Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 29(5): 1773 – 1791 (2025)
www.ejabf.journals.ekb.eg

Modulation of Growth, Blood Biochemistry, and Liver and Gill Growth-Related Gene Expression by Dietary Yeast in Heat-Stressed Nile Tilapia

Inas S. Ghaly[1], Dalia M. Aboelhassan[1*], Hesham Abozaid[2], Hayam Mansour[1], Mostafa F. Abdelzaher[3], Hamed A.A. Omer[2], Hasnaa A. Radwan[1], Ibrahim M. Farag[1], Yasser A. A. El-Nomeary [2]

[1]Cell Biology Department, Biotechnology Research Institute, National Research Centre, 33 El-Bohouth Street, P.O:12622, Dokki, Giza, Egypt.
[2]Animal Production Department, Biological Agriculture Research Institute, National Research Centre, 33 El-Bohouth Street, P.O:12622, Dokki, Giza, Egypt.
[3]Hydrobiology Department, Veterinary Research Institute, National Research Centre, 33 El-Bohouth Street, P.O:12622, Dokki, Giza, Egypt.

***Corresponding Author: dalia_hemdan@yahoo.com**

ARTICLE INFO

Article History:
Received: July 5, 2025
Accepted: Sep. 10, 2025
Online: Oct. 3, 2025

Keywords:
The Nile tilapia,
Dried yeast,
Growth performance,
Blood biochemistry,
Gene expression,
Thermal stress

ABSTRACT

This study investigated the effects of dietary dried yeast on growth performance, blood constituents, and gene expression in the Nile tilapia fries reared under different water temperatures. A total of 180 fries (initial average weight 146.17 ± 0.845 g per aquarium) were distributed into 18 aquaria (10 fries each) and assigned to six treatments: G1, G2, and G3 consisted of a basal diet at 28, 31, and 34°C, respectively, while G4, G5, and G6 received the basal diet supplemented with 1.2% dried yeast for 60 days, followed by exposure to 28, 31, and 34°C, respectively, for 15 days to simulate thermal stress. Growth parameters including final weight (FW), total body weight gain (TBWG), average daily gain (ADG), specific growth rate (SGR), relative growth rate (RGR), feed intake (FI), crude protein intake (CPI), and protein efficiency ratio (PER) were significantly improved, while feed conversion ratio (FCR) was reduced in yeast-fed groups (G4–G6). Serum biochemical analysis revealed reduced AST and cholesterol levels with yeast supplementation under elevated temperature, while ALT and albumin showed significant variations. Gene expression analysis showed that 34°C with yeast supplementation was the most favorable condition for upregulating IGF1, IGF2, and GH in liver tissues and GH in gills, whereas 28°C with yeast promoted IGF1 and IGF2 in gills. Additionally, 31–34°C with yeast improved liver and kidney functions. Overall, yeast supplementation, particularly at 34°C, enhanced growth, blood biochemistry, and growth-related gene expression, supporting its application in aquaculture under thermal stress.

INTRODUCTION

Fish are poikilothermic organisms whose metabolism, growth, and immunity are closely regulated by the thermal conditions of their aquatic environment **(Khallaf *et al.*,**

2021; Abozaid *et al.*, 2025). Temperature is therefore one of the most critical environmental factors in aquaculture, directly influencing feeding activity, feed conversion, reproduction, and disease resistance.

The Nile tilapia (*Oreochromis niloticus*), a member of the Cichlidae family, is among the most important warm-water fish cultured worldwide **(FAO, 2003; Azaza *et al.*, 2008)**. This species originates from tropical and subtropical freshwater habitats and demonstrates tolerance to a wide thermal range, surviving up to 40°C **(Azaza, 2004)**. However, growth is severely reduced below 16°C, and mortality occurs below 10°C **(Chervinski, 1982)**. The optimal rearing temperature range has been reported between 24–32°C **(Chilton & Beamish, 1982)**, with superior growth and feed utilization at 26–30°C compared to either cooler or warmer conditions **(Azaza *et al.*, 2008; Pandit & Nakamura, 2010)**. More recently, **Khallaf *et al.* (2021)** confirmed that maximum performance is achieved at 30–34°C, while temperatures above this threshold impair growth. Identifying effective strategies to support tilapia production under varying temperature conditions is therefore essential for aquaculture sustainability.

In addition to environmental management, feed quality remains a cornerstone of aquaculture performance. Feeds account for the largest share of production costs, and their formulation strongly affects growth efficiency, survival, and profitability **(Abozaid *et al.*, 2025b; El-Nadi *et al.*, 2025a, b)**. Functional feed additives, particularly probiotics, have attracted increasing attention for their ability to enhance growth, immunity, and disease resistance while reducing reliance on antibiotics **(Nguyen *et al.*, 2020; Hossain *et al.*, 2020a, b)**. Probiotics such as *Saccharomyces cerevisiae* (Sc) are widely recognized as effective and safe dietary supplements in aquaculture **(Abu-Elala *et al.*, 2013; El-Wardany *et al.*, 2016; Yang *et al.*, 2020)**.

Saccharomyces cerevisiae is a yeast historically used in food and pharmaceutical industries, valued for its high content in biologically active compounds such as selenium, zinc, glutathione, β-glucans, and mannan-oligosaccharides **(Agbor *et al.*, 2007; Lai *et al.*, 2008; Banu *et al.*, 2020; Fath El-Bab *et al.*, 2022)**. These compounds provide multiple functional benefits. β-glucans have been reported to enhance growth and immune responses in poultry and fish **(Ezzat *et al.*, 2024)**. On the other hand, mannan-oligosaccharides exert antimicrobial, antiviral, and immunomodulatory effects **(Patel & Goyal, 2011; Meyer *et al.*, 2015)**. In aquaculture, *S. cerevisiae* supplementation has been shown to improve growth performance, feed utilization, and disease resistance in the Nile tilapia and other cultured species **(Abdel-Tawwab *et al.*, 2008; Eshak *et al.*, 2010; Ozório *et al.*, 2012; Iwashita *et al.*, 2015; Abass *et al.*, 2018; Sutthi & Thaimungpbol, 2020; Islam *et al.*, 2021; Abozaid *et al.*, 2024; Ghaly *et al.*, 2024)**.

At the molecular level, recent studies have demonstrated that *S. cerevisiae* supplementation influences the expression of growth-related and immune genes **(Cuesta *et al.*, 2003)**. For example, significant upregulation of IGF1, IGF2, and GH has been observed in tilapia, while sea bream showed enhanced IL-1β expression following yeast

supplementation **(Fath El-Bab *et al*., 2022; Ghaly *et al*., 2024)**. These findings suggest that the growth-promoting effects of yeast are mediated not only through improved feed efficiency but also via modulation of key genetic pathways controlling growth and immunity.

Although both temperature and dietary yeast supplementation play vital roles in tilapia aquaculture, their interactive effects remain poorly understood. Temperature determines the metabolic potential of fish, while yeast provides nutritional and immunological support that may mitigate the negative impacts of thermal stress. A better understanding of this interaction could provide aquaculture with practical tools to optimize growth performance and resilience under fluctuating environmental conditions. The present study was therefore conducted to evaluate the combined effects of rearing temperature and dietary dried yeast (*Saccharomyces cerevisiae*) supplementation on the Nile tilapia fries. Specifically, it assessed growth performance, feed utilization, blood biochemical markers, and the expression of growth-related genes (IGF1, IGF2, and GH), thereby providing new insights into strategies for improving fish productivity and health under thermal stress.

MATERIALS AND METHODS

Experimental site and collaboration

The experiment was conducted at the Fish Experimental Laboratory, Animal Production Department, Biological Agriculture Research Institute, National Research Centre (NRC), Dokki, Cairo, Egypt in collaboration with the Cell Biology Department and Hydrobiology Department, Veterinary Research Institute, NRC.

Experimental fish and acclimation

A total of 180 healthy Nile tilapia (*Oreochromis niloticus*) fries were obtained from Abbassa Fish Hatchery, Sharkia Governorate, Egypt. Fish were transported to the laboratory and acclimated for two weeks in glass aquaria (80 × 40 × 30cm; water volume: 60L) containing dechlorinated tap water. During acclimation, fish were maintained on a control diet to stabilize their physiological status. Following acclimation, fish (average initial weight: 146.17 ± 0.845 g per aquarium) were randomly distributed into 18 aquaria at a stocking density of 10 fries per tank.

Experimental design and diets

The experiment lasted for 75 days, from early April to mid-June 2024. Fish were divided into six groups (three replicates per group), as follows:

G1: Control, basal diet without yeast, reared at 28°C
G2: Control, basal diet without yeast, reared at 31°C
G3: Control, basal diet without yeast, reared at 34°C
G4: Basal diet + 1.2% dried yeast (12 g/kg), reared at 28°C
G5: Basal diet + 1.2% dried yeast (12 g/kg), reared at 31°C

G6: Basal diet + 1.2% dried yeast (12 g/kg), reared at 34°C

All fish were initially acclimated at 28°C for 60 days. Following this acclimation period, fish in the treatment groups were gradually exposed to elevated temperatures of either 31 or 34°C for 15 days, while the control group remained at 28°C for the entire 75-day experimental period. Thus, the "stress" period refers specifically to the final 15 days of exposure to 31 or 34°C after the acclimation at 28°C.

Diets were formulated to be iso-nitrogenous and iso-caloric, with dried yeast incorporated at 1.2% of the diet. Yeast supplementation at 12g/ kg was administered consistently throughout the entire 75-day experimental period. This included both the 60-day acclimation phase and the subsequent 15-day thermal exposure phase. Therefore, the treatment groups (G4–G6) received continuous yeast supplementation without withdrawal at any stage.

The proximate composition of the experimental diets is shown in Table (1). All aquaria were continuously aerated with air pumps, and 30% of the water volume was exchanged daily with fresh dechlorinated water to maintain water quality. Dissolved oxygen, pH, and ammonia were monitored weekly and maintained within the optimal range for the Nile tilapia culture.

Table 1. Composition of the different experimental diets

Item	**Experimental diets**	
	D_1 **Fed to G_1, G_2 and G_3** **Basal diet**	**D_2** **Fed to G_4, G_5 and G_6** **Tested diet**
Composition of tested diets		
Protein concentration (56%)	17.00	17.00
Soybean meal (44%)	40.00	40.00
Ground yellow corn (8%)	28.00	28.00
Wheat bran (13%)	10.00	8.80
Vegetable oil	3.00	3.00
Vitamin and Minerals	2.00	2.00
mixture*	00.00	1.20
Dried yeast		

*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).

Parameters of growth performance

Body weight gain (BWG) = Final weight - Initial weight.

Survival rate (SR %) = Number of fish at final / Number of fish at start x100.

Specific growth rate (SGR) =

[In final weight (g) - In initial weight (g)] / Experimental days *100

Calculation of feed conversion ratio (FCR)

FCR = total dry matter intake, (TDMI), g / total body weight gain (TBWG),

The composition of the different experimental diets is presented in Table (1).

Calculation of crude protein efficiency ratio (CPER)

(PER) = total body weight gain (TBWG), g / total crude protein intake (TCPI), g.

Feed efficiency

Feed efficiency (FE %) = [weight gain (g) / feed intake (g)]

B**lood sampling**

Blood samples were collected from the caudal vein of 18 fish using a 3mL syringe after anesthetization with clove oil (0.5mL/ L). Samples were placed in clean, dry centrifuge tubes at room temperature until clotting occurred, then centrifuged at 3000rpm for 15min. The separated serum was collected and stored at −20°C until biochemical analyses.

Analytical procedures

The proximate composition of experimental diets and fish body composition was analyzed according to the methods of the **AOAC (2016)**.

Biochemical analysis

Alanine aminotransferase (ALT), aspartate aminotransferase (AST), albumin (ALB), blood urea, creatinine and total cholesterol (gm/dl) were assessed following established protocols **(Wu *et al*., 2006)** with commercially available kits (Spectrum Diagnostics, Egypt). The completion of biochemical reactions was determined according to kit instructions using a spectrophotometer (AGILENT CARY 100/300 Series UV-Vis, United States).

Gene expression analysis

Total RNA was extracted from liver and gill tissues using TRIzol Reagent (Invitrogen, Thermo Fisher Scientific). RNA concentration and purity were assessed using a NanoDrop 2000 spectrophotometer (Thermo Fisher Scientific). Complementary DNA (cDNA) was synthesized from total RNA using the High-Capacity cDNA Synthesis Kit (Applied Biosystems, Thermo Fisher Scientific) according to the manufacturer's protocol. Quantitative real-time PCR (qPCR) was conducted with the Quant Studio™ 5 Real-Time PCR System (Applied Biosystems). Each 20µL reaction mixture contained 10µL SYBR Green I Master Mix (Roche Diagnostics GmbH), 1µL of each forward and reverse primer, 2µL cDNA template, and 6µL nuclease-free water. The thermal cycling program consisted of an initial denaturation at 95°C for 10min, followed by 40 cycles of 95°C for 15s, 60°C for 30s (annealing), and 72°C for 30s (extension). β-Actin was used as the housekeeping gene for normalization, and relative gene expression levels were calculated using the $2^{-\Delta\Delta Ct}$ method, as described by **Livak and Schmittgen (2001)**. The primer sequences used for gene expression analysis are provided in Table (2).

Table 2. Primer sequences used for gene expression analysis

Gene	Primer Sequences	Accession no.	Reference
GH	F: CTGTCTGTCTGTCTGTCAGTCGT R: AGAGGAGACGCCCAAACAC	M97766.1	Rentier-Delrue *et al.*, 1989.
IGF-1	F: CCCGAACTTCCTCGACTTGA R: CCTCAGCCAGACAAGACAAAAA	AF033797	Wang *et al.*, 2019.
IGF-2	F: CCCCTGATCAGCCTTCCTA R: GACAAAGTTGTCCGTGGTGA	EU272150	Wang *et al.*, 2019.
β-actin	F: ACCCACACAGTGCCCATC R: CAGGTCCAGACGCAGGAT	EF026001.1	Monteiro *et al.*, 2009.

Calculated data

Energy calculations

The gross energy (GE, kcal/kg DM) of the experimental diets and fish body composition was estimated according to **Blaxter (1968)** and **MacRae and Lobley (2003)**, using the following caloric conversion factors: crude protein (CP) = 5.65 kcal/g, ether extract (EE) = 9.40 kcal/g, and crude fiber (CF) and nitrogen-free extract (NFE) = 4.15 kcal/g.

Metabolizable energy (ME) was calculated following the recommendations of the **NRC (2011)**, applying conversion factors of 4.50, 8.15, and 3.49 kcal/g for protein, fat, and carbohydrate, respectively. The protein–energy ratio (mg CP/kcal ME) was also determined according to the **NRC (2011)**.

Statistical analysis

All collected data were analyzed using one-way analysis of variance (ANOVA) in SPSS version 26.0 (IBM, 2020). Significant differences among treatment means were identified using Duncan's Multiple Range Test **(Duncan, 1955)**. Results were considered statistically significant at $P< 0.05$.

RESULTS

Chemical analysis of different experimental diets

As presented in Table (3), the crude protein content of the two tested diets was 30.15 and 30.80%, respectively. The corresponding gross energy values were 4559 and 4543 kcal/kg DM, while the metabolizable energy (ME) values were 353.94 and 351.37 kcal/kg DM. Moreover, the protein–energy ratio was calculated at 85.18 and 87.66mg CP/kcal ME for the respective diets. These values are considered adequate to meet the nutritional requirements of the Nile tilapia and indicate that the experimental rations were iso-caloric and iso-nitrogenous, thereby ensuring comparability across treatments.

Table 3. Chemical analysis of different experimental diets

Item	Experimental diets	
	D_1	D_2
	Fed to G_1, G_2 and G_3	Fed to G_4, G_5 and G_6
Moisture	8.15	9.48
Dry matter (DM)	91.85	90.52
Chemical analysis on DM basis		
Organic matter (OM)	93.66	93.14
Crude protein (CP)	30.15	30.80
Crude fiber (CF)	6.55	6.85
Ether extract (EE)	4.18	4.10
Nitrogen free extract (NFE)	52.78	51.39
Ash	6.34	6.86
Gross energy kcal/ kg DM	4559	4543
Gross energy cal/ g DM	4.559	4.543
Metabolizable energy kcal/ kg DM	353.94	351.37
Protein energy ratio (mg CP/ Kcal ME)	85.18	87.66

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 performance

As shown in Table (4), the inclusion of dried yeast at a level of 12g/ kg diet resulted in a significant ($P< 0.05$) improvement in final weight (FW), total body weight gain (TBWG), average daily gain (ADG), specific growth rate (SGR), and relative growth rate (RGR) in fish reared at all tested water temperatures (28, 31, and 34°C; groups G4, G5, and G6) compared to their respective control groups (G1, G2, and G3). Notably, fish fed the yeast-supplemented diet and reared at 34°C (G6) exhibited the highest growth performance values across all parameters (FW, TBWG, ADG, SGR, and RGR) relative to the other groups (G1–G5). Regarding survival, G5 recorded a mortality rate of 6.67%, whereas all other groups (G1, G2, G3, G4, and G6) maintained 100% survival. In terms of feed utilization, fish fed diets containing dried yeast (G4, G5, and G6) also showed higher values of feed intake (FI) and crude protein intake (CPI) compared to their non-supplemented counterparts (G1, G2, and G3) reared under the same water temperatures. The highest values of feed intake (FI) and crude protein intake (CPI) were observed in fish of group G6, recording 656.05 and 206.06g, respectively. Moreover, the feed conversion ratio (FCR) was significantly ($P< 0.05$) improved in groups G4, G5, and G6 (yeast-supplemented diets at 28, 31, and 34°C) compared to their corresponding non-supplemented groups (G1, G2, and G3). Similarly, the protein efficiency ratio (PER) was

significantly ($P< 0.05$) higher in fish from groups G4, G5, and G6 than in fish from groups G1, G2, and G3 reared at the same water temperatures.

Table 4. Live body weight, feed intake & utilization, specific growth rate and relative growth rate of *Nile tilapia (O. niloticus)* fed diets contained dried yeast and reared in different water temperature

Item	Experimental groups						SEM	Sign. $P<0.05$
	Fish fed basal diet and reared in water temperature at			Fish fed diet contained 12 g dried yeast/kg diet and reared in water temperature at				
	(28°C)	(31°C)	(34°C)	(28°C)	(31°C)	(34°C)		
	G_1	G_2	G_{13}	G_4	G_5	G_6		
Number of fish	30	30	30	30	30	30	-	-
Live body weight, g								
IW, g	145	152	144	145	145	146	0.845	NS
FW, g	367^{d}	360^{e}	363^{de}	469^{c}	475^{b}	489^{a}	13.96	*
TBWG, g	222^{c}	208^{d}	219^{c}	324^{b}	330^{b}	343^{a}	14.19	*
Duration experimental	75 days							
ADG, g	2.96^{c}	2.77^{d}	2.92^{c}	4.32^{b}	4.40^{b}	4.57^{a}	0.189	*
Feed intake and utilization								
FI, g	551.46^{cd}	557.34^{c}	546.42^{d}	637.14^{b}	642.18^{b}	656.05^{a}	11.48	*
FCR	2.484^{b}	2.680^{c}	2.495^{b}	1.966^{a}	1.946^{a}	1.913^{a}	0.076	*
FCP%	30.15	30.15	30.15	30.80	30.80		30.80	-
CPI, g	166.27^{cd}	168.04^{c}	164.75^{d}	196.24^{b}	197.79^{b}	202.06^{a}	3.963	*
PER	1.335^{c}	1.238^{d}	1.329^{c}	1.651^{b}	$1.668a^{b}$	1.698^{a}	0.046	*
Specific growth rate and Relative growth								
SGR	0.72^{c}	0.68^{d}	0.72^{c}	0.91^{b}	$0.92a^{b}$	0.94^{a}	0.027	*
RGR	1.50^{c}	1.35^{d}	1.50^{c}	2.20^{b}	2.25^{b}	2.35^{a}	0.101	*
SR %	100	100	100	100	93.33	100	-	-
Dead number	Zero	Zero	Zero	Zero	2	Zero	-	-
Mortality rate %	Zero	Zero	Zero	Zero	6.67	Zero	-	-

a, b, c, d and e: 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. Average daily gain, g (ADG). SGR: Specific growth rate. RGR: Relative growth rate. FI: Feed intake. FCR: Feed conversion ratio. FCP%: Feed crude protein percentages. CPI: Crude protein intake. PER: Protein efficiency ratio.

Biochemical parameters of the different experimental groups

As shown in Table (5), the present study evaluated the effects of dietary yeast supplementation on the biochemical parameters of *O. niloticus* reared at different water temperatures. The results revealed significant differences in AST activity, which showed a marked decrease with increasing temperature. Yeast inclusion significantly reduced

AST levels in fish reared at room temperature and 34°C (G6), while only a slight reduction was observed at 31°C (G5) compared to the control at room temperature. In contrast, ALT activity showed no significant differences among most groups, except for the yeast-fed group at 31°C (G5), which exhibited a non-significant increase. Serum albumin concentrations displayed a non-significant decrease across most treatments compared to the control at room temperature, whereas a significant increase ($P< 0.05$) was recorded in the control group at 31°C (G2). Regarding kidney function indicators, serum creatinine levels did not differ significantly among treatments, except for a significant decrease in the yeast-fed group at 31°C (G5) compared to the control. Similarly, blood urea concentrations showed no significant variation among groups. For metabolic function, serum cholesterol levels significantly ($P< 0.05$) decreased with rising water temperature in both control and yeast-fed groups relative to the control at room temperature.

Table 5. Changes in biochemical parameters of *O. niloticus* fed diets with yeast and exposure to different temperature during the experimental period

Item	Experimental groups						SEM	Sign. $P<0.05$
	Fish fed basal diet and reared in water temperature at			Fish fed diet contained 12 g dried yeast/kg diet and reared in water temperature at				
	(28°C)	(31°C)	(34°C)	(28°C)	(31°C)	(34°C)		
	G_1	G_2	G_3	G_4	G_5	G_6		
AST (IU/L)	141.00^{a}	104.50^{c}	96.50^{d}	68.00^{f}	128.50^{b}	82.50^{e}	6.094	*
ALT (IU/L)	16.50^{a}	10.50^{c}	11.50^{bc}	13.00^{b}	17.50^{a}	12.00^{bc}	0.661	*
Albumin (mg/dl)	0.75^{b}	1.05^{a}	0.50^{d}	0.45^{d}	0.65^{bc}	0.55^{cd}	0.051	*
Creatinine (mg/dl)	0.45^{b}	0.55^{a}	0.35^{c}	0.30^{c}	0.35^{c}	0.15^{d}	0.031	*
Urea (mg/dl)	5.50^{a}	4.50^{b}	4.00b^{c}	3.50^{c}	5.50^{a}	4.50^{b}	0.204	*
Total cholesterol (mg/dl)	246.5^{a}	204.0^{b}	171.5^{c}	139.5^{e}	169.5^{c}	162.0^{d}	8.36	*

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

SEM: Standard error of the mean, NS: Not significant, *: Significant at ($P < 0.05$), AST: Aspartate aminotransferase

Levels of gene expressions

The results of IGF-1, IGF-2, and GH gene expression in the liver and gill tissues of *O. niloticus* fed the basal diet with or without yeast (*Saccharomyces cerevisiae*) supplementation under three temperature conditions (28, 31, and 34°C) are summarized in Figs. (1, 2).

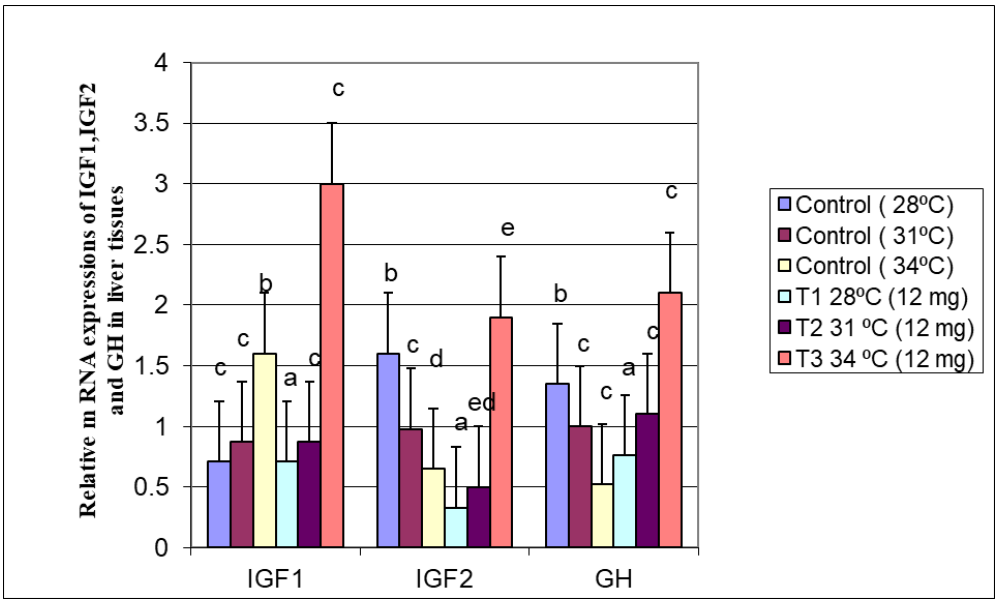

Fig. 1. Relative mRNA expression of IGF1, IGF2, and GH genes in liver tissues of the farmed Nile tilapia fish after feeding diets contained 12g dried yeast/kg diet at three different incubation temperature degrees (28, 31 and 34ºC). Different letters are significantly different at $P < 0.05$.

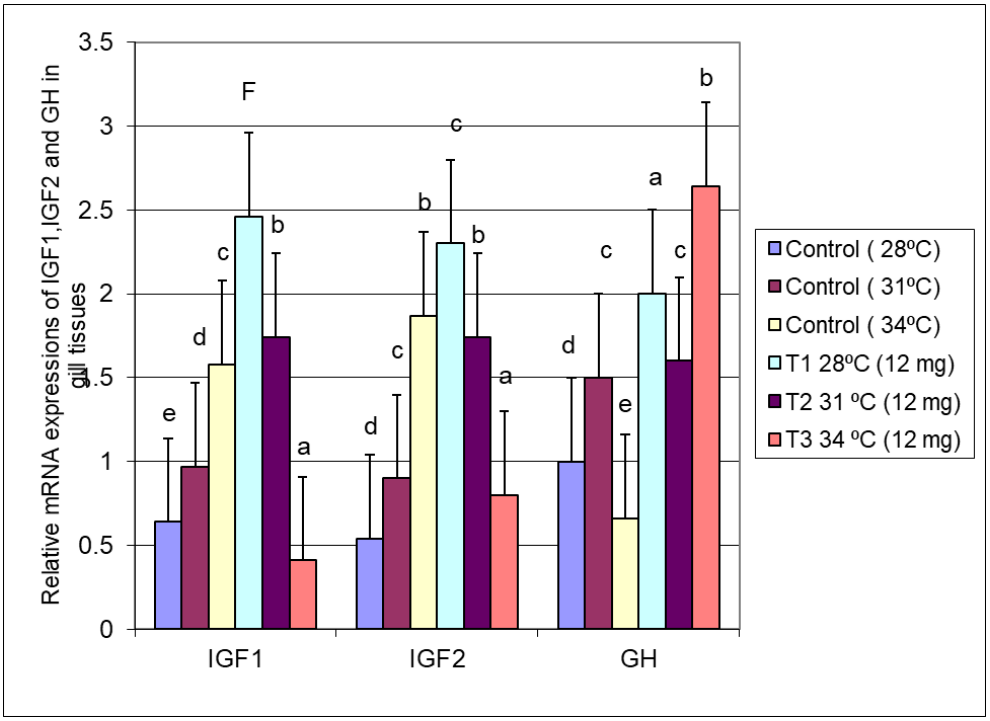

Fig. 2. Relative mRNA expression of IGF1, IGF2, and GH genes in gill tissues of the farmed Nile tilapia fish after feeding diets contained 12g dried yeast/kg diet at three different incubation temperature degrees (28, 31 and 34ºC). Different letters are significantly different at $P< 0.05$.

The results of liver tissues

a. Expression level of IGF-1 gene

The results demonstrated that gene expression in fish exposed to 34°C was significantly upregulated compared to those maintained at 28 and 31°C. Specifically, the expression level of IGF-1 was significantly higher ($P< 0.05$) in fish reared at 34°C and fed a diet supplemented with 12g/ kg *S. cerevisiae* (G6) compared to G4 and G5. In contrast, the expression levels of IGF-1 in G4 and G5 were similar to those observed in their respective controls. Overall, the conditions of 34°C (control G3) and 34°C with yeast supplementation (G6) were the most favorable for enhancing IGF-1 gene expression, with G6 showing the greatest improvement.

b. Expression level of IGF -2 gene

The results revealed that the exposure to 28°C (control 1) caused significant elevation of gene expression as compared to other controls (31 or 34°C). However, the expression level was significantly up regulated ($P< 0.05$) in G4 with respect to those recorded in other treatments (G4 or G5).

C. Expression level of GH gene

Moreover, the expression level of GH gene was significantly up regulated ($P< 0.05$) at 28^{o}C compared to other temperature degrees (31 or 34^{o}C). However, the expression level was significantly increased in G6 comparing with those observed in the other two treatments (G4 or G5).

The results of gill tissues

a.Expression level of IGF-1 gene

The results noted that the exposure to 34^{o}C led to high significant ($P< 0.05$) gene expression as compared to the exposure to 28 or 31^{o}C. However, the expression level in the treatment 1 (G4) was revealed to be significantly up regulated in comparison with G5 or G6. The G6 had the lowest gene expression.

b. Expression level of IGF-2 gene

Also, the expression level of IGF-2 gene was significantly higher ($P< 0.05$ or $P< 0.01$) due to the exposure to temperature degree (34^{o}C) compared to the other two degrees, 28 or 31^{o}C. Whereas the treatment 1 (G4) was recorded with a significant elevation of gene expression comparing with other two treatments G5 or G6. The G6 had the lowest gene expression.

C. Expression level of GH gene

The present findings showed that the exposure to 31^{o}C resulted in significant up regulation with respect to exposure to 28 or 34^{o}C. The gene expression level was the lowest at 34^{o}C. Whereas, the treatment 3 (G6) demonstrated the best one, where the gene expression was significantly increased compared to those detected in G4 or G5. G5 had the lowest gene expression level.

DISCUSSION

The present study investigated the effects of dietary supplementation with *Saccharomyces cerevisiae* (Sc) at 12g/ kg diet under different thermal regimes (28, 31, and 34°C) on growth performance, feed utilization, biochemical parameters, and the expression of growth-related genes (IGF-1, IGF-2, and GH) in the Nile tilapia (*Oreochromis niloticus*). The chemical analysis of the tested diets revealed that crude protein, energy values, and protein-to-energy ratios were within the optimal range required to support tilapia growth. Importantly, both basal and yeast-supplemented diets were iso-nitrogenous and iso-caloric, which eliminates nutritional variability and emphasizes that observed responses were primarily driven by yeast inclusion and thermal effects rather than dietary imbalance.

Growth performance results clearly demonstrated that the inclusion of *S. cerevisiae* significantly enhanced final body weight, weight gain, average daily gain, specific growth rate, and relative growth rate across all three water temperatures. The highest values were obtained in fish fed yeast diets at 34°C (G6 group), suggesting a strong synergistic effect of yeast supplementation and elevated temperature **(Abozaid *et al*., 2025b)**. In contrast, fish reared at the same temperatures without yeast consistently exhibited lower performance indices, highlighting the protective and growth-promoting role of yeast. Feed intake (FI) and crude protein intake (CPI) were the highest in yeast-fed fish, reflecting improved diet palatability and nutrient absorption. Feed conversion ratio (FCR) and protein efficiency ratio (PER) were also significantly improved ($P< 0.05$) in yeast-fed groups, confirming the positive impact of yeast on nutrient utilization efficiency. These results are consistent with previous studies **(Lara-Flores *et al*., 2003; Diab *et al*., 2006; Davis & Peterson, 2006; Goda *et al*., 2012; Sutthi & Thaimuangphol, 2020; Abozaid *et al*., 2024; Abozaid *et al*., 2025b)**, which reported that yeast supplementation improves growth rates and feed efficiency in tilapia and other aquaculture species. The beneficial effects can be attributed to yeast-derived bioactive compounds such as β-glucans, mannan oligosaccharides, nucleotides, and vitamins, which act as prebiotics, enhance gut morphology, stimulate enzymatic activity, and improve nutrient bioavailability.

In addition to growth performance, yeast supplementation significantly influenced physiological and biochemical responses. Serum liver enzymes (AST and ALT) are commonly used as indicators of hepatic health and stress. In the present study, AST activity declined significantly with increasing temperature, particularly in yeast-fed fish at 28 and 34°C, indicating reduced hepatocellular damage and better adaptation to heat stress. ALT activity showed non-significant changes across most groups, except for a slight increase at 31°C in yeast-fed fish, which may reflect transient metabolic adjustments rather than pathological damage. Serum albumin levels remained relatively stable, although a significant increase was observed in the control group at 31°C, possibly

reflecting dehydration or altered protein metabolism under thermal stress. Kidney function markers, including blood urea and serum creatinine, showed no major differences among groups, except for a significant reduction in creatinine in yeast-fed fish at 31°C, suggesting a nephroprotective effect of yeast supplementation **(Ramos *et al*., 2017)**. Cholesterol levels decreased significantly ($P< 0.05$) with increasing temperature, both in control and yeast-fed fish, reflecting altered lipid metabolism under thermal stress. Interestingly, yeast-fed fish showed lower cholesterol values, supporting earlier findings **(McGill, 2016)** that yeast β-glucans regulate lipid metabolism and improve cardiovascular health. These biochemical outcomes collectively demonstrate that yeast supplementation enhances physiological resilience and mitigates some negative impacts of high temperature on fish health.

At the molecular level, the expression of growth-related genes IGF-1, IGF-2, and GH was significantly influenced by both dietary yeast and temperature. Expression levels were the highest at 34°C, particularly in fish fed yeast-supplemented diets, where IGF-1 expression was markedly upregulated compared to all other groups. IGF-2 and GH expression followed similar trends, with yeast-fed fish at 34°C showing superior activation compared to their respective controls. These findings suggest that yeast supplementation stimulates the somatotropic axis, enhancing growth-promoting signals under thermal stress conditions. Similar patterns of temperature- and diet-induced gene expression modulation have been reported in the gilthead seabream **(Ortuno *et al*., 2002; Saera-Vila *et al*., 2007; Bildik *et al*., 2019)**, the rainbow trout **(Gabillard *et al*., 2003)**, and the mirror carp **(Huang *et al*., 2015)**. The stimulatory effects of *S. cerevisiae* may be explained by its high content of antioxidants, glutathione, nucleotides, vitamins, and trace elements, which reduce oxidative stress, improve immune responses, and enhance protein synthesis **(Lai *et al*., 2008; Abd-El-Moneim *et al*., 2017; Fath El-Bab *et al*., 2022)**. Interestingly, gene expression results also indicated tissue-specific responses. In liver tissue, IGF-1 was particularly sensitive to the combined effect of yeast and elevated temperature, whereas in gill tissue, yeast supplementation enhanced IGF-1 and IGF-2 expression at 28°C, while GH expression peaked at 34°C. This tissue-dependent regulation may reflect different functional roles of liver and gills in growth and metabolism under stress **(Madkour *et al*., 2024)**. The liver acts as the central metabolic hub, producing IGF-1 in response to GH stimulation, while gills play an important role in osmoregulation and oxygen exchange, which become more critical under thermal stress. Thus, the observed differences may indicate coordinated physiological adaptation facilitated by yeast supplementation. The overall findings of this study have important implications for sustainable aquaculture. Climate change is expected to increase global water temperatures, posing challenges for tilapia production **(Abozaid *et al*., 2025a, b; Omer *et al*., 2025)**. The ability of *S. cerevisiae* to enhance growth performance, improve biochemical health, and stimulate growth-related gene expression under elevated temperatures suggests its potential as a functional feed additive for climate-resilient

aquaculture. Beyond growth, yeast supplementation also provides immunomodulatory and stress-protective benefits, which are critical for maintaining productivity under suboptimal environmental conditions.

CONCLUSION

The present study demonstrated that dietary supplementation with *S. cerevisiae* at 12g/ kg diet significantly improves growth performance, feed utilization, biochemical health, and gene expression of the Nile tilapia across a range of water temperatures, with the most pronounced effects at 34°C. These findings not only reinforce the role of yeast as a valuable feed additive but also highlight its importance in mitigating the impacts of thermal stress, thereby supporting the development of sustainable aquaculture practices in the face of climate variability.

REFERENCES

Abass, D.A.; Obirikorang, K.A.; Campion, B.B.; Edziyie, R.E. and Skov, P.V. (2018). Dietary supplementation of yeast (*Saccharomyces cerevisiae*) improves growth, stress tolerance, and disease resistance in juvenile Nile tilapia (*Oreochromis niloticus*). Aquac. Int., 26(3): 843–855.

Abd-El-Moneim, O.M.; Abd El-Kader, H.A.; Abd El-Rahim, A.H.; Radwan, H.A.; Fadel, M. and Farag, I.M. (2017). Modulatory role of *Saccharomyces cerevisiae* against cadmium-induced genotoxicity in mice. J. Arab Soc. Med. Res., 12(1): 27–38.

Abdel-Tawwab, M.; Abdel-Rahman, A.M. and Ismael, N.E. (2008). Evaluation of commercial live bakers' yeast, *Saccharomyces cerevisiae* as a growth and immunity promoter for fry Nile tilapia, Oreochromis niloticus (L.) challenged in situ with Aeromonas hydrophila. Aquaculture, 280(1–4): 185–189.

Abozaid, H.; Elnadi, A.S.M.; Aboelhassan, D.M.; El-Nomeary, Y.A.A.; Omer, H.A.A. and Abbas, W.T. (2024). Using the dried yeast (*Saccharomyces cerevisiae*) as a growth promoter in the Nile tilapia (*Oreochromis niloticus*) diets. *Egypt. J. Aquat. Biol. & Fish.*, 28(2): 699–716. www.ejabf.journals.ekb.eg

Abozaid, H.; Elnady, A.S.M.; Aboelhassan, D.M.; Omer, H.A.A.; El-Nomeary, Y.A.A.; Samy, A.; Abdelzaher, M.F.; Ghaly, I.S.; Radwan, H.A. and Farag, I.M. (2025a). Mitigating heat stress in the Nile tilapia (*Oreochromis niloticus*) using dietary nano zinc oxide: Impacts on growth, biochemistry, and growth-related genes. Egypt. J. Aquat. Biol. & Fish., 29(4): 2087–2105. www.ejabf.journals.ekb.eg

Abozaid, H.; El-Nomeary, Y.A.A.; Omer, H.A.A.; Aboelhassan, D.M.; Ghaly, I.S. and Radwan, H.A. (2025b). Synergistic Effects of Elevated Water Temperatures and

Dietary Dried Yeast on the Growth Performance and Fed Utilization of the Nile Tilapia (*Oreochromis niloticus*). *Egypt.* J. Aquat. Biol. & Fish., Vol. 29(5): 107–121.

Abu-Elala, N.; Marzouk, M. and Moustafa, M. (2013). Use of different *Saccharomyces cerevisiae* biotic forms as immune-modulator and growth promoter for *Oreochromis niloticus* challenged with some fish pathogens. Int. J. Vet. Sci. Med., 1(1): 21–29.

Agbor, G. (2007). Antioxidants: Case study in. Pak. J. Biol. Sci., 10(4): 537–544.

Allain, C.C.; Poon, L.S.; Chan, C.S.; Richmond, W. and Fu, P.C. (1974). Enzymatic determination of total serum cholesterol. Clin. Chem., 20: 470–475.

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

Azaza, M.S.; Dhraïef, M.N. and Kraïem, M.M. (2008). Effects of water temperature on growth and sex ratio of juvenile Nile tilapia *Oreochromis niloticus* (Linnaeus) reared in geothermal waters in southern Tunisia. J. Therm. Biol., 33(2): 98–105.

Azaza, M.S. (2004). Tolérance à la température et à la salinité chez le tilapia du Nil (*Oreochromis niloticus* L., 1758) en élevage dans les eaux géothermales du sud tunisien. Tunisia: Faculty of Sciences of Tunis.

Banu, M.R.; Akter, S.; Islam, M.R.; Mondol, M.N. and Hossain, M.A. (2020). Probiotic yeast enhanced growth performance and disease resistance in freshwater catfish gulsa tengra, *Mystus cavasius*. Aquac. Rep., 16: 100237.

Bildik, A.; Asıcı Ekren, G.S.; Akdeniz, G. and Kıral, F. (2019). Effect of environmental temperature on heat shock proteins (HSP30, HSP70, HSP90) and IGF-I mRNA expression in *Sparus aurata*. Iran. J. Fish. Sci., 18(4): 1014–1024.

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

Chervinski, J. (1982). Environmental physiology of tilapias. In The Biology and Culture of Tilapia. Proc. 7th ICLARM Conf., Manila, Philippines: International Center for Living Aquatic Resources Management, pp. 119–128.

Chilton, D.E. and Beamish, R.J. (1982). Age determination methods for fishes studied by the ground fish program at the Pacific Biological Station. Department of Fisheries and Oceans, Ottawa, Canada.

Cuesta, R.A.; Ortun, J.; Esteban, M.A. and Meseguer, J. (2003). Immunostimulant properties of a cell wall-modified whole Saccharomyces cerevisiae strain administered by diet to sea bream (*Sparus aurata* L.). Vet. Immunol. Immunopathol., 96: 183–192.

Davis, K.B. and Peterson, B.C. (2006). The effect of temperature, stress, and cortisol on plasma IGF-I and IGFBPs in sunshine bass. Gen. Comp. Endocrinol., 149(3): 219–225.

Diab, A.S.; Abdel-Hadi, Y.M.; Ahmed, M.H.; Saber, S.F. and Aboel-Atta, M.E. (2006). Outdoor study on the use of Echinacea (*Echinacea purpurea*), Marjoram

(*Origanum dictamnus*) and yeast (*Saccharomyces cerevisiae*) as feed additives for *Oreochromis niloticus*. Egypt. J. Agric. Res., 84(18): 537–551.

Doumas, B.L.; Watson, T. and Biggs, W.A. (1971). Albumin standards and measurement of serum with bromocresol green. Clin. Chim. Acta., 31: 87–96.

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

Ellefson, R.D. and Caraway, W.T. (1976). Fundamentals of clinical chemistry. In: Tietz, N.W. (Ed.), W.B. Saunders, Philadelphia, pp. 506.

El-Nadi, A.S.M.; Omer, H.A.A.; Khames, D.K.; Zaki, E.M.; Anees, D.M.R. and Hessein, A.A.A. (2025a). Partial or complete replacement of yellow corn with biscuit by-product in diets for the Nile tilapia (*Oreochromis niloticus*) fingerlings. Egypt. J. Aquat. Biol. & Fish., 29(4): 4917–4940.

El-Nadi, A.S.M.; Omer, H.A.A.; Khames, D.K.; Zaki, E.M.; Anees, D.M.R. and Hessein, A.A.A. (2025b). Discarded sun-dried potatoes (*Solanum tuberosum* L.) as untraditional source of energy in the Nile tilapia (*Oreochromis niloticus*) fingerlings diets. Egyptian Journal of Aquatic Biology & Fisheries, 29(4): 4941–4963. ISSN 1110–6131.

El-Wardany, I.; Shourrap, M.I.; Madkour, M. and Abd El-Azeem, N.A. (2016). Effect of age at mating and silver nanoparticles administration on progeny productive performance and some blood constituents in Japanese quail. Int. J. ChemTech Res., 9(8): 21–34**.**

Eshak, M.G.; Khalil, W.K.; Hegazy, E.M.; Farag, I.M.; Fadel, M. and Stino, F.K. (2010). Effect of yeast (*Saccharomyces cerevisiae*) on reduction of aflatoxicosis, enhancement of growth performance and expression of neural and gonadal genes in Japanese quail. J. Am. Sci., 6(12).

Ezzat, W.; Mahrose, K.M.; Rizk, A.M.; Ouda, M.M.; Fathey, I.A.; Othman, S.I. and Abd El-Hack, M.E. (2024). Impact of β-glucan dietary supplementation on productive, reproductive performance and physiological response of laying hens under heat stress conditions. Poult. Sci., 103(1): 103183.

Fath El-Bab, A.F.; Majrashi, K.A.; Sheikh, H.M.; Shafi, M.E.; El-Ratel, I.T.; Neamat-Allah, A.N. and Naiel, M.A. (2022). Dietary supplementation of Nile tilapia (*Oreochromis niloticus*) with β-glucan and/or *Bacillus coagulans*: Synergistic impacts on performance, immune responses, redox status and expression of some related genes. Front. Vet. Sci., 9: 1011715.

Gabillard, J.C.; Rescan, P.Y.; Fauconneau, B.; Weil, C. and Le Bail, P.Y. (2003). Effect of temperature on gene expression of the GH/IGF system during embryonic development in rainbow trout (*Oncorhynchus mykiss*). J. Exp. Zool. Part A: Comp. Exp. Biol., 298(2): 134–142.

Ghaly, I.S.; Abozaid, H.; Mansour, H.; Abdelzaher, M.F.; Radwan, H.A.; Aboelhassan, D.M.; El-Nomeary, Y.A.A.; Awad, E. and Farag, I.M. (2024).

Protective efficacy of dietary yeast (*Saccharomyces cerevisiae*) against microplastic toxicity in the Nile tilapia (*Oreochromis niloticus*): Studies on growth performance, gene expression, biochemistry, and immune response. Egypt. J. Aquat. Biol. & Fish., 28(5): 865–883. www.ejabf.journals.ekb.eg

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. J. Agric. Sci. Technol. B, 2(1B): 15–28.

Harold, V. (1975). Colorimetric determination of glutamate pyruvate and oxaloacetic transaminase. In: Practical Clinical Biochemistry, 4th ed., p. 294.

Hossain, M.M.; Ali, M.L.; Khan, S.; Haque, M.M. and Shahjahan, M. (2020a). Use of Asian water grass as feed of grass carp. Aquac. Rep., 18: 100434.

Hossain, M.M.; Rahman, M. H.; Ali, M. L.; Khan, S.; Haque, M. M. and Shahjahan, M. (2020b). Development of a low-cost polyculture system utilizing *Hygroryza aristata* floating grass in the coastal wetlands of Bangladesh. Aquaculture, 527, 735430.

Huang, C.X.; Chen, N.; Wu, X.J.; Huang, C.H.; He, Y.; Tang, R. and Wang, H.L. (2015). The zebrafish miR-462/miR-731 cluster is induced under hypoxic stress via hypoxia-inducible factor 1α and functions in cellular adaptations. FASEB J., 29(12): 4901–4913.

Islam, S.M.; Rohani, M.F. and Shahjahan, M. (2021). Probiotic yeast enhances growth performance of Nile tilapia (*Oreochromis niloticus*) through morphological modifications of intestine. Aquac. Rep., 21: 100800.

Iwashita, M.K.P.; Nakandakare, I.B.; Terhune, J.S.; Wood, T. and Ranzani-Paiva, M.J.T. (2015). Dietary supplementation with *Bacillus subtilis*, *Saccharomyces cerevisiae* and *Aspergillus oryzae* enhance immunity and disease resistance against Aeromonas hydrophila and *Streptococcus iniae* infection in juvenile tilapia *Oreochromis niloticus*. Fish Shellfish Immunol., 43(1): 60–66.

Khallaf, E.A.; Alnenaei, A.A.; El-Messady, F.A. and Hanafy, E. (2021). Effect of temperature rise on growth performance, feed intake, feed conversion ratio and sex ratio of the Nile tilapia, *Oreochromis niloticus*. Egypt. J. Aquat. Biol. & Fish., 25(3): 159–169.

Lai, Y.L.; Annadurai, G.; Huang, F.C. and Lee, J.F. (2008). Biosorption of Zn(II) on the different Ca-alginate beads from aqueous solution. Bioresour. Technol., 99(14): 6480–6487.

Lara-Flores, M.; Olvera-Novoa, M.A.; Guzman-Méndez, B.E. and Lopez-Madrid, W. (2003). Use of the bacteria Streptococcus faecium and Lactobacillus acidophilus and the yeast *Saccharomyces cerevisiae* as growth promoters in Nile tilapia (*Oreochromis niloticus*). Aquaculture, 216: 193–201.

Livak, K.J. and Schmittgen, T.D. (2001). Analysis of relative gene expression data using real-time quantitative PCR and the $2^{-\Delta\Delta CT}$ method. *Methods*, 25(4): 402–408. https://doi.org/10.1006/meth.2001.1262

MacRae, J. and Lobley, G.E. (1982). Some factors which influence thermal energy losses during the metabolism of ruminants. Livest. Prod. Sci., 9(4): 447–455. https://doi.org/10.1016/0301-6226(82)90050-1

Madkour, M.; Alaqaly, A.M.; Soliman, S.S.; Ali, S.I. and Aboelazab, O. (2024). Growth performance, blood biochemistry, and mRNA expression of hepatic heat shock proteins of heat-stressed broilers in response to rosemary and oregano extracts. J. Therm. Biol., 119: 103791.

McGill, M.R. (2016). The past and present of serum aminotransferases and the future of liver injury biomarkers. EXCLI J., 15: 817.

Meyer, A.; Noël, M.; Vasseur, J.J. and Morvan, F. (2015). Hetero-click conjugation of oligonucleotides with glycosides using bifunctional phosphoramidites. Eur. J. Org. Chem., (13): 2921-2927.

Monteiro, S.M.; dos Santos N.M.; Calejo M.; Fontainhas-Fernandes A. and Sousa M. (2009). Copper toxicity in gills of the teleost fish, *Oreochromis niloticus*: effects in apoptosis induction and cell proliferation. Aquat. Toxicol., 94(3): 219-228.

Nguyen, V.; Riley, S.; Nagel, S.; Fisk, I. and Searle, I.R. (2020). Common vetch: a drought tolerant, high protein neglected leguminous crop with potential as a sustainable food source. Front. Plant Sci., 11: 818.

NRC (2011). National Research Council. Nutrient Requirement of Fish. National Academy Press, Washington, DC, USA.

Ortuno, J.; Cuesta, A.; Rodriguez, A.; Esteban, M.A. and Meseguer, J. (2002). Oral administration of yeast, *Saccharomyces cerevisiae*, enhances the cellular innate immune response of gilthead seabream (*Sparus aurata* L.). Vet. Immunol. Immunopathol., 85: 41–50.

Omer, H.A.; Elnadi, A.S.; Abozaid, H.; El-Nomeary, Y.A.; Aboelassan, D.M. and Samy, A. (2025). Effects of dietary nano zinc oxide supplementation and rearing temperature on the performance and thermal resistance of the Nile tilapia (*Oreochromis niloticus*) fingerlings. Egypt. J. Aquat. Biol. Fish., 29(4): 499–517.

Ozório, R.O.A.; Portz, L.; Borghesi, R. and Cyrino, J.E.P. (2012). Effects of dietary yeast (*Saccharomyces cerevisiae*) supplementation in practical diets of tilapia (*Oreochromis niloticus*). Animals, 13, 2(1): 16–24. doi:10.3390/ani2010016

Pandit, N.P. and Nakamura, M. (2010). Effect of high temperature on survival, growth and feed conversion ratio of Nile tilapia, *Oreochromis niloticus*. Our Nature, 8(1): 219–224.

Patel, S. and Goyal, A. (2011). Functional oligosaccharides: production, properties and applications. World J. Microbiol. Biotechnol., 27(5): 1119–1128.

Pisani, T.; Gebski, G.P. and Leary, E.T. (1995). Accurate direct determination of low-density lipoprotein cholesterol assay. Arch. Pathol. Lab. Med., 119: 1127.

Ramos, M.A.; Batista, S.; Pires, M.A.; Silva, A.P.; Pereira, L.F.; Saavedra, M.J. and Rema, P. (2017). Dietary probiotic supplementation improves growth and the intestinal morphology of Nile tilapia. Animal, 11(8): 1259–1269.

Reitman, S.M.D. and Frankel, S. (1957). A colorimetric method for determination of serum glutamic oxaloacetic acid and glutamic pyruvic acid transferases. Am. J. Clin. Pathol., 28: 56–63.

Rentier-Delrue, F.; Swennen, D.; Prunet, P.; Lion, M. and Martial, J.A. (1989). Tilapia prolactin: molecular cloning of two cDNAs and expression in Escherichia coli. DNA, 3: 261–270.

Saera-Vila, A.; Calduch-Giner, J.A. and Pérez-Sánchez, J. (2007). Co-expression of IGFs and GH receptors (GHRs) in gilthead sea bream (*Sparus aurata* L.): sequence analysis of the GHR-flanking region. J. Endocrinol., 194(2): 361–372.

SPSS (2020). Statistical Package for the Social Sciences (Software version 22.0).

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.

Tietz, N.W. (1986). A method for the rapid determination of albumin of blood plasma. P.589 in Textbook of Clinical Chemistry. W.B Saunders Company, Philadelphia.

Tietz, N.W. (1990). Clinical guide to laboratory tests. 2nd ed. Philadelphia: WB Saunders, pp. 566.

Wang, B.; Xu, Y.; Liu, X.; Liu, Q.; Liu, Y.; Zhang, Y. and Shi, B. (2019). Molecular characterization and expression profiles of insulin-like growth factors in yellowtail kingfish (*Seriola lalandi*) during embryonic development. Fish Physiology and Biochemistry, 45: 375-390.

Wu, A.H.B. (2006) Tietz clinical guide to laboratory tests, 4th edn. Elsevier Health Sciences, St. Louis.

Yang, X.; Chi, S.; Tan, B.; Nie, Q.; Hu, J.; Dong, X. and Zhang, S. (2020). Yeast hydrolysate helping the complex plant proteins to improve the growth performance and feed utilization of *Litopenaeus vannamei*. Aquaculture Reports, 17: 100375.