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Effect of Zeolite on Aquaculture Water Quality, Fish and Microalgae Growth

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ABSTRACT

The study examined the effects of different zeolite doses on water quality parameters, fish growth performance, algae growth, and economic return from concrete ponds cultured with mono-sex male tilapia. Zeolite was used at varying doses: T1 (2.5kg/ m³), T2 (5kg/ m³), T3 (7.5kg/ m³), T4 (10kg/ m³), along with a control (Cont.: without zeolite). The results showed significant differences between the treatment groups and the control for both water quality parameters. Tilapia growth was found to be within optimal limits. The mean dissolved oxygen levels in T3 and T4 were most suitable for tilapia growth and supporting high fish production. pH levels were generally within the ideal range for tilapia. Water clarity was significantly higher in T4 compared to the control, and the addition of zeolite reduced ammonia levels while enhancing microalgae cultivation. Additionally, zeolite decreased both nitrate and nitrite levels in the water. Phosphorus removal by zeolite increased with rising pH. Zeolite significantly affected all growth indices, except the survival rate (SR) in T1. The effect of zeolite on growth and algal biomass was most pronounced in T3. The addition of zeolite significantly improved fish growth performance. While the highest weight gain (WG), average daily weight gain (ADWG), specific growth rate (SGR), and condition factor (CF) values were recorded in T4, the highest net profit percentage was achieved with T3. Based on these results, the study suggests that zeolites can enhance water quality, algal growth, fish productivity, and economic return from fish farming.

INTRODUCTION

Aquaculture is one of the main productions according to the United Nations' Food and Agriculture Organization 2030 schedule for numerous reasons, such as available protein resources, food safety and maintainable development goals. In this situation, alternative feed additives are necessary to support sustainable methods and aquaculture growth **(UN General Assembly, 2015; Fontinha *et al.*, 2020; Genç *et al.*, 2020)**. Aquaculture accounts for one-third of global fisheries production **(Lowther, 2005; Shen *et al.*, 2021; FAO, 2022)**. The presence of phytoplankton and the yield of the algal growth have economic importance in aquaculture to increase fish production **(López-Ruiz 7 Gómez 1994; Vasconcelos *et al.*, 2004)**. Currently, the phytoplankton has several industrial applications, specifically in the enhancement of fish farming nurseries, where it characterizes a significant section of commercial hatchery expenses **(López-Ruiz & Gómez, 1994)**.

Total fisheries production in Egypt from all sources reached about two million tons, 80% of which is from aquaculture **(GAFRD, 2019, 2020)**. The Nile tilapia is considered an important freshwater fish and the most common species in Egypt because of its ability to withstand a lot of environmental conditions and stress situations **(El-Sayed, 2006)**.

Water quality, particularly the levels of dissolved oxygen and ammonia, is a key factor in aquaculture, as it is essential for ensuring fish growth and achieving optimal production **(Santhosh & Singh, 2007; Far Eastern Agriculture, 2016; Ali & Felafel, 2024)**. Therefore, they are constantly monitored to maintain optimal conditions for growing fish that vary from one species to another **(Zain *et al.*, 2018, 2019; Shalaby *et al.*, 2021)**. In case of dissolved oxygen, its concentration is one of the most important factors controlling fish growth **(Francis-Floyd *et al.*, 2009)**. In fish farming ponds, fish growth and productivity increase with increasing dissolved oxygen concentrations, while fish growth and productivity decrease when dissolved oxygen is depleted **(Bhatnagar & Garg, 2000; Bartholomew, 2010)**. Therefore, the amount of dissolved oxygen must be maintained for successful fish productivity **(Middleton & Reeder, 2003)**. Aeration is an effective way to provide dissolved oxygen in fish farming.

In addition, fish performance is greatly affected by ammonia nitrogen concentration, which is the main factor limiting water quality in aquaculture **(Ghiasi & Jasour, 2012; Zain *et al.*, 2018; Fayed *et al.*, 2019)**. Ammonia nitrogen is produced from the decomposition of fish waste and non-nutritious fish feed **(El-Gendy *et al.*, 2015)**. It is considered a major pollution in aquaculture that can have adverse effects such as reduced growth and fish productivity and increased oxygen consumption **(Francis-Floyd *et al.*, 2009)**. Therefore, it is important to remove ammonia for improving water quality in fish farming.

In light of the shortage of fresh water and the need to expand aquaculture to meet the growing population demand, it is necessary to rely on more efficient methods to increase fish productivity **(Fayed *et al.*, 2019; Ali & Felafel, 2024)**. One of those methods is using of natural zeolites to increase the growth of *Tilapia zillii* **(Yildirim *et al.*, 2009)** and *Oreochromis niloticus* **(El-Gendy *et al.*, 2015)**. The use of natural zeolite minerals is one of the solutions for continued sustainability in fish farming **(Abdel Rahim, 2017)**. It is a safe inert substance with a brief environmental life that doesn't harm aquatic life. It is composed of microporous crystalline aluminosilicates of sodium or calcium **(Ghiasi & Jasour, 2012)** which is abundant and readily accessible (in the surface and near to mono-mineral deposits). Therefore, it is normally inexpensive. Instead of being taken out of nature, where it is generally extracted in the form of fragile solid rocks, zeolites can also be artificially produced. It is characterized by the ion exchange process **(López-Ruiz, 1999)**. Clinoptilolite is the best type of zeolite for ammonia removal through the ion exchange process **(Emadi *et al.*, 2001; Farhangi & Rostami-Charati, 2012)** by exchanging sodium ions for ammonium ions and converting ammonia from the toxic non-ionized form to ionized ammonia **(Singh *et al.*, 2004)**. Thus, improving the water quality and growth performance of fish can be achieved by suing zeolite **(Obradovic *et al.*, 2006; Yildirım *et al.*, 2009)**. Zeolite is used as a feed additive in aquaculture **(Ghasemi *et al.*, 2018; Hassaan *et al.*, 2020; Zahran *et al.*, 2020)** to promote microalgae **(Fachini & Vasconcelos, 2006)** and aquaculture **(Abdel-Rahim, 2017; Ghasemi *et al.*, 2018)**. Application of zeolites for stimulating the growth of marine micro-algae culture, particularly diatoms to fed fish was reported by **López-Ruiz *et al.* (1995)**. For optimum effects, zeolite should be used at the recommended dosage. However, it is difficult to determine a specific dose of zeolite when expanding aquaculture since it depends on several factors, including fish stocking density, water quality, feed protein content, and nutrition continuity **(Abdel-Rahim, 2017; Ghasemi *et al.*, 2018)**. Adding zeolite to water or to fish feed improves growth performance **(Farhangi & Rostami-Charati, 2012; Ghiasi & Jasour 2012; Zain *et al.*, 2018)**. Economic analysis of the effects of natural zeolite doses (0, 1, 2 and 3%) in the Nile tilapia diets showed that the highest return was with 3% zeolite **(Al Amir *et al.*, 2022)**.

For these reasons, the main objective of the present experimental study was to determine the appropriate dosage for usage in freshwater aquaculture ponds, as well as the impact of zeolite doses on water quality, fish and algae growth, and economic return in various treatments utilizing concrete ponds.

MATERIALS AND METHODS

Study area

The present experimental study was conducted at El Qanater El-khairiya Research Station of the National Water Research Center (NWRC), Qalyubia Governorate, Egypt.

Experimental design

To investigate the effect of zeolite concentrations on water quality, the growth of the Nile tilapia (*Oreochromis niloticus*) fingerlings, and microalgae, fifteen concrete ponds were used. Each pond had a volume of 9m³ of water, with dimensions of 3m length × 3 m width × 1m depth. The ponds were continuously aerated by an air compressor. The experiment included five treatments: four treatments with different zeolite doses (T1: 2.5kg/ m³, T2: 5kg/ m³, T3: 7.5kg/ m³, and T4: 10kg/ m³), as well as a control treatment (Cont.) with no zeolite. Three replicates were conducted for each treatment. Yemeni zeolite was used, with its chemical composition shown in Table (1).

Table 1. Chemical composition (%) of Yemeni zeolite **(Ali & Felafel, 2024)**

Elements	Percentage (%)
SiO_2 (Silicon Oxide)	68.34
Al_2O_3 (Aluminum Oxide)	11.82
Fe_2O_3 (Iron III Oxide)	2.12
CaO (Calcium Oxide)	1.61
MgO (Magnesium Oxide)	0.64
Na_2O (Sodium Oxide)	1.13
K_2O (Potassium Oxide)	2.35
TiO (Titanium Oxide)	2.03
Loss of ignition	9.15

The experimental period and inoculation of fish

The experiment continued for 20 weeks (140 days) starting from the 7th of June until the 25th of October 2023. Fingerlings of the mono-sex male Nile tilapia with an average initial weight of 3 ± 0.08g were used in all treatments. They were acquired from a commercial farm and were transported in oxygenated plastic bags to the experimental unit and were stocked in the reception ponds for 2 weeks to adapt them to the experiment conditions. Fish were randomly distributed and stocked with a density of 25 fingerlings/m^3 (225 fingerlings/pond).

Feeding

The fish were fed a floating-type artificial feed, pelleted and containing 30% crude protein. The feed was composed of proteins, carbohydrates, lipids, amino acids, vitamins, and mineral salts. All fish in every treatment received the feed at a rate of 3% of the average fish weight in the pond for the first two months. Afterward, the feeding rate was reduced to 2% of the average weight until the end of the experiment. The fish were fasted every Friday. Feeding occurred twice daily, at 9:00 AM and 3:00 PM. Every two weeks, the amount of feed given was adjusted based on the average weight of the fish.

Change the pond water

For all treatment, the percentage of water change rates of ponds was 25 every two weeks during the experiment, in addition to compensating for water losses with evaporation from the free surface. Accordingly, the total amount of water used (m^3) was calculated during the experiment period of 140 days, as shown in Table (2).

Table 2. Different amounts of water used during the experiment period

Volume of water	Control.	Different Treatments			
		T1	T2	T3	T4
The volume of water used at the beginning of the trial (m^3)	9.00	9.00	9.00	9.00	9.00
The volume of renewable water during the trial period (m^3)	26.55	26.55	26.55	26.55	26.55
Total volume of water used during the trial period (m^3)	35.55	35.55	35.55	35.55	35.55

The average rate of evaporation from the free surface in areas with a semi-tropical climate, as in Egyptian environmental conditions, especially in the Nile Delta region, was estimated at an average of 5 liters/m^2/day **(Meleha, 2005; Ali & Khedr, 2018)**.

The amounts of water used during the experiment period was calculated as follows:

- Replacing water with evaporation from the free surface, liters/pond/day = 5 x 9 = 45 liters = 0.045 m^3/day.
- Total amount of renewable water replacing losses with evaporation from the free surface during 140 days (m^3) = 0.045 x 140 = 6.3 m^3.
- The total amount of renewable water at 25% of the pond volume during the trial period = 2.25 x 9 (number of water changes) = 20.25 m^3.
- The total amount of water used during the experiment period (m^3) = the amount of water used to fill each basin at the beginning of the experiment + the amount of water renewed to replace the loss with evaporation from the free surface + the amount of water renewed every two weeks at 25% of the pond volume for a number 9 times = 9 m^3 + 6.3 m^3 + 20.25 m^3 = 35.55 m^3/pond.

Water quality parameters

It is necessary to ensure that the water quality is at optimal levels during the process of raising fish in ponds. Therefore, the water quality standard was examined to observe any changes that might have occurred as a result of the addition of the different zeolite concentrations throughout the trial period. The suitable range of water quality for the Nile tilapia culture was used according to **Boyd and Tucker (1998)**, **WHO (1999)**, **AFCD (2009)**, **Boyd (2013)**, **Bhatnagar and Devi (2019)** and **Bhuyan *et al.* (2020)**.

Physical parameters of water temperature, dissolved oxygen (DO), pH, electrical conductivity (EC), and transparency were measured daily. Those parameters were monitored by the thermometer model Thermo-Orion, the combined electrode connected to a pH meter, and the combined electrode connected to a (DO) meter, digital electrical conductivity meter, and Secchi disk, respectively. The chemical parameters in the different water treatments were monitored every 2 weeks between 08:00 am. and 10:00 am. Water samples were collected and analyzed in the laboratories of NWRC. Ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), and phosphate (PO_4^{3-}) were determined spectrophotometrically according to the international standard criteria **(APHA, 2017)**.

Biological parameters

Phytoplankton identification and counting

Every two weeks, 250ml of water samples were collected for quantitative and qualitative phytoplankton analysis. The samples were preserved using 4% neutral formalin and Lugol's iodine solution, then transferred into a glass cylinder with additional Lugol's iodine solution added to a faint tea color, covered with aluminum foil, and given five days to settle **(APHA, 2012)**. After siphoning off 90% of the supernatant fluid, the sample volume was set at a fixed 25ml and was placed in a tiny plastic vial for microscopic inspection. To count and identify phytoplankton species, the drop method was utilized **(APHA, 2012)**. Triplicate samples (2 or 5μl) were gathered and analyzed using an inverted microscope (ZEISS IM 4738) at a magnification of 400× and 1000× (with oil immersion). Results of phytoplankton density were presented as a number of cells per liter (cell l^{-1}).

Algal taxa were identified using approved references, such as **Pascher (1976)**, **Prescott (1978)**, **Mizuno (1990)**, **Popovsky and Pfiester (1990)**, **Krammer and Lang-Bertalot (1991)**, **Huynh and Serediak (2006)** and **Vuuren *et al.* (2006)**.

Phytoplankton biomass

Water samples with defined volumes were filtered via GF/F glass microfiber filter paper in order to determine the chloride concentration. A Jenway 6800 double-beam visible spectrophotometer (Bibby Scientific Ltd., Staffordshire, UK) was used to estimate Chl a, which was extracted using 90% acetone and was determined using the equations of **Jeffrey and Humphrey (1975)**. **Stel'makh *et al.* (2009)** reported that the phytoplankton growth rate (μ) was determined using the formula μ = ln (Chlt/Chl0) under rising Chl concentration in all treatments. For every therapy, Chl a's starting and ending concentrations are Chl0 and Chlt, respectively.

Fish sampling and growth performance

Every two weeks, a cast net was used to randomly choose thirty fish from each pond. In order to properly obtain excess weight, eating was stopped for 12 hours before to sampling. Digital weighting instrument (model: FSH, A&D Corporation, Korea) and a measuring scale were used to determine each person's weight and length. Following the measurement, the fish were put back in the pond. By eliminating dead fish and tracking the mortality rate every day, the survival rate was determined. All of the fish were eventually collected following the last sampling. The following equations were used to compute the growth performance parameters in accordance with **Ricker (1975)**, **Carlos (1988)**, **Chowdhury *et al.* (2020)** and **Zhao *et al.* (2021a)**:

- Length Gain (cm) = Mean final length (cm) – Mean initial length (cm)
- Percent Length Gain (%) = Length gain (cm)/Initial length (cm) × 100
- Weight Gain (WG) (g) = Final weight (FW) (g) – Initial weight (IW) (g)
- Percent Weight Gain (%) = Weight gain(g)/Initial weight(g) × 100
- Average Daily Weight Gain (ADWG) (g/day) = WG (g) / times (days)
- Specific Growth Rate (SGR) (%/day) = {ln FW (g) - ln IW (g)}/times (days) x 100
- Condition Factor (CF) = (Final weight(g) / Final length(cm)^3) × 100
- Survival rate (SR) (%) = (final number of fish / initial number of fish) × 100.
- Feed Conversion Ratio (FCR) = dry feed fed (kg) / live weight gain (kg)

At the end of the experiment, after 140 days, the water was removed from the ponds. Fish were harvested from ponds, weighed, and counted. Gross yield (kg/m^3) was calculated for the weighted total of fish harvested.

Sampling collection

A 1-liter sample of all treatments was collected every two weeks for chemical and biological analyses. In addition, 30 fish from each treatment were randomly collected using a net to make the necessary measurements of the length and weight of the fish.

Economic return of using zeolite doses on fish productivity

The direct economic return of using zeolite at different doses on fish productivity was estimated by calculating production costs (fixed and operating) and revenues to determine the net profit and comparing it to the control.

- Fixed and operating production costs included the following:
  - ✓ Fingerlings cost (EGP/pond) = 225 fingerlings per pond × 600 EGP per thousand fingerlings = 135 EGP /pond.
  - ✓ Feed cost = Weight of feed used per treatment during the season x Price per kg of feed (26 EGP).
  - ✓ Zeolite cost = Weight of zeolite used per treatment × Price per kg of zeolite (20 EGP).
  - ✓ Water change motor cost (EGP /pond/Season) = the cost of operating a 1 HP motor with a capacity of 30 liters/minute was calculated, to change water at a rate of 25% per 15 day (2.25 m^3/15 day) throughout the season = 72 EGP /pond/Season.
  - ✓ Pumping air blower cost (EGP /pond/Season) = the cost of operating a 1 HP motor with a capacity of 0.750 kWh was calculated, at an operation rate of one hour every four hours per day throughout the season = 23.3 EGP /pond/Season.
  - ✓ Consumption of water motor, pumping air blower, water and air connections, fishing gear and others = 100 EGP.
- Total revenue = Average weight of fish in the pond for three replicates of each treatment (kg) × Price (EGP /kg fish). This price is calculated for each treatment based on the average weight of fish in each pond at the end of the experiment according to the market price.
- Net Profit (EGP /pond) = Total Revenue (EGP/pond) – Total Costs (EGP/ pond).
- Net profit percentage (%) = Total Revenue (EGP) – Total Costs (EGP)/ Total Costs (EGP) × 100

While, the indirect economic return of water unit productivity was estimated through net fish production (kg/m^3) for different zeolite dosage treatments and compared with the control.

Data analysis

Microsoft Excel (MS Excel) 2019 was used to record the characteristics of water quality and fish growth collected data. MS Excel and SPSS were utilized for the analysis of the data, which were displayed as mean ± standard error (SE). For the statistical analysis of the data, SPSS version 20 with one-way ANOVA was utilized. $P \leq 0.05$ was used to determine statistical significance differences between the means of the treatments. MS Excel was used to create the graphs.

RESULTS

1. Water quality parameters

Through four treatments (T1, T2, T3 and T4) in addition to the control, the water quality parameters and their variations are displayed in Table (3) along with a mean (± SE) and *P*-value. Each different zeolite treatments (T1, T2, T3 and T4) were compared with the control throughout the trial period. The present result showed that the treatment and control groups differed significantly ($P< 0.05$) in every parameter except temperature (Table 3). The average temperature in the control and treatment ponds was roughly similar. The average temperatures for Cont., T1, T2, T3, and T4 were 26.19, 25.57, 25.47, 25.42, and 25.29°C, respectively. The mean concentration of dissolved oxygen ranged from 4.29 to 5.85mg/ l during the experiment period. The highest value was recorded in treatment T4, while the lowest value was recorded in Cont. The level of dissolved oxygen (DO) varied slightly between treatment T1 and T2 and control ponds, but its level increased in treatments T3 and T4 (Table 3). Concerning the pH values, the present result showed that their averages were 7.85, 7.92, 7.99, 8.12, and 8.23 in cont., T1, T2, T3, and T4, respectively. The average pH value in the control ponds was significantly lower ($P< 0.05$) compared to the other treatment ponds, while treatment T4 recorded the highest value (Table 3). The statistical analysis revealed significant differences in the mean electrical conductivity (EC) values when the control (Cont.) was compared with each zeolite treatment. The mean EC values for Cont., T1, T2, T3, and T4 were 406.5, 400.6, 394.0, 382.2, and 372.3μS/ cm, respectively (Table 3).

The average transparency values for Cont., T1, T2, T3, and T4 were 29.9, 34.4, 38.1, 45.2, and 49.4, respectively (Table 3).

The mean ammonia values were 0.104, 0.089, 0.062, 0.036, and 0.025mg/ L for Cont., T1, T2, T3, and T4, respectively. The control treatment (0.104mg/ L) had the highest ammonia concentration compared to the other zeolite treatments (Table 3).

The average nitrate values were 7.02, 5.75, 4.39, 2.89, and 1.91mg/ L for Cont., T1, T2, T3, and T4, respectively. The lowest nitrate value was found in T4, while the highest was recorded in the control (Table 3).

The average nitrite values were 0.119, 0.108, 0.098, 0.062, and 0.039mg/ L for Cont., T1, T2, T3, and T4, respectively. The lowest nitrite concentration was observed in T4, while the highest was in the control (Table 3).

Regarding orthophosphate (PO_4-P), the average values for Cont., T1, T2, T3, and T4 were 1.13, 0.98, 0.84, 0.62, and 0.38mg/ L, respectively. The lowest orthophosphate concentration was recorded in T4, while the highest was in the control (Table 3).

The statistical analysis showed significant differences ($P< 0.05$) when comparing the mean values of nitrate (NO_3), nitrite (NO_2), ammonia (NH_3), and phosphate between the control (Cont.) and each zeolite treatment.

Table 3. Effect of the different zeolite doses on the water quality parameters (mean ±SD) in the concrete ponds cultured with the mono-sex male Nile tilapia during the trial period

Parameter	Zeolite doses (kg/m^3 water) in the different treatments									Suitable range	Reference
	Cont.	T_1	*p*-value	T_2	*p*-value	T_3	*p*-value	T_4	*p*-value		
Temp. (°C)	26.2±0.8	25.6±0.7	0.71	25.5±0.6	0.75	25.4±0.7	0.8	25.3±0.7	0.72	26–32	**Bhatnagar & Devi (2019)**
DO (mg/l)	4.3±0.7	4.6±0.6	0.01	4.7±0.6	< 0.001	5.5±0.4	< 0.001	5.9±0.3	< 0.001	> 5.0	**Boyd & Tucker (1998)**
pH	7.9±0.1	7.9±0.1	< 0.001	8.0±0.1	< 0.001	8.1±0.2	< 0.001	8.2±0.3	< 0.001	7.0-8.5	**(WHO)**
EC (µS/cm)	407±27	401±24	< 0.001	394±22	< 0.001	382±15	< 0.001	372±9	< 0.001	0-800	**Bhuyan *et al*. (2020)**
Transparency (cm)	30±10	34±8	0.032	38±8	0.043	45±5	0.01	49±4	0.022	-	-
NH_4-N (mg/l)	0.10±0.04	0.09±0.04	< 0.001	0.06±0.02	< 0.001	0.04±0.01	< 0.001	0.03±0.01	< 0.001	< 0.15	**Boyd (2013)**
NO3-N (mg/l)	7.0±3.4	5.8±2.7	0.001	4.4±1.9	< 0.001	2.9±1.1	< 0.001	1.9±0.6	< 0.001	0.2–10	**AFCD, 2009**
NO2-N (mg/l)	0.12±0.07	0.11±0.07	< 0.001	0.10±0.1	< 0.001	0.06±0.03	< 0.001	0.04±0.01	< 0.001	< 0.3	**Boyd & Tucker (1998)**
PO4-P (mg/l)	1.1±0.5	1.0±0.4	0.001	0.8±0.3	0.002	0.6±0.2	< 0.001	0.4±0.1	< 0.001	0.1-1.0	**WHO, 1999**

Results are presented as mean ± SE. Means with a *p*-value less than 0.05 ($P< 0.05$) are significant. DO = dissolved oxygen; EC = electrical conductivity; NH_4-N = ammonia; NO_3-N = nitrate; NO_2-N = nitrite; PO_4-P = phosphorus.

2. Growth performance of the Nile tilapia

The specific growth performance parameters of the experimental fish in the treatment and control ponds are presented in Table (4). Growth performance was cleared in terms of weight gain (WG), average daily weight gain (ADWG), specific growth rate (SGR), condition factor (CF), and survival rate (SR) for the trial period of 140 days and were analyzed statistically. The growth performance rates were varied with the different treatments during the trial period. Concerning the WG and ADWG values, the present statistical analysis showed their highest values in T1 (122.24, 0.87), T2 (141.78, 1.01), T3 (158.41, 1.13), and T4 (170.73, 1.22) when they compared with control (101.99, 0.73) as shown in Table 4. Also, the treatment T4 tended to be the highest value. The SGR and CF values in the treatments were significantly ($P<0.05$) enhanced compared with control (Table 4). The average SGR in the experimental ponds in the current study varied from 2.54 to 2.88 %/day. The SGR was found to be highest in the treatment T4 (2.88 %/day) while the lowest was found in the control (2.54 %/day). At the same time, the average CF ranged from 1.22 in the control to 1.43 in the treatment T4. Concerning the survival rate (SR) the present statistical analysis showed that (SR) was statistically higher in all zeolite treatment ponds of T2, T3 and T4 compared with the control, while zeolite treatment pond T1 failed to show significant differences compared with the control ponds (Table 4).

Table 4. Effect of the different zeolite doses on growth performance (mean ±SD) of the mono-sex male Nile tilapia cultured in concrete ponds during the trial period

Growth rate parameter	Zeolite doses (kg/m^3 water) in the different treatments								
	Cont.	T_1	*P*-value	T_2	*P*-value	T_3	*P*-value	T_4	*P*-value
Initial Weight (g)	3.0±0.14	3.1±0.16	0.122	3.0±0.2	0.245	3.1±0.2	0.189	3.1±0.2	0.134
Final Weight (g)	105±3.2	125±3.4	< 0.001	149±3.2	< 0.001	162±3.7	< 0.001	174±3.5	< 0.001
Weight Gain (WG) (g)	102±3.1	122±3.6	< 0.001	142±3.2	< 0.001	158±3.8	< 0.001	171±3.6	< 0.001
Initial length (cm)	5.5 ± 0.05	5.5 ± 0.05	0.112	5.2 ± 0.05	0.187	5.0 ± 0.05	0.071	4.8 ± 0.04	0.092
Final length (cm)	10.3 ± 0.05	10.7 ± 0.04	0.06	11.2 ± 0.05	< 0.001	11.4 ± 0.05	< 0.001	11.9 ± 0.05	< 0.001
Length gain (cm)	4.8± 0.08	5.2± 0.07	0.002	6.0± 0.06	< 0.001	6.4± 0.07	< 0.001	7.1± 0.07	< 0.001
ADWG (g/day)	0.7±0.02	0.9±0.02	< 0.001	1.0±0.02	< 0.001	1.1±0.03	< 0.001	1.2±0.03	< 0.001
SGR (%/day)	2.5±0.04	2.7±0.04	< 0.001	2.8±0.04	< 0.001	2.8±0.04	< 0.001	2.9±0.04	< 0.001
Condition factor (CF)	1.2±0.06	1.3±0.07	< 0.001	1.3±0.08	< 0.001	1.4±0.09	< 0.001	1.4± 0.08	< 0.001
Survival rate (SR) (%)	82±0.74	93±0.57	0.082	97±0.57	< 0.001	98±0.21	< 0.001	99±0.21	< 0.001
FCR	1.3± 0.02	1.1± 0.01	0.002	1.0± 0.01	0.003	1.0± 0.02	0.002	1.0± 0.01	0.002

Results are displayed as mean ± SE. Means with a p-value less than 0.05 ($P< 0.05$) are significant. ADWG = average daily weight gain; SGR = specific growth rate; FCR = feed conversion ratio.

Concerning the feeding procedure, Fig. (1) shows the amount of feed (g) used to feed the mono-sex male Nile tilapia in the different treatment ponds after every two weeks throughout the experiment period. In addition, the total amount of feed (kg) utilized for feeding the fish in the different treatments throughout the experimental period is shown in Fig. (2). While, the average weight of8 the mono-sex male Nile tilapia in the different zeolite treatments after every two weeks throughout the experiment period is shown in Table (5).

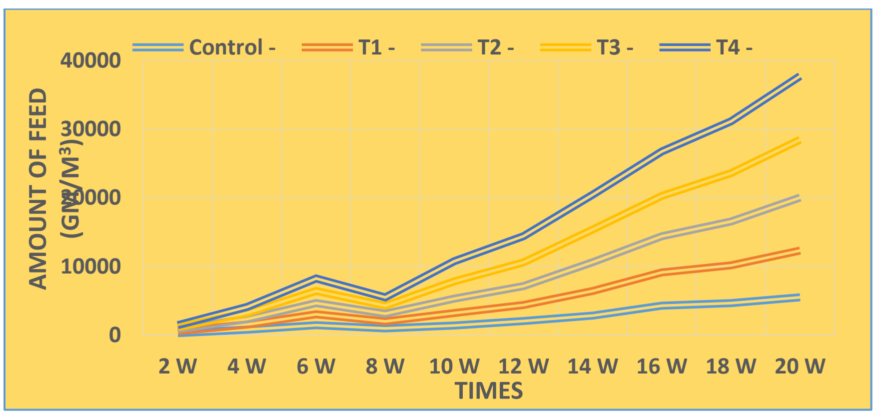

Fig. 1. Amount of feed (g) used to feed the mono-sex male Nile tilapia in concrete ponds after every two weeks throughout the experiment period

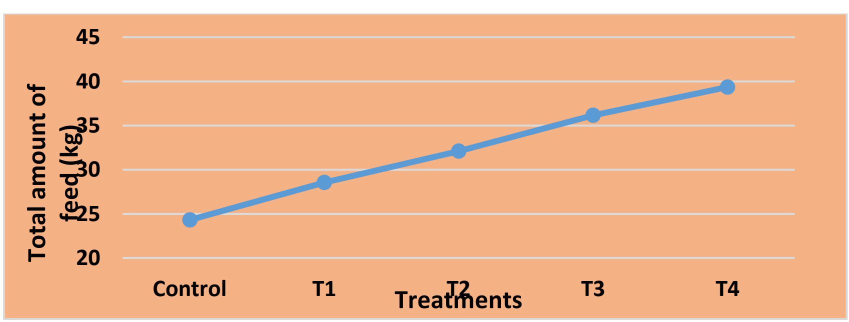

Fig. 2. Total amount of feed (kg) used to feed the mono-sex males of Nile tilapia in concrete ponds throughout the experimental period

Table 5. Average weight (gm) of mono-sex males of the Nile tilapia in concrete ponds for different zeolite treatments after every two weeks throughout the experiment period

Measurement period	Control	Different Zeolite Treatments (kg/m^3)			
		T1	T2	T3	T4
Zero Time	3	3	3	3	3
2 W	8	8	8	9	9
4 W	15	16	17	18	19
6 W	18	20	22	25	30
8 W	22	28	32	39	45
10 W	32	36	42	53	59
12 W	44	55	65	73	79
14 W	66	75	81	91	100
16 W	72	85	98	109	116
18 W	85	105	119	130	143
20 W	105	125	145	162	174

Where: W= week

3. Impact of zeolite on algal growth and its biomass

The results showed that the total phytoplankton density at the beginning of the study (zero time) was 23 × 10⁴ cells/L, with Chlorophyceae being the dominant class. The total number of species at this time was modest (17 species), but it increased rapidly over time. Fig. (3) illustrates the total algal density in the control and various treatment groups (T1, T2, T3, and T4) throughout the study period. The results also indicated that, like at zero time, the Chlorophyceae class remained dominant. The highest total density was recorded in treatment T3, as shown in Fig. (3). Fig. (4) displays the distribution of the overall phytoplankton density for each of the dominant phytoplankton classes across the different treatments throughout the trial period. Compared to the other treatments, T3 demonstrated the greatest improvement in algal growth, with a density of 326 × 10⁴ cells/L. This result aligns with the 231µg/ L algal biomass concentration observed in T3. Treatment T3 had a more significant effect than the other treatments. Consistent with these findings, the chlorophyll a concentration increased during the treatment period, especially in T3, as shown in Fig. (5).

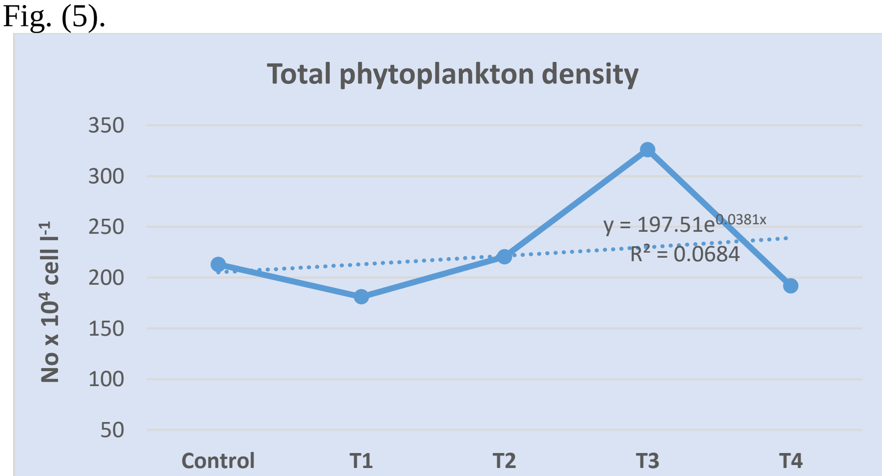

Fig. 3. The average of total phytoplankton density in the different treatments during the trial period

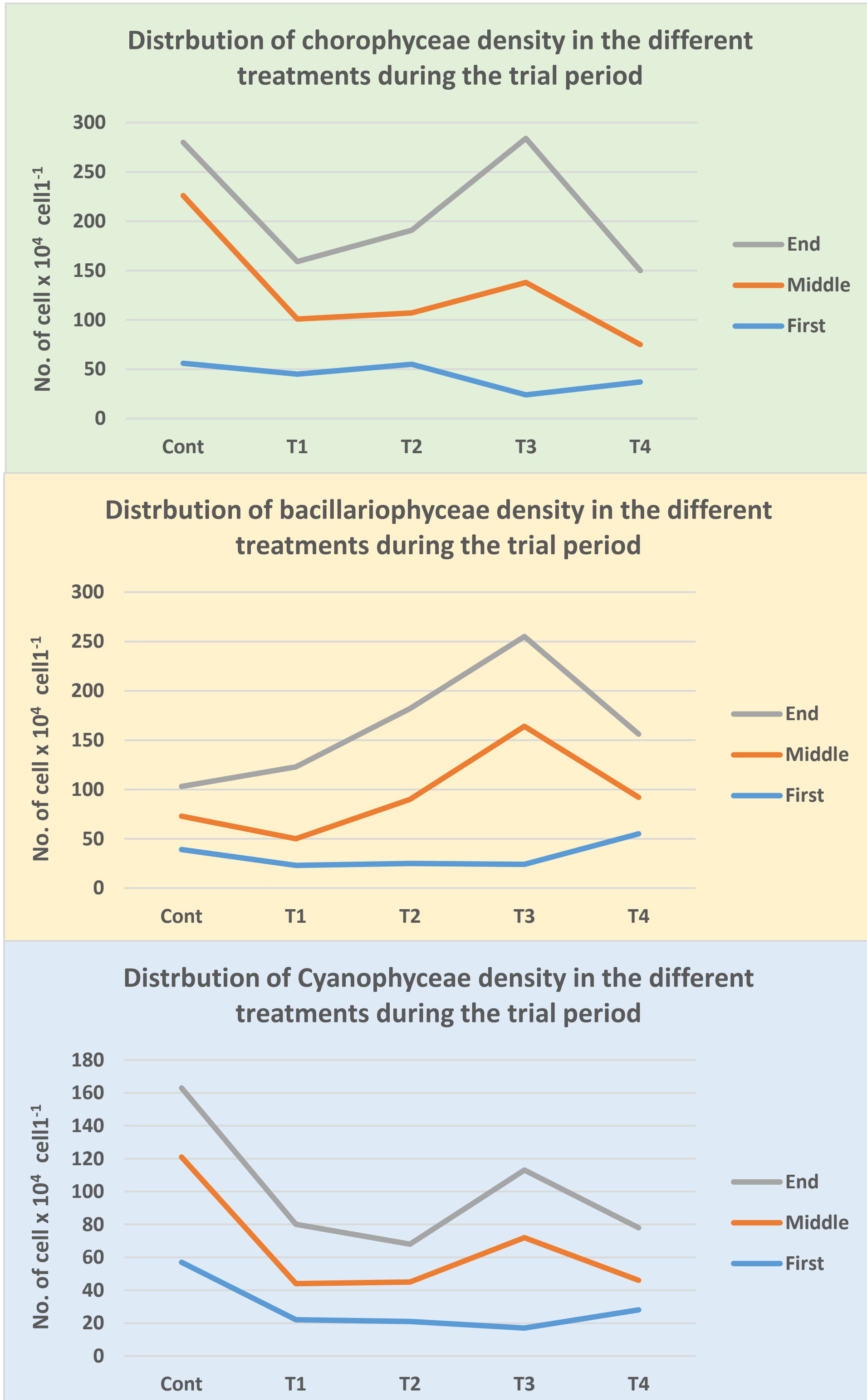

Fig. 4. Distribution of the total phytoplankton density for both the dominant phytoplankton classes recorded in the different treatments during the trial period in the first, middle and end of the experiment

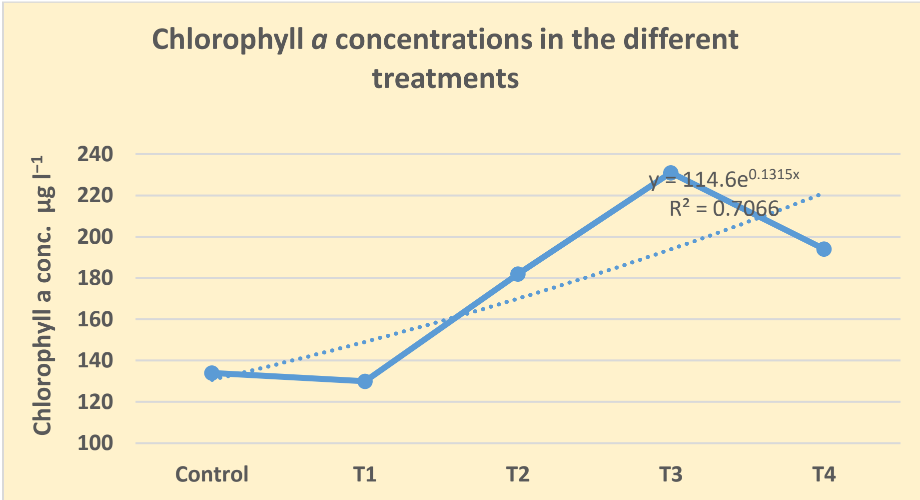

Fig. 5. The average of chlorophyll a concentration in the different treatments during the trial period

4. Fish production

Concerning the total fish production, the present study showed that the trial treatments of the mono-sex male Nile tilapia produced more total fish production (kg/pond) and net fish production (kg/m^3) than the control, as shown in Table (6). The highest values of total fish production and the net fish production were recorded in treatment T4 with values of 38.46kg/ pond and 4.29kg/ m^3, respectively.

Table 6. The effect of zeolite doses on total production (kg/pond) and net production (kg/m^3) of the mono-sex male Nile tilapia cultured in concrete ponds during the trial period

Parameter	Zeolite doses (kg/m^3) in the different treatments				
	Cont. 0	T1 2.5	T2 5	T3 7.5	T4 10
Total of fish production (kg/ pond)	18.59±0.21	25.77±0.19	31.37±0.22	35.42±0.09	38.46±0.10
Net of fish production (kg/ m^3)	2.07±0.02	2.86±0.02	3.49±0.02	3.94±0.01	4.29±0.01

5. Economic return of using zeolite on fish productivity

Costs, revenues, net profit and net profit percentage were calculated to determine the direct economic return from fish productivity for all zeolite treatments and control, as shown in Table (7). The present result showed that net profit (EGP) and net profit percentage (%) were the highest in all treatment forms than their values compared with the control. The maximum net profit (EGP) and net profit percentage (%) were recorded in treatment T3 with values of 573.0 EGP and 21.87 %. (Table 7).

Table 7. Direct economic return from using zeolite treatments and control on the mono-sex male Nile tilapia productivity

Fixed and operating costs (EGP /pond)	Control	Different Treatments			
		T_1	T_2	T_3	T_4
Fingerlings cost	135	135	135	135	135
Feed cost	631.8	742.3	834.6	939.9	1023.1
Zeolite cost	0	450	900	1350	1800
Water change motor cost	72	72	72	72	72
Pumping air blower cost	23.3	23.3	23.3	23.3	23.3
Consumption of water motor, pumping air blower, water and air connections and other	100	100	100	100	100
Total of fixed and operating costs (EGP /pond)	962.1	1522.6	2064.9	2620.2	3153.4
Revenues (EGP /pond)					
Average weight of fish in the pond for three replicates of each treatment (kg)	18.59	25.63	31.32	35.48	38.63
***Price of fish (EGP /kg)**	55	65	75	90	90
Total revenues (EGP /pond)	1022.5	1666.0	2349.0	3193.2	3476.7
Net profit (EGP)	60.4	143.4	284.1	573.0	323.3
Net profit percentage (%)	6.28	9.42	13.76	21.87	10.25

*Price per kg for average fish weight per treatment at the end of the experiment according to market price.

Based on the gained result in Table (6), the indirect economic return was calculated depending on the net of fish production of water unit (kg/m^3). The water unit (m^3) for all zeolite treatments achieved the highest fish productivity compared with the control. The water units for fish productivity were 2.86, 3.49kg/ m^3, 3.94kg/ m^3, 4.29 and 2.07kg/ m^3 for the treatments of T1, T2, T3, T4 and the control, respectively.

DISCUSSION

Water quality parameters

Similar to the finding of **Kusar and Salim (20060**, **Ngugi *et al.* (2007)** and **Yıldırım *et al.* (2009)**, the present result showed that the average water temperature values were found to be within the limits of optimal growth for tilapia, and there was no significant difference (P< 0.05) between the different treatments and the control groups. The mean dissolved oxygen contents, especially in T3 and T4, were suitable for tilapia growth and could sustain high fish production; this result coincides with the finding of **Riche and Garling (2003)**, **Bhatnagar *et al.* (2004)** and **Bhatnagar and Singh (2010)**. The lowest value of DO in the control could be attributed to the relatively high ammonia concentration compared to the different treatments. This agrees with the finding of **Mokhtari-Hosseini *et al.* (2016)**, who mentioned that the presence of ammonia could lead to the consumption of oxygen in the water. While, dissolved oxygen levels above 5mg/ l have been shown to decrease FCR **(Li *et al.*, 2020)**, increase feeding rate, and accelerate growth **(Vaage & Myrick, 2022)**.

The present study showed that the pH levels were generally within the range that tilapia thrives best which concurs with the finding of **BFAR (1992)**, **Wurts and Durborow (1992)** and **Bhatnagar *et al.* (2004)**, who suggested that ponds' ideal pH levels should be between 6.5 and 9. Moreover the present study showed the average values of pH for T1, T2, T3, and T4 showed significant variation ($P< 0.05$) compared with the control. According to **Stone and Thomforde (2004)**, **Stone *et al.* (2013)** and **Bhuyan *et al.* (2020)**, the EC readings were within the optimal range for high fish production. Water clarity (transparency) in the ecosystem is affected mainly by the concentration of detritus or phytoplankton **(HELCOM, 2023)**. The present study showed that the average values for transparency in T1, T2, T3, and T4 showed significant variation ($P< 0.05$) compared to the control, and the highest value was recorded in T4 (49.4cm). This might be related to the decreasing of phytoplankton crop in T4. This finding coincides with the finding of **Delince (1992)** and **Haroon *et al.* (2018)**, who mentioned that transparency of water is generally influenced by floating substances or abundance of microorganisms in the water, turbidity and suspended matter. The result of ammonia is similar to the finding of **Danabas and Altun (2011)**, **Ghiasi and Jasour (2012)**. Moreover, it is within the optimum level for tilapia growth (0.02–0.05 mg/l) according to **BFAR (1992)** and **TNAU (2008)**. It is clear that zeolite replaced sodium ions with ammonium ions and prevented the rise in its level, thus maintaining the ammonia balance away from toxic ammonia **(Ghiasi & Jasour, 2012)**. Additionally, the present study showed that the value of ammonia tended to be relatively higher in the control treatment than those in different zeolite treatments, possibly resulting from feed addition and nitrogenous excretory leading to the accumulation of ammonia; this coincides with the finding of **Azim *et al.* (2002)**, who confirmed the effect of feeding on increasing ammonia concentration in the feeding-only treatment. Thus, the addition of zeolite led to a reduction in the ammonia levels in water compared to the control; this result corroborates those of **Huang *et al.* (2010)**, **Zhang *et al.* (2011)**, **Mazloomi and Jalali (2016)** and **Beigbeder (2023)** and significantly enhanced the microalgae group cultivation **(López-Rosales *et al.*, 2022)**. The nitrate concentration was within the advised range according to **Boyd and Tucker (1998)**. The addition of zeolite decreased the level of nitrate in water, which is consistent with the finding of **Gangadhar *et al.* (2016)**. The nitrite content was below the values according to **AFCD (2009)**, who stated that the nitrite concentration must be lower than 0.2mg/ l. The results prove that the phosphorus removal by zeolite increases **(Jean-Baptiste Beigbeder, 2023)** with increasing pH. This was consistent with the results obtained by **Zain *et al.* (2019)**. The average values of NH_4-N, NO_3-N, NO_2-N, PO_4-P, DO, and EC for T1, T2, T3, and T4 showed significant variation ($P < 0.05$) compared to control. The results in Table (3) clear that the water quality during the trial period was in the considered suitable range for the culture of the mono-sex male Nile tilapia. Improvement in water quality could be better achieved by adding zeolite (10kg/ m^3 water). According to **Ali and Felafel (2024)**, putting zeolite on the bed of the concrete pond was the best case. **Boyd (1998)** reported that fish ponds with good water quality are expected to give higher fish productivity than ponds with poor water quality. The results concluded that high concentrations of zeolite significantly improved water quality.

Growth performance

At the start of the experiment, the average weight of the fish ranged from 3.01 to 3.09 g for the control and other treatments. The results showed that fish weight increased with higher doses of zeolite. By the end of the experiment, the average weight of the fish in the control group was 105g, while in the T4 treatment, it was 174g. These findings are consistent with those of **Giasi and Jasour (2012)**, who reported that the final weight of angelfish (freshwater fish) was higher with the addition of zeolite compared to the control group (without zeolite).

The highest weight gain (WG) and average daily weight gain (ADWG) values were recorded in the T4 treatment, with all zeolite treatments showing highly significant differences ($P< 0.001$) compared to the control. Similarly, the highest specific growth rate (SGR) was recorded in the T4 treatment, and all zeolite treatments showed highly significant differences ($P< 0.005$) when compared to the control. The average condition factor (CF) also followed the same pattern, consistent with the findings of **Saeed *et al.* (2015)**, who observed high CF values ranging from 1.56 to 1.67 during their treatments.

Additionally, the highest survival rate (99.01%) was observed in the T4 treatment. This result aligns with the findings of **Osman *et al.* (2008)** and **Saeed *et al*. (2015)**.

Furthermore, the present study demonstrated that the T4 treatment achieved the best growth performance in terms of WG, ADWG, SGR, and CF, while the control group showed the poorest growth performance. Based on these findings, it can be concluded that the T4 treatment, which included an optimal amount of zeolite added to the concrete pond bed as per **Ali and Felafel (2024)**, improved water quality and enhanced growth performance, leading to an increase in fish body weight. These results are in line with the findings of **Saeed *et al.* (2015)**, who showed that zeolite addition improves water quality and fish productivity in fish ponds. Additionally, research by **Obradovč *et al*. (2006)** and **Zain *et al.* (2018)** found that the use of zeolite, combined with proper management, resulted in better growth and improved water conditions.

Impact of zeolite on algal growth and its biomass

The current investigation observed that zeolites have the ability to enhance microalgae growth. The total densities of both Bacillariophyceae and Chlorophyceae were at their highest in the T3 treatment compared to the other treatments. The Chlorophyceae class remained dominant throughout the study period. The effects of the T3 treatment were more significant compared to the other treatments.

It was found that the total density of Bacillariophyceae increased during the experiment as the dose of zeolite increased. The effects of zeolites on algal development can be summarized as follows: ammonia concentrations decreased, while macronutrients, particularly silicon, increased, stimulating algal growth. Some researchers have highlighted that zeolite enhances diatom growth by leaching silicon into seawater **(Chien, 1992)**.

The increase in Chlorophyceae density in the T3 treatment in the current study aligns with the findings of **Nieves *et al*. (2002)**, who suggested that zeolite may also promote the growth of microalgae that do not require silicon, such as flagellates and other species. Additionally, **Vasconcelos *et al*. (2004)** reported an increase in the yield of marine microalgae that do not depend on silicon.

Fish production

For both total production and net production, the present study showed that T4 was the most effective treatment out of all treatments. In comparison with the control ponds, the harvest weights in treatments of T1, T2, T3, and T4 were greatest. This result coincides with the finding of **Xia *et al.* (2009)** who mentioned that natural zeolite promoted fish growth and survivability. This could be because the ponds treated with zeolite had better-water quality.

Economic return of using zeolite on fish productivity

The direct economic return in Table (7) shows that adding zeolite doses increased fish productivity (kg/m^3), net profit (EGP) and net profit percentage (%) for all treatments, compared statistically with the control. Moreover, the present result showed that the treatment of T4 had the highest fish productivity, followed by T3, T2, and T1. In addition, the highest net profit was recorded in treatment T3, followed by T4, T2, and T1. However, when calculating the net profit percentage (%) for costs and revenues, T3 was the highest, followed by T2, T4, and finally T1. Therefore, the best treatment in terms of direct economic feasibility was T3. On the other hand, the indirect economic return of water unit productivity (kg/m^3) for treatments T1, T2, T3, T4 reached 1.38, 1.69, 1.90, 2.07 folds more than the control. We concluded that the use of zeolite doses increased the fish productivity and net profit percentage, and the highest return was recorded with T3 (7.5%). This finding is similar to that of **Al Amir *et al.* (2022)**, who demonstrated that adding zeolite at different doses (0, 1, 2, and 3%) to the Nile tilapia diets resulted in the highest return at the 3% dose. Additionally, we concluded that the use of zeolite maximized the utilization of water per unit (m^3) in fish production.

CONCLUSION

The findings of the current study showed that water quality remained within an acceptable range for mono-sex male Nile tilapia culture throughout the trial period. Additionally, high dissolved oxygen concentrations, optimal temperature values, and lower ammonia levels in various treatments contributed to an enhanced fish growth. The use of an appropriate zeolite dose, combined with good management practices, resulted in improved water conditions and growth performance in freshwater fish.

The study also demonstrated that the T3 (7.5kg/ m^3) and T4 (10kg/ m^3) zeolite treatments were ideal for addition to the concrete pond bed to improve water quality, algal growth, and fish body weight. However, the best treatment in terms of direct economic return was T3.

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