surrounded by the nucleus, and noticeable follicle cell. The dopamine and medroxyprogesterone treatments presented previtellogenic and vitellogenic phase. On the contrary, the control showed mature phase (Figure 4). On the vitellogenic phase, oocyte appears bigger than previtellogenic phase. There is the nucleolus surrounded by the nucleus, the follicle which surrounded oocyte, and it contains lipid granules. On the contrary, the matured phase, oocyte reached double size compared to the vitellogenic phase and the ovary was full of matured oocyte.

Specific growth rate

The specific growth rate of D2 (dopamine 10^{-10} mol) and M2 (medroxyprogesterone 3 mL) presented a significant result compared to the
control (P<0.05). The D1 (dopamine 10^{-5} mol), M1 (medroxyprogesterone 1.5 mL), D1M1 (dopamine 10^{-5} + medroxyprogesterone 1.5 mL), D2M1 (dopamine 10^{-10} + medroxyprogesterone 1.5 mL), D1M2 (dopamine 10^{-5} mol + medroxyprogesterone 3 mL), and D2M2 (dopamine 10^{-10} + medroxyprogesterone 3 mL) showed a higher result, however it was not different significantly (P>0.05). It indicated that the application of dopamine and medroxyprogesterone was potential to boost the growth hormone in the female broodstock of giant freshwater prawn.

**Survival rate**

The survival rate of D2 treatment (60%) was higher than the other treatments. On the contrary, D1 (dopamine 10^{-5} mol), M1 (medroxyprogesterone 1.5 mL), D1M1 (dopamine 10^{-5} + medroxyprogesterone 1.5 mL), D2M1 (dopamine 10^{-10} + medroxyprogesterone 1.5 mL), D1M2 (dopamine 10^{-5} mol + medroxyprogesterone 3 mL), and D2M2 (dopamine 10^{-10} + medroxyprogesterone 3 mL) treatment ranged from 20–46.67%.

**Discussion**

Dopamine and medroxyprogesterone induction in giant freshwater prawn affected the estradiol-17β concentration. In Figure 1, the D2M2 treatment had the lowest estradiol concentration compared with the other treatments. It is supported by Tinikul et al. (2008), who found that application a certain dosage of dopamine (2.5 × 10^{-5} and 2.5 × 10^{-7}) was able to decrease vitellogenin content in GSI IV compared with the control.
addition, 1.25 mg of medroxyprogesterone was potential to inhibit gonad maturation in male rat Sprague Dawley strain (Yurnadi et al., 2011). Dopamine and medroxyprogesterone induction in giant freshwater prawn decline the estradiol-17β concentration in the hemolymph. It was presumed that the $10^{-6}$ mol of dopamine premix and 3 mL of medroxyprogesterone was able to repressed the estradiol concentration. It is in line with Fingerman (1997) who stated that dopamine holds a certain role as a gonad maturation inhibitor in prawn through X organ neuroendocrine cell stimulation in medulla terminal in the eyestalk and then synthesize the GIH.

The collection of gonad sample was managed to observe the gonad development. The GSI value at the end of the study showed declining point when dopamine and medroxyprogesterone were delivered. The statement is supported by Daido et al. (2014). Medroxyprogesterone has a certain role to repress ovulation by inhibiting hypophysis to secrete gonad maturation hormone (LH and FSH). Tinikul et al. (2009) stated that dopamine inhibits the gonad maturation process and oocyte development in giant freshwater prawn. On the contrary, Chen et al. (2018) mentioned that dopamine was able to surpress the synthesis and secretion of gonadotropin in teleost. Supporting the later statement, Ciechanowska et al. (2018) also described that dopamine restrains the GnRH biosynthesis process in goat.

The gonad histology at the end of the study explained that dopamine and medroxyprogesterone were in the previtellogenic and vitellogenic phase. It can be seen from Figure 4 that several oogonia cells were in the early stage and developed oocytes were spotted because of the cytoplasm development compared to the control treatment which the nucleus was fused. According to the gonad histology by Ngernsoungnern et al. (2009), in the previtellogenesis phase, oocyte was on the oval-shaped, nucleolus was surrounded by nucleus, and follicle cell was spotted. Compared to the vitellogenic phase, oocyte appeared bigger than the previtellogenic phase, nucleolus was surrounded by the nucleus as well, and there were fatty follicle cell surrounding the oocyte. The control treatment presented bigger oocyte in the vitellogenic phase and ovariurn was full of matured oocyte. The particular character was considered as matured individual (Soonklang et al., 2012; Kankuan et al., 2017).

The specific growth rate in the D2 treatment (dopamine $10^{-10}$ mol) was higher that the others. It was preassumed that a low dosage of dopamine was adequately effective to boost a higher growth. According to Jin and Hashizume (2014), dopamine is involved in growth hormone and prolactin regulation mechanism in goat. Dopamine restrained the somatostatin hormone in hypothalamus, thus the growth hormone releasing hormone (GHRH) was able to be stimulated to secrete growth hormone.

The declined survival rate at the end of the study was presumably caused by stress condition during the injection. Stress affects the immune system through metabolic mechanism (Yeh et al., 2010; Leland et al., 2013). Chang et al. (2007) stated that two hours after dopamine injection in dosage $10^{-4}$, $10^{-7}$, and $10^{-8}$ mol, the oxyhemocyanin decreased significantly. Oxyhemocyanin is a blue pigment formed by the oxygen and hemocyanin in ratio 1:2 (Cheng et al., 2013), while hemocyanin is a glycoprotein contained copper and it is usually found in the hemolymph (Zheng et al., 2016). The declined oxyhemocyanin disrupted the metabolism, osmoregulation, and resporation system which later caused stress and unable to adapt to the environment (Chang et al., 2016). Adding the previous statement, Camacho-Jimenez et al. (2017) reported that a $2 \times 10^{4}$ mol of dopamine potentially controlled the osmoregulation system in the whiteleg shrimp Litopenaeus vannamei. Osmoregulation is a homeostatis system to maintain the milieu intérieur stability through osmotic balance regulation amongst intracell and extracell (Maghfiroh et al., 2019).

Molting is the detachment of older cuticula and forms a new cuticula layer (Rocha et al., 2012). The molting process is usually followed by the length, weight, and width changes (Fujaya et al., 2011). In crustaceans, molting is triggered by several factors, i.e. growth, reproduction, and stress (Hess, 2014). The giant freshwater prawn is a cannibal (Mendler et al., 2015). When molting occurs, it lacks of strength. It provokes the stronger and not-experiencing-molting individual to attack them. This leads to death for those which experiencing molting at a certain time (Mendler et al., 2015).

**CONCLUSION**

The provision of dopamin $10^{-10}$ mol/ind, medroxyprogesterone 150 mg/3 mL/body
weight, and $10^{-10}$ mol/ind of dopamine premix and medroxyprogesterone 150 mg/3 mL/body weight effectively inhibited reproduction and escalated growth rate through estradiol repression.

ACKNOWLEDGMENT

Authors would like to express gratitude to the Fish Breeding Research Center, Subang, West Java, especially the head of Fish Breeding Research Center and giant freshwater prawn team, for every sincere support and facility that we’ve been used in the study.

REFERENCES

Allayie SA, Ravichandran S, Bhat BA. 2010. Role of mandibular glands in growth of mangrove crab Charybdis lucifera Fabricius, 1798. World Journal of Zoology 5: 125–128.

Camacho-Jimenez L, Díaz F, Munoz-Márquez ME, Farfan C, Re AD, Ponce-Rivas E. 2017. Hyperglycemic and osmotic effects of dopamine and recombinant hormone CHH-B1 in the Pacific white shrimp Litopenaeus vannamei. Marine and Freshwater Behaviour and Physiology 50: 67–79.

Cavalli OC, Lavens P, Sorgeloos P. 2001. Reproductive performance of Macrobrachium rosenbergii females in capacity. Journal of the World Aquaculture Society 32: 60–67.

Chang CH, Wu ZR, Chen CS, Kuo CM, Cheng W. 2007. Dopamine modulates the physiological response of the tiger shrimp Penaeus monodon. Aquaculture 270: 333–342.

Chang ES, Mykles DL. 2011. Regulation of crustacean molting: a review and our perspectives. General and Comparative Endocrinology 172: 323–330.

Chang Z, Ke Z, Chang C. 2016. Roles of dopamine receptors in mediating acute modulation of immunological responses in Macrobrachium rosenbergii. Fish & Shellfish Immunology 49: 286–297.

Chen J, Cao M, Zhang A, Shi M, Tao B, Li Y, Wang Y, Zhu Z, Trudeau VL, Hu W. 2018. Growth hormone overexpression disrupts reproductive status through actions on leptin. Frontiers in Endocrinology 9: 131.

Cheng HY, Shieh LW, Chen JC. 2013. Changes in hemolymph oxyhemocyanin acis-based balance and electrolytes in Marsupenaeus japonicas under combined ammonia and nitrite stress. Aquatic Toxicology 130–131: 132–138.

Ciechanowska M, Lapota M, Paruszewska P, Radawiec B, Przekop F. 2018. The influence of dopaminergic system inhibition on biosynthesis of gonadotrophin-releasing hormone (GnRH) and GnRH receptor in anoestrous sheep; hierarchical role of kisspeptin and RFamide-related peptide-3 (RFRP-3). Reproduction, Fertility and Development 30: 672–680.

Daido I, Tahir AM, Chalid T. 2014. Changes of body mass index and lipid profile in injectable depot medroxyprogesterone acetate and levonorgestrel implant acceptors. Indonesian Journal of Obstetrics and Gynecology 2: 1–15.

Effendi I. 2004. Pengantar Akuakultur. Depok (ID): Penebar Swadaya.

Effendie MI. 2002. Biologi Perikanan. Bogor (ID): Yayasan Pustaka Nusantara.

Fingerman M. 1997. Roles of neurotransmitters in regulating reproductive hormone release and gonadal maturation in decapod crustaceans. Invertebrate Reproduction and Development 31: 47–54.

Fujaya Y. 2011. Growth and molting of mud crab administered by different doses of vitomolt. Jurnal Akuakultur Indonesia 10: 24–28.

Hess WN. 2014. Actors influencing molting in the crustacean Crangon armillatus. Marine Biological Laboratory 81: 215–220.

Jin J, Hashizume T. 2014. Effects of hypothalamic dopamine on growth hormone-releasing hormone-Induced growth hormone secretion and thyrotropin-releasing hormone-induced prolactin secretion in goats. Animal Science Journal 86: 634–640.

Kankuan W, Wanichanon C, Titone R, Enghusophon A, Sumpownton C, Suphamungmee W, Morani F, Masini M, Novelli M, Isidoro C, Sobhon P. 2017. Starvation promotes autophagy-associated maturation of the ovary in the giant freshwater prawn Macrobrachium rosenbergii. Frontiers in Physiology 8: 1–8.

Leland JC, Butcher PA, Broadhurst MK, Paterson BD, Myaer DG. 2013. Damage and physiological stress to juvenile eastern rock lobster Sagmariasus verreauxi discarded after trapping and hand collection. Fisheries Research 137: 63–70.

Maghfiroh A, Anggoro S, Purnomo PW. 2019. Osmoregulation patterns and factors of vanname shrimp conditions Litopenaeus vannamei cultivated in intensive Mojo Ulujami Pemalong. Journal of Maqueres 8: 177–184.
Mendler S, Donald LM. 2015. Physiology: Muscle structure, fiber types and physiology crustaceans. New York: Oxford University Press.

Nagaraju GPC. 2011. Review Reproductive regulators in decapod crustaceans: an overview. The Journal of Experimental Biology 214: 3–15.

Ngernsoungnern P, Ngernsoungnern A, Sobhon P, Sretarugsa P. 2009. Gonadotropin releasing hormone (GnRH) and a GnRH analog induce ovarian maturation in the giant freshwater prawn, Macrobrachium rosenbergii. Invertebrate Reproduction and Development 53: 125–135.

Ra’anan Z, Sagi A, Wax Y, Karplus I, Hulata G, Kuris A. 1991. Growth, size rank, and maturation of the freshwater prawn Macrobrachium rosenbergii: analysis of marked prawns in an experimental population. Biological Bulletin 181: 379–386.

Rocha J, Garcia−Carreno FL, Muhlía−Almazán A, Peregrino−Uriarte AB, Gloria−Yepiz−Plascencia, Cordova−Murueta JH. 2012. Cuticular chitin synthase and chitinase mRNA of whiteleg shrimp Litopenaeus vannamei during the molting cycle. Aquaculture 330−333: 111–115.

Soonklang N, Wanichanon C, Stewart MJ, Stewart P, Meeratana P, Hanna PJ, Sobhon P. 2012. Ultrastructure of differentiating oocytes and vitellogenesis in the giant freshwater prawn, Macrobrachium rosenbergii (de Man). Microscopy Research and Technique 00: 1–14.

Steele WB, Garcia SN, Huggett DB, Vanables BJ, Barnes SE, Point TWL. 2013. Tissue-specific bioconcentration of the synthetic steroid hormone medroxyprogesterone acetate in the common carp Cyprinus carpio. Enviromental Toxicologi abd Pharmacology 36: 1120–1126.

Suherman SK. 2008. Farmakologi dan Terapi. Edisi 5 FKUI. Jakarta: Gaya Baru.

Swetha CH, Sainath SB, Reddy PR, Reddy PS. 2011. Reproductive endocrinologi of female crustacean: perspective and prospective. Marine Science Research and Development 3: 1–13.

Thongbuakaew T, Suwansa-ard S, Sretarugsa P, Sobhon P, Cummins SF. 2019. Identification and characterization of a crustacean female sex hormone in the giant freshwater prawn, Macrobrachium rosenbergii. Aquaculture 507: 56–68.

Tinikul Y, Mercier AJ, Sobhon P. 2009. Distribution of dopamin and octopamine in the central nervous system and ovary during the ovarian maturation cycle of the giant freshwater prawn Macrobrachium rosenbergii. Tissue Cell 41: 430–442.

O’Connell LA, Fontenot MR, Hofmann HA. 2013. Neurochemical profiling of dopaminergic neurons in the forebrain of a cichlid fish Astatotilapia burtoni. Journal of Chemical Neuroanatomy 47: 106–115.

Vinagre AS, Chung JS. 2016. Effects of starvation on energy metabolism and crustacean hyperglycemic hormone (CHH) of the Atlantic ghost crab Ocypode quadrata (Fabricius, 1787). Marine Biology 163: 1–11.

Yeh ST, Li CC, Tsui WC, Lin YC, Chen JC. 2010. The protective immunity of white shrimp Litopenaeus vannamei that had been immersed in the hot-water extract of Gracilaria tenuistipitata and subjected to combined stresses of Vibrio alginolyticus injection and temperature change. Fish and Shellfish Immunology 29: 271–278.

Yurnadi AY, Suryandari DA, Moeloek N. 2011. Combination of depot medroxy progesterone acetate and javanese long pepper extract on body weight, hematology, and blood biochemistry as a safe contraception model. Makara Sains 15: 155–162.

Zheng L, Zhao X, Zhang P, Chen C, Liu S, Huang R, Zhong M, Wei C, Zhang Y. 2016. Hemocyanin from shrimp Litopenaeus vannamei has antiproliferative effect against HeLa cell in vitro. PLoS ONE 11: 1–15.