The use of natural feed for the growth of green lobster (*Panulirus homarus*) in submerged cages in Pangandaran Regency

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Abstract. This study aims to examine the growth and survival rates of green lobsters by consistently providing feed enriched with calcium and phosphorus in the form of natural feed. This is pivotal because the growth process of green lobsters entails a molting phase that is highly prone to mortality due to cannibalism. The research adopted a Completely Randomized Design with four different treatments, specifically types of natural feed: anchovies, tiny shrimp, golden apple snails, and barnacles, each undergoing four replications. The measured parameters included Specific Growth Rate (SGR), Feed Conversion Efficiency (FCE), the histological condition of the intestines and hepatopancreas of the green lobsters, and the water quality at the study site. The most significant growth rate observed was in treatment D (anchovies), achieving 1.90±0.5117%, while the feed conversion efficiency stood at 10.16±2.7395. The histological examination of the green lobster intestines revealed a villi length of 447.64 μm with a count of 15 villi. This significant growth is attributed to the high calcium and phosphorus content in anchovies, recorded at 972 mg 100 g^{-1} and 253 mg 100 g^{-1}, respectively, which significantly contributed to the highest individual weight growth of green lobsters in this study.
Key Words: calcium, green lobster, natural feed, phosphorus, submerged cage.

Introduction. In 2018, Indonesia emerged as the second-largest lobster producer worldwide, trailing only behind Vietnam, with a total yield of 556 tons. Notably, the bulk of Indonesia's lobster production is derived from wild capture rather than aquaculture (Budiyanto 2021).

A significant challenge faced in lobster aquaculture is cannibalism during the molting phase (Ahvenharju 2007; Pratiwi et al 2016; Lesmana & Mumpuni 2021), a critical period when stronger lobsters prey on their weaker, molting counterparts. This vulnerability is primarily due to delayed shell hardening, a condition stemming from inadequate calcium absorption, known as gastrolithiasis (Ahvenharju 2007; Handayani & Syahputra 2018). For lobsters and other crustaceans, calcium and phosphorus are vital for growth, especially for the exoskeleton's hardening post-molting (Kunkel et al 2012). Zaidy & Hadie (2009) noted that the optimal calcium requirement during this phase is 2.5%, with a minimum phosphorus requirement of 1.2%. However, internal (hemolymph) and environmental sources fulfill merely 10% and 0.34% of these needs, respectively, necessitating dietary supplementation of these minerals (Hadie et al 2010).

In the wild, lobsters' diets are diverse, comprising fish (1.81%), mollusks (49.80%), detritus (3.66%), and crustaceans (44.5%) (Purnamaningtyas & Nurfiani 2017). The practice of using fish without economic importance as feed in lobster farming has been criticized for its environmental detriments (Irvin & Shanks 2015b; Junaidi 2016), inefficient feed conversion rates (Jones 2010; Irvin & Shanks 2015b), and insufficient calcium and phosphorus content, ranging between 4.15–49.52% (Talat et al 2005; Susi 2013). Furthermore, artificial feeds can lead to wastage if not properly formulated (Niode et al

2017). Conversely, research by Irvin & Shanks (2015a) indicates that natural feeds, rich in attractants, significantly enhance feeding responses and growth in crustaceans.

Among the natural feeds, several are noted for their high calcium and phosphorus content, crucial for lobsters. These include small shrimp (*Acetes* sp.), golden apple snail (*Pomacea canaliculata*), and barnacles (*Cirripedia*). Specifically, anchovies contain 972 mg of calcium and 253 mg of phosphorus per 100 g, small shrimp (*Acetes* sp.) offers 757 mg of calcium and 292 mg of phosphorus (Directorate of Nutrition 1992; Yanti et al 2022), golden apple snails provide 129.18 mg of calcium and 60.52 mg of phosphorus (Putri et al 2019), and barnacles deliver 727 mg of calcium (Rahmaningtyas et al 2017).

Natural feed with a well-balanced and appropriate proportion of essential nutrients plays a crucial role in supporting optimal lobster growth. The availability of nutrients, including proteins, lipids, carbohydrates, vitamins, and minerals, directly influences metabolic processes, physiological development, and overall health. A nutritionally suitable natural feed enhances feed efficiency, promotes higher survival rates, and contributes to uniform growth patterns. Ensuring the appropriate composition of natural feed is essential in aquaculture practices, as it directly affects the growth performance and sustainability of lobster cultivation. For instance, it is necessary for the activation of phospholipase C, an enzyme involved in cellular signal transduction and lipid metabolism (Berridge et al 2003).

In most fish species, signs of phosphorus deficiency include poor growth, reduced feed efficiency, inadequate bone mineralization, skeletal deformities, low ash content, and elevated body fat levels (Lall 2003). Furthermore, phosphorus supplementation is essential for the deposition of magnesium (Mg) and zinc (Zn) in fish (Ye et al 2006). This study aims to identify the optimal natural feed for green lobsters (*Panulirus homarus*) and its effects on their growth rate, feed efficiency, and the histological condition of the intestine and hepatopancreas.

Material and Method

Description of the study sites and periods. The research was conducted from October to December 2023. Lobster maintenance occurred in a longline submerged cage system within the Floating Net Cages (KJA) at the Faculty of Fisheries and Marine Sciences, Universitas Padjadjaran, on the East Coast waters, Pangandaran Regency, West Java. Weight measurements took place in the Fisheries Laboratory, Tropical Fisheries and Marine Sciences Program, PSDKU of Universitas Padjadjaran. The condition of the intestine and hepatopancreas was examined in the Biology Laboratory, Faculty of Mathematics and Natural Sciences, Universitas Padjadjaran.

Data type. The test subjects in this study were lobsters with an initial weight ranging from 70 to 90 g and a length of 13 to 16 cm, with a total of 100 individuals per cage. The green lobsters were sourced from natural catches by fishermen in the waters of Pangandaran District. The diet consisted of four types of feed: anchovies (*Stolephorus* sp.) that have 16% protein (Gunawan 2003), small shrimp (*Acetes* sp.) that have 16.2% protein (Directorate of Nutrition 1992), golden apple snails (*Pomacea canaliculata*) that have 10.5% protein (Putri 2019), and barnacles (*Cirripedia*) that have 46.6% protein (Rahmaningtyas 2017), in the dry weight. The feed was administered in the evening, totaling 20% of the biomass weight. Golden apple snails and barnacles were cut into smaller sizes before being fed to the lobsters. Feeding was conducted by lifting the cages to the surface and, after the feeding process, submerging them back to a depth of 5 m.

Data collection. Over a 60-day period, we conducted data collection, involving 10-day measurements of lobster length and weight until the conclusion of the maintenance phase. For each measurement session, five lobsters from each treatment group were selected for evaluation. The length measurements were carried out using a millimeter block with a precision of 1 mm, and weight was assessed with a digital scale (0.1 g accuracy). Additionally, we collected water quality data, encompassing clarity, current speed, temperature, dissolved oxygen, pH, and salinity. These parameters were recorded at the study's onset and conclusion, both in the morning and evening. The villi count was determined through dissection of the intestine and hepatopancreas, followed by microscopic examination. The villi observed in this study were taken from 10 lobsters in each replication.

Maintenance methods. Lobsters were accommodated in submerged cages with dimensions of 272 cm length, 250 cm width, and 135 cm height, constructed from square high-density polyethylene (HDPE) poles. This experiment using 20 cages, divided into 4 treatments and 5 repetitions. These cages, once affixed to floats, were submerged to a depth of 5 m.

Statistical analysis. This study employed a completely randomized design (CRD) with four treatments, each replicated four times. Investigated parameters included the specific growth rate (SGR), feed efficiency ratio (FER), histology of the intestine and pancreas, and water quality. Water quality was determined at the start and at the end of the experiment. It included clarity measured using a Secchi disk, current velocity using a flow meter, temperature using a thermometer, dissolved oxygen (DO) using a DO meter, pH levels using a pH meter, and salinity using a refractometer. Water quality and gastrointestinal conditions underwent descriptive analysis. Water quality and gastrointestinal conditions underwent descriptive analysis. Meanwhile, performance metrics such as SGR and FER were subjected to statistical examination using analysis of variance (ANOVA). Upon identifying significant treatment effects, Duncan's Multiple Range Test was applied to discern differences at a 95% confidence interval.

For calculating the specific growth rate (SGR), the formula proposed by Hariati (1989) is used as follows:

$$SGR = \frac{Wt - W0}{t} \times 100\%$$

Where: SGR - specific growth rate (%); Wt - average weight at the end of research (g); W0 - average weight at the beginning of research (g); t - research period (days).

Feed efficiency Ratio is calculated using the equation used by Amalia & Arini (2013), namely:

$$FER = \frac{\mathrm{Wt} - \mathrm{W0}}{\mathrm{F}} \times 100\%$$

Where: FER - feed efficiency ratio (%); F - amount of feed given during research (g); Wt - average weight at the end of research (g); Wo - average weight at the beginning of research (g).

Results and Discussion

Growth. Figure 1 presents the incremental increase in the average lobster weight during each sampling period (every 10 days).

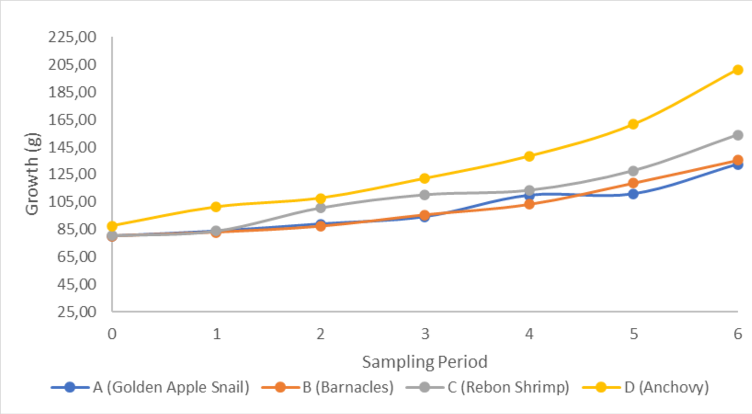

Figure 1. Green lobster (*Panulirus homarus*) growth pattern in 60 days.

Throughout the study, the average weight of lobsters in each treatment exhibited a consistent upward trend. The overall growth pattern of lobsters from day 1 to day 60 followed a logarithmic phase, characterized by rapid growth and continuous weight gain.

Specific growth rate. The 60-day observation period revealed an uptick in the lobsters' average SGR having significant differences, with notable variances across treatments ($p<0.05$). The highest average SGR was recorded in treatment D, which entailed anchovy feeding, marking a rate of 1.90% (Figure 2).

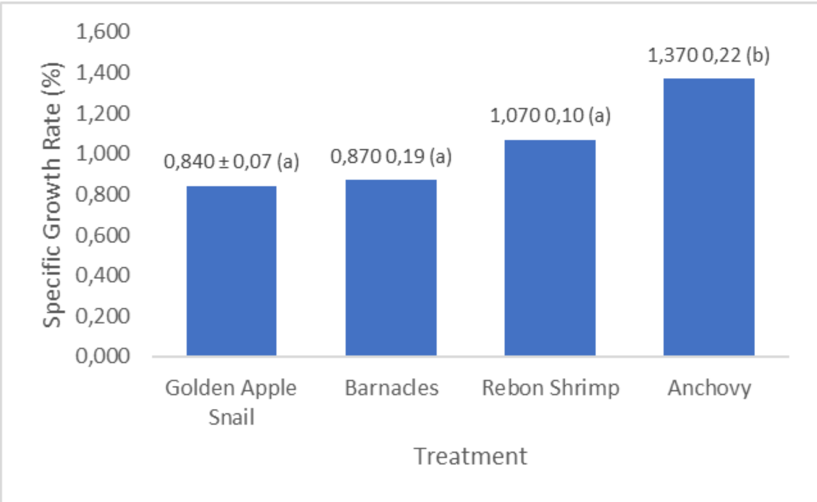

Figure 2. Green lobster (*Panulirus homarus*) specific growth rate; different letters above bars show significant differences ($p<0.05$).

This enhanced growth rate in treatment D could be ascribed to the anchovies' fulfillment of the lobsters' calcium and phosphorus requirements, thereby spurring growth. According to Nurfaidah & Agustono (2021), calcium significantly contributes to the molting cycle as a gastrolith, aiding in shell hardening post-molt. Safir et al (2023) highlight that increased molting frequency correlates with improved growth rates, indicating accelerated growth with more frequent molting episodes (Handayani & Syahputra 2018). Kurniasih (2008) observed that crustaceans fed nutritionally rich diets experience quicker exoskeletal changes, as the energy from food directly supports growth and maintenance.

Calcium, by activating key enzymes in metabolic pathways, facilitates essential energy production processes such as glycolysis and the citric acid cycle (Berridge et al 2003) underpinning its crucial role in molting among crustaceans.

Feed efficiency. This study's calculations reveal that utilizing different types of natural feed for lobsters results in varying feeding efficiency values, as depicted in Figure 3. Notably, the efficiency of feed provision significantly varies across different treatments ($p<0.05$). Throughout the 60-day observation period, the highest feeding efficiency, at 10.16%, was observed in treatment D, where lobsters were fed anchovies. It is proposed that the anchovies' high calcium and phosphorus content contributes to the observed feed efficiency.

Anchovies are particularly effective in meeting the essential calcium and phosphorus requirements for lobster growth. In contrast, feeds deficient in these elements can lead to calcium and phosphorus deficiencies in lobsters. Zainuddin (2010) emphasized that such deficiencies not only impede growth, but also result in decreased feed efficiency and, over time, could cause malformation. Astawan (2008) elaborated that anchovies offer significant nutritional value, including a comprehensive range of amino acids, calcium, phosphorus, minerals, and iron. Figure 4 provides an overview of calcium homeostasis in crustaceans.

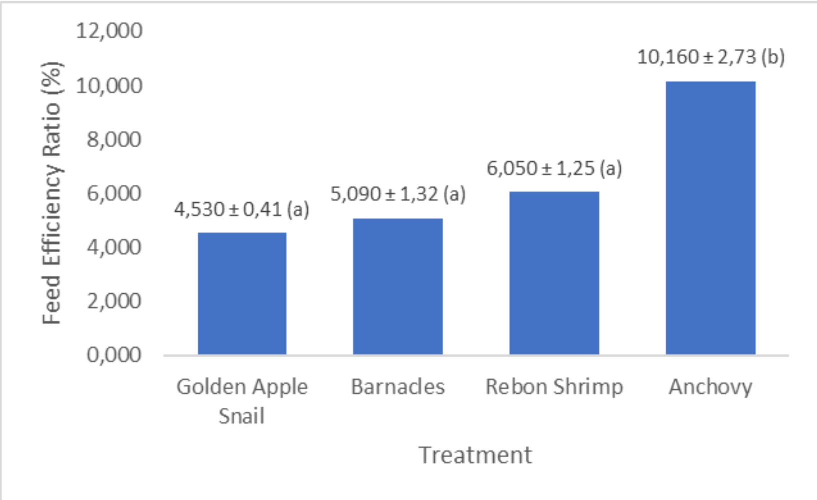

Figure 3. Green lobster (*Panulirus homarus*) feed efficiency; different letters above bars show significant differences ($p<0.05$).

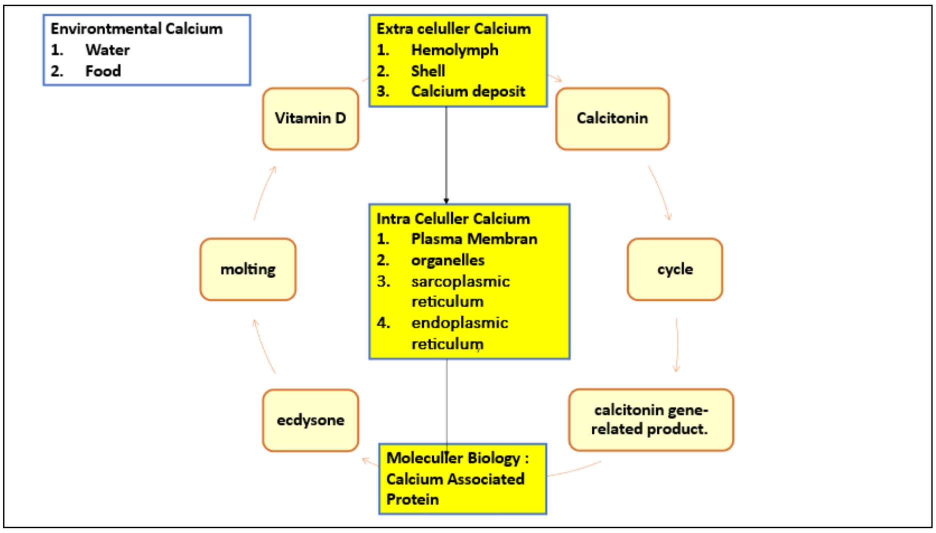

Figure 4. Calcium homeostasis in crustaceans (Weaver et al 1996).

The study posits that the additional calcium found in anchovies may expedite shell hardening, thus enhancing growth rates in length. Calcium is vital for the formation and hardening of the crustacean shell, potentially reducing the recovery time post-molting. This assertion is supported by Yulihartini et al (2016), who discovered that adequate calcium intake can accelerate the molting process. A reduced recovery period post-molting correlates with enhanced growth (Kunkel et al 2012). Following molting, lobsters initially harden their exoskeleton, a process facilitated by utilizing stored calcium (Kunkel et al 2012). Notable increases in carapace width and length, alongside weight gain and daily growth rate, signify substantial growth in lobsters.

Weight growth is an essential physiological development indicator in crustacean animals, where growth is influenced by various factors, including molting (Tahya et al 2016). Unlike fish, crustaceans exhibit distinct growth characteristics, primarily due to the molting events in their lifecycle (Saputra & Indaryanto 2019). Lobster growth is notably rapid during the post-molt phase, during which growth is maximized through the absorption of various substances from the environment and the intake of specific minerals, particularly Ca and P from the feed, to restore carapace strength (Safir et al 2023). The metabolic capability of lobsters prior to molting significantly influences their ability to achieve substantial growth. This factor is critical, as a failure to accumulate sufficient energy can result in mortality during the molting phase (Kunkel et al 2012).

Intestinal histology of lobster. Lobsters exhibit a digestive system markedly distinct from that of fish, primarily processing food within the hepatopancreas, as can be seen in Figure 5. This system includes the mouth, stomach, hepatopancreas, and intestine, with the hepatopancreas acting as the foregut and the intestine mirroring the hindgut's functions (Rostika 2023).

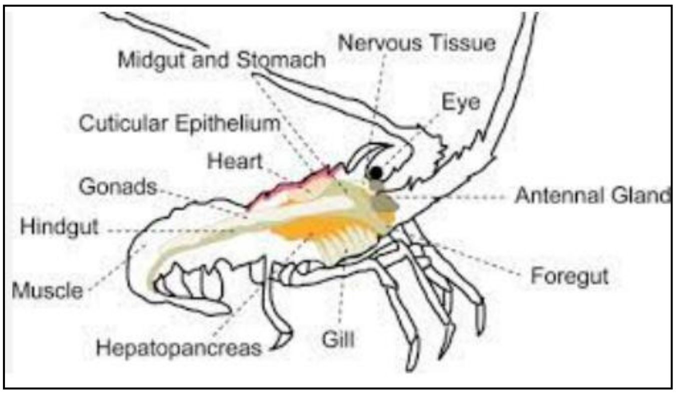

Figure 5. Lobster internal organs, foregut and hindgut (Ross et al 2019).

The length of villi in green lobsters varies from 320.84 to 447.64 μm, with villi counts ranging from 10.2 to 15, as can be seen in Table 1.

Table 1

Average number and length of green lobster (*Panulirus homarus*) villi

Treatment	*Number of villi*	*Villi length (μm)*
A	*10.2*	326.942±86.38
B	*8.4*	320.84±76.16
C	*14.6*	374.468±71.41
D	*15*	447.64±70.98

The longest villi observed in lobsters fed with anchovies (treatment D), reached 447.64 μm. This enhancement may be attributed to the high nutritional value of anchovies, which are rich in proteins, minerals, and other essential nutrients. According to Purwati et al (2005), an improved digestive tract promotes the growth of intestinal villi, thus facilitating better digestion and nutrient absorption, notably proteins and calcium.

Research by Haetami et al (2022) and Rostika et al (2024) on the morphometrics of intestinal villi and weight gain in green lobster indicated that an increase in the dimensions of the crypts within the villi expands the nutrient absorption area, positively affecting growth. Monitoring the digestive system is essential for evaluating digestive efficiency, as the intestine plays a crucial role in nutrient absorption and digestion (Rašković et al 2009). The intestine's performance is directly linked to the growth of green lobsters.

The size of the villi correlates with the nutrient absorption rate. Longer villi areas lead to increased nutrient uptake, influencing the development of internal organs. Additionally, the length of the villi aids in nutrient absorption through specialized cells, transported to the body via capillary tissue and lymphatic vessels, and then distributed to cells throughout the body by the bloodstream (Siagian 2016).

It is theorized that diets including natural sources with shells, such as snails, barnacles, and shrimp, may reduce cannibalism and enhance lobster survival due to the shell's Ca and P content. This is in line with Suptijah (2012), who mentioned that Ca from crustacean shells is readily utilized by the body.

Predatory behavior among lobsters signifies aggression and dominance within shared habitats (Safir et al 2023). Cannibalism increases during molting periods, as lobsters become vulnerable due to their softer exoskeletons and emit a distinctive scent that attracts predators (Handayani & Syahputra 2018). Therefore, Ca is vital in reducing the time required for lobsters to harden their exoskeletons, thereby minimizing predation risks during molting.

Water quality. Monitoring water quality is a pivotal aspect of ensuring the viability of green lobsters in research contexts. This study focused on several water quality parameters: clarity, current velocity, temperature, dissolved oxygen (DO), pH levels, and salinity. The findings confirmed that the water quality adheres to the established standards for green lobster maintenance, with temperature ranging between 27–29°C, DO levels from 6.4 to 8.8 ppm, pH between 7 and 8, salinity at 34–35 ppt (as per SNI 8116:2015 standards), clarity at 3.1 m (Radiarta et al 2015), and current velocity at 19.5 cm s^{-1} (Prasetya & Hasidu 2022).

At East Pangandaran Beach, the clarity was recorded at 3.1 m, signifying an optimal environment for green lobsters. Water clarity is influenced by the presence of particles either floating or suspended in the water. An increase in these particles results in murkier water conditions.

The current velocity at East Pangandaran Beach was measured at 19.5 cm s^{-1}, falling slightly below the recommended range of 20-40 cm s^{-1} for lobster aquaculture in cage culture systems (KJA) (Prasetya & Hasidu 2022). Current circulation is crucial in such aquaculture setups; a weak current fails to remove leftover feed, leading to its accumulation and potential toxicity (Louhenapessy et al 2023). On the other hand, an excessively strong current poses risks to the integrity and growth within the KJA. A current velocity that is too low is deemed unsuitable for aquaculture practices (Adipu et al 2014).

The temperature range observed during the study (27-29°C) aligns with findings by Faris et al (2023), which highlighted an optimal hatching rate of 91.5% for lobster eggs at 29°C. Temperature fluctuations are known to adversely affect lobsters, impeding their growth and molting processes (Handayani & Wardhana 2022).

In this study, the DO levels were observed to range from 6.4 to 8.8 mg L^{-1}. These levels are in alignment with seawater quality standards for cage culture systems, which recommend a DO parameter of greater than 5 mg L^{-1}. Therefore, the DO levels recorded in this study are deemed highly conducive for lobster growth. It is critical to acknowledge that a reduction in DO levels within a water body can detrimentally affect growth, metabolic performance, and molting processes. Furthermore, it may lead to a compromised immune system in lobsters, thereby diminishing their resistance to diseases (Setyowati et al 2013).

The study also measured acidity levels, or pH, which reflects the concentration of hydrogen ions, indicating the water's acidic and basic properties. The pH values recorded ranged from 7 to 8, aligning well with, and slightly lower than, the prescribed seawater quality standard. According to Regulation PP 22 of 2021, the optimal pH range for marine life is between 7 and 8.5.

Regarding salinity, the study found values between 34 and 35 ppt, aligning with standards recognized as favorable for lobster growth. This is corroborated by research from

Amali & Sari (2020), which suggests a salinity range of 36-42 ppt as crucial for the survival of marine organisms. A decrease in salinity levels can significantly impact the dynamics and composition of marine populations, as each species has a specific tolerance limit to salinity variations (Rahman & Mansyur 2016).

Conclusions. The study concludes that feeding lobsters with anchovies is the most effective method among the treatments tested. This conclusion is supported by data indicating a specific growth rate of 1.37, a feed efficiency of 10.16%, an intestinal villi length of 447.64 μm, and a villi count of 15. The beneficial effects observed could be attributable to the high Ca and P content in anchovies, with concentrations of 972 and 253 mg 100 g^{-1}, respectively. Further studies are needed to determine which nutrients contributed to the most significant individual weight gain in green lobsters among all treatments evaluated in this study and also the other factors that interact with Ca and P beneficial effects.

Conflict of Interest. The authors declare that there is no conflict of interest.

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