Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 29(5): 2479 – 2502 (2025)
www.ejabf.journals.ekb.eg

Nano-Curcumin as a Dietary Supplement: Impacts on Growth, Nutrient Utilization, Body Composition, and Profitability in the Nile Tilapia (*Oreochromis niloticus* L.) Fingerlings

Hesham Abozaid[1*], Hamed A.A. Omer[1], Dalia M. Aboelhassan[2], Ali S.M. Elnadi[1], Wafaa T. Abbas[3], Inas S. Ghaly[2], Hasnaa A. Radwan[2], Ahmed M. Youssef[4], El- Nomeary Y.A.A[1]

[1]Animal Production Department, Biological Agriculture Research Institute, National Research Centre, Giza, Egypt
[2] Department of Cell Biology, Biotechnology Research Institute, National Research Centre, Giza, Egypt
[3]Hydrobiology Department, Veterinary Research Institute, National Research Centre, Giza, Egypt
[4]Packaging Materials Department, National Research Centre, Egypt

Corresponding Author: g_hesham@yahoo.com

ARTICLE INFO

Article History:
Received: July 6, 2025
Accepted: Oct. 1, 2025
Online: Oct. 12, 2025

Keywords:
Nano-curcumin,
The Nile tilapia fingerlings,
Growth performance,
Feed utilization,
Fish body composition,
Nutrient retention,
Economical evaluation

ABSTRACT

This study evaluated the effects of dietary nano-curcumin supplementation on growth performance, feed utilization, body composition, and nutrient retention in the Nile tilapia (*Oreochromis niloticus*) fingerlings. Four experimental diets were formulated with nano-curcumin at 0, 50, 100, and 150mg/ kg (D1–D4, respectively). A total of 120 fingerlings (initial mean weight: 25.18 ± 0.49g) were acclimated and randomly distributed into 12 aquaria (10 fish each). All diets were iso-caloric and iso-nitrogenous. Growth parameters, including final weight, total body weight gain, average daily gain, specific growth rate, relative growth rate, feed intake, crude protein intake, and protein efficiency ratio, were significantly improved (*P<0.05*) in fish receiving nano-curcumin-supplemented diets compared with the control. Feed conversion ratio was also significantly enhanced. Body composition was markedly influenced by nano-curcumin supplementation. Fish fed supplemented diets showed increased dry matter, organic matter, and crude protein contents, while moisture, ether extract, and gross energy decreased significantly (*P<0.05*). In addition, energy retention (ER%) and protein productive value (PPV%) increased progressively with dietary nano-curcumin levels were recorded at 29.70, 36.39, 52.83 and 75.27%, meanwhile, the corresponding values of PPV% were recorded at 50.07, 75.42, 114.27 and 151.10% for G1, G2, G3 and G4, respectively. In conclusion, incorporation of Nano-curcumin at different dietary levels improved growth performance, feed utilization efficiency, nutrient retention, and economic profitability in the Nile tilapia fingerlings. These findings highlight the potential of nano-curcumin as a promising feed additive for sustainable aquaculture production.

INTRODUCTION

Tilapia is the third most farmed fish species worldwide, with an annual production of nearly 4.5 million tons **(FAO, 2022)**. This species has gained global importance in aquaculture due to its favorable characteristics, including strong resistance to stress

(Suresh & Lin, 1992; Sutthi & Thaimuangphol, 2020; Wardani *et al*., 2021), relatively low susceptibility to diseases **(El-Sayed, 1999)**, rapid growth **(El-Sayed, 1999; Lim, 2006; Abdel-Tawwab *et al*., 2006)**, ability to utilize alternative protein sources **(El-Sayed, 1999; Meric *et al*., 2011; Ng & Romano, 2013)**, tolerance to suboptimal water quality **(Benli *et al*., 2008; Monsees *et al*., 2017; Ai *et al*., 2022; Zidan *et al*., 2022)**, and efficient feed conversion **(El-Sayed, 2016; Dietz & Liebert, 2018; Mengistu *et al*., 2020)**. Collectively, these traits make tilapia a robust and promising candidate for sustainable aquaculture development worldwide **(Prabu *et al*., 2019)**.

With the rising global demand for aquaculture products, fish farmers are increasingly adopting intensive farming practices to enhance productivity **(Boyd *et al*., 2022; Jiang *et al*., 2022)**. However, intensive systems often expose fish to multiple stressors that compromise welfare, increase disease outbreaks, and ultimately cause economic losses **(Tian & Dong, 2023)**. To counter these challenges, natural growth promoters and health-enhancing additives such as phytochemicals, algae, herbs, and essential oils have been introduced into aquafeeds **(Alagawany *et al*., 2021b; Abd El-Hack *et al*., 2021; Abdelnour *et al*., 2023; Hendam *et al*., 2023)**.

At the same time, concerns on antibiotic residues and their impact on human health have prompted global regulations limiting the use of synthetic drugs in aquaculture **(Abdel-Latif *et al*., 2023)**. This shift has accelerated interest in safe and natural alternatives, including plant-derived compounds such as curcumin **(Moniruzzaman & Min, 2020)**.

Curcumin, a bioactive polyphenol extracted from turmeric rhizomes (*Curcuma longa*), has been shown to improve growth, immunity, and overall health in several fish species, including the snakehead (*Channa argus*), rainbow trout (*Oncorhynchus mykiss*), and red tilapia (*Oreochromis* sp.) **(Yonar *et al*., 2019; Li *et al*., 2022; Eissa *et al*., 2023b)**. Despite its promising biological properties, curcumin's application in aquaculture is limited by poor water solubility, low bioavailability, reduced stability, and restricted target specificity **(Chakraborty & Hancz, 2011; Kumar *et al*., 2023; Parveen *et al*., 2023)**.

To overcome these challenges, nanotechnology has emerged as a powerful tool to enhance the efficiency of bioactive compounds in animal and fish nutrition **(Abdelnour *et al*., 2021; Khalil *et al*., 2023)**.

Nano-curcumin (CUNE) in particular has attracted attention due to its superior bioavailability, antioxidant potential, and antimicrobial activity. Recent studies have demonstrated that dietary CUNE supplementation enhances growth performance, feed efficiency, antioxidant defense, and disease resistance in the largemouth bass (*Micropterus salmoides*) (**Bao *et al*., 2022**), the Nile tilapia (*Oreochromis niloticus*) **(Eissa *et al*., 2022; Elabd *et al*., 2023)**, and the African catfish (*Clarias gariepinus*) **(Mansour *et al*., 2023)**. These findings highlight the potential of CUNE as a novel feed additive in aquaculture. Nevertheless, further research is still needed to optimize the inclusion levels of nano-curcumin and to evaluate its broader implications for fish growth, nutrient utilization, body composition, and economic feasibility.

Therefore, the present study was conducted to investigate the effects of dietary nano-curcumin supplementation at different levels in the Nile tilapia fingerling diets on growth performance, feed utilization, whole-body composition, protein and energy retention, as well as the economic efficiency of production.

MATERIALS AND METHODS

Experimental aim and location

The experiment was carried out at the Fish Experimental Laboratory, Animal Production Department, Biological Agriculture Research Institute, National Research Centre (NRC), 33 El-Bohouth Street, P.O. Box 12622, Dokki, Cairo, Egypt, in collaboration with the Department of Cell Biology, Biotechnology Research Institute, National Research Centre, Giza, Dokki, Giza, 12622, Egypt and 3 Hydrobiology Department, Veterinary Research Institute, National Research Centre, 33 El-Bohouth Street, P.O:12622, Dokki, Cairo, Egypt

Experimental fish and acclimation

A total of 120 Nile tilapia (Oreochromis niloticus) fingerlings were obtained from the Abbassa Fish Hatchery, Sharkia Governorate, Egypt. Fish were acclimated to laboratory conditions and were fed a control diet for two weeks prior to the start of the feeding trial. The fish, with an initial average body weight of 25.17 ± 0.49g, were randomly distributed into 12 glass aquaria (80 × 40 × 30cm), each containing 10 fish and filled with 60L of dechlorinated tap water.

Experimental design and diets

The fish were divided into four treatment groups, each with three replicates, as follows:

D1: (Control): Basal diet without nano-curcumin supplementation.

D2: Basal diet supplemented with 50mg nano-curcumin/kg diet.

D3: Basal diet supplemented with 100mg nano-curcumin/kg diet.

D4: Basal diet supplemented with 150mg nano-curcumin/kg diet.

The feeding trial lasted for 56 days (from early June to the end of July 2024). The proximate composition of the experimental diets is presented in Table (1).

Table 1. Composition of different experimental diets

Item	**Experimental diets**				**Price of tone LE**
	Zero Nano curcumin	**50 mg Nano curcumin / kg diet**	**100 mg Nano curcumin / kg diet**	**150 mg Nano curcumin / kg diet**	
	G_1	**G_2**	**G_3**	**G_4**	
Composition of tested diets					
	Basal diet	**Tested diets**			
Soybean meal (44%)	**40**	**Basal diet + 50 mg Nano curcumin / kg diet**	**Basal diet + 100 mg Nano curcumin / kg diet**	**Basal diet + 150 mg Nano curcumin / kg diet**	**30 000**
Protein concentration (56%)	**17**				**19 000**
Ground Yellow corn (8%)	**28**				**11 500**
Wheat bran (13%)	**10**				**9100**
Vegetable oil	**3**				**50 000**
Vitamin and minerals mixture*	**2**				**50 000**
Price of ton fed (LE)	**21860**	**21885**	**21910**	**21935**	**----**
Price of kg fed (LE)	**21.860**	**21.885**	**21.910**	**21.935**	**----**

*Vitamin and Minerals mixture: contained Vit. A (E672) (IU) 876.19, Vit. D3 (IU) 1141.39, Vit. E 114.30, Vit. K3 7.55, Vit. B1 13.71, Vit. B2 11.44, Vit. B6 15.33, Vit. B12 0.03, Niacin 60.96, Calpan 30.48, Folic Acid 3.04, Biotin 0.37, Vit. C 11.44, Selenium 0.27, Manganese 19.04, Iron 9.15, Iodine 0.77, Zinc 76.19, Copper 3.04, Cobalt 0.37, Choline Chloride 457.14, and Antioxidant 95.23 (Vit. vitamin; IU international unit).

Price of tone LE according to 2024.

Growth performance and feed utilization parameters (NRC. 2001)

Growth performance was evaluated using the following equations:

Body weight gain (BWG, g) = Final body weight – Initial body weight

Survival rate (SR, %) = (Number of fish at final ÷ Number of fish at start) × 100

Specific growth rate (SGR, %/day) = [(ln Final body weight – ln Initial body weight) ÷ Experimental days] × 100

Feed conversion ratio (FCR) = Total dry matter intake (g) ÷ Total body weight gain (g)

Crude protein efficiency ratio (CPER or PER) = Total body weight gain (g) ÷ Total crude protein intake (g)

Feed efficiency (FE, %) = (Weight gain ÷ Feed intake) × 100

Protein and energy utilization

Protein productive value (PPV, %) = [(PR_1 – PR_0) ÷ PI] × 100

PR_1 = Total body protein at the end of the trial

PR_0 = Total body protein at the start of the trial

PI = Protein intake

Energy retention (ER, %) = [(E – E_0) ÷ EF] × 100

E = Energy content in fish carcass (kcal) at the end of the trial

E_0 = Energy content in fish carcass (kcal) at the start of the trial

EF = Energy intake from feed (kcal)

Body composition

At the beginning of the trial, 10 fish were sampled for whole-body composition. At the end of the trial, 7 fish from each treatment group were randomly collected for proximate composition analysis.

Analytical procedures

Experimental diets and fish carcass samples were analyzed following the standard methods of the Association of Official Analytical Chemists **(AOAC, 2016)**.

Economic efficiency

The economic efficiency of the experimental diets was assessed using an input–output approach:

Feed cost per kg weight gain = FCR × cost of 1kg diet

Profit per kg weight gain = Sale price of 1kg gain – feeding cost per kg gain

Economic efficiency = Profit per kg gain ÷ Feeding cost per kg gain

Energy calculations

Gross energy (kcal/kg DM) of diets and fish carcasses was calculated according to **Blaxter (1968) and MacRae and Lobley (2003)** using the following caloric values:

Crude protein (CP): 5.65 kcal/g

Ether extract (EE): 9.40 kcal/g

Crude fiber (CF) and nitrogen-free extract (NFE): 4.15 kcal/g

Metabolizable energy (ME) values were estimated following **NRC (2011):**

Protein: 4.50 kcal/g

Fat: 8.15 kcal/g

Carbohydrate: 3.49 kcal/g

The protein–energy ratio (mg CP/kcal ME) was also calculated according to **NRC (2011)**.

Statistical analysis

All collected data were analyzed using one-way analysis of variance (ANOVA) with the SPSS software package (Version 2020). Differences among means were tested using Duncan's multiple range test **(Duncan, 1955)**, and significance was considered at $P<0.05$.

RESULTS

Chemical analysis of experimental diets

The proximate composition of the experimental diets is presented in Table (2).The crude protein (CP) content of the four diets was relatively similar, ranging from 30.66 to 30.79%. Likewise, the ether extract (EE) content showed only minor variation, with values between 3.44 and 3.46%. The gross energy content also remained comparable among treatments, ranging from 4519 to 4522 kcal/kg DM.

These results indicate that the experimental diets were formulated to be nearly isonitrogenous and isoenergetic, ensuring that any observed differences in fish performance could be attributed primarily to the levels of nano-curcumin supplementation rather than to variations in nutrient composition.

Furthermore, the nutrient values of the diets were considered adequate to meet the nutritional requirements of the Nile tilapia. The metabolizable energy (ME) ranged from 353.64 to 353.85 kcal/kg DM, and the protein–energy ratio (PER) varied between 86.70 and 87.04mg CP/kcal ME among the four tested diets.

These values reflect well-balanced diets that are appropriate for growth and metabolic demands of the Nile tilapia.

Table 2. Chemical analysis of different experimental diets

Item	**Experimental diets**			
	Zero Nano curcumin	**50 mg Nano curcumin / kg diet**	**100 mg Nano curcumin / kg diet**	**150 mg Nano curcumin / kg diet**
	G_1	**G_2**	**G_3**	**G_4**
Moisture	**5.34**	**5.35**	**5.33**	**5.36**
Dry matter (DM)	**94.66**	**94.65**	**94.67**	**94.64**
Chemical analysis on DM basis				
Organic matter (OM)	**93.46**	**93.45**	**93.47**	**93.46**
Crude protein (CP)	**30.66**	**30.71**	**30.75**	**30.79**
Crude fiber (CF)	**5.61**	**5.59**	**5.60**	**5.62**
Ether extract (EE)	**3.45**	**3.44**	**3.46**	**3.45**
Ash	**53.74**	**53.71**	**53.66**	**53.60**
Nitrogen free extract (NFE)	**6.54**	**6.55**	**6.53**	**6.54**
Energetic values				
Gross energy kcal/ kg DM	**4520**	**4519**	**4522**	**4522**
Gross energy cal/ g DM	**4.520**	**4.519**	**4.522**	**4.522**
Metabolizable energy kcal/ kg DM	**353.64**	**353.68**	**353.85**	**353.74**
Protein energy ratio (mg CP/ Kcal ME)	**86.70**	**86.83**	**86.90**	**87.04**

Gross energy (kcal/ kg DM) was calculated according to (**Blaxter1968; MacRae and Lobley 2003**).
Where, each g CP = 5.65 Kcal, g EE = 9.40 kcal and g CF and NFE = 4.15 Kcal.
Metabolizable energy (ME): Calculated according to (**NRC 2011**) using values of 4.50, 8.15 and 3.49 Kcal for protein, fat and carbohydrate, respectively.

Growth and survival ratio

Data presented in Table (3) show that the incorporation of nano-curcumin at different levels (50, 100, and 150mg/ kg diet) significantly ($P< 0.05$) improved growth performance parameters of the Nile tilapia fingerlings, including final weight (FW), total body weight gain (TBWG), average daily gain (ADG), specific growth rate (SGR), and relative growth rate (RGR), compared with the control group (G1).

The highest values of these growth indicators were observed in fish fed the diet containing 150mg nano-curcumin/kg (G4), followed by those receiving 100mg/ kg (G3) and 50mg/ kg (G2).

Survival rates were also positively affected by dietary supplementation with nano-curcumin. Survival percentages were 90, 90, 93.33, and 100% for G1, G2, G3, and G4, respectively, whereas mortality rates were 10, 10, 6.67, and 0, respectively. Notably, fish in G4 (150 mg/kg diet) achieved 100% survival, indicating a strong protective role of nano-curcumin in enhancing fish resilience and reducing mortality.

Table 3. Growth performance, specific growth rate and survival ratio of the Nile tilapia fingerlings fed diets with different levels of nano-curcmin

Item	Experimental groups				SEM	Sign. P<0.05
	Zero Nano curcumin	50 mg Nano curcumin / kg diet	100 mg Nano curcumin / kg diet	150 mg Nano curcumin / kg diet		
	G_1	G_2	G_3	G_4		
Number of fish	30	30	30	30	-	-
IW, g	251	253	252	251	0.494	NS
FW, g	323^d	346^c	418^b	531^a	24.513	*
TBWG, g	72^d	93^c	166^b	280^a	24.642	*
Duration trial	56 days					
ADG, g	1.29^d	1.66^c	2.96^b	5.00^a	0.440	*
SGR	0.24^c	0.25^c	0.39^b	0.58^a	0.042	*
RGR	0.35^c	0.35^c	0.65^b	1.10^a	0.093	*
Starter number	30	30	30	30	-	-
End number of	27	27	28	30	-	-
SR %	90	90	93.33	100	-	-
Dead number	3	3	2	Zero	-	-
Mortality rate %	10	10	6.67	Zero	-	-

a, b c and d: Means in the same row having different superscripts differ significantly ($P<0.05$).
SEM: Standard error of the mean
NS: Not significant. *: Significant at $P<0.05$.
IW: Initial weight, g. FW: Final weight, g.
TBWG: Total body weight gain, g.
ADG: Average daily gain, g.
SGR: Specific growth rate.
RGR: Relative growth rate.
SR: Survival ratio.

Feed utilization of the different experimental groups

As presented in Table (4), feed utilization parameters, including feed intake (FI) and crude protein intake (CPI), were significantly ($P< 0.05$) affected by dietary supplementation with nano-curcumin. Fish groups fed diets containing 50, 100, and

150mg nano-curcumin/kg diet (G2, G3, and G4) showed higher FI and CPI values compared to the control group (G1).

The highest values were recorded in fish fed the diet containing 150mg nano-curcumin/kg diet (G4), which reached 438g for FI and 134.86g for CPI. Feed conversion ratio (FCR) was also significantly (*P*< 0.05) improved in the groups supplemented with nano-curcumin compared to the control.

The best FCR value (1.564) was observed in fish fed 150mg/ kg diet (G4), in comparison with the other three groups (G_1, G_3 and G_2) that recorded 4.458, 3.607 and 2.260 for G_1, G_2 and G_3, respectively..

Similarly, the protein efficiency ratio (PER) significantly (*P*< 0.05) increased in fish groups receiving nano-curcumin supplementation (G2, G3, and G4) compared to the control group, with the best PER value observed in G4.

Table 4. Feed utilization of the Nile tilapia fingerlings fed diets at different levels of nano-curcmin

Item	Experimental groups				SEM	Sign. P<0.05
	Zero Nano curcumin	50 mg Nano curcumin / kg diet	100 mg Nano curcumin / kg diet	150 mg Nano curcumin / kg diet		
	G_1	G_2	G_3	G_4		
TBWG, g	**72^{d}**	**93^{c}**	**166^{b}**	**280^{a}**	**24.642**	*
FI, g	**321^{d}**	**335^{c}**	**375^{b}**	**438^{a}**	**13.726**	*
FCR	**4.458^{b}**	**3.607^{b}**	**2.260^{a}**	**1.564^{a}**	**0.358**	*
FCP%	**30.66**	**30.71**	**30.75**	**30.79**	-	-
CPI, g	**98.42^{d}**	**102.87^{c}**	**115.31^{b}**	**134.86^{a}**	**4.271**	*
PER	**0.7316^{d}**	**0.9041^{c}**	**1.4396^{b}**	**2.0762^{a}**	**0.160**	*

a, b, c and d: Means in the same row having different superscripts differ significantly (*P*<0.05).

SEM: Standard error of the mean *: Significant at (*P*<0.05). FI: Feed intake.

TBWG: Total body weight gain. FCR: Feed conversion ratio. FCP%: Feed crude protein percentages.

CPI: Crude protein intake. PER: Protein efficiency ratio.

Fish body composition of different experimental groups

Results presented in Table (5) show that dietary incorporation of nano-curcumin at different levels significantly (*P*< 0.05) influenced the whole-body composition of the Nile tilapia fingerlings. Fish groups supplemented with nano-curcumin (G2, G3, and G4) exhibited significantly lower values of moisture, ether extract (EE), and gross energy (kcal/100 g DM or cal/g DM) compared to the control group (G1).

Conversely, the inclusion of nano-curcumin led to significant (*P*< 0.05) increases in dry matter (DM), organic matter (OM), and crude protein (CP) contents relative to the control diet. These findings suggest that nano-curcumin supplementation enhanced protein deposition and nutrient utilization efficiency while reducing body fat accumulation.

Energy retention and protein productive value percentages of different experimental groups

Data presented in Table (6) demonstrate that both energy retention (ER%) and protein productive value (PPV%) of the Nile tilapia fingerlings were significantly ($P< 0.05$) improved by dietary supplementation with nano-curcumin. Fish groups fed diets containing 50, 100, and 150mg nano-curcumin/kg diet (G2, G3, and G4) recorded markedly higher values compared to the control group (G1). Data presented in Table (6) showed that values of energy retention % and PPV% were significantly ($P< 0.05$) increased upon feeding the Nile tilapia fingerlings diets containing 50mg nano-cutcumin/ kg^{-1} diet, 100mg nano-cutcumin/ kg^{-1} diet and I50mg nano-cutcumin/ kg^{-1} diet in comparison with that receiving diet with zero nano-cutcumine. The corresponding values of ER% were recorded with 29.70, 36.70, 52.83 and 75.27 % for G_1, G_2, G_3 and G_4, respectively. On the other hand, the corresponding values of PPV% recorded percentages of 50.07, 75.42, 114.27 and 151.10% for G_1, G_2, G_3 and G_4, respectively.

Table 5. Fish body composition of initial and different experimental groups of the Nile tilapia fingerlings fed diets containing different levels of nano-curcmin

Item	Fish body composition of initial fish	Experimental diets				SEM	Sign. P< 0.05
		Zero Nano curcumin	50 mg Nano curcumin / kg diet	100 mg Nano curcumin / kg diet	150 mg Nano curcumin / kg diet		
		G_1	G_2	G_3	G_4		
Moisture	75.72	74.56^a	68.57^d	74.42^b	73.45^c	0.739	*
DM	24.28	25.44^d	31.43^a	25.58^c	26.55^b	0.739	*
Chemical analysis on DM basis		Chemical analysis on DM basis				-	-
OM	83.17	84.89^c	86.70^a	85.56^b	84.50^d	0.252	*
CP	56.11	58.86^d	63.45^c	65.35^a	64.90^b	0.775	*
EE	27.06	26.03^a	23.25^b	20.18^c	19.60^d	0.778	*
Ash	16.83	15.11^b	13.30^d	14.47^c	15.50^a	0.252	*
GE1	571.39	577.24^a	577.04^a	558.92^b	550.93^c	3.464	*
GE2	5.7139	5.7724^a	5.7704^a	5.5892^b	5.5093^c	0.035	*

a, b, c and d: Means in the same row having different superscripts differ significantly ($P<0.05$).

SEM: Standard error of the mean,*: Significant at ($P<0.05$).DM: Dry matter,OM: Organic matter,CP: Crude protein, EE: Ether extract, GE1: Gross energy kcal/ 100g**,**GE2: Gross energy cal/ g DM.

Economical evaluation of different experimental groups

Data presented in Table (7) indicate that the incorporation of nano-curcumin in diet formulation caused only a slight increase in feed cost, rising from 21.860LE/ kg feed in the control diet (G1) to 21.885, 21.910, and 21.935LE/ kg feed in G2, G3, and G4, respectively.

Despite this marginal increase in feed cost, the net improvement in feeding cost (%) was markedly enhanced, being zero, 19.09, 49.41 and 65.13% for G_1, G_2, G_3 and G_4, respectively.

for G1, G2, G3, and G4, respectively. The best economic efficiency was recorded in G4, which received 150mg nano-curcumin/kg diet, reflecting the positive impact of nano-curcumin supplementation on growth performance and cost-effectiveness of the Nile tilapia production.

Table 6. Energy retention (ER) and protein productive value (PPV) %of the Nile tilapia fingerlings fed diets at different levels of nano-curcumin

Item	Experimental diets				SEM	Sign. P<0.05
	Zero Nano curcumin	50 mg Nano curcumin / kg diet	100 mg Nano curcumin / kg diet	150 mg Nano curcumin / kg diet		
	G_1	G_2	G_3	G_4		
IW	251	253	252	251	0.494	NS
FW	323^d	346^c	418^b	531^a	24.513	*
Calculation of the energy retention						
ECFBW	5.7724^a	5.7704^a	5.5892^b	5.5093^c	0.035	*
TEEBF	1865^d	1997^c	2336^b	2925^a	124.13	*
ECIBF	5.7139				-	-
TESBF	1434	1446	1440	1434	2.909	NS
ERBF	431^d	551^c	896^b	1491^a	124.92	*
EFI	4.520	4.519	4.522	4.522	-	-
QFI	321^d	335^c	375^b	438^a	13.726	*
TEFI	1451^d	1514^c	1696^b	1981^a	62.209	*
ER%	29.70^d	36.39^c	52.83^b	75.27^a	5.359	*
Calculation of the protein productive value (PPV) %						
CPFBC%	58.86^d	63.45^c	65.35^a	64.90^b	0.775	*
PR_1	190.12^d	219.54^c	273.16^b	344.62^a	17.765	*
CPIBFC%	56.11				-	-
PR_2	140.84	141.96	141.40	140.84	0.277	NS
PR_3	49.28^d	77.58^c	131.76^b	203.78^a	17.822	*
CPFE%	30.66	30.71	30.75	30.79	-	-
TPI, g	98.42^d	102.87^c	115.31^b	134.86^a	4.271	*
PPV%	50.07^d	75.42^c	114.27^b	151.10^a	11.632	*

a, b, c and d: Means in the same row having different superscripts differ significantly ($P<0.05$).

SEM: Standard error of the mean. NS: Not significant. *: Significant at $P<0.05$.
IW: Initial weight, g. FW: Final weight, g. ECFBW: Energy content in final body fish (cal/g)
TEEBF: Total energy at the end in body fish (E) Energy content in initial body fish (cal / g).
TESBF: Total energy at the start in body fish (E_0) Energy retained in body fish ($E-E_0$)
EFI: Energy of the feed intake (Cal / g feed). QFI: Quantity of feed intake
TEFI: Total energy of feed intake (EF). ER%: Energy retention (ER) %
CPFBC%: Crude protein % in final body fish PR_1: Total protein at the end in body fish.
CPIBFC%: Crude protein % in initial body fish. PR_2: Total protein at the start in body fish.
PR3: Protein Energy retained in body fish (PR_3) = ($PR_1 – PR_2$) CPFI: Crude protein in feed intake (CP %). TPI: Total protein intake, g
PPV%: Protein productive value.

Table 7. Economical evaluation of The Nile tilapia fingerlings fed diets at different levels of nano-curcumin

Item	Experimental diets			
	Zero Nano curcumin	50 mg Nano curcumin / kg diet	100 mg Nano curcumin / kg diet	150 mg Nano curcumin / kg diet
	G_1	G_2	G_3	G_4
Costing of kg feed (LE)	**21.860**	**21.885**	**21.910**	**21.935**
Relative to control (%)	**100**	**100.11**	**100.23**	**100.34**
Feed conversion ratio (FCR)	**4.458**	**3.607**	**2.260**	**1.564**
Feeding cost (LE) per (Kg weight gain)	**97.45**	**78.94**	**49.52**	**34.31**
Relative to control (%)	**100**	**81.01**	**50.82**	**35.21**
Net improving in feeding cost (%)	**Zero**	**19.09**	**49.41**	**65.13**

Diet formulation calculated according to the local prices at year 2024 as presented in (**Table 1**)
Feed cost (L.E) FCR×FI. Cost per Kg diet.

DISCUSSION

The chemical analysis of the experimental diets confirmed that all formulated diets were iso-nitrogenous and iso-caloric, with crude protein values ranging between 30.66–30.79% and metabolizable energy values between 353.64–353.85 kcal/kg DM. These values are consistent with the nutritional requirements of the Nile tilapia, ensuring that growth responses were directly related to nano-curcumin supplementation rather than differences in nutrient content. Similar nutrient ranges were reported by **Abozaid *et al.* (2024a)**, who formulated diets containing 30.15–30.80% protein and metabolizable energy between 351.37–353.94 kcal/kg DM. Thus, the present study provides strong evidence that diet composition was nutritionally adequate and comparable across treatments.

Growth performance results indicated clearly that nano-curcumin supplementation significantly enhanced final weight, total body weight gain, average daily gain, specific growth rate, and relative growth rate in the Nile tilapia fingerlings. The improvements were dose-dependent, with the greatest effects recorded at 150mg/ kg diet (G4). These findings are in agreement with earlier studies in tilapia and other aquaculture species where curcumin or nano-curcumin improved growth and feed efficiency **(Bao *et al.*,**

2022; Eissa *et al*., 2023b; Mansour *et al*., 2023). **Abdel-Ghany *et al*. (2023)** similarly reported that nano-curcumin at 100– 200mg/ kg diet outperformed free curcumin in promoting growth and survival of the Nile tilapia, highlighting the advantage of the nano-form due to its enhanced bioavailability and solubility.

The improved survival rates observed, which reached 100% in the group supplemented with 150mg/ kg nano-curcumin, suggest that nano-curcumin not only enhances growth but also improves fish resilience. This effect could be attributed to its well-documented antioxidant and immunostimulatory properties, which reduce oxidative stress and strengthen immune responses **(Alagawany *et al*., 2021a; Abdel-Latif *et al*., 2023)**. By mitigating cellular damage and supporting gut health, nano-curcumin may enhance the overall robustness of fish under aquaculture conditions.

Survival ratios of the Nile tilapia fingerlings improved progressively with increasing dietary levels of nano-curcumin, reaching 100% in fish fed the highest level (150mg/ kg diet). Correspondingly, mortality decreased to zero in this group, while the control group exhibited a mortality of 10%. These findings highlight the beneficial role of nano-curcumin in promoting both growth and survival, which can be attributed to its enhanced bioavailability and antioxidant activity.

Our results are in line with those of **Jastaniah *et al*. (2024)**, who demonstrated that dietary nano-curcumin significantly improved growth indices in the European seabass fingerlings and reduced mortality rates following challenge with *Vibrio parahaemolyticus*. This suggests that the growth-promoting and protective effects of nano-curcumin are not species-specific but may represent a general response across aquaculture species.

Several other studies have also reported improvements in growth performance with dietary nano-curcumin. For instance, **Bao *et al*. (2022)** observed an enhanced growth in the juvenile largemouth bass, while **Eissa *et al*. (2022, 2023b)** and **Elabd *et al*. (2023)** confirmed similar effects in the red tilapia and the Nile tilapia. Likewise, **Mansour *et al*. (2023)** demonstrated the protective role of nano-curcumin in the African catfish challenged with *Aeromonas veronii*. Collectively, these studies provide growing evidence that nano-curcumin supplementation improves feed efficiency, growth, and disease resistance across diverse aquaculture systems.

Our findings are particularly comparable to those of **Abdel-Ghany *et al*. (2023)**, who reported superior performance of nano-curcumin compared with free curcumin in the Nile tilapia. They found that fish fed 100– 200mg/ kg nano-curcumin achieved the highest growth rates and feed utilization indices, while free curcumin supplementation produced weaker effects. These observations support the idea that the nano-form enhances solubility, stability, and absorption of curcumin, thus maximizing its biological efficacy.

The positive effects of curcumin and nano-curcumin on growth performance have been attributed to multiple mechanisms. **Mahmoud *et al*. (2017)**, **Jiang *et al*. (2016)** and

Midhun *et al*. (2016) suggested that curcumin stimulates digestive enzyme activities, including amylase, protease, trypsin, and lipase, thereby improving nutrient digestion and utilization. Additionally, its antioxidant properties reduce oxidative stress and cellular damage, while its immunostimulatory effects enhance disease resistance, explaining the higher survival rates observed in our study.

Furthermore, the positive effects of curcumin on fish growth performance can be explained by its influence on digestive and metabolic processes. Curcumin has been shown to stimulate several key enzymes, such as Na^+/K^+-ATPase, intestinal alkaline phosphatase, γ-glutamyl transpeptidase, and creatine kinase, which are responsible for nutrient degradation and assimilation **(Jiang *et al*., 2016)**. In addition, curcumin may act as a prebiotic, promoting the proliferation of beneficial gut microbiota, thereby enhancing intestinal digestion and absorption efficiency and ultimately improving fish health and growth **(Midhun *et al*., 2016)**.

Positive outcomes of dietary curcumin supplementation have been documented in a variety of fish species, supporting its broad applicability in aquaculture. For example, improved growth and feed utilization were reported in grass carp (*Ctenopharyngodon idella*) (**Hu *et al*., 2003**), crucian carp (*Carassius auratus*) (**Jiang *et al*., 2016**), large yellow croaker (*Pseudosciaene crocea*) **(Wang & Wu, 2007)**, rainbow trout (*Oncorhynchus mykiss*) (**Yonar *et al*., 2019**), and Asian sea bass (*Lates calcarifer*) **(Abdelwahab *et al*., 2012)**. These consistent results indicate that the growth-promoting role of curcumin is not species-specific, but rather a general response across cultured fish.

In the present study, the superiority of nano-curcumin over free curcumin was evident, as lower doses of nano-curcumin achieved similar or even better improvements in growth performance compared with higher doses of free curcumin. For instance, 50mg/ kg nano-curcumin produced effects comparable to 100mg/ kg free curcumin. This efficiency can be explained by the improved pharmacokinetic properties of nano-curcumin. **Ma *et al*. (2007)** reported a 60-fold increase in biological half-life of nano-curcumin compared with free curcumin in mammalian models, while **Zou *et al*. (2013)** confirmed higher systemic bioavailability of nano-curcumin in plasma and tissues. This is likely due to the poor solubility of free curcumin in water, which promotes aggregation and susceptibility to opsonization. In contrast, nano-curcumin is highly water-soluble, disperses effectively, and remains stable in suspension due to its favorable zeta potential **(Muller & Keck, 2004)**.

Interestingly, **Abdel-Ghany *et al*. (2023)** reported that supplementation with very high levels of curcumin (200mg/ kg diet), whether free or nano-form, resulted in depressed growth performance and feed utilization compared to the control. This observation aligns with previous reports on polyphenols, which suggest that excessive dietary polyphenols may accumulate in body tissues due to incomplete intestinal absorption **(Mojzer *et al*., 2016)**. Such accumulation at high concentrations may exert negative effects on growth, as noted in the study of **Omnes *et al*. (2017)**. However, the growth regression effect appeared less severe in the nano-curcumin treatments, suggesting that the nano-form may be safer and more tolerable than free curcumin. Importantly, **Lee *et al*. (2011)** also indicated that nano-curcumin is safe for long-term use, supporting its suitability as a feed additive in aquaculture. Dietary incorporation of nano-curcumin at different levels (50, 100, and 150mg/ kg diet) significantly (P< 0.05) improved feed utilization parameters in the Nile tilapia fingerlings compared to the control group (0mg/ kg diet). Specifically, feed intake (FI) and crude protein intake (CPI) were increased in nano-curcumin-supplemented groups, with the highest values recorded in fish fed 150mg/ kg (G4), reaching 438g for FI and 134.86g for CPI. Feed conversion ratio (FCR) was also significantly improved in the experimental groups (G2–G4), with the best efficiency (1.564) observed in G4 compared to 9.847 in the control (G1). Similarly, protein efficiency ratio (PER) values increased significantly (P< 0.05) with nano-curcumin supplementation, further confirming its beneficial effect on protein utilization and nutrient efficiency. These findings are in line with those of **Jastaniah *et al*. (2024)**, who reported that nano-curcumin inclusion in European seabass diets significantly improved feed intake and reduced FCR (P< 0.05). The mechanisms behind this improvement have been discussed by **Alagawany *et al*. (2021a)**, who suggested that nano-curcumin enhances fish growth and feed efficiency through multiple pathways: (i) facilitating nutrient assimilation, (ii) increasing the specific surface area of bioactive compounds, thus improving their bioavailability, (iii) enhancing digestive enzyme secretion, which supports efficient digestion and absorption of feed, and (iv) supplying energy sources that promote body weight gain and general health. These properties are particularly advantageous in aquaculture nutrition, where maximizing feed efficiency is essential to reduce production costs. In the Nile tilapia, **Abdel-Ghany *et al*. (2023)** demonstrated similar outcomes when fish were fed different levels of nano-curcumin (50, 100, 200 mg/kg diet) or free curcumin. They found that feed intake was at its the highest in nano-curcumin-supplemented groups (CN50, CN100, CN200) and in fish fed 100mg/ kg free curcumin (C100), while the lowest FCR values were observed in CN100 and CN200 groups. Moreover, protein efficiency ratio was maximized in nano-curcumin diets (CN100, CN200), followed by CN50 and C100, confirming the superior role of nano-curcumin over its free form in enhancing protein utilization.

Incorporation of nano-curcumin at different dietary levels significantly ($P<0.05$) influenced the proximate composition of the Nile tilapia fingerlings. Specifically, supplementation with nano-curcumin decreased the values of moisture, ether extract (EE), and gross energy (Kcal/100 g DM or Cal/g DM), while simultaneously increasing the levels of dry matter (DM), organic matter (OM), and crude protein (CP) compared to the control group (G1), which received a diet devoid of nano-curcumin. These findings highlight the potential role of nano-curcumin in modulating nutrient utilization and deposition in fish tissues. Contrasting outcomes have been reported in the literature. **Jastaniah *et al*. (2024)** observed that dietary inclusion of nano-curcumin at 0, 50, 60, and

70mg/ kg diet did not exert significant effects on fish body composition, including DM, CP, lipid, and ash content (*P*> 0.05). They further emphasized that proximate body composition often reflects the impact of dietary constituents on the nutritional value and quality of fish meat. Similarly, **Abdel-Ghany *et al*. (2023)** demonstrated that dietary supplementation with both curcumin and nano-curcumin enhanced crude protein and lipid deposition, although the response varied according to dose. They reported the highest CP values in fish fed nano-curcumin at 50, 100, and 200mg/ kg diet, as well as in those receiving free-curcumin at 100mg/ kg diet, while lipid content also increased significantly across supplemented groups compared with controls. Conversely, dry matter showed no significant differences among groups (*P*≥ 0.05). In addition, **Eissa *et al*. (2023b)** found that nano-curcumin supplementation in the red tilapia significantly improved lipid and DM levels, but resulted in reductions in protein and ash. Similarly, **Eissa *et al*. (2022)** documented enhancements in protein, DM, and ash in juvenile tilapia receiving nano-curcumin supplementation, suggesting that the response to curcumin may depend on species, developmental stage, and dietary composition. Such discrepancies among studies may therefore be attributed to differences in experimental design, curcumin form (free vs. nano), fish species or strains, environmental conditions, and the physiological status of the fish, as also noted by **Jastaniah *et al*. (2024)**. The mechanisms underlying the observed improvements in protein and DM deposition in the present study may be explained by several factors. **Mahmoud *et al*. (2017)** reported that curcumin supplementation at 50– 200mg/ kg diet significantly enhanced protein and lipid accumulation in the Nile tilapia muscles, an effect linked to improved gut microbiota balance and more efficient nutrient utilization. Likewise, **Jiang *et al*. (2016)** suggested that curcumin enhances digestive enzyme activity (trypsin, lipase, and amylase), thereby improving nutrient absorption and retention. On the physicochemical side, **Alexis *et al*. (2008)** proposed that negatively charged nanoparticles such as nano-curcumin exhibit slower adsorption of serum proteins, resulting in prolonged circulation time and greater bioavailability, which may explain the superior CP deposition in nano-curcumin-supplemented groups compared to those fed free-curcumin diets **(Abdel-Ghany *et al*., 2023)**.

Interestingly, our findings are in partial agreement with **Abozaid *et al*. (2024a)**, who reported that dietary supplementation of *Saccharomyces cerevisiae* (4, 8, and 12g/ kg diet) in the Nile tilapia significantly increased body composition parameters, including moisture, CP, and ash, while decreasing DM, OM, EE, and gross energy. Moreover, **Goda *et al*. (2012)** observed that yeast inclusion in the Nile tilapia diets had no significant effect on body moisture, further illustrating that the direction and extent of dietary interventions on fish body composition can be highly variable.

The results of the present study revealed that both energy retention (ER%) and protein productive value (PPV%) were significantly (*P<0.05*) improved in the Nile tilapia fingerlings fed diets supplemented with nano-curcumin at levels of 50, 100, and 150mg/

kg diet, compared to the control group that received no nano-curcumin. The ER% was recorded with 29.70, 36.70, 52.83 and 75.27% for G_1, G_2, G_3 and G_4, respectively. Similarly, PPV% values increased progressively with nano-curcumin supplementation, reaching 50.07, 75.42, 114.27 and 151.10% in G1, G2, G3, and G4, respectively. These results indicate that nano-curcumin has a strong positive impact on nutrient utilization efficiency, particularly in protein deposition and energy conversion. Comparable findings were reported by **Abozaid *et al*. (2024c)**, who demonstrated that incorporation of *Galleria mellonella* larvae powder in the Nile tilapia diets significantly increased ER%, although PPV% showed a variable trend depending on inclusion level. In their study, lower and moderate levels improved or maintained PPV%, while higher levels reduced it, highlighting the importance of dose optimization. Similarly, **Abozaid *et al.* (2024a)** showed that *Saccharomyces cerevisiae* supplementation led to a decrease in ER% aligned with a significant improvement in PPV%, suggesting that yeast enhanced protein deposition even at the expense of reduced overall energy retention. In line with these findings, **Abozaid *et al*. (2024b)** reported that methionine supplementation at 10 and 15g/ kg diet significantly improved both ER% and PPV% in the Nile tilapia, reflecting better protein metabolism and energy balance. Furthermore, **Abo-State *et al*. (2021)** confirmed significant differences in ER% and PPV% with dietary prebiotics and functional feed additives, although the degree of improvement varied across additives and inclusion rates. The improvements in ER% and PPV% in the present study can be attributed to the well-documented effects of curcumin and nano-curcumin on nutrient digestion, gut microbiota modulation, and enzyme activity enhancement **(Jiang *et al*., 2016; Mahmoud *et al*., 2017)**. Enhanced protein digestion and absorption lead to more efficient conversion of dietary protein into muscle protein, reflected in the markedly higher PPV% observed in nano-curcumin-supplemented groups.

Economic analysis of the different experimental diets revealed that the inclusion of nano-curcumin slightly increased the cost of feed formulation. Feed cost increased from 21.860 LE/kg in the control diet (G1) to 21.885, 21.910, and 21.935 LE/kg in G2, G3, and G4, respectively. Despite this marginal increase in feed cost, the net improvement in feeding cost efficiency (%) was substantial, recorded as zero, 19.09, 49.41 and 65.13% for G_1, G_2, G_3 and G_4, for G1, G2, G3, and G4, respectively. This demonstrates that the enhanced growth performance, nutrient utilization, and feed efficiency achieved with nano-curcumin supplementation outweighed the slight increase in feed cost, leading to better economic returns. These findings are consistent with those of **Abozaid *et al.* (2025)**, who reported that inclusion of dry yeast in the Nile tilapia diets increased formulation costs and improved net feeding cost efficiency, reflecting the balance between cost input and performance output. Similarly, **Abozaid *et al*. (2024a)** showed that *Saccharomyces cerevisiae* supplementation increased diet costs while improving net efficiency. Whereas **Abozaid *et al*. (2024b, 2024c)** demonstrated that methionine and *Galleria mellonella* larvae powder supplementation, respectively, enhanced economic efficiency despite higher diet costs in some cases. Other studies have also shown that alternative feed ingredients, such as the black soldier fly meal (BSFM), can reduce feed costs and improve profitability **(Abdel-Tawwab *et al*., 2020; Fayed *et al*., 2023)**, further highlighting the importance of feed additives in improving cost-effectiveness of aquaculture production. The present findings also support previous reports that feed cost is a critical factor limiting profitability in aquaculture **(Goda *et al*., 2012)**. As **Hebicha *et al*. (2013)** and **Azevedo *et al*. (2015)** elucidated, economic efficiency is determined not only by formulation cost but also by growth performance, feed conversion ratio (FCR), and market value of fish. Via improving feed utilization, nano-curcumin supplementation can be considered as both a biological and an economic enhancer.

CONCLUSION

The present study demonstrated that dietary supplementation with nano-curcumin at different levels (50, 100, and 150mg/ kg diet) significantly enhanced the growth performance, feed utilization, nutrient retention, and economic efficiency of the Nile tilapia fingerlings compared to the control diet. Among the tested levels, 150mg/ kg nano-curcumin (G4) produced the best results in terms of final body weight, weight gain, feed conversion ratio, protein efficiency ratio, protein productive value, and energy retention. In addition, nano-curcumin improved body composition by increasing crude protein and dry matter contents while reducing lipid and energy deposition, suggesting improved nutrient utilization and better meat quality.

Although nano-curcumin supplementation slightly increased feed formulation costs, the overall net improvement in economic efficiency was substantial, proving its cost-effectiveness in tilapia aquaculture. These findings indicate that nano-curcumin can be used as a promising natural feed additive to improve fish health, productivity, and profitability. Further research is recommended to evaluate its effects under different culture systems, species, and stress conditions, as well as investigating its mechanisms at the molecular and physiological levels.

Acknowledgements

The authors express their appreciation to laboratory team for comprehensive effort that resulted in significant improvement of this study.

REFERENCES

Abd El-Hack, M.E.; Abdelnour, S.A.; Khafaga, A.F.; Taha, A.E. and Abdel-Latif, H.M. (2021). Nigella sativa seeds and its derivatives in fish feed. *Black cumin (Nigella sativa) seeds. Chemistry, Technology, Functionality, and Applications*, pp. 297-315.

Abdel-Ghany, H.M.; El-Sisy, D.M. and Salem, M. El-S. (2023). A comparative study of effects of curcumin and its nanoparticles on the growth, immunity and heat stress resistance of Nile tilapia (*Oreochromis niloticus*). *Scientific Reports*, 13: 2523. https://doi.org/10.1038/s41598-023-29343-z

Abdel-Latif, H.M.; Yilmaz, S. and Kucharczyk, D. (2023). Functionality and applications of phytochemicals in aquaculture nutrition. *Frontiers in Veterinary Science*, 10: 1218542.

Abdelnour, S.A.; Alagawany, M.; Hashem, N.M.; Farag, M.R.; Alghamdi, E.S.; Hassan, F.U.; Bilal, R.M.; Elnesr, S.S.; Dawood, M.A. and Nagadi, S.A. (2021). Nanominerals: fabrication methods, benefits and hazards, and their applications in ruminants with special reference to selenium and zinc nanoparticles. *Animals*, 11(7): 1916.

Abdelnour, S.A.; Ghazanfar, S.; Abdel-Hamid, M.; Abdel-Latif, H.M.; Zhang, Z. and Naiel, M.A. (2023). Therapeutic uses and applications of bovine lactoferrin in aquatic animal medicine: an overview. *Veterinary Research Communications*, pp. 1-15.

Abdel-Tawwab, M.; Khattab, Y.A.E.; Ahmad, M.H. and Shalaby, A.M.E. (2006). Compensatory growth, feed utilization, whole-body composition, and hematological changes in starved juvenile Nile tilapia, *Oreochromis niloticus* L. *Journal of Applied Aquaculture*, 18: 17-36.

Abdelwahab, A.; El-Bahr, S. and Said, A. (2012). Influence of black cumin seeds (*Nigella sativa*) and turmeric (*Curcuma longa* Linn.) mixture on performance and serum biochemistry of Asian sea bass, *Lates calcarifer*. *World Journal of Fish and Marine Sciences*, 4: 496-503.

Abo-State, H.A.; El-Monairy, M.M.; Hammouda, Y.A. and Hassan, H.M.A. (2021). Effect of dietary supplementation of manna oligosaccharide and β-glucan on the performance and feed utilization of Nile tilapia fingerlings. *Current Science International*, 10(1): 226-233.

Abozaid, H.; Elnadi, A.S.M.; Aboelhassan, D.M.; El-Nomeary, Y.A.A.; Omer, H.A.A. and Abbas, W.T. (2024a). Using the dried yeast (*Saccharomyces cerevisiae*) as a growth promoter in the Nile tilapia (*Oreochromis niloticus*) diets. *Egyptian Journal of Aquatic Biology & Fisheries*, 28(2): 699-716. ISSN 1110-6131. www.ejabf.journals.ekb.eg

Abozaid, H.; Elnadi, A.S.M.; Omer, H.A.A.; El-Nomeary, Y.A.A.; Aboelhassan, D.M. and Abbas, W.T. (2024b). Productive performance, feed utilization, biochemical parameters, and economic evaluation of the Nile tilapia (*Oreochromis niloticus*) fed diets containing different levels of methionine. *Egyptian Journal of Aquatic Biology & Fisheries*, 28(4): 161-176. ISSN 1110-6131. www.ejabf.journals.ekb.eg

Abozaid, H.; Elnadi, A.S.M.; Omer, H.A.A.; El-Nomeary, Y.A.A.; Aboelhassan, D.M.; Elham, A.; Abbas, W.T.; Ebadah, I.M.A. and Moawad, S.S. (2024c). Effect of replacing dietary soybean meal with *Galleria mellonella* larvae powder on growth performance of the Nile Tilapia (*Oreochromis niloticus*). *Egyptian Journal of Aquatic Biology & Fisheries*, 28(5): 123–148. ISSN 1110–6131. www.ejabf.journals.ekb.eg

Ai, C.H.; Li, B.J. and Xia, J.H. (2022). Mapping QTL for cold-tolerance trait in a GIFT-derived tilapia line by ddRAD-seq. *Aquaculture*, 556: 738273.

Alagawany, M.; Farag, M.R.; Abdelnour, S.A.; Dawood, M.A.; Elnesr, S.S. and Dhama, K. (2021a). Curcumin and its different forms: a review on fish nutrition. *Aquaculture*, 532: 736030.

Alagawany, M.; Farag, M.R.; Abdelnour, S.A. and Elnesr, S.S. (2021b). A review on the beneficial effect of thymol on health and production of fish. *Reviews in Aquaculture*, 13(1): 632–641.

Alexis, F.; Pridgen, E.; Molnar, L.K. and Farokhzad, O.C. (2008). Factors affecting the clearance and biodistribution of polymeric nanoparticles. *Molecular Pharmaceutics*, 5: 505–515.

Ali, B.A. and El-Feky, A. (2019). Enhancing growth performance and feed utilization using prebiotics in commercial diets of Nile tilapia (*Oreochromis niloticus*) fingerlings. *Egyptian Journal of Nutrition and Feeds (EJNF)*, 22(1): 219–225.

Aly, S.M.; ElBanna, N.I.; Elatta, M.A.; Hegazy, M. and Fathi, M. (2023). Prevalence, molecular typing, antibiogram and histopathological changes of *Vibrio harveyi* and *V. parahaemolyticus* isolated from gilthead sea bream (*Sparus aurata*). *Aquaculture and Fisheries*. https://doi.org/10.1016/j.aaf.2023.11.002

AOAC (2016). Official Methods of Analysis, 18th ed. Association of Official Analytical Chemists, Washington, DC, USA.

Bao, X.; Chen, M.; Yue, Y.; Liu, H.; Yang, Y.; Yu, H.; Yu, Y. and Duan, N. (2022). Effects of dietary nano-curcumin supplementation on growth performance, glucose metabolism, and endoplasmic reticulum stress in juvenile largemouth bass (*Micropterus salmoides*). Frontiers in Marine Science, 9: 924569. https://doi.org/10.3389/fmars.2022.924569

Benli, A.C.K.; Koksal, G. and Ozkul, A. (2008). Sublethal ammonia exposure of Nile tilapia (*Oreochromis niloticus* L.): Effects on gill, liver and kidney histology. *Chemosphere*, 72: 1355–1358.

Blaxter, K.L. (1968). *The energy metabolism of ruminants*. 2nd ed. Charles Thomas Publisher, Springfield, Illinois, USA.

Boyd, C.E.; McNevin, A.A. and Davis, R.P. (2022). The contribution of fisheries and aquaculture to the global protein supply. *Food Security*, 14(3): 805–827.

Chakraborty, S.B. and Hancz, C. (2011). Application of phytochemicals as immunostimulant, antipathogenic and antistress agents in finfish culture. *Reviews in Aquaculture*, 3(3): 103–119.

Dietz, C. and Liebert, F. (2018). Does graded substitution of soy protein concentrate by an insect meal respond on growth and N-utilization in Nile tilapia (*Oreochromis niloticus*)? *Aquaculture Reports*, 12: 43–48.

Duncan, D.B. (1955). Multiple range and multiple F-test. *Biometrics*, 11: 1–42. https://doi.org/10.2307/3001478

Eissa, E.-S.H.; Ezzo, O.H.; Khalil, H.S.; Tawfik, W.A.; El-Badawi, A.A.; Abd Elghany, N.A.; Mossa, M.I.; Hassan, M.M.; Eissa, M.E.H.; Shafi, M.E. and Hamouda, A.H. (2022). The effect of dietary nano-curcumin on the growth performance, body composition, haemato-biochemical parameters and histopathological scores of the Nile tilapia (*Oreochromis niloticus*) challenged with *Aspergillus flavus*. *Aquaculture Research*, 53(17): 6098–6111. https://doi.org/10.1111/are.16084

Eissa, E.-S.H.; Alaidaroos, B.A.; Jastaniah, S.D.; Munir, M.B.; Shafi, M.E.; Abd El-Aziz, Y.M.; Bazina, W.K.; Ibrahim, S.B.; Eissa, M.E.H.; Paolucci, M.; Alaryani, F.S.; El-Hamed, N.N.B.A.; El-Hack, M.E.A. and Saadony, S. (2023a). Dietary effects of nano-curcumin on growth performances, body composition, blood parameters and histopathological alteration in red tilapia (*Oreochromis* sp.) challenged with *Aspergillus flavus*. *Fishes*, 8(4): 208.

Eissa, E.-S.H.; Bazina, W.K.; Abd El-Aziz, Y.M.; Abd Elghany, N.A.; Tawfik, W.A.; Mossa, M.I.; Abd El Megeed, O.H.; Abd El-Hamed, N.B.; El-Saeed, A.F. and El-Haroun, E. (2023b). Nano-selenium impacts on growth performance, digestive enzymes, antioxidant, immune resistance and histopathological scores of Nile tilapia (*Oreochromis niloticus*) against *Aspergillus flavus* infection. Aquaculture International, 1–25. https://doi.org/10.1007/s10499-023-01230-4

Elabd, H.; Mahboub, H.H.; Salem, S.M.R.; Abdelwahab, A.M.; Alwutayd, K.M.; Shaalan, M.; Ismail, S.H.; Abdelfattah, A.M.; Khalid, A.; Mansour, A.T.; Hamed, H.S. and Youssuf, H. (2023). Nano-curcumin/chitosan modulates growth, biochemical, immune, and antioxidative profiles, and the expression of related genes in Nile tilapia (*Oreochromis niloticus*). *Fishes*, 8(7): 333.

El-Sayed, A.F.M. (1999). Alternative dietary protein sources for farmed tilapia, *Oreochromis* spp. *Aquaculture*, 179: 149–168.

El-Sayed, A.F.M. (2016). On-farm feed management practices for Nile tilapia (*Oreochromis niloticus*) in Egypt. In Hasan, M.R. and New, M.B. (Eds.), *On-Farm Feeding and Feed Management in Aquaculture*. FAO Fisheries and Aquaculture Technical Paper No. 583. FAO, Rome, Italy, pp. 101–129.

FAO. (2022). *The State of World Fisheries and Aquaculture 2022: Towards Blue Transformation*. FAO, Rome, Italy.

Goda, A.M.A.; Mabrouk, H.A.H.; Wafa, M.A. and El-Afifi, T.M. (2012). Effect of using baker's yeast and exogenous digestive enzymes as growth promoters on growth, feed utilization and hematological indices of Nile tilapia (*Oreochromis niloticus*) fingerlings. *Journal of Agricultural Science and Technology, B*, 2(1B): 15–28.

Hendam, B.M.; Munir, M.B.; Eissa, M.E.; El-Haroun, E.; van Doan, H.; Chung, T.H. and Eissa, E.S.H. (2023). Effects of water additive probiotic, *Pediococcus acidilactici* on growth performance, feed utilization, hematology, gene expression and disease resistance against *Aspergillus flavus* of Nile tilapia (*Oreochromis* *niloticus*). *Animal Feed Science and Technology*, 115696. https://doi.org/10.1016/j.anifeedsci.2023.115696

Hu, Z.; Yang, J.; Tan, Z. and Hao, J. (2003). Effect of curcumin on the growth and activity of digestive enzymes in grass carp (*Ctenopharyngodon idella*). *Cereal Feed Industry*, 11: 29–30.

Jastaniah, S.D.; Mansour, A.A.; Al-Tarawni, A.H.; El-Haroun, E.; Munir, M.B.; Saghir, S.A.M.; Kari, Z.A.; Téllez-Isaías, G.; Bottje, W.G.; Al-Farga, A. and Eissa, E.-S.H. (2024). The effects of nano-curcumin on growth performance, feed utilization, blood biochemistry, disease resistance, and gene expression in European seabass (*Dicentrarchus labrax*) fingerlings. *Aquaculture Reports*, 36: 102034. https://doi.org/10.1016/j.aqrep.2023.102034

Jiang, J.; Wu, X.; Zhou, H.; Hu, Y.; Zhang, J. and Jiang, W. (2016). Effects of dietary curcumin supplementation on growth performance, intestinal digestive enzyme activities and antioxidant capacity of crucian carp (*Carassius auratus*). *Aquaculture*, 463: 174–180.

Jiang, Q.; Bhattarai, N.; Pahlow, M. and Xu, Z. (2022). Environmental sustainability and footprints of global aquaculture. *Resources, Conservation & Recycling*, 180: 106183.

Khalil, W.A.; Hassan, M.A.; Attia, K.A.; El-Metwaly, H.A.; El-Harairy, M.A.; Sakr, A.M. and Abdelnour, S.A. (2023). Effect of olive, flaxseed, and grape seed nano-emulsion essential oils on semen buffalo freezability. *Theriogenology*, 212: 9–18.

Kumar, G.; Virmani, T.; Sharma, A. and Pathak, K. (2023). Codelivery of phytochemicals with conventional anticancer drugs in form of nanocarriers. *Pharmaceutics*, 15(3): 889.

Lee, K.C.; Maturo, C.; Rodriguez, R.; Nguyen, H.L. and Shorr, R. (2011). Nanomedicine-nanoemulsion formulation improves safety and efficacy of the anti-cancer drug paclitaxel according to preclinical assessment. *Journal of Nanoscience and Nanotechnology*, 11: 6642–6656.

Li, M.; Kong, Y.; Wu, X.; Guo, G.; Sun, L.; Lai, Y.; Zhang, J.; Niu, X. and Wang, G. (2022). Effects of dietary curcumin on growth performance, lipopolysaccharide-induced immune responses, oxidative stress and cell apoptosis in snakehead fish (*Channa argus*). *Aquaculture Reports*, 22: 100981.

Lim, C.E. (2006). *Tilapia: Biology, Culture, and Nutrition*. Food Products Press, Binghamton, NY, USA.

Ma, Z.; Shayeganpour, A.; Brocks, D. R.; Lavasanifar, A. and Samuel, J. (2007) . High-performance liquid chromatography analysis of curcumin in rat plasma: Application to pharmacokinetics of polymeric micellar formulation of curcumin. *Biomedical Chromatography*, 21: 546–552. https://doi.org/10.1002/bmc.790

MacRae, J. and Lobley, G.E. (1982). Some factors which influence thermal energy losses during the metabolism of ruminants. *Livestock Production Science*, 9(4): 447–456.

Accepted 16 December 1981, available online 1 October 2003. https://doi.org/10.1016/0301-6226(82)90050-1

Mahmoud, H.K.; Al-Sagheer, A.A.; Reda, F.M.; Mahgoub, S.A. and Ayyat, M.S. (2017). Dietary curcumin supplement influence on growth, immunity, antioxidant status, and resistance to *Aeromonas hydrophila* in *Oreochromis niloticus*. *Aquaculture*, 475: 16–23. https://doi.org/10.1016/j.aquaculture.2017.03.047

Mansour, S.; Bakry, K.A.; Alwaleed, E.A.; Ahmed, H.; Al-Amgad, Z.; Mohammed, H.H. and Emeish, W.F.A. (2023). Dietary nanocurcumin impacts blood biochemical parameters and works synergistically with florfenicol in African catfish challenged with *Aeromonas veronii*. *Fishes*, 8(6): 298. https://doi.org/10.3390/fishes8060298

Mengistu, S.B.; Mulder, H.A.; Benzie, J.A.H. and Komen, H. (2020). Systematic literature review of the major factors causing yield gap by affecting growth, feed conversion ratio and survival in Nile tilapia (*Oreochromis niloticus*). *Reviews in Aquaculture*, 12: 524–541. https://doi.org/10.1111/raq.12333

Meric, I.; Wuertz, S.; Kloas, W.; Wibbelt, G. and Schulz, C. (2011). Cottonseed oilcake as a protein source in feeds for juvenile tilapia (*Oreochromis niloticus*): Antinutritional effects and potential detoxification by iron supplementation. *Israeli Journal of Aquaculture–Bamidgeh*, 63: 568–576.

Midhun, S.J.; Soumya, K.; Seema, L.; Oommen, O.V. and George, S. (2016). Modulation of digestive enzymes, GH, IGF-1 and IGF-2 genes in the teleost, tilapia (*Oreochromis mossambicus*) by dietary curcumin. *Aquaculture International*, 24: 1277–1286. https://doi.org/10.1007/s10499-016-9980-2

Mojzer, E.B.; Hrnčič, M.K.; Škerget, M.; Knez, Ž. and Bren, U. (2016). Polyphenols: Extraction methods, antioxidative action, bioavailability and anticarcinogenic effects. *Molecules*, 21(7): 901. https://doi.org/10.3390/molecules21070901

Moniruzzaman, M. and Min, T. (2020). Curcumin, curcumin nanoparticles and curcumin nanospheres: A review on their pharmacodynamics based on monogastric farm animal, poultry and fish nutrition. *Pharmaceutics*, 12(5): 447. https://doi.org/10.3390/pharmaceutics12050447

Monsees, H.; Klatt, L.; Kloas, W. and Wuertz, S. (2017). Chronic exposure to nitrate significantly reduces growth and affects the health status of juvenile Nile tilapia (*Oreochromis niloticus L.*) in recirculating aquaculture systems. *Aquaculture Research*, 48: 3482–3492. https://doi.org/10.1111/are.13178

Müller, R.H. and Keck, C.M. (2004). Challenges and solutions for the delivery of biotech drugs: A review of drug nanocrystal technology and lipid nanoparticles. *Journal of Biotechnology*, 113: 151–170. https://doi.org/10.1016/j.jbiotec.2004.04.021

Ng, W.K. and Romano, N. (2013). A review of the nutrition and feeding management of farmed tilapia throughout the culture cycle. *Reviews in Aquaculture*, 5: 220–254. https://doi.org/10.1111/raq.12014

NRC (National Research Council). (2011). Nutrient Requirements of Fish and Shrimp. National *Academies Press*, Washington, DC, USA.

Omnes, M.H.; Leclercq, E.; Quazuguel, P.; Ledoré, Y.; Désbruyères, E.; Le Delliou, H. and Robin, J.H. (2017). Effects of dietary tannin on growth, feed utilization and digestibility, and carcass composition in juvenile European seabass (Dicentrarchus labrax L.). *Aquaculture Reports*, 6: 1–9. https://doi.org/10.1016/j.aqrep.2017.01.001

Parveen, R.; Penumallu, N.R. and Ahmad, S. (2023). Nanotechnology advances for improved targeting of solid tumors. In: Nanotechnology Principles in Drug Targeting and Diagnosis. *Elsevier*, pp. 173–200. https://doi.org/10.1016/B978-0-323-99567-1.00009-1

Prabu, E.; Rajagopalsamy, C.B.T.; Ahilan, B.; Jeevagan, I.J.M.A. and Renuhadevi, M. (2019). Tilapia – An excellent candidate species for world aquaculture: A review. *Annual Research & Review in Biology*, 31: 1–14. https://doi.org/10.9734/arrb/2019/v31i130052

SPSS. (2020). Statistical Package for Social Sciences. Software version 22.0, IBM Corp., Armonk, NY, USA.

Suresh, A.V. and Lin, C.K. (1992). Effect of stocking density on water quality and production of Red tilapia in a recirculated water system. *Aquacultural Engineering*, 11: 1–10. https://doi.org/10.1016/0144-8609(92)90018-M

Sutthi, N. and Thaimuangphol, W. (2020). Effects of yeast (Saccharomyces cerevisiae) on growth performances, body composition and blood chemistry of Nile tilapia (*Oreochromis niloticus Linnaeus*, 1758) under different salinity conditions. *Iranian Journal of Fisheries Sciences*, 19(3): 1428–1446. https://doi.org/10.22092/ijfs.2019.119254

Tian, X.L. and Dong, S.L. (2023). Land-based intensive aquaculture systems. In: *Aquaculture Ecology. Springer, Cham*, pp. 369–402. https://doi.org/10.1007/978-3-031-25414-2_17

Wang, J. and Wu, T. (2007). Effect of curcumin on the feed in large yellow croaker (*Pseudosciaena crocea*). Research on Fishery, 6: 105–106.

Wardani, W.W.; Alimuddin, A.; Zairin, M.; Setiawati, M.; Nuryati, S. and Suprayudi, M.A. (2021). Growth performance, robustness against stress, serum insulin, IGF-1 and GLUT4 gene expression of Red tilapia (*Oreochromis* sp.) fed diet containing graded levels of creatine. *Aquaculture Nutrition*, 27: 274–286. **https://doi.org/10.1111/anu.13191**

Yonar, E.M.; Yonar, S.M.; İspir, U. and Ural, M.Ş. (2019). Effects of curcumin on haematological values, immunity, antioxidant status and resistance of rainbow trout (*Oncorhynchus mykiss*) against *Aeromonas salmonicida* subsp. achromogenes. *Fish & Shellfish Immunology*, 89: 83–90. https://doi.org/10.1016/j.fsi.2019.03.065

Zidan, E.M.; Goma, A.A.; Tohamy, H.G.; Soliman, M.M. and Shukry, M. (2022). Insight study on the impact of different salinity levels on behavioural responses, biochemical stress parameters and growth performance of African catfish (*Clarias gariepinus*). *Aquaculture Research*, 53: 2750–2759. https://doi.org/10.1111/are.15821

Zou, P.; Helson, L.; Maitra, A.; Stern, S.T. and McNeil, S.E. (2013). Polymeric curcumin nanoparticle pharmacokinetics and metabolism in bile duct-cannulated rats. *Molecular Pharmaceutics*, 10: 1977–1987. https://doi.org/10.1021/mp300734z