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Effects of garlic supplementation on the growth performance rate in climbing perch *(Anabas testudineus)* diet

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Abstract The study of garlic supplementation on the growth of *Anabas testudineus* or climbing perch resulted to the final weight of length gain (LG), weight Gain (WG), percentage weight gain, (PWG), averaged diary growth (ADG), specific growth rate (SGR) and survival rate (SR) were significantly differed. Statistically significant ($p<0.05$) was showed in diet supplemented with 20 g of garlic/1 kg of diet which showed the highest mean, followed by the garlic supplements with 10, 5, and 0 g kg^{-1} of diet, respectively. All observed values were averaged daily feed intake. (ADFI), Feed conversion ratio (FCR) and feed efficiency (FE) were significantly different ($p<0.05$). Diet supplemented with 20 g of garlic/1 kg of diet had the best average, followed by namely, 10, 5, and 0 g of garlic supplement/1 kg of diet, respectively. Water temperature, pH and dissolved oxygen (DO) were significantly different ($p<0.05$). Diets supplemented with garlic 20 g/1 kg of diet had the highest mean, followed by garlic supplements at 10, 5, and 0 g kg^{-1} of diet, respectively. All observed values were fillet proportion, skeleton proportion, and fish weight/liver weight index (Hepatosomatic index, HSV) were significantly different ($p<0.05$). Diet supplemented with 20 g of garlic/1 kg of diet showed the best average, followed by garlic supplements with 10, 5, and 0 g kg^{-1} of diet, respectively. The fish weight index per internal organ weight (Viscerosomatic index, VSI) was not significantly different ($p>0.05$). Therefore, garlic can be added to fish diet up to 20 g kg^{-1} of diet, which revealed a beneficial effect on the growth of fish.

Keywords: Climbing perch, *Anabas testudineus*, Garlic, Fish diet

Introduction

The Thai climbing perch, whose scientific name is *Anabas testudineus* (Debroy, 2022), is an economically important freshwater fish. It's a fish that is found and lives in general freshwater sources and grows well in both freshwater and brackish water. It is known as a widely consumed fish because it has a good taste with a tender and chewy texture. It is consumed in many ways, for example,

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fresh fish and diet processing. According to reports in 2017, Thai climbing perch production was 277 tons, valued at 423.7.7 (Department of Fisheries, 2019). When considering the overall supply side of the country, the amount of fish production was still low. Compared to the amount of other types of fish, there is a tendency to grow more and more. Aquaculture today faces many problems, such as quality fish feed, including some aspects of water quality in the pond. All of these factors are the causes that cause aquatic animals both directly and indirectly. There was reduced growth, weak health, a low survival rate, and eventually death. Therefore, farmers need to solve the problem by using various kinds of chemicals, such as antibiotics or vitamin C, which have the effect of inhibiting the steroids that cause stress (Gower, 1984). But there are still problems with food safety. Especially when the European Union (EU) sets the policy of zero tolerance or the rule that drug residue must be zero, causing the aquaculture industry to turn to natural methods and more biological to reduce the problem of using chemicals, including disinfectants, insecticides, and antibiotics, in aquaculture that affect the growth rate and have a higher survival rate. Some plants have properties equivalent to chemicals used in aquaculture, such as garlic.

Allium sativum, more commonly referred to as garlic, belongs to the Alliaceae family (Gafar *et al*., 2012). It is closely related to plants like onions, shallots, and leeks. Garlic is widely recognized and utilized in Asia for its medicinal properties, thanks to its various bioactive compounds and health benefits. It has a distinct pungent and spicy taste, which becomes significantly milder and sweeter when cooked. The garlic bulb, the most frequently used part of the plant, consists of numerous fleshy sections known as cloves. These cloves are utilized as seeds, in cooking (both raw and cooked), and for medicinal purposes. Garlic contains 0.1-0.4% volatile oil and 33 types of organosulfur (Londhe *et al.,* 2011), such as Allicin (allyl sulfenic acid), Alliin (S-allyl-L-cysteine sulfoxide), S-allylcysteine (SAC), Ajoene, Diallyl disulfide (DADS), Dithiin (Gafar *et al*., 2012), and other substances with important biological activity such as amino acids, enzymes and minerals (Selenium and Germanium) (Londhe *et al*., 2011; Skidmore-Roth, 2009)., and many other thiosulfinates that are known to exert multiple benefits, e.g., anti-oxidant, anti-inflammatory, and anti-apoptotic effects. Several compounds found in garlic have been shown to offer protective effects, as evidenced by studies conducted in both in vitro and in vivo systems (Wichai *et al*., 2019).

Garlic for the benefit of aquaculture can be used as a stimulant to eat food, stimulates digestive enzymes, promote growth, stimulates the secretion of gastric juice, including saliva, and is used as a growth-stimulating supplement in place of antibiotics (Saleh *et al.*, 2018; Attia *et al.*, 2020). It is a medicinal plant effective against bacteria, fungi, parasites, and viruses (Harris, 2001). Garlic is commonly used to treat or prevent various diseases in humans and aquatic animals. Garlic also has antimicrobial properties (Anthony *et al*., 2005) and is a good antioxidant as well (Allison *et al.*, 2006). It helps improve digestion efficiency and is beneficial to the division of bacterial cells living in the small intestine. On the other hand, Yang *et al*. (2010) studied using inappropriate levels of garlic extract to result in delayed embryo development. Therefore, garlic is not a suitable dietary supplement for all types of fish. The appropriate amount of feeding depends on the species and ages of the aquatic animals. Thus, studies are needed to determine the appropriate concentration level of garlic supplementation for each type of fish.

The objective was to evaluate the effects of varying levels of garlic *(Allium sativum)* supplementation in the diet of climbing perch *(Anabas testudineus)* on their growth performance, feed efficiency, survival rate, and physiological parameters. The optimal concentration of garlic supplementation that maximized growth, improved survival rate, and enhanced overall feed utilization efficiency were also determined.

Materials and methods

Preparing the experimental pond

Fishes were raised in a cement pond with a diameter of 100 cm, a height of 50 cm, and a water depth of 30 cm (0.79 square meters). Air was allowed to pass through the sand head throughout the experiment.

Preparation of experimental animals

Thai climbing perch (*Anabas testudineus*) were taken from commercial fish farms that were 30 days old and had been bred. Average size and weight 1.73±0.37 g, released rate 40 individuals/pond (50.63 individuals/square meter), 12 ponds, divided into four experimental sets, three replicates each before starting the experiment. Feed fish was used by commercial diet in the proportion of 5% of their body weight, two meals per day. When experimenting, feed the experimental animals until they were full, two meals per day (09:00 a.m. and 5:00 p.m.). Water was changed every seven days at 80% of the total water volume. The water quality was measured before looking at all the sediment, then added new water to the same volume.

Preparation of experimental diet

Thai garlic from Sisaket province was peeled and washed. They were cut into thin pieces and baked in an oven at 50 °C for 72 h. The dried pieces were ground into powder in a blender (Mohebbi *et al*., 2012) and stored at 4 °C before being mixed with experimental diet until satiated (Table 1).

Table 1. Formulation and proximate composition analysis of experimental diets with varying garlic inclusion levels

Ingredient (% dry weight)	Dietary garlic (g kg^{-1})			
	Control	5	10	20
Fish meal (CP 60%)	320	320	320	320
Soybean meal	160	160	160	160
Tapioca residue	160	160	160	160
Tapioca Chip	160	155	150	145
Rice bran	85	85	85	85
Palm kernel meal	80	80	80	80
Thickener	25	25	25	25
Vit–min premixa	10	10	10	10
Garlic powder	0	5	10	20
Proximate composition				
Dry matter	90.02	90.01	89.9	89.8
Organic matter	30.0	30.2	30.3	30.3
Crude protein	27.7	27.7	27.7	27.7
Ash	14.7	14.7	14.7	14.7
Ether extract	3.3	3.4	3.5	3.7
Crude fiber	9.6	9.6	9.6	9.6

Experimental plan

This experiment used a completely randomized design of 4 experimental units, 3 replicated per experiment to study the effect of garlic supplementation on the growth of 8 week as follows: experimental set 1: Garlic supplement 0 g kg^{-1} of diet (control), experimental set 2: Garlic supplement 5 g kg^{-1} of diet, experimental set 3: Garlic supplement 10 g kg^{-1} of diet and experimental set 4: Garlic supplement 20 g kg^{-1} of diet

Data collection

Growth rate of fish randomly was collected for 30% of each fish sample in duplicate, recording data every 2 weeks for 8 weeks. The percentage weight gain (PWG) according to the method of De Silva and Anderson (1995).

$$PWG\ (\%) = \frac{\text{Final weight - Initial weight}}{\text{Initial weight}} \times 100$$

The mean length gain (LG) was calculated as follows: De Silva and Anderson (1995).

$$LG\ (cm) = \text{Final length} - \text{Initial length}$$

The specific growth rate (SGR) was calculated according to the way of Steffens (1989).

$$SGR\ (\%/day) = \frac{(\ln \text{final weight} - \ln \text{Initial weight})}{\text{number of days}} \times 100$$

The average daily growth (ADG) was calculated as follows: De Silva and Anderson (1995).

$$ADG\ (g/fish/day) = \frac{\text{body weight gain (g)}}{\text{number of days}}$$

The survival rate (SR) was done according to the way of Steffens (1989).

$$\text{Survival rate}\ (\%) = \frac{\text{number of surviving at the end of the production cycle}}{\text{total number at the beginning of the cycle}} \times 100$$

The efficiency of diet using for the fish was recorded at the end of the 8-week experiment and the average daily feed intake (ADFI) calculated as follows: De Silva and Anderson (1995).

$$ADFI\ (g/day) = \frac{\text{amount of diet eaten (g).}}{\text{number of days}}$$

The feed conversion ratio (FCR) was calculated according to the method of Steffens (1989).

$$FCR = \frac{\text{Total weight of diet (dry) eaten by fish}}{\text{increased fish weight}}$$

The feed efficiency (FE) was calculated as follows: De Silva and Anderson (1995).

$$FE\ (\%) = 1 / \text{Feed conversion ratio} \times 100$$

Water quality in fishponds was recorded for water quality in fish ponds at depth 15 cm every week at 11:00 a.m. before changing water (8 weeks), recorded water temperature (°C), pH value, and dissolved oxygen (DO).

Carcass composition

At the end of the experiment, five fish samples were collected. The experiment was repeated by cutting open the abdomen and dividing the carcasses into three parts: fillet, skeleton, and viscera organ. Then, each part of the carcass was weighed and the data were calculated the proportion.

Fillet (%) = Meat weight x 100

weight of fish

Skeleton (%) = $\frac{\text{Skeleton weight}}{\text{weight of fish}} \times 100$

Hepatosomatic index (HIS) (Anwar and Jafri, 1995)

HSI (%) = $\frac{\text{liver weight (g)}}{\text{weight of fish (g)}} \times 100$

Viscerosomatic index (VSI) (Anwar and Jafri, 1995)

VSI (%) = $\frac{\text{internal organ weight (g)}}{\text{weight of fish (g)}} \times 100$

Results

Growth performance rate of Anabas testudineus

The results indicated significant differences in final weights across the diets ($p < 0.05$). The diet with 20 g of garlic per kg achieved the highest average final weight of 32.08 ± 0.52 g, compared to 31.43 ± 0.48 g for the 10 g/kg diet, 30.27 ± 0.42 g for the 5 g/kg diet, and 30.10 ± 0.96 g for the control diet. Length gain (LG) also varied significantly ($p < 0.05$), with the 20 g/kg garlic diet yielding the greatest mean length of 6.03 ± 0.17 cm. This was followed by 5.83 ± 0.16 cm for the 10 g/kg diet, 5.43 ± 0.13 cm for the 5 g/kg diet, and 5.37 ± 0.31 cm for the control diet. Weight gain (WG) differed significantly as well ($p < 0.05$), with the 20 g/kg garlic diet showing the highest mean WG of 30.35 ± 0.52 g, surpassing the 10 g/kg diet at 29.70 ± 0.48 g, the 5 g/kg diet at 28.54 ± 0.42 g, and the control diet at 28.37 ± 0.97 g. Percent weight gain (PWG) also exhibited significant differences ($p < 0.05$), with the 20 g/kg garlic diet achieving the highest mean PWG of 1,754.59 ± 30.06%, compared to 1,716.57 ± 27.88% for the 10 g/kg diet, 1,649.97 ± 24.26% for the 5 g/kg diet, and 1,639.77 ± 55.83% for the control diet. The average daily gain (ADG) was statistically significant ($p < 0.05$), with the 20 g/kg garlic diet showing the highest mean ADG of 1.54 ± 0.009 g/fish/day, while the 10 g/kg diet had a mean of 0.53 ± 0.009 g/fish/day, the 5 g/kg diet had 0.51 ± 0.008 g/fish/day, and the control diet had 0.507 ± 0.017 g/fish/day. Specific growth rate (SGR) also varied significantly ($p < 0.05$), with the 20 g/kg garlic diet presenting the highest mean SGR of 6.09 ± 0.03%/day, followed by the 10 g/kg diet at 6.06 ± 0.029%/day, the 5 g/kg diet at 5.98 ± 0.025%/day, and the control diet at 5.97 ± 0.06%/day. Survival rate (SR) showed significant differences ($p < 0.05$) as well, with the 20 g/kg garlic diet achieving the highest mean SR of 98.33 ± 1.44%, compared to 96.67 ± 1.44% for the 10 g/kg diet, 95.00 ± 2.50% for the 5 g/kg diet, and 87.50 ± 2.50% for the control diet (Table 2).

Table 2. Fish growth performance and survival rates after 8 weeks of feeding on diets supplemented with various levels of garlic

Growth performance and survival rate	Garlic powder (g kg^{-1} of diet)			
	0	5	10	20
Initial weight (g)	1.73±0.000	1.73±0.000	1.73±0.000	1.73±0.000
Final weight (g)	30.10±0.96^{a}	30.27±0.420^{a}	31.43±0.482^{b}	32.08±0.520^{c}
LG (cm)	5.37±0.309^{a}	5.43±0.134^{a}	5.83±0.158^{b}	6.03±0.174^{c}
WG (g)	28.37±0.966^{a}	28.54±0.420^{a}	29.70±0.482^{b}	30.35±0.520^{c}
PWG (%)	1,639.77±55.830^{a}	1,649.97±24.260^{a}	1,716.57±27.880^{b}	1,754.59±30.060^{c}
ADG (g/fish/day)	0.507±0.0170^{a}	0.51±0.008^{a}	0.53±0.009^{b}	0.54±0.009^{c}
SGR (%/day)	5.97±0.060^{a}	5.98±0.025^{a}	6.06±0.029^{b}	6.09±0.030^{c}
SR (%)	87.5±2.500^{a}	95.00±2.500^{b}	96.67±1.443^{b}	98.33±1.443^{b}

Each value is presented as the mean ± standard deviation. Means within the same row followed by different superscript letters are significantly different ($p < 0.05$). Abbreviations: LG = Mean length gain; WG = Weight Gain; PWG = Percentage Weight Gain; ADG = Average diary growth; SGR = Specific growth rate; SR = survival rate

Feed efficiency

The efficiency of the diet used by fish that received a diet mixed with garlic at different levels was evaluated. Samples were randomly collected from 30% of each replicate, and data were recorded every two weeks for eight weeks. The results showed that the average daily feed intake (ADFI) was significantly different ($p < 0.05$). The diet fortified with 20 g of garlic per kg of diet had the best average value of 0.78 ± 0.010 g/day, followed by diets supplemented with 10, 5, and 0 g of garlic per kg of diet, with values of 0.84 ± 0.017, 0.93 ± 0.025, and 0.98 ± 0.012 g/day, respectively. The feed conversion ratio (FCR) was also significantly different ($p < 0.05$). The diet supplemented with 20 g of garlic per 1 kg had the best average FCR of 1.503 ± 0.080, followed by diets with 10, 5, and 0 g of garlic per kg of diet, with values of 1.68 ± 0.184, 1.79 ± 0.085, and 1.97 ± 0.026, respectively. Feed efficiency (FE) showed a significant difference ($p < 0.05$) as well. The diet supplemented with 20 g of garlic per 1 kg had the highest mean FE value of 66.60 ± 0.623%, followed by diets with 10, 5, and 0 g of garlic per kg of diet, with values of 50.75 ± 0.780%, 55.86 ± 0.660%, and 59.26 ± 0.398%, respectively (Table 3).

Table 3. Feed efficiency of fish after 8 weeks of being fed diets containing varying levels of garlic supplementation

feed efficiency	Garlic powder (g kg^{-1} of diet)			
	0	5	10	20
ADFI (g/day)	0.98±0.012^{a}	0.93±0.025^{b}	0.84±0.017^{c}	0.78±0.010^{d}
FCR	1.97±0.026^{a}	1.79±0.085^{b}	1.68±0.184^{c}	1.503±0.080^{d}
FE (%)	50.75±0.780^{a}	55.86±0.660^{b}	59.26±0.398^{b}	66.60±0.623^{c}

Each value is presented as the mean ± standard deviation. Means within the same row followed by different superscript letters are significantly different ($p < 0.05$). Abbreviations: ADFT = Average Daily Feed Intake; FCR = Feed conversion ratio; FE = Feed efficiency

Water quality

Water quality in the fishponds was assessed after feeding the fish diets containing various garlic levels. Every two weeks over an eight-week period, 30% of the fish were randomly sampled, and the corresponding data were recorded. The findings showed that water temperature varied significantly between groups ($p < 0.05$). The highest average temperature was observed in the group receiving 20 g of garlic per kg, with a mean of 25.37 ± 0.115 °C. This was followed by the groups receiving 10, 5, and 0 g of garlic per kg, with mean temperatures of 25.27 ± 0.115, 25.13 ± 0.060, and 25.03 ± 0.153 °C, respectively. pH levels were also significantly different ($p < 0.05$), with the 20 g/kg garlic-supplemented group showing the highest mean pH value of 7.27 ± 0.115. The diets containing 10, 5, and 0 g of garlic per kg had mean pH values of 6.97 ± 0.115, 6.77 ± 0.058, and 6.70 ± 0.058, respectively. Dissolved oxygen (DO) concentrations were likewise significantly affected ($p < 0.05$), with the highest mean DO level recorded in the group supplemented with 20 g of garlic per kg at 6.20 ± 0.058 g/L. This was followed by the 10, 5, and 0 g/kg garlic groups, with mean values of 6.10 ± 0.058, 6.03 ± 0.015, and 6.00 ± 0.058 g/L, respectively (Table 4).

Table 4. Water quality parameters for fish fed diets with varying levels of garlic supplementation over an 8-week period

Water quality	Garlic powder (g kg^{-1} of diet)			
	0	5	10	20
Temperature (°C)	25.03±0.153[a]	25.13±0.060[ab]	25.27±0.115[bc]	25.37±0.115[c]
pH	6.70±0.058[a]	6.77±0.058[a]	6.97±0.115[b]	7.27±0.115[c]
DO/1 (mg/L)	6.00±0.058[a]	6.03±0.015[a]	6.10±0.058[b]	6.20±0.058[c]

Each value is presented as the mean ± standard deviation. Means within the same row followed by different superscript letters are significantly different ($p < 0.05$). Abbreviations: DO = Dissolved Oxygen

Carcass composition

The carcass composition of Climbing perch fed diets with varying levels of garlic was evaluated. Every two weeks over an eight-week period, 30% of the fish samples were randomly collected in duplicate, and data were recorded. The results revealed significant differences in fillet proportion ($p < 0.05$). The diet with 20 g of garlic per kg exhibited the highest mean fillet proportion of 32.48 ± 1.184%, compared to 31.12 ± 0.910% for the 10 g/kg diet, 31.47 ± 0.579% for the 5 g/kg diet, and 31.88 ± 0.793% for the control diet. Significant differences were also found in skeletal proportion ($p < 0.05$), with the 20 g/kg garlic diet having the lowest mean value of 58.81 ± 0.477%, whereas the 10, 5, and 0 g/kg diets had mean values of 59.51 ± 0.362%, 60.02 ± 0.777%, and 60.63 ± 0.814%, respectively. The hepatosomatic index (HSI) showed significant differences ($p < 0.05$) as well, with the 20 g/kg garlic diet having the highest mean HSI of 1.95 ± 0.129%, followed by 1.89 ± 0.148% for the 10 g/kg diet, 1.68 ± 0.088% for the 5 g/kg diet, and 1.64 ± 0.065% for the control diet. The viscerosomatic index (VSI) did not show significant differences ($p > 0.05$), with the 20 g/kg garlic diet having the highest mean VSI of 8.71 ± 1.023%, compared to 8.61 ± 0.585% for the 10 g/kg diet, 8.5 ± 0.613% for the 5 g/kg diet, and 8.25 ± 0.634% for the control diet (Table 5).

Table 5. Carcass composition of fish after 8 weeks of feeding on diets supplemented with varying garlic levels

Carcass composition	Garlic powder (g kg^{-1} of diet)			
	0	5	10	20
Fillet (%)	31.12±0.910[a]	31.47±0.579[ab]	31.88±0.793[b]	32.48±1.184b[c]
Skeleton (%)	60.63±0.814[a]	60.021±0.777[b]	59.51±0.362[c]	58.81±0.477[d]
HIS (%)	1.64±0.065[a]	1.68±0.088[a]	1.89±0.148[b]	1.95±0.129[b]
VSI (%)	8.25±0.634	8.5±0.613	8.61±0.585	8.71±1.023

Each value is presented as the mean ± standard deviation. Means within the same row followed by different superscript letters are significantly different ($p < 0.05$). Abbreviations: HIS = Hepatosomatic index; VSI = Viscerosomatic index

Discussion

Growth performance rate

The growth performance rate of a diet supplemented with garlic has shown valuable outcomes. Mean length gain, weight gain, percentage weight gain, average daily growth, specific growth rate, and survival rate were consistent with the findings of Zeng *et al.* (1996), who reported that the use of synthetic allicin at 50 mg per kg of diet in climbing perch increased weight gain and survival rates by more than 2-3% after 45 days. The feed conversion ratio improved by 11%, and the biological appraisal was 12% higher than in the control group. Jia *et al*. (1999) observed that supplementing garlic-derived allicin at concentrations of 50 and 100 mg per kg in the diet of soft-shelled turtles resulted in weight gain increases of 26.97% and 45.36% ($P < 0.01$), improvements in feed conversion ratios by 15.18% and 17.37%, and survival rate enhancements of 2.44% and 2.96%, respectively, compared to a control group. Similar outcomes were reported in common carp with allicin and iodized allicin at a dosage of 100 mg per kg of diet (Jia *et al*., 1997, 1999; Hu, 1999). Shalaby *et al*. (2006) found that increasing levels of *Allium sativum* significantly improved the weight and specific growth rate of *Oreochromis niloticus*, aligning with findings from Khattab *et al*. (2004) and Khalil *et al*. (2001). Garlic is known to enhance digestion by improving intestinal efficiency, which increases energy availability and supports better growth. Tang *et al*. (1997) demonstrated that allicin from garlic can react with vitamin B1 to produce allithiamine, a more stable and digestible form of vitamin B1. Allithiamine also inhibits the action of thiaminase, which promotes the utilization of vitamin B1 and thereby supports fish growth.

Feed efficiency

The experiment showed that the feed efficiency of cichlid fish diets supplemented with garlic was notably improved. Feed efficiency, average daily feed intake, and feed conversion ratio were enhanced compared to the control group, consistent with the findings of Fo *et al*. (1990). Their research showed that incorporating 1% garlic into the diet of grass carp *(Ctenopharyngodon idella)* and common carp *(Cyprinus carpio)* for three months acted as a growth stimulant. This addition improved the feed rate for both species and reduced the feed coefficient by 23.5%. Similarly, Khalil *et al*. (2001) found that garlic boosts the immune system, enhances gastrointestinal motility, and helps regulate the secretion of digestive enzymes, which aids in digestion and nutrient absorption.

Water quality

Garlic has been shown to control the number of foreign substances, bacteria, and fungi in aquatic environments (Fazlolahzadeh *et al*., 2011). The active compounds in garlic that contribute to its effects on the immune system include diallyl disulfide (DADS), which has antibacterial properties, and ajoene and allicin, which have antibacterial, antifungal, and antiviral activities. Garlic juice also stimulates the phagocytosis process in white blood cells (Ndong and Fall, 2007). An experiment on water quality in fishponds supplemented with garlic showed improved dissolved oxygen levels and pH, likely due to the antimicrobial and antiparasitic properties of garlic, which contribute to the overall health of the cultured organisms. Amagase *et al*. (2001) noted that garlic serves as an immune stimulant in aquaculture settings. Metwally (2009) further confirmed that garlic feeding significantly enhanced antioxidant enzyme activities, such as glutathione peroxidase, superoxide dismutase (SOD), and catalase (CAT), in *O. niloticus* compared to a control group. This enhancement in antioxidant activity contributed to improved water quality, which in turn lowered mortality rates and fostered a more favorable growth environment.

Carcass composition

In the experiment, the carcass composition of fish fed with garlic-supplemented diets showed improved values for fillet yield, skeleton weight, and the fish weight/liver weight index (hepatosomatic index) compared to the control group. These improvements may be attributed to certain properties of garlic that help strengthen the immune system, enhance gastrointestinal motility, and regulate the secretion of various enzymes involved in digestion and nutrient absorption. Khalil *et al*. (2001) and Xiang and Liu (2002) reported that dietary supplementation of garlic (25-100 mg per kg of diet) increases crude protein in fish flesh and reduces crude lipid content in *Colossoma barchypomum*. Luo *et al.* (2008) found that compounds from *Eucommia ulmoides* and garlic improve the meat quality of grass carp (*C. idellus*). Aly *et al*. (2008) also noted that post-harvest meat quality and shelf life of fish-fed garlic supplements were enhanced, while Metwally (2009) reported a significant increase in the protein content of whole fish and a significant reduction in fat and total ash content in the garlic-fed group. These findings are consistent with those of Xiang and Liu (2002), Abdelhamid *et al*. (2002), Khattab *et al.* (2004), Shalaby *et al*. (2006), and El-Dakar *et al.* (2007). The hepatosomatic index improved, which was related to reductions in lipid peroxides, uric acid, blood glucose, total fat, triglycerides, and cholesterol, as reported by Mamdouh and Abdel-Raheim (2003).

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