Production performance of freshwater redclaw crayfish, *Cherax quadricarinatus*, in an aquaponics system based on phytoremediation technology

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Abstract. Phytoremediation with aquatic plant through aquaponic system is an integrated system between aquaculture and hydroponic using recirculation system. This research aims to determine the ability of phytoremediation of freshwater redclaw crayfish (*Cherax quadricarinatus*) waste by water spinach and mustard greens, to determine the physiological profile and performance of *C. quadricarinatus* maintained with the system of phytoremediation-based aquaponics. The research was conducted on a laboratory scale with experimental methods, using a completely randomized design (CRD). The research method was carried out through the application of 3 treatments, namely control (without plants), phytoremediation by water spinach (*Ipomoea aquatica*), and phytoremediation by mustard greens (*Brassica juncea*) with four replications each. Parameters that were observed include plant growth performance, phytoremediation profile by plants, physiological profile and growth performance of freshwater crayfish. Aquaponic system using water spinach and mustard greens reduced wastewater in freshwater *C. quadricarinatus* culture, particularly the nitrate and ammonia (NH_3), by 83.33-90.91% and 38.09-59.09%, respectively. In this study, the aspartate-transaminase (AST) and alanin-transaminase (ALT) values in the controls were higher compared to treatments, this shows that *C. quadricarinatus* is experiencing stress. The cultivation wastewater containing unused *C. quadricarinatus* feed and feces could support the growth of spinach and mustard green at aquaponic system without nutrient addition

Key Words: phytoremediation, crayfish, cultivation waste, plant, growth performance.

Introduction. The well-known freshwater redclaw crayfish are from the genus *Cherax* (Olszewski 1980). One species of freshwater lobster which is included in the genus *Cherax* is *Cherax quadricarinatus* or commonly known as redclaw crayfish which originates from the northern Australian continent (Queensland and Northern Territory) and southern Papua New Guinea (Munasinghe et al 2004). Freshwater crayfish have a promising future in the fishing industry. Apart from being easy to maintain, crayfish are resistant to disease, omnivorous, grow quickly and have a high egg production capacity. Freshwater crayfish deserve to be widely developed in society in terms of technical aspects of cultivation and market potential, so that they can increase economic value (Jones 1995). The development of the freshwater lobster business cannot be separated from a high market demand, especially the export market. Demand for freshwater crayfish for consumption coming from several countries such as Malaysia, Singapore, Taiwan, Hong Kong, China, Japan and Korea. Australia, New Zealand, France, the Netherlands, Germany, Belgium, Canada and the United States make crayfish a favorite food because they believe it is healthier than seafood (FAO 2016).

FAO noted that there are at least 13 largest freshwater lobster producing countries, namely Australia, Mexico, Argentina, Uruguay, Ecuador, Indonesia, Belize, China, Israel, Morocco, Panama, Spain and the United States (Parnes & Sagi 2022). As one of the freshwater lobster producing countries, Indonesia needs efforts to increase production through hatcheries. Freshwater lobster hatchery activities are often hampered by low survival rates and seed rearing techniques that are still difficult to understand (Jones 1995). The problem faced in freshwater crayfish cultivation activities is cultivation waste such as ammonia (NH_3). This causes a decrease in the quality of cultivation water and can cumulatively cause a decrease in lobster performance and death. The main sources of cultivation waste that have the potential to pollute the cultivation environment are uneaten feed residue and excretory products such as feces, urine and metabolic waste (Cripps & Bergheim 2000). The accumulation of food waste and fish waste during nursery often causes a decrease in water quality in nursery ponds, resulting in toxic effects on fish. The toxicity of ammonia depends on several factors such as the life stage of the fish. Some studies have reported more influence of ammonia on growth performance (Lin et al 2002). Ammonia is the main nitrogenous waste product excreted by aquatic biota, existing in equilibrium as ammonia molecules (NH_3) and ammonium ions (NH_4^+) in the aquatic environment (Gomułka et al 2014). Conventional water quality management can be done by changing cultivation water periodically, but it is less effective because it requires quite a lot of water and is expensive (Rezagama et al 2017).

Cultivation wastewater containing organic materials will be used by plants as nutrients for growth (Sikawa & Yakupiyiyage 2010). The principle of a recirculation system is the reuse of water that has been released from cultivation activities (Effendi et al 2015). The advantage of a recirculation system is that it can minimize the use of water and reduce organic materials such as ammonia, nitrite, and pH buffers (Yanong 2012). Phytoremediation with aquatic plant through aquaponic system is an integrated system between aquaculture and hydroponic using recirculation system. The waste of this system can be absorbed by aquatic plant. In aquaponics, nutrient-rich effluent from fish tanks is used as nutrient source of hydroponic production beds for growing vegetables, herbs, and flowers. This negates the cost of a biofilter used for other recirculating aquaculture systems, and is more environmentally sustainable (Allsopp et al 2009). Phytoremediation is a cheap and energy-saving alternative method that acts on biological processes, where plants are used to remove nutrients and waste from the cultivation medium (McGee & Circha 2000). Comparative physiological studies of hematology and blood biochemistry of several lobster species are of great interest. A number of cultivable crustacean species have been examined for hematological properties to determine the range of normal values and deviations, which may indicate disturbances in physiological processes (Lesmana et al 2022).

There are advantages to using phytoremediation: (i) it is economically feasible phytoremediation is an autotrophic system powered by solar energy, so it is easy to manage, and installation and maintenance costs are low, and (ii) it is environmentally friendly, can reduce exposure to pollutants in the environment and ecosystem (Zhang et al 2014). The formulation of the problem in this research is: whether the use of phytoremediation technology by plants is able to reduce waste (zero waste) from crayfish cultivation activities and whether reducing this waste can improve crayfish growth performance. This research aimed to determine the ability of phytoremediation of freshwater crayfish waste by water spinach and mustard greens plants, to determine the physiological profile and performance of crayfish maintained using a phytoremediation-based aquaponics system.

Material and Method

Containers and media research. The experiment was conducted in an indoor laboratory using 20 containers (for 5 treatments in 4 replications) of 56 x 40 x 18 cm^3 in aquaponic systems. The treatment consisted of four containers without plant, four containers with 5 water spinach plant, four containers with 10 water spinach plant, four containers with 5 mustard greens plant and four containers with 10 mustard greens plant.

Crayfish. Specimens of *C. quadricarinatus* an average body weight of 17 g ind^{-1}, served as experimental animal. *C. quadricarinatus* were obtained from Ciherang Lobster Farm catches in West Java Province, Bogor District, Indonesia.

Experimental design. A completely randomized experimental model with four treatments and three repetitions was employed in this investigation as the methodology, which is detailed in Table 1.

Table 1

Research layout

Code	*Treatment*
C	Without Plant (Control)
K5	With 5 water spinach plant specimens (*Ipomea aquatica*)
K10	With 10 water spinach plant specimens (*Ipomea aquatica*)
S5	With 5 mustard greens plant specimens (*Brassica juncea*)
S10	With 10 mustard greens plant specimens (*Brassica juncea*)

Tank preparation and acclimatization. The 20 tanks with filtration utilized in this study were cleaned and sanitized before being dosed with 5 mg L^{-1} of chlorine. Following a thorough cleaning, the tanks were drained and filled with 20 L of water. The procedure of acclimatizing crayfish took place in the acclimatization tank for 7 days.

Feed management. Mung beans were used as feed. There were two feedings every day at 7:00 am and 17:00 evening.

Water quality parameters. According to APHA (2012), there were performed daily measurements of the water's pH, salinity, temperature, and dissolved oxygen (DO). Ammonia, nitrate and ortoposphate levels in the water were measured on day 0 and then every 10 days until the study's conclusion.

Phisiologycal and biochemical response parameters. According to Blaxhall & Daisley (1973), the measurement of total hemocyte count (THC) of the hemolymph was carried out. The blood biochemical analysis consisted of blood glucose (GH), triglycerides (TG), total cholesterol (TC), alanine-transaminase (ALT) and aspartatetransminase (AST). An ARKRAY blood chemistry analyzer (SPOTCHEM-EZ sp 4430) with a paper test indicator for each parameter was used to conduct the analysis. On a panel inside the tool, paper test indicators are produced and set up. The blood chemical analyzer machine is configured and coded in accordance with the course of therapy; after a 10-minute analysis, the machine automatically prints out the results.

Production performance parameters. Weight was addressed by biometric measurements taken every ten days on *C. quadricarinatus*. Every 10 days during the maintenance, the specific growth rate was observed. At the conclusion of the research, the lobster survival rate was assessed.

Data analysis. This study employed a totally random design (CRD). Analysis of variance (ANOVA) with a 95% confidence interval was used to statistically analyze the data of THC, blood glucose (GH), triglycerides (TG), total cholesterol (TC), alanine-transaminase (ALT), aspartate-transaminase (AST), absolute weight, specific growth rate, survival rate, and production performance of plant. In order to detect significant differences between treatments, a Tukey test was performed. Data on water quality were descriptively examined.

Results

Physiological and biochemical response. At the end of the trial, the triglycerides, cholesterol, and hemolymph's pH levels in crayfish were substantially different between treatments, according to the physiological and biochemical analysis ($P<0.05$). Table 2 displays the physiological and biochemical responses of *C. quadricarinatus* to various sistem of aquaponic. Triglycerides level of crayfish reared with five plants of mustard greens (S5) were higher than in control specimens ($P<0.05$). Cholesterol values of crayfish reared with control (C) showed higher cholesterol values compared to treatment ($P<0.05$). Hemolymph's pH values of crayfish reared with five plant of mustard greens (S5) showed lower values compared to control ($P<0.05$).

Table 2
Physiological and Biochemical response of *Cherax quadricarinatus* to different treatments

Parameter	*Treatment*				
	C	*K5*	*K10*	*S5*	*S10*
THC (x 10^3 cell mm^{-3})	6.89±0.77^a	8.53±0.67^a	8.15±0.33^a	7.92±0.48^a	8.58±0.38^a
GH (mg 100 mL^{-1})	24.90±0.39^a	24.13±0.39^a	25.42±1.43^a	22.83±1.85^a	25.42±0.15^a
TG (mg dL^{-1})	79.54±1.01^c	95.08±2.86^{bc}	81.38±3.49^c	115.89±2.59^a	108.47±4.63^{ab}
TC (mg dL^{-1})	112.93±2.40^a	92.76±0.82^b	107.32±1.84^a	89.27±1.66^b	92.36±1.19^b
ALT (U L^{-1})	703.2±56.4^a	578±202^{ab}	522.1±46.7^{ab}	353.9±96.9^b	648.9±76.3^{ab}
AST (U L^{-1})	895.2±160^a	788.9±118.3^a	714.63±16.74^a	864.4±99.9^a	795.1±62.0^a
Hemolymph's pH	7.56±0.07^a	7.66±0.11^a	7.44±0.22^a	7.02±0.15^b	7.46±0.17^a

Production performance of Cherax quadricarinatus. For all treatments, the starting mean weight of individuals in the various crayfish groups is approximately 17 g. *C. quadricarinatus* raised in aquaponic system with 5 mustard greens (S5) had the highest absolute weight and specific growth rates (Figure 2) after 40 days of feeding ($P<0.05$). However, the maximum survival rate was seen in *C. quadricarinatus* kept in aquaponic system with 10 water spinach plants (K10) ($P>0.05$). Figures 1 through Figure 3 show the growth and survival rates of freshwater crayfish raised in various plants for 40 days.

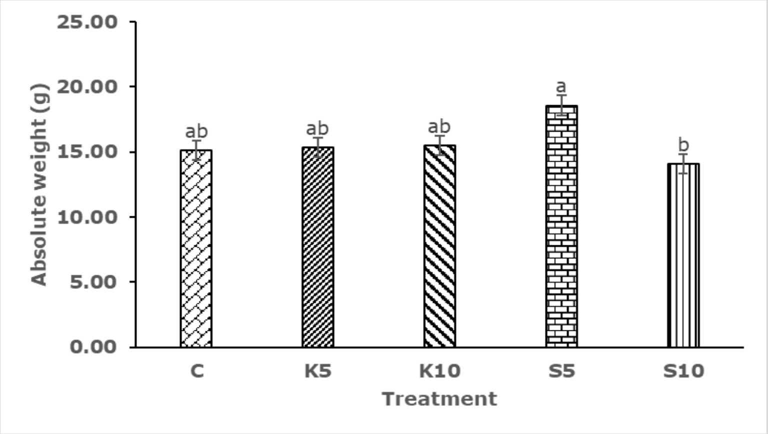

Figure 1. Absolute weight of *Cherax quadricarinatus.*

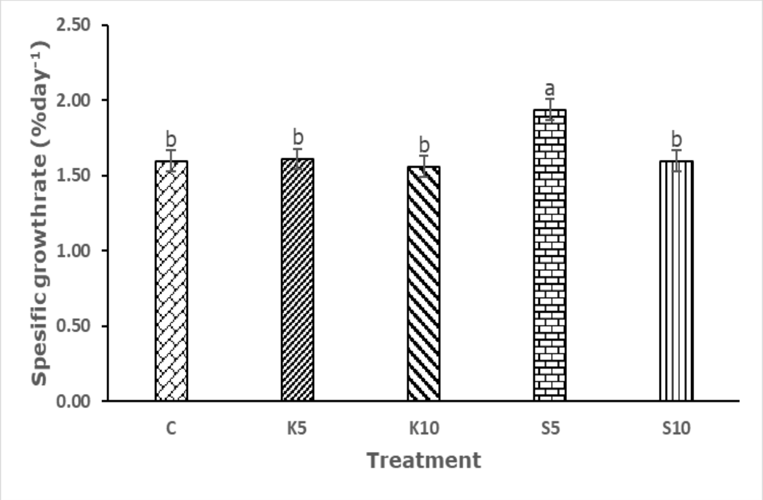

Figure 2. Specific growth rate of *Cherax quadricarinatus*.

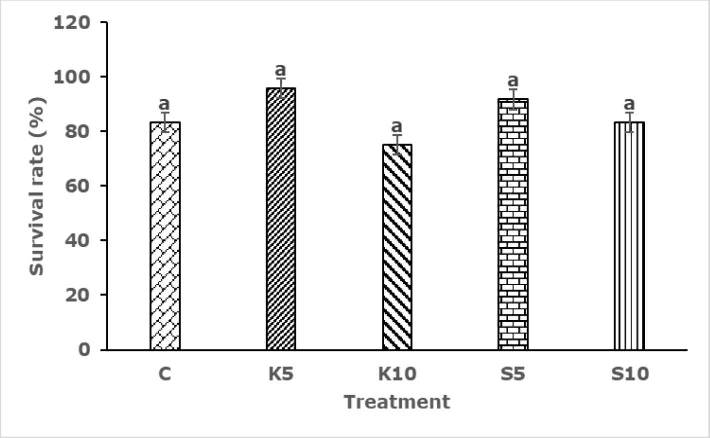

Figure 3. Survival rate of *Cherax quadricarinatus.*

Production performance of plants. The height range of water spinach at early planting (days 0) was 28.85–29.46 cm. The height range at the conclusion of the experiment was 89.80-108.42 cm. As the experiment came to an end, the height of the mustard greens varied from 18.97-19.63 cm to 28.73-29.29 cm. This demonstrated that vegetables may be grown in an aquaponic system without the need for additional nutrients.

Table 3

Production performance of water spinach and mustard greens

Parameter	*Treatment*			
	K5	*K10*	*S5*	*S10*
		Shoot (cm)		
Initial	20.05±0.57^{a}	19.83±0.65^{a}	11.38±0.97^{b}	10.98±0.94^{b}
Final	73.80±3.03^{b}	89.82±3.21^{a}	20.21±3.14^{c}	20.50±1.62^{c}
		Root (cm)		
Initial	9.41±1.45^{a}	9.03±0.155^{a}	8.26±0.94^{b}	7.98±0.77^{b}
Final	16.03±2.44^{b}	18.52±2.25^{a}	9.08±0.85^{c}	8.23±0.34^{c}
		Plant (cm)		
Initial	29.46±1.96^{a}	28.85±0.71^{a}	19.63±1.88^{b}	18.97±1.68^{b}
Final	89.80±3.28^{b}	108.42±3.90^{a}	29.29±0.94^{c}	28.73±0.72^{c}

Water quality. Temperature is an important variable that affects the physical, chemical, and biological parameters of waters (Effendi 2003). The temperature during observation was relatively constant, ranging from 24.15–29.18°C. The results of statistical tests showed that temperature changes were significantly different between treatments on days 0 until 30 ($p<0.05$). The results of temperature measurements during the study are presented in Table 4.

Table 4

Average values for temperature parameters during *Cherax quadricarinatus* maintenance period

Days	*Treatment*				
	C	*K5*	*K10*	*S5*	*S10*
0	26.95±0.17^{c}	27.98±0.34^{b}	29.08±0.85^{a}	29.18±0.43^{a}	29.08±0.17^{a}
5	25.90±0.00^{c}	26.53±0.26^{b}	27.02±0.14^{a}	27.02±0.14^{a}	27.02±0.22^{a}
10	24.65±0.06^{b}	25.25±0.35^{a}	25.60±0.40^{a}	25.70±0.25^{a}	25.55±0.27^{a}
20	25.93±0.13^{ab}	25.88±0.17^{b}	26.08±0.21^{ab}	26.20±0.12^{a}	26.33±0.28^{a}
30	24.33±0.05^{ab}	24.15±0.17^{b}	24.58±0.28^{a}	24.55±0.06^{a}	24.38±0.17^{ab}
40	25.30±0.43^{a}	24.83±0.22^{b}	25.00±0.22^{ab}	25.08±0.17^{ab}	24.88±0.29^{b}

pH. The pH value describes hydrogen ions in water. pH is closely related to carbon dioxide and alkalinity (Effendi 2003). During the observation, the pH of the water fluctuated relatively. The results of statistical tests showed that changes in pH were significantly different between treatments on days 10-40 ($p>0.05$). The results of pH measurements during the study are presented in Table 6.

Table 5

Average values for pH parameters during *Cherax quadricarinatus* maintenance period

Days	*Treatment*				
	C	*K5*	*K10*	*S5*	*S10*
0	8.76±0.08^{a}	8.77±0.11^{a}	8.71±0.38^{a}	8.80±0,16^{a}	8.96±0.18^{a}
5	8.66±0.35^{a}	8.73±0.46^{a}	8.83±0.15^{a}	8.84±0.20^{a}	8.86±0.24^{a}
10	7.53±0.15^{c}	7.88±0.09^{b}	8.14±0.05^{a}	8.07±0.09^{ab}	8.06±0.09^{ab}
20	7.42±0.08^{b}	7.61±0.09^{ab}	7.85±0.14^{a}	7.82±0.19^{a}	7.72±0.21^{a}
30	7.14±0.07^{c}	7.49±0.07^{b}	7.82±0.24^{a}	7.83±0.09^{a}	7.85±0.11^{a}
40	6.52±0.49b	7.43±0.02a	7.69±0.25^{a}	7.66±0.09^{a}	7.69±0.22^{a}

Dissolved oxygen (DO). The results of statistical tests showed that the decrease in dissolved oxygen was not significantly different between treatments ($p>0.05$). The results of dissolved oxygen measurements during the study are presented in Table 6.

Table 6

Average values for dissolved oxygen parameters during *Cherax quadricarinatus* maintenance period

Days	*Treatment*				
	C	*K5*	*K10*	*S5*	*S10*
0	9.63±0.62^{a}	8.85±0.99^{a}	7.53±2.10^{a}	8.90±1.79^{a}	9.18±0.74^{a}
5	10.25±0.41^{a}	9.18±0.46^{a}	9.55±0.17^{a}	9.43±0.83^{a}	9.88±0.38^{a}
10	6.45±0.34^{a}	6.18±0.22^{a}	7.03±0.72^{a}	7.08±0.67^{a}	7.20±0.82^{a}
20	6.33±0.75^{a}	6.33±0.26^{a}	4.88±0.64^{a}	6.35±0.49^{a}	4.83±1.23^{a}
30	8.95±0.19^{a}	8.93±0.05^{a}	9.45±0.41^{a}	9.50±0.35^{a}	9.53±0.24^{a}
40	8.98±0.09^{a}	9.05±0.24^{a}	9.03±0.13^{a}	9.08±0.09^{a}	9.18±0.22^{a}

Ammonia (NH$_3$). The results of statistical tests showed that the reduction of ammonia was significantly different between treatments ($p<0.05$). Based on Figure 4, there has been a reduction in ammonia in K5 (83.33%), K10 (90.91%), S5 (59.09%), S10 (38.09%).

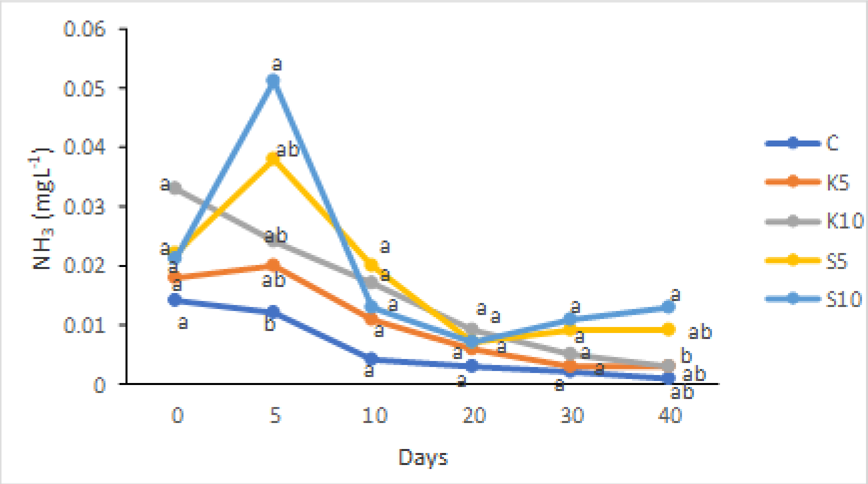

Figure 4. Average value for ammonia.

Nitrate (NO_3). During the observation, the concentration of nitrate increased. The percentage of increase in nitrate concentration in the control, water spinach, and mustard greens treatments was 92.68% (C), 88.34% (K5), and 93.51% (K10), 94.36 (S5) and 96.57% (S10). The results of statistical tests showed that the increase in nitrate was significantly different between treatments ($p<0.05$) on days 10 and 20. The results of nitrate measurements during the study are presented in Table 7.

Table 7
Average values for nitrate (NO_3) concentrations (mg L^{-1}) during *Cherax quadricarinatus* maintenance period

Days	*Treatment*				
	C	*K5*	*K10*	*S5*	*S10*
0	0.39±0.00^{a}	0.57±0.00^{a}	0.37±0.00^{a}	0.37±0.00^{a}	0.17±0.00^{a}
5	0.72±0.06^{a}	0.35±0.02^{b}	0.55±0.16^{ab}	0.63±0.14^{ab}	0.59±0.16^{ab}
10	2.12±0.21^{a}	0.74±0.36^{b}	1.32±0.21^{b}	1.04±0.25^{b}	0.97±0.20^{b}
20	1.55±1.15^{a}	0.58±0.20^{a}	1.81±0.36^{a}	1.08±0.14^{a}	1.13±0.70^{a}
30	2.70±1.40^{a}	1.99±0.36^{a}	2.54±0.86^{a}	2.55±0.46^{a}	1.90±0.63^{a}
40	5.33±2.40^{a}	4.89±3.96^{a}	5.70±2.37^{a}	6.56±0.39^{a}	4.96±2.37^{a}

Orthophosphate (PO_4-P). Orthophosphate concentrations tend to fluctuate during observation and the lowest average concentration is found in the water spinach treatment. The percentage increase in orthophosphate concentration in the control, water spinach and mustard greens treatments was 91.74% (C), 91.20% (K5), 96.31% (K10), 91.15% (S5), 93.75% (S10). The results of statistical tests showed that the decrease in orthophosphate was not significantly different between treatments and observation times ($p>0.05$). The results of orthofosfat measurements during the study are presented in Table 8.

Table 8
Average values for orthophosphate (PO_4-P) concentrations (mg L^{-1}) during *Cherax quadricarinatus* maintenance period

Days	*Treatment*				
	C	*K5*	*K10*	*S5*	*S10*
0	0.41±0.00^{a}	0.43±0.00a	0.21±0.00a	0.58±0.00a	0.31±0.00^{a}
5	0.37±0.15^{a}	0.24±0.09a	0.49±0,13a	0.33±0.13a	0.44±0.02^{a}
10	1.73±2.37^{a}	0.27±0.14a	1.72±2.53a	0.19±0.06a	0.14±0.06^{a}
20	0.32±0.25^{a}	0.20±0.09^{a}	0.82±0.80^{a}	0.11±0.03^{a}	0.25±0.05^{a}
30	1.19±0.18^{a}	0.80±0.12^{a}	0.98±0.35^{a}	1.39±0.31^{a}	1.27±0.67^{a}
40	5.33±2.40^{a}	4.89±3.96^{a}	5.70±2.37^{a}	6.56±0.39^{a}	4.96±2.37^{a}

Discussion. Triglycerides and cholesterol represent two classes of lipids circulating in crustacean hemolymph (Musgrove & Babidge 2003). Triglycerides are generally considered to be the main metabolic reserve in an organism (Gurr et al 2002) and are integral to energy generation. In contrast, cholesterol plays a more structural role as a major component of cell membranes (Gurr et al 2002). Cholesterol, a steroid, is also used in the synthesis of several hormones (Kanazawa & Koshio 1993), which control many aspects of crustacean physiology especially during the molting cycle (Chang & Mikles 2011). Hemolymph's pH values of crayfish reared with five plant of mustard greens (S5) showed lower pH values compared to control ($P<0.05$). Other biochemical indicators of hemolymph were analyzed in this study are the AST, ALT, and ALP enzyme groups. These parameters are widely used by researchers as indicators of liver and kidney function. The level of these enzymes should be at a low and constant concentration, under normal conditions, but the concentration will increase in response to liver damage and environmental influences (Luo et al 2013). In this study, the AST and ALT values in the controls were higher compared to treatment.

Growth statistics demonstrate that a crayfish with 5 mustard greens (S5) provides a high value. It is believed that because of their gloomy environment, which affects their feeding, since *C. quadricarinatus* are nocturnal and actively engaged in foraging during the night period. In this research, vegetables may be grown in an aquaponic system without the need for additional nutrients. According to Turcios & Papenbrock (2014), the inorganic chemicals found in aquaculture systems mostly meet the nutrient needs of plants and algae. The use of nutrient by plant and microorganism in this experiment was likely denoted by the reduction of ammonia and nitrate within the culture of crayfish together with water spinach, compared with that of control (crayfish only). The concentration of contaminants to be removed should be from low to medium due to excess concentration may inhibit plant growth (EPA 2000).

Lewis et al (1978) report on the possibility of recirculation in aquaculture systems for plant growing. Hormones and chemicals shouldn't be added to the system, as demonstrated by the combination of fish and plant culture, where the plants serve as both a biofilter and human food, such as salads and vegetables. The profitability of the farms and the efficacy of wastewater treatment can both be increased by optimizing the integration of algal and macrophyte cultures (Castine et al 2013). Living things require dissolved oxygen for development, respiration, metabolism, and the breakdown of organic matter. According to observations, the oxygen concentration is still between 4.83 and 9.88 mg L^{-1}, which is a sufficient range for the growth of fish and plants. Sikawa & Yakupiyiyage (2010) stated that 2.5 mg L^{-1} is the ideal oxygen concentration for plant root respiration. Plant roots and leaves will wilt at oxygen concentrations less than 0.16 mg L^{-1}, and nutrient absorption will not be at its best (Ginting & Rakian 2008).

Waste from fish aquaculture is generated by excrement and unused fish feed. Fish will suffer as a result of the buildup of toxic waste in the water, resulting in a reduction in water quality (Stephens & Farris 2004). Treatment of maintenance water can lead to an improvement in its quality. Physical, chemical, biological, or a combination of these methods can be used to treat wastewater (Crab et al 2007). Using plants to remove contaminants in the form of organic materials, nutrients, and heavy metals is a technique known as phytoremediation with recirculation (Apriadi et al 2014). Using plant media and microbes, phytoremediation reduces pollutants and organic compounds (EPA 2000). Temperature, water pH, and dissolved oxygen levels are only a few of the variables that affect the physical, chemical, and biological processes involved in phytoremediation (EA 2000). According to Boyd & Lichtkoppler (1979), the accumulation of excrement and residual feed, microbial decomposition, fish oxygen consumption, and rising water temperatures are all suspected causes of the drop in dissolved oxygen during observation. Fish farming waste comes from feces and feed remains, and it decomposes into inorganic compounds (Effendi et al 2015). Leftover feed and fish feces contain high amounts of nitrogen. Inorganic nitrogen consists of ammonia (NH_3), ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), and nitrogen molecules (N_2) (Effendi et al 2015).

Plant development, phytoremediation, and the breakdown of organic materials are all impacted by the pH level in the air. The pH range that was observed was 7.14–8.96. Tarre & Green (2004) claim that because nitrifying bacteria grow better at a pH of 7-8, which is optimal for the organic material breakdown. Fish thrive best at a pH of 6–9 (Yusuf 2008). Conversely, 5.5-7 is the ideal pH range for plant growth since it allows for optimal nutrient absorption (Lestari 2013). The growth of green mustard and water spinach was sluggish during the monitoring period. The reason for this is believed to be that the pH of the air was higher than the optimal level for plant growth. Fish, plants, decomposing organic debris, and the phytoremediation process are all impacted by the temperature, as an environmental parameter. The temperature range of 24.15–29.18°C during the observation is still suitable for the growth of waste-decomposing bacteria, water spinach, and lobster. 25–30°C is the ideal temperature range for water spinach growth (Indah et al 2014).

The overall ammonite concentration varied during the observation period. It is believed that the nitrification process by bacteria is the cause of the drop in ammonia content. Ammonium (NH_4^+), which is ionized, and free ammonia (NH_3), which is not ionized, make up total ammonia. Compared to ammonium, free ammonia is more hazardous to aquatic biota (Crab et al 2007). If there is a drop in dissolved oxygen and a rise in pH and water temperature, ammonia becomes more harmful to aquatic life (Effendi 2003). Wahyuningsih et al (2015) state that at pH 7, the majority of the total ammonia will ionize into ammonium, and at pH>8.75, 30% of the total ammonia will transform into the more dangerous free ammonia. Nitrate is the main form of nitrogen compound in water and is a nutrient for the growth of plants and algae in water (Effendi 2003). Orthophosphate is a dissolved inorganic compound utilized by plants and fish as an essential compound for growth (Effendi 2003).

Nitrobacter bacteria aid in the reduction of ammonia during the nitrification process. According to Crab et al (2007) and Rijn et al (2006), nitrification is the aerobic process of ammonia oxidation into ammonium, nitrate, and nitrite. Substratum and dissolved oxygen, organic matter, temperature, pH, alkalinity, salinity, and turbulence are some of the variables that affect the nitrification process (Crab et al 2007). Nitrifying bacteria may thrive well when the dissolved oxygen >1 mg L^{-1}, the temperature ranges 25–35°C and the pH ranges 7.5-8.6, which promotes the nitrification (Crab et al 2007). A smooth nitrification process occurs a when the dissolved oxygen ranges from 1.31 to 5.21 mg L^{-1}, temperature from 27 to 30°C, and pH from 6 to 8.

Conclusions. Production performance of freshwater crayfish grown with plant is higher than without plant. The present study indicated that spinach and mustard greens plants might serve for freshwater crayfish wastewater quality phytoremediation. However further investigations at larger scales and longer experimental durations must be pursued. Aquaponic system using water spinach and mustard greens reduced wastewater in the freshwater crayfish culture, in particular the nitrate and ammonia (NH_3), by 83.33-90.91% and 38.09-59.09%, respectively. In this study, the AST and ALT values in the controls were higher compared to treatment, this shows that the crayfish is experiencing stress. The crayfish cultivation wastewater containing unused feed and feces could support the growth of spinach and mustard green at aquaponic system without nutrient addition.

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