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Effects of *Saccharomyces cerevisiae* postbiotics on growth performance and feed utilization of Nile Tilapia fingerlings

*[1,2]NDAMBUKI, N., M., [1]OGWENY, V.O., [3]MAINA, J.G., [1]KARANJA, D.N., [1]NJERU, N.P., [4]MUTHOKA, M., [5]MOHAN, C.V., [6]SARAYA, T.

[1]Department of Veterinary Pathology, Microbiology and Parasitology, University of Nairobi, P.O. Box 29053-00625, Nairobi, Kenya
[2]Faculty of Bioscience Engineering, Ghent University, Coupure Links 9000 Gent
[3]Department of Animal Production, University of Nairobi, P.O. Box 29053-00625, Nairobi, Kenya
[4]Department of Animal and Fisheries Sciences, Maseno University, P.O. Box Private Bag, Maseno, Kenya
[5]Sustainable Aquaculture, Worldfish, Penang, Malaysia
[6]Department of Aquatic Animal Health and Welfare, Norwegian Veterinary Institute, Oslo, Norway

***Corresponding author:** merceline.ndinda@gmail.com

Abstract

Aquaculture is a major contributor to global food and nutrition security, yet its productivity is constrained by challenges such as slow growth and high disease prevalence in cultured species. The use of functional feed additives has emerged as a sustainable alternative to antibiotics. With the potential to improve growth performance and enhance fish health. This study evaluated the effects of the growth performance and nutrient utilization of Nile tilapia (*Oreochromis niloticus*). A feeding trial was conducted in which monosex tilapia fingerlings were randomly distributed into four dietary treatments in a completely randomized design, each with three replications and a stocking density of 25 fish per tank. The basal diet (30% crude protein; 3000 kcal DE/kg) was supplemented with SCFP at 0g/kg (control), 2 g/kg, 4g/kg, or 6g/kg. Fish were fed three times daily at approximately 3% of their body weight for the duration of the trial. Growth performance and feed utilization parameters were monitored biweekly and analyzed at the end of the experiment. Data were subjected to one-way analysis of variance (ANOVA), and significant means were separated using Tukey's test at a significance level of $p>0.05$. Fingerlings fed the 4g/kg diet exhibited the highest growth performance, followed by those receiving 6 g/kg and 2 g/kg, while the control group showed significantly lower performance. No significant differences were observed between the 4g/kg and 6g/kg groups. Survival was significantly lower in the control, but did not significantly differ among supplemented groups. Overall, the findings demonstrate that dietary supplementation with yeast-based postbiotics, particularly 4g/kg, can effectively enhance growth performance and support improved production efficiency in tilapia aquaculture.

Key words: *Aquaculture; Postbiotics; Survival; Sustainability; Water quality*

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Introduction

Aquaculture has grown to become the fastest-growing food production technology in the world (Anderson *et al*., 2017). It is practiced with a variety of intensities and techniques (Hancz, 2022). The growth of aquaculture can be attributed to factors such as increased technological advancement, the need to increase food security, an overall increase in the general population and public awareness on the role of fish in diversified and healthy diets, and an increase in the overall income globally (Munguti *et al*., 2021). Aquaculture production in Kenya has experienced remarkable growth in recent years, rising from 4,218 metric tons (MT) in 2006 to a peak of 18,542 MT in 2019 (Opiyo *et al.* 2020). This rapid expansion has positioned aquaculture as a lucrative industry and a pivotal contributor to addressing the escalating global food demand (Bartley, 2022). However, this intensification and accompanying high stocking densities, pond water fertilization, and increased water exchange, lead to potential pathogen introductions and reduced survival rates (Boyd *et al*., 2020). Another major concern in aquaculture is the cost and quality of feeds, which constitute nearly 70% of total production expenses in intensive systems, significantly impacting the industry's overall profitability (Ragasa *et al.,* 2022). Feed quality, acceptability, and utilization are pivotal factors that profoundly affect water quality, growth, survival, and overall production efficiency in aquaculture (Peixoto *et al*., 2019).

The intensified practices in aquaculture and substandard feeds often lead to deterioration in water quality, stress in fish (Peixoto *et al.,* 2019), slowed growth, opportunistic bacterial proliferation and increased disease outbreaks, mass mortalities and economic losses (Wang *et al*., 2020). Traditional approaches to increasing aquaculture production and managing diseases have frequently involved the use of chemical growth promoters, antibiotics and chemotherapeutics (Mog *et al*., 2020). These practices have given rise to issues such as bioaccumulation and the development of antibiotic-resistant pathogens, posing health risks to humans (Banua *et al.,* 2020). Eco-friendly approaches have emerged as promising alternatives for improving growth and fish health management, providing viable alternatives to chemical growth promoters, antibiotics and vaccines (Soliman *et al.,* 2019).

One such eco-friendly approach is the utilization of postbiotics, which are byproducts secreted by live probiotic microorganisms. Postbiotics demonstrated the capacity to enhance production and feed utilization while improving intestinal barrier function and mucosal immunity (Bedford and Gong 2018). They exhibit a range of beneficial effects for the host, such as anti-inflammatory, antiproliferative, immunomodulatory, and antioxidant effects (Vallejo-Cordoba *et al*., 2020). They are now considered potential food additives and dietary supplements for aquatic organisms (Vallejo-Cordoba *et al.,* 2020). Postbiotics have also been shown to enhance nutrient availability by improving the action of digestive enzymes (Dawood *et al.,* 2019). Among postbiotics, yeast stands out as a promising option due to its high potential content of β-glucans, mannan oligosaccharides (MOS), and nucleic acids, which enhance growth, energy, and nutrient digestibility (Sunitha and Bright-Singh, 2013). Several studies have revealed that *Saccharomyces cerevisiae*, a type of yeast, can enhance the growth performance of aquaculture species (Banua *et al.* 2020; Agboola *et al.,* 2021;).

While numerous studies have demonstrated the positive effects of postbiotics on stress tolerance, immunity, and disease resistance in Nile tilapia (del Valle *et al.,* 2023; Meng *et al.,* 2023), none have specifically addressed the role of postbiotics in improving the growth performance and feed utilization indices of Nile tilapia fingerlings. Therefore, the present study was designed to investigate the effect of postbiotic supplementation on the growth performance parameters of Nile tilapia (*Oreochromis niloticus*) fingerlings.

Materials and methods

Study site

This study was conducted at the University of Nairobi, Upper Kabete campus in the Department of Veterinary Pathology, Microbiology, and Parasitology.

Feeding protocol

A diet (Table 1) was formulated to contain 30%

protein and 3000 Kcal of DE per kilogram. The energy, protein, ether extract, crude fiber, calcium, and phosphorus levels were according to stipulated recommendations for tilapia diets (NRC 2011).

Table 1

Composition of the basal diet fed to Oreochromis niloticus fingerlings

Ingredient	(%)*
Maize	24.2
Wheat pollard	10.0
Wheat bran	5.0
Freshwater shrimp meal	20.0
Soybean meal sol. Ext.	15.6
Corn gluten meal	16.0
Corn oil	2.70
Dicalcium Phosphate (DCP)	5.60
Limestone	0.00
HCL- Lysine	0.10
DL-Methionine	0.30
Salt	0.20
Vitamin/ Mineral premix	0.50
Total	100.0

*The percentages represent the proportion of each ingredient in the basal diet fed to *O. niloticus* fingerlings. Vitamin/ Mineral premix refers to a mixture of essential vitamins and minerals added to the diet to meet the nutritional requirements of the fish. All values are expressed as percentages by weight.

A commercial yeast-based postbiotic (Diamond V XPC®) was added at four levels: 0g, 2g, 4g, and 6g per kg of formulated basal feed to make four experimental diets. This feed was then moistened and extruded through a 2mm diameter meat mincer. The moist pellets were then air-dried and stored in a cool, dry place.

Table 2

Calculated composition of diet fed to Oreochromis niloticus fingerlings.

Nutrient	*Value
DE (Kcal/kg)	3000
Crude protein (%)	30.0
Crude fiber (%)	5.0
Ether extract (%)	0.50
Calcium (%)	1.50
Phosphorus (%)	0.70

*These values represent the nutritional content of the diet fed to *O. niloticus* fingerlings, ensuring proper nutrient intake for growth and development.

Experimental fish, rearing facilities, and feeding

Monosex tilapia (*Oreochromis niloticus*) fingerlings sourced from Paradise Fish Farm, a reputable commercial hatchery, were used in this study. Prior to commencing the experiment, the fingerlings were acclimatized for two weeks to experimental conditions. They were kept in aerated aquaria measuring 60 cm in length, 60 cm in width, and 50 cm in height at a stocking density of 25 fish per aquarium. During the acclimatization period, they were fed on the control diet (No postbiotic).

Following the acclimatization period, the fish were starved for 24 hours, after which their weights and lengths were recorded, serving as the baseline values for the experiment. Subsequently, the fingerlings were randomly allocated to four diet groups of aquaria of 60 × 60 × 50 cm, each with three replicates at a stocking density of 25 fish per aquarium. A total of 300 fingerlings were required to accommodate the three treatments and the control group. They were labeled as Ca, Cb, and Cc for the control group (with zero postbiotic inclusion), T1a, T1b, and T1c for the first treatment (with 2g postbiotic per kg of feed), T2a, T2b, and T2c for the second treatment (with 4g postbiotic per kg of feed), and T3a, T3b, and T3c for the third treatment (with 6g postbiotic per kg of feed).

Table 3

Levels of yeast-based postbiotic supplementation in the diets

Diet	**Control**	**Treatment 1**	**Treatment 2**	**Treatment 3**
Level of postbiotic supplemented/ Kg of feed	No Postbiotic	2 Grams	4 Grams	6 Grams

*Note***:** The table illustrates the levels of yeast-based postbiotic supplementation in the diets. Four different diets are represented: Control (no postbiotic) and three treatment groups with varying levels of postbiotic supplementation.

The fish were fed 3% of their body weight three times daily, at 9.00 a.m., 12.30 p.m., and 3.00 p.m. To ensure appropriate nutrition, the feed ratio was adjusted accordingly after each sampling.

Monitoring of water quality in the aquariums

During the feeding period, various physicochemical parameters of water, including dissolved oxygen (D.O.), temperature, and pH, were closely monitored on-site using a multiparameter meter model number H19828 (Hanna Instruments Ltd., Chicago, USA). The determination of total ammonium nitrogen was done using the indophenol blue spectrophotometric method, employing a spectrophotometer (Varian Cary® 50 UV-Vis Spectrophotometer, Varian, Inc., USA) as described by Li *et al.* (2019). The obtained values were subsequently used to calculate the

unionized ammonia content. Continuous and closely monitored aeration was ensured by an electric aerator pump fitted with an appropriate filter to maintain optimum water conditions in each aquarium. The filter was routinely removed and cleaned twice daily to remove accumulated waste and to ensure efficient functioning. As an additional management of solid organic waste comprising fish excreta and unconsumed feed, siphoning out of settled material at the bottom of the aquaria was carefully done twice a day. Approximately two-thirds of the experimental water volume was also routinely exchanged with fresh potable water three times a week as a measure to aid in keeping water parameters within optimal levels. To maintain constant temperature across all treatments, all aquariums were fitted with thermostatically controlled water heaters, with the temperature set at 28^{o}C. The trial was done for 55 days.

Data collection

Sampling

All fish from each aquarium were gently removed using a scoop net every 10 days and subsequently counted and weighed with a precise weighing balance to establish the pool weight. Mortality was closely monitored daily, and the obtained data were recorded for subsequent analysis and to facilitate the calculation of other growth-related parameters.

Evaluation of growth performance

Growth-related parameters were calculated using the following formulae (Khanjan *et al.*, 2017).

i. Mean weight gain (MWG) = final mean weight (FMW) – initial mean weight (IMW)
ii. Specific growth rate (SGR) = 100 × (ln(FMW) - ln(IMW)) / time in days
iii. Condition factor (K) = $100W/L^3$ (where W= weight of fish in grams; L = total length of fish in millimeters)
iv. Survival rate (%) = 100 × (number of fish at the end of the experiment/number of fish at the beginning of the experiment)
v. Feed conversion ratio (FCR) = average feed consumed by fish (g) / mean weight gain (MWG) in grams
vi. Protein efficiency ratio = wet weight gain / dry weight of protein consumed.

Statistical data analysis

Data sets were tested for normality using the Kolmogorov-Smirnov test, while Levene's statistic was used to test for equaly of variance. One-way analysis of variance (ANOVA) (Genstat version 14) followed by Tukey's test to separate significant treatment means were used to analyze water parameters, growth performance, and feed utilization, where the level of significance was set as $P<0.05$.

Ethical consideration

Before commencing the research, clearance was obtained from the Faculty of Veterinary Medicine's Biosafety, Animal Use REF: FVM BAUEC/2023/423

Results

Growth performance and feed utilization indicators

The growth and feed utilization indicators of *O. niloticus* fed on different diets (control, T1, T2, and T3) are summarized in Table 4. There were significant differences ($p<0.05$) between fish fed the control diet (T0) (No postbiotic) and those fed diets containing the postbiotic (T1, T2, T3), and also between fish fed diets with different levels of the postbiotic on growth and feed utilization indicators.

The analysis revealed that fish fed diets containing postbiotics had markedly higher final weights compared to the control group. Specifically, final weight gains were 15.96 g/fish for treatment T1 , 18.77 g/fish for T2, and 17.83 g/fish for T3 , in contrast to 14.91 g/fish in the control. These differences were statistically significant ($p < 0.05$), confirming that even the lowest inclusion level of postbiotics improved fish growth compared to the control diet.

Similarly, the mean weight gain over the study period was significantly enhanced by the dietary treatments. Fish fed the T1 diet recorded a mean weight gain of 9.07 g/fish, while those on T2 and T3 diets achieved 11.97 g/fish and 11.19 g/fish respectively, as opposed to 7.35 g/fish in the control group ($p<0.05$). Post hoc comparisons indicated that the weight gain in the T1 group was significantly lower than in both the T2 and T3 groups, suggesting that increasing the postbiotic concentration to 4 g/kg maximizes the growth benefit. No significant differences ($p > 0.05$) were observed between the T2 and T3 groups,

implying that increasing the postbiotic level beyond 4 g/kg does not further enhance growth performance.

The results of specific growth followed a similar trend to the other growth indicators. Fish fed the control diet had significantly ($P < 0.05$) lower specific growth rate (1.33 % per day) than those fed on diets containing the postbiotic. Among the fish fed diets containing the postbiotic, those fed on T2 and T3 diets had significantly higher ($p<0.05$) average specific growth rates (1.85 and 1.79 %, respectively than those fed diets containing a lower level of the postbiotic (1.53%). Condition factor was not significantly ($p>0.05$) affected by treatments. There were no significant differences ($P >0.05$) between the fish fed diets based on the postbiotic and those fed on the control diet.

The survival rate was significantly influenced by treatments. There were significant differences ($P < 0.05$) between fish fed the control diet and those fed diets containing the postbiotic, but there were no differences ($P>0.05$) among fish fed different levels of the postbiotic.

Results of feed utilization indicators; feed conversion ratio (FCR) and protein efficiency ratio(PER) showed a similar trend as the growth indicators, whereas fish fed on the control diet (T0) had the worst FCR (2.14), which was significantly higher than of fish fed diets containing the postbiotic 1.90, 1.69 and 1.72 for fish fed (T1, T2 and T3 diets respectively.

Protein utilization was significantly affected by the inclusion and level of postbiotics in the diet. Fish fed the control diet (T0) had the lowest protein utilization (1.57 grams weight gain/ gram of protein consumed, compared to those fed diets containing the postbiotic 1.8, 2.31, and 2.1 grams weight gain/gram of protein consumed for treatments T1, T2, and T3, respectively. There were no differences in PER between fish fed diet T1 and T2.

Fish in all treatment groups displayed robust health and body condition. The condition factor of fish in all the treatments ranged from 1.40 to 1.42, with no significant difference among the treatments. Similarly, there were no significant differences in survival rates between fish in the T1, T2, and T3 groups (84%, 92%, and 92%), respectively. However, the Control group exhibited significantly lower survival (69%) compared to those fed on diets containing the postbiotic (Table 4.1).

Table 4

Growth and feed utilization indicators of O. niloticus fish, comparing the Control group (0g postbiotic) with the treatment groups: T1 (2g postbiotic), T2 (4g postbiotic), and T3 (6g postbiotic per kg of feed), expressed as mean±S.E.

Variable	Control	T1	T2	T3	*P*-value
Initial mean weight	6.84±0.04	6.89 ± 0.07	6.80 ± 0.00	6.64 ± 0.34	
Final mean weight	14.19±0.07^{a}	15.96±0.50^{b}	18.77±0.24^{c}	17.83±0.38^{c}	0.000
Mean weight gain (g)	7.35 ± 0.06^{a}	9.07 ± 0.49^{b}	11.97± 0.24^{c}	11.19± 0.29^{c}	0.000
Average daily growth (cm)	0.13 ± 0.00^{a}	0.16 ± 0.01^{b}	0.22 ± 0.01^{c}	0.20 ± 0.01^{c}	0.000
Specific growth rate (SGR)	1.33 ± 0.01^{a}	1.53 ± 0.06^{b}	1.85 ± 0.02^{c}	1.79 ± 0.02^{c}	0.000
Condition factor	1.40±0.003^{a}	1.42±0.008^{a}	1.40±0.003^{a}	1.41±0.003^{a}	0.088
Survival rate (%)	69.33 ± 1.3^{a}	84.00± 2.31^{b}	92.00± 4.62^{b}	92.00± 2.31^{b}	0.002
Food conversion ratio (FCR)	2.14± 0.01^{a}	1.90 ± 0.03^{b}	1.69 ± 0.11^{c}	1.72 ± 0.10^{c}	0.001
Protein efficiency ratio (PER)	1.57±0.06^{a}	1.80±0.03^{b}	2.31±0.20^{c}	2.10±0.28^{c}	0.013

Note: Identical superscripts within the same row indicate non-statistically significant differences, as determined by one-way ANOVA, while non-identical superscripts indicate statistically significant differences ($P < 0.05$).

Growth and feed utilization indicators of *O. niloticus* fish, comparing the Control group (0g postbiotic) with the treatment groups: T1 (2g postbiotic), T2 (4g postbiotic), and T3 (6g postbiotic per kg of feed), expressed as mean±S.E.

Figure 1

Polynomial relationship between fish body weight gain (%) and varying levels of postbiotic supplementation

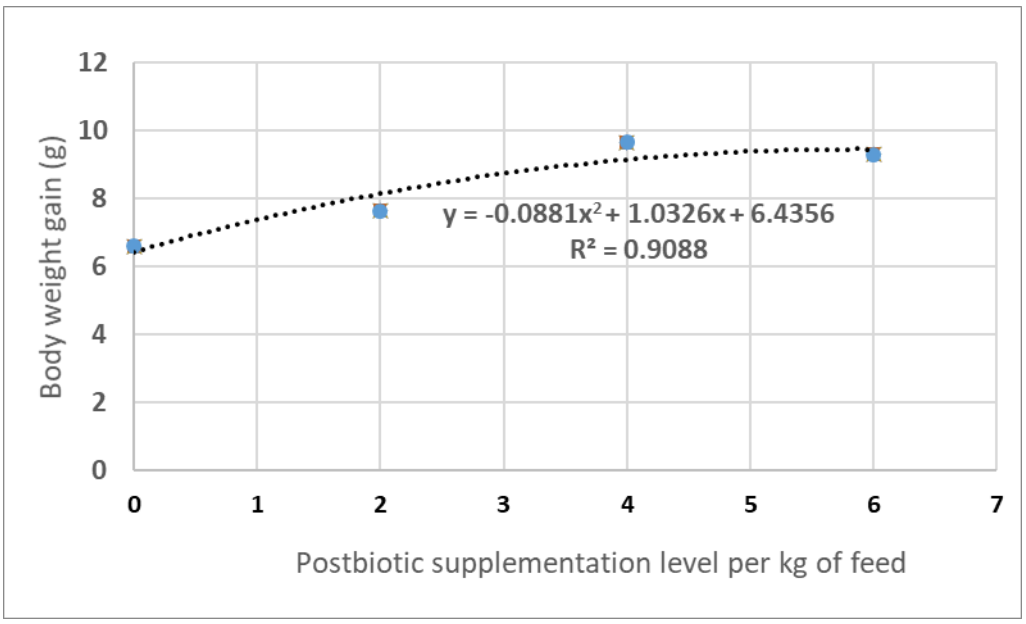


Figure 2

Polynomial relationship between fish survival rate (%) and varying levels of postbiotic supplementation

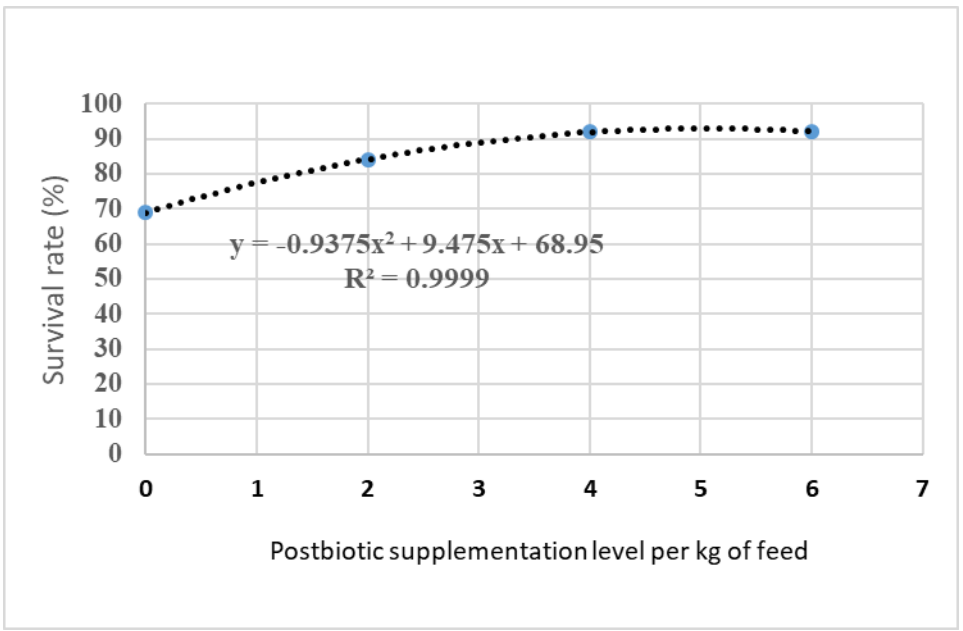


Figure 3

Polynomial relationship between fish feed conversion ratio and varying levels of postbiotic supplementation

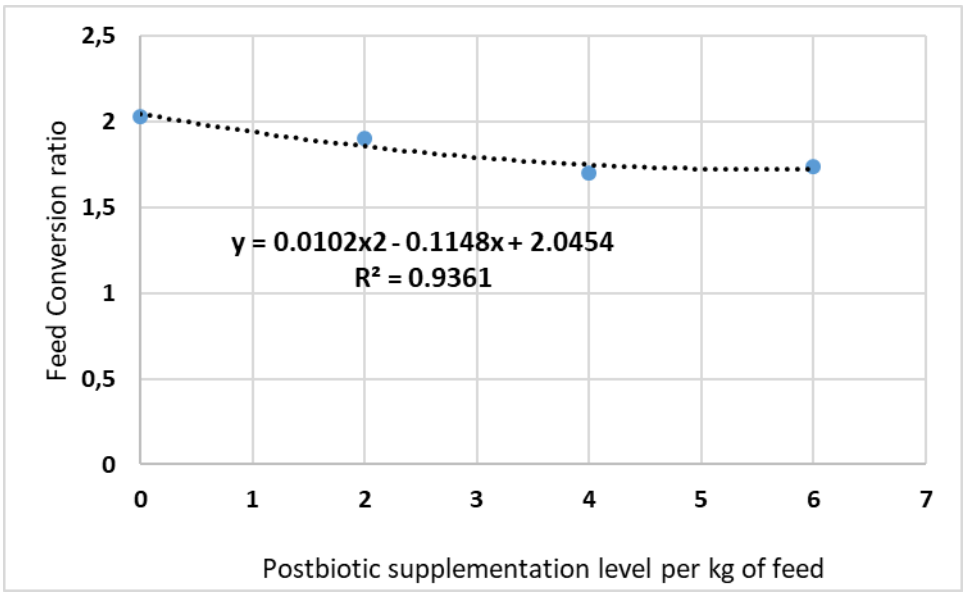
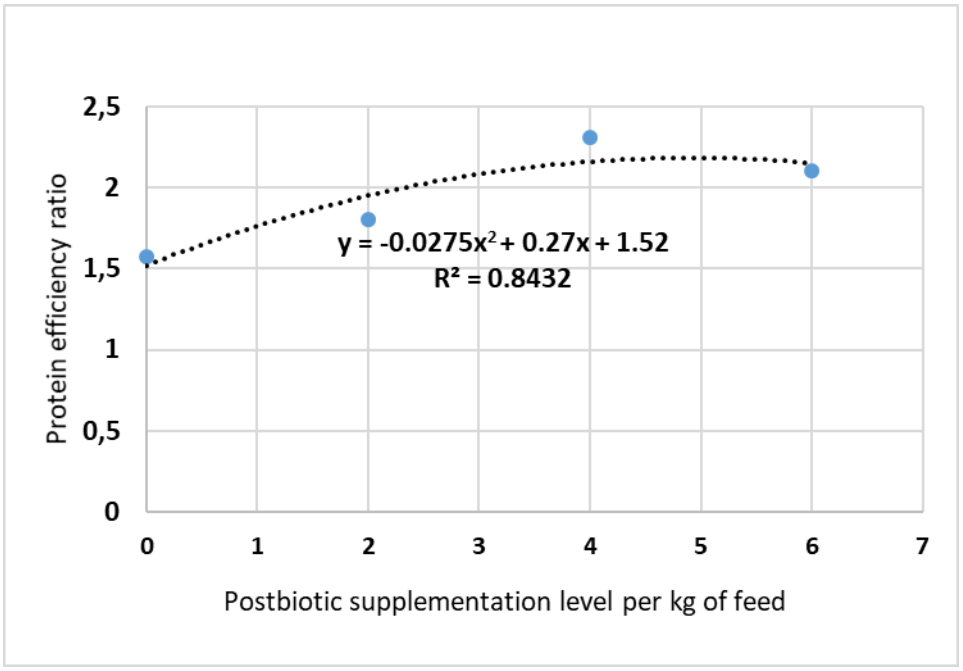


Figure 4

Polynomial relationship between fish protein efficiency ratio and varying levels of postbiotic supplementation



Water Quality Parameters

Dissolved oxygen, pH, temperature, phosphorus, total ammonia, nitrates, and turbidity levels were all within the acceptable range for optimal growth of *O. niloticus* fingerlings (Table 5). There was no significant difference in all measured water quality parameters ($P > 0.05$).

Table 5

Water quality parameters in control- (0g postbiotic) and the treatments; T1 (2g postbiotic), T2 (4g postbiotic), T3 (6g postbiotic) treatments as determined by one-way ANOVA ($p < 0.05$).

Variable	Control	T1	T2	T3	*P*-value	Ideal ranges
Dissolved oxygen (mg/L)	5.32±0.06	5.32±0.06	5.29±0.07	5.35±0.07	0.949	>3 (Effendi *et al.* 2020)
pH	7.63±0.05	7.67±0.06	7.57±0.06	7.62±0.05	0.667	5.5-9.5 (Makori *et al*. 2017)
Temperature (°C)	26.79±1.07	26.12±0.44	30.56±4.40	26.56±0.06	0.487	20-35 (Hassan et al 2013)
Phosphorus (Mg/L)	0.04±0.01	0.03±0.01	0.03±0.00	0.05±0.01	0.483	<0.5 (Vijuksungsith *et al.* 2023)
Total Ammonia (Mg/L)	1.63±0.09	1.71±0.11	1.59±0.08	1.63±0.10	0.840	<1 (Amin *et al*. 2022)
Nitrates (Mg/L)	5.79±1.36	5.79±1.34	5.32±1.25	6.40±1.48	0.956	<150 (Sallenave, 2016)
Turbidity	2.73±0.79	2.37±0.51	1.85±0.47	2.02±0.54	0.728	<50 (Ardjosoediro & Ramnarine 2002)

Note: The table presents water quality parameters for the control group (0g postbiotic) and three treatment groups (T1, T2, T3) with varying levels of postbiotic supplementation. Values are expressed as mean ± standard deviation. The P-value indicates the significance of differences among the groups as determined by one-way ANOVA ($p < 0.05$).

Discussion

Impact of postbiotics on tilapia growth performance

This study aimed to investigate the effects of *Saccharomyces cerevisiae* postbiotic supplementation on growth performance and feed utilization indices of Nile tilapia fingerlings. Postbiotics are composed of metabolic products of live microorganisms that modify the composition and functions of the host microbiota (Vinderola *et al.,* 2022). The performance metrics assessed included final weight, mean weight gain, average daily growth, specific growth rate, survival rate, feed conversion ratio, and protein efficiency ratio. Notably, fingerlings on the 4g postbiotic/kg (T2) supplementation exhibited superior growth and feed utilization, followed by those fed the diets containing 6g postbiotic/kg (T3), 2g postbiotic/kg (T1), and the fish fed the control diet (no postbiotic supplementation) performed the least in all parameters assessed compared to the treated groups (Table 4).

The growth, feed utilization, and survival improved with an increase in postbiotic supplementation up to 4g/kg. However, when the postbiotic supplementation was beyond that level, a slight reduction in growth performance was observed, although it was not significantly different from the treatment with 4g postbiotic/kg (T2). The improved growth and feed utilization performance in the postbiotic-supplemented treatments can be attributed to the growth-promoting effects of postbiotics, which predominantly stem from their ability to alter the general structure of the gut microbiota in host organisms (Wu *et al.,* 2020).

Consequently, this leads to enhanced growth and

overall health of the host (Wu *et al.,* 2020; Danladi *et al.,* 2022; Da Silva-Vale *et al*., 2023). Additionally, postbiotics play a pivotal role in promoting a balanced intestinal microbiota, consequently improving nutrient absorption (Liu *et al.,* 2023). Their beneficial effects have been associated with the intricate interactions between fundamental microbiological components that effectively imitate probiotic activities and the host (Wegh *et al.,* 2019).

Furthermore, the high growth performance among postbiotic-supplemented treatments could be attributed to their wide range of positive physiological benefits, making them promising alternatives to antibiotics and antibiotic growth promoters in aquaculture. Their antimicrobial, immunostimulating, and growth promotion effects have been extensively documented (Bedford and Gong, 2018; Quintanilla-Pineda *et al.,* 2023). Moreover, they enhance the digestibility and nutrient utilization by stimulating enzyme secretion, which in turn aids in the improvement of absorption, mobilization, and transport of nutrients (Ceulemans *et al.,* 2009). Additionally, postbiotics act as feeding stimulants, increasing feed intake and thereby reducing feed and nutrient waste (Ceulemans *et al.,* 2009). Quintanilla-Pineda *et al* (2023) also reported that postbiotics have a positive influence on the expression of genes responsible for growth and nonspecific immunity, thereby contributing to improved growth performance.

The outcomes of this study are in agreement with previous research conducted by Aguilar-Toalá *et al.* (2018) and Puccetti *et al*. (2020), which reported that postbiotics possess favorable attributes that result in enhanced growth rates. Their efficacy can be attributed to multiple mechanisms of action, including their contribution through reinforcement of the gut lining barrier function, optimization of metabolic responses, and enhancement of immunity (Schulze and Szopinska-Morawska, 2021). Moreover, postbiotics have the potential to influence appetite either through the gut or the central nervous system (Schulze and Szopinska-Morawska, 2021).

The present study further corroborates the findings of previous research by Wu *et al.* (2020), demonstrating that a postbiotic-supplemented diet significantly improves growth and feed efficiency in sturgeon and enhances immunity against *L. garvieae* in rainbow trout (*Oncorhynchus mykiss*) (Mora-Sánchez *et al.,* 2020; Pérez-Sánchez *et al.,* 2020). Additionally, the study concurs with Kamilya *et al* (2015), who found that *Bacillus amyloliquefaciens* FPTB16 and *Bacillus subtilis* FPTB13 heat heat-inactivated at 60°C for two hours, yielded more positive results in activating cellular immune parameters in catla (*Catla catla*) compared to live treatment. Furthermore, Barnes and Durben (2010) reported notable growth increase, improved feed conversion ratio, and reduced mortality rates in Rainbow trout fed on a fully-fermented yeast culture supplement compared to those fed on a control diet without yeast supplementation. Similar benefits were observed in Rainbow trout *Oncorhynchus mykiss*, with reduced mortality and significantly improved feed conversion ratio following postbiotic supplementation (Barnes and Durben, 2010).

Additionally, the present study's results align with those of Harikrishnan *et al.* (2011), who documented that *Saccharomyces cerevisiae*-supplemented diets stimulate growth, blood biochemistry, feed efficiency, and non-specific immune responses in *uronema marinum*-infected olive flounder (*Paralichthys olivaceus*). However, the findings of this study contrast with those of Pérez-Sánchez *et al.* (2021), who observed no significant difference ($p > 0.05$) in final weight between fish fed on a postbiotic-enriched diet and the control group at levels of 3.0 mg/g of feed and 0 mg/g of feed, respectively. Similarly, no significant difference (p=0.94) was found in the final total biomass between the control and experimental groups (Pérez-Sánchez *et al.,* 2021). The high growth performance recorded in the postbiotic-supplemented treatments signifies the potential of yeast-based postbiotics as an effective means to enhance the growth performance of Nile tilapia fingerlings. Further, the growth performance of *O. niloticus* is greatly influenced by physicochemical parameters.

Condition factor (K)

The condition factor offers insights into the animal's physical well-being within its habitat (Gomiero and de Souzan, 2005). The condition factor (K) of *O. niloticus* fingerlings in this study

exhibited a range of 1.40 to 1.42. Notably, the condition factor values observed across all dietary treatments were consistently above 1. This greater-than-unity condition factor signifies favorable fish health and indicates an isometric growth pattern, a desirable attribute in aquaculture (Ayoade, 2011). Variations in condition factor can sometimes arise due to the influence of factors such as sex (Olurin and Aderibigbe, 2006). However, it is important to highlight that such influences did not apply to our study results, as exclusively monosex male *O. niloticus* were employed in all dietary treatments. Remarkably, the fish in all treatment groups displayed robust health and body condition. This collective outcome underscores the suitability of all tested fish diets within this study for potential application in the commercial production of *O. niloticus*. The consistently elevated condition factors and overall health of the fish further endorse the viability of these dietary interventions for successful aquaculture endeavors.

Survival rate

The survival rates of the fingerlings exhibited consistent trends across the various postbiotic-supplemented treatments, while the control group had significantly lower survival rates. These outcomes align with findings documented by Aly *et al.* (2008), who observed similar survival rate patterns in treatments with probiotic-supplemented feed in comparison to the control group. This association between survival rates and probiotic supplementation underscores the potential benefits of enhancing gut health. A deeper examination of the gut immune system sheds light on the mechanisms behind these survival rate improvements. For instance, Picchietti *et al.* (2007) elucidated that early feeding with an alternative health product (AHP) supplemented diet elevated the count of Ig+ cells and acidophilic granulocytes in the gut of sea bream. This intricate interaction underscores the capacity of postbiotics to stimulate the gut's immune response, thereby correlating with the observed improvement in fry survival.

Water quality parameters

Dissolved oxygen (DO), pH, temperature, phosphorus, total ammonia, nitrates, and turbidity (Table 5) fell within the acceptable range for optimal growth (Boyd and Tucker, 2012), underscoring that they did not exert any adverse effects on the fish's development. This aligns with the resilient nature of tilapia, which is known to thrive in a wide array of environmental conditions.

One of the pivotal factors influencing the physiology of tilapia is water temperature. As ambient temperatures rise, fish metabolic rates increase, leading to increased food demand (Shackleton, 2012). Additionally, temperature can impact energy consumption and metabolic needs (Byström *et al.,* 2006). However, excessive temperatures can hinder growth. The current study recorded water temperatures ranging from 26.12 to 30.56°C, which, though slightly higher than values reported in other studies (Abdel-Aziz *et al.,* 2023), still fell within the optimal range of 20 to 35°C for tilapia growth (Hassan *et al.,* 2013).

Dissolved oxygen (DO) concentration significantly influences fish health, with low levels causing stress, poor appetite, slow growth, and increased disease susceptibility (Abd El-Hack *et al.,* 2022). Prior research indicated that DO concentrations below 0.8 to 3 mg L^{-1} could impair Nile tilapia growth and feed efficiency (Tran-Ngoc *et al.,* 2016; Ani *et al.,* 2022). In contrast, the current study observed DO levels ranging from 5.22 to 5.42 mg L^{-1}, well above the minimum requirement of 3 mg L^{-1} (Effendi *et al*., 2020). Moreover, the pH levels, spanning 7.57 to 7.67, were within the suitable range of 5.5–9.5 for tilapia growth (Makori *et al.,* 2017).

Total ammonia, a significant nitrogenous waste product, is linked to fish health. High concentrations are toxic and impede tilapia growth (El-Sherif and El-Feky, 2008; Morrow, 2009). The present study documented total ammonia levels from 1.59 to 1.71 mg L^{-1} and nitrates (NO_3) levels from 5.32 to 6.40 mg L^{-1}, both of which remained within acceptable limits for freshwater fish (Abd El-Hack *et al.,* 2022).

Turbidity levels, affecting fish appetite and gill function, were assessed. High turbidity can hinder feeding efficiency and gaseous exchange (Mallekh *et al.,* 1998; McKenzie *et al.,* 2020). In this study, turbidity ranged from 1.85 to 2.73 mg/L, well below the threshold of 50 mg/L associated with reduced growth (Ardjosoediro and Ramnarine, 2002). Additionally, phosphate levels,

ranging from 0.03 to 0.05 mg/L, remained within acceptable bounds.

Conclusion

Among the treatments, fish fed on T2 (4 grams of postbiotic/kg) displayed the most remarkable growth performance. It was closely followed by fish fed on T3 (6 grams of postbiotic/kg), and then fish fed on T1 (2 grams of postbiotic/kg).

Fish fed on T2 (4g postbiotic) exhibited the most favorable feed conversion ratio (FCR) and protein efficiency ratio (PER), suggesting improved utilization of dietary nutrients in this group. These findings indicate that higher postbiotic supplementation levels may contribute to better nutrient utilization and growth in *O. niloticus*.

The control group exhibited significantly lower survival rates compared to the treatment groups, suggesting that postbiotics could have improved the immune response in treatment-fed fed with postbiotic-supplemented feed, making them more resilient to environmental stressors and pathogens. This highlights the importance of postbiotics in enhancing the overall survival of *O. niloticus*.

Recommendations

Aquaculture practitioners should consider incorporating postbiotic supplementation, particularly at 4g/kg, into the diets of Nile tilapia fingerlings as a sustainable approach to improve disease resistance, enhance growth and feed utilization.

Given the significant improvement in disease resistance observed after postbiotic supplementation, aquaculture practitioners should incorporate postbiotics into the diets of Nile tilapia fingerlings to enhance their immunity against bacterial infections such as *Aeromonas veronii*.

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Conflict of interest

The authors declare no conflict of interest.

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