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Effects of Climatic Changes on Fish Productivity, and Its Impact on Food Security

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Abstract

The current study aimed to examine 200 water and 300 Tilapia fish samples either from wild Nile stream or aquaculture ponds located in Qalubiya governorate during summer and winter seasons of 2024. Physico-chemical characterization of water samples revealed slight variation in the pH values even tend to be more alkaline in summer season. While wild water samples recorded significant higher temperature especially at the mid-day (31.1^{o}C), lower dissolved oxygen (10.58 mg/L), higher salinity (0.04 %) and ammonia values (13.2 µg/L) during summer season; where, aquaculture ponds have been kept under control revealing lower grades of fluctuations. Regarding fish samples, higher body weight and overall acceptability were recorded in summer season, particularly for aquaculture fish samples (174.4 g and 9.38, respectively). Regarding body composition, significant variation between wild and cultured fish samples in different seasons was recorded. Results showed correlated reduction in protein and ash content in the examined samples during summer season; while significant increasing in fat, moisture and carbohydrate contents was recorded in the same season. Furthermore, cultured fish samples showed higher nutritional value than wild samples along the study period. Moreover, results revealed slight lower pH of cultured fish samples than wild samples in the same season; while higher TVN and TBA values were recorded in the wild fish samples than the cultured one. Furthermore, higher aerobic plate count (log CFU/g) was recorded during summer season either for wild or aquaculture fish samples, Enterobacteriaceae was, also, detected in 80.0, 88.0, 94.0 and 96.0% of the examined wild and cultured fish samples during winter and summer seasons, respectively; where higher incidence was detected in summer season and cultured fish samples. On the other hand, fungal populations revealed detection of mould and yeast growth on 48.0, 50.0, 24.0 and 30.0% of the examined wild and cultured samples during winter and summer seasons, respectively; where higher incidence was recorded in winter season's examined samples. Referring to the obtained results, seasonal variation revealed significant impact either on water or fish characters recommending regular monitoring of physico-chemical and microbiological properties for water and fish as well.

Keywords: *Climate change, Ecosystem, Nile river, Tilapia niloticus.*

Introduction

Nile Tilapia (*Oreochromis niloticus*) is a vital species for aquaculture and wild fisheries in Egypt. The effects of climate change on the nutritive value and microbiological quality of both wild and cultured Nile Tilapia are significant, influenced by alterations in temperature, water quality, and ecological conditions **(Younis *et al.*, 2024)**.

Environmental researches have been indicated that climate change is likely to increase global temperatures by 1.4 to 6.4°C, which can adversely affect the growth and reproductive cycles of Nile Tilapia **(Khallaf *et al.*, 2020)**. Increased temperatures can lead to stress, impacting the growth rates and overall health **(FAO, 2020)**.

The nutritive value of Nile Tilapia is influenced by their diet, which can be affected by environmental changes **(Abd El-Hack *et al.*, 2022)**. Studies have shown that the nutritional composition varies based on the rearing conditions—wild Tilapia often have different fatty acid profiles compared to those raised in aquaculture systems **(Idam *et al.*, 2023)**. Additionally, variations in water quality parameters such as pH, dissolved oxygen, and ammonia levels can further influence the fish's health and nutritional content **(Ashiqul Alam *et al.*, 2021).**

pH value is the only measurement which has been commonly used as a physical method for quality assessment of fish meat. The pH is an important determinant of microbial growth and seafood, with a high pH having a high spoilage potential and a short shelf life **(Newton and Gell, 1981)**. While, TVN is considered a marker of the quality and freshness of fish flesh, and it is a group of nitrogen-containing compounds, including NH3 and amines, originated from protein degraded by bacteria and enzymes' activities **(Rathod and Pagarkar, 2013).**

The microbiological quality of Nile Tilapia is crucial for food safety **(Onjong *et al.*, 2018)**. Changes in climatic conditions can alter the prevalence of pathogens in aquatic environments **(Levy *et al.*, 2018)**. Higher temperatures may promote the growth of harmful bacteria, affecting both wild and cultured populations **(Okon *et al.*, 2024).** Studies have highlighted that Tilapia from warmer waters might exhibit higher microbial loads, which could pose risks to human health if consumed **(Siddique *et al.*, 2024).**

The impact of climate change on Nile Tilapia encompasses a range of factors including nutritive value, microbiological quality, and keeping quality criteria.
Therefore, the current study aimed to evaluate the impact of unintended environmental changes on both wild and cultured Tilapia fish in Qalubiya governorate.

Material and Methods

Collection of fish and water samples

A total of 200 samples water samples (n=50/season from each water source); and 300 apparently healthy wild (n=75/season), and cultured (n=75/season) Tilapia fish samples were collected from wild Nile stream and aquaculture fish pond during summer and winter seasons of 2024.

Fifty water samples (2-3 liters) were seasonally collected from studied points in clean polyethylene bottles, five meters below the water surface and away from the shore, filtered and kept cool until analysis.

Fish Nile Tilapia (*Oreochromis niloticus*) samples (19.8 ± 2.31 cm and 120.40 ± 52.64 g) were also collected at the same time, transferred to the laboratory using an ice box as soon as possible and kept at -20℃ until examined.

Performed Examinations

Examinations of water samples

Water was examined three times daily, on site of collection, at 6:00 am, 12:00 pm and 6:00 pm for its temperature and pH using high-quality calibrated pH meter accompanied by internal thermometer (Adwa AD 1200- pH and temperature meter).

Moreover, water samples were, also, examined to determine the dissolved oxygen (DO) using DO meter, degree of salinity depending on the conductivity, and ammonia levels according to **EPA (1993).**

Fish samples examinations

Gross examination of the collected fish samples regarded weight and overall appearance including eye, operculum, scales, fins, coloration, emaciation and any deformities (ten scaling score; where 10 represent excellence and 1 represents the lowest acceptability).

Moreover, protein and fat content, total energy, ash and carbohydrate were determined as a nutritive value evaluation according to **AOAC (2012).**

On the other hand, fish samples were evaluated microbiologically for their aerobic plate count (APC) according to **ISO 4833-1 (2013)**. Isolation and identification of Enterobacteriaceae, mould and yeast according to **Quinn *et al.* (2011)**, after incubation on tryptone soy broth (37^{o}C/24h) for microbial enrichment.

Regarding to the keeping quality parameters, pH, TVN and TBA values were determined in fish samples according to **EOS 63-11 (2006), EOS 63-9 (2006),** and **EOS 63-10 (2006),** respectively.

Statistical analyses were performed by application of Analysis of Variance (ANOVA) test between three parameters or more, and independent T Test between two comparable parameters according to Differences between means were at the 5% probability level, using Duncan's multiple range test for comparative of means, on SPSS software v.20**.**

Results

Water sample examinations

Table (1). pH value of water at the examined points

Water pH							
Wild Nile stream				Aquaculture ponds			
Winter		Summer		Winter		Summer	
Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD
7.3-7.6	7.62 ± 0.3	7.8-8.2	7.96 ± 0.1	7.8-8.3	8.06 ± 0.2	7.8-8.5	8.14 ± 0.3

*: Superscript star means significant difference when $P \leq 0.05$

Table (2). Mean values of water temperature (^{o}C) at the examined points

	Water temperature							
	Wild stream				Aquaculture ponds			
	Winter		Summer		Winter		Summer	
Time	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD
6:00 am	12.3-13.0	12.72 ± 0.31^{c}	23.7-25.1	24.3 ± 0.53^{c}	27.3-27.7	27.5±0.2^{a}	28.4-29.1	28.8±0.4^{c}
12:00 pm	15.2-16.0	15.58 ± 0.32^{a}	29.2-32.5	31.1 ± 1.29^{a}	27.4-27.8	27.6±0.2^{a}	29.3-30.2	29.7±0.5^{a}
6:00 pm	14.2-15.0	14.56 ±0.36^{b}	25.4-26.8	25.96 ± 0.54^{b}	27.3-27.8	27.5±0.3^{a}	28.7-29.5	29.1±0.4^{b}

abc: Different superscript letters mean significant variation when $P \leq 0.05$

Table (3). Salinity (%) of water at the examined points

Water Salinity (S%)							
Wild Nile stream				Aquaculture ponds			
Winter		Summer		Winter		Summer	
Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD
0.02-0.04	0.03 ± 0.01	0.03-0.05	0.04 ± 0.01	0.02-0.05	0.03 ± 0.01*	0.03-0.08	0.05 ± 0.01*

*: Superscript star means significant difference when $P \leq 0.05$

Table (4). Dissolved oxygen (DO) values (mg/L) of water at the examined points

DO (mg/L)							
Wild Nile stream				Aquaculture ponds			
Winter		Summer		Winter		Summer	
Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD
9.5-14.3	11.52 ± 1.7*	8.4-12.1	10.58 ± 1.6*	11.8-16.3	13.76 ± 1.7*	9.2-13.5	11.7 ± 1.6*

*: Superscript star means significant difference when $P \leq 0.05$

Table (5). Mean values of ammonia (µg/L) of water at the examined points

Ammonia (µg/L)							
Wild Nile stream				Aquaculture ponds			
Winter		Summer		Winter		Summer	
Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD
5.8-8.4	7.1 ± 1.0*	10.2-17.5	13.2 ± 2.7*	11.9-13.4	12.66 ± 0.5*	13.2-16.5	15.2 ± 1.5*

*: Superscript star means significant difference when $P \leq 0.05$

Fish Sample examinations

Table (6). Gross examination of fish samples

		Winter season		Summer season	
		Wild fish samples	Aquaculture fish samples	Wild fish samples	Aquaculture fish samples
Body weight (gm)	Range	90-105	130-140	100-120	158-180
	Mean ± SD	96.4 ± 6.1*	134.6 ± 4.6*	108 ± 7.6*	174.4 ± 5.3*
Overall appearance	Eye	8.5±0.1	9.2±0.1	8.9±0.1	9.8±0.1
	Operculum	8.3±0.1	8.8±0.1	9.2±0.1	9.7±0.1
	Scales	8.2±0.1	8.7±0.1	9.0±0.1	9.8±0.1
	Fins	8.3±0.1	8.6±0.1	8.9±0.1	9.8±0.1
	Coloration	8.1±0.1	9.2±0.1	9.1±0.1	9.7±0.1
	Body condition	7.2±0.1	9.2±0.1	8.5±0.1	9.8±0.1
	Deformities	7.7±0.1	7.8±0.1	7.2±0.1	7.0±0.1
	Range	7.2-8.5	7.8-9.2	8.5-9.2	7.0-9.8
	Mean ± SD	8.04 ± 0.2*	8.78 ± 0.3*	8.68 ± 0.2*	9.38 ± 0.1*

*: Superscript star means significant difference when $P \leq 0.05$

Table (7). Nutritive values (%) of the examined fish samples

		Winter season		Summer season	
		Wild fish samples	**Aquaculture fish samples**	**Wild fish samples**	**Aquaculture fish samples**
Protein	**Range**	15.2-16.1	18.3-19.0	14.4-15.5	16.8-18.0
	Mean ± SD	15.7 ± 0.4 *	18.6 ± 0.3*	14.8 ± 0.3*	17.5 ± 0.3*
Fat	**Range**	3.0-3.3	5.1-5.5	4.0-4.82	7.2-7.8
	Mean ± SD	3.12 ± 0.1*	5.3 ±0.2*	4.4 ± 0.3*	7.44 ± 0.2*
Ash	**Range**	1.52-1.60	1.80-1.97	1.1-1.3	1.70-1.89
	Mean ± SD	1.56 ± 0.03*	1.86 ± 0.07*	1.19 ± 0.08*	1.78 ± 0.07*
Moisture	**Range**	77.3-79.0	76.8-77.2	79.8-80.2	78.5-79.0
	Mean ± SD	78.1 ± 0.7*	76.9 ± 0.1*	79.9 ± 0.1*	78.7 ± 0.2*
Carbohydrate	**Range**	0.25-0.31	0.48-0.60	0.32-0.42	0.58-0.73
	Mean ± SD	0.28 ± 0.03*	0.54 ± 0.05*	0.37 ± 0.04*	0.66 ± 0.06*

*: Superscript star means significant difference when $P \leq 0.05$

Table (8). Keeping quality parameters of the examined fish samples

			Winter season		Summer season	
	MPLs **(EOS, 2020)**		**Wild fish samples**	**Aquaculture fish samples**	**Wild fish samples**	**Aquaculture fish samples**
pH		**Range**	6.5-6.8	6.3-6.7	6.3-6.6	6.2-6.5
		Mean ± SD	6.62 ± 0.1	6.5 ± 0.2	6.38 ± 0.1	6.32 ± 0.1
TVN (mg%)	**35 mg N/100 g**	**Range**	10.0-14.0	8.0-12.0	15.0-18.5	12.0-18.0
		Mean ± SD	11.76 ± 1.1*	10.48 ± 1.4*	16.6 ± 1.1*	15.68 ± 2.0*
TBA (mg malonaldhyde/ Kg)	**4.5 mg MDA / Kg**	**Range**	0.5-0.9	0.4-0.7	0.8-1.2	0.7-1.0
		Mean ± SD	0.7 ± 0.2*	0.54 ± 0.1*	1.1 ± 0.2*	0.82 ± 0.1*

*: Superscript star means significant difference when $P \leq 0.05$

Table (9). Microbiological quality of the examined fish samples (n = 50)

		Winter season		Summer season	
		Wild fish samples	**Aquaculture fish samples**	**Wild fish samples**	**Aquaculture fish samples**
APC	**Mean count ± SD (log CFU/g)**	3.5 ± 0.5	3.7 ± 0.2	4.6 ± 0.1	4.7 ± 0.1
Enterobacteriaceae	**Incidence (%)**	80.0	88.0	94.0	96.0
	Identified isolates (%)	*E. coli* (30.0%)	*E. coli* (32.0%)	*E. coli* (40.0%)	*E. coli* (56.0%)
		Klebsiella sp. (10.0%)	ND	*Klebsiella* sp. (14.0%)	*Klebsiella* sp. (16.0%)
		C. freundii (20.0%)	ND	*C. freundii* (18.0%)	*C. freundii* (24.0%)
		Enterobacter sp. (6.0%)	*Enterobacter* sp. (8.0%)	*Enterobacter* sp. (10.0%)	*Enterobacter* sp. (14.0%)
		Proteus sp. (4.0%)	*Proteus* sp. (6.0%)	*Proteus* sp. (12.0%)	*Proteus* sp. (12.0%)
Fungi	**Incidence (%)**	48.0	50.0	24.0	30.0
	Identified isolates (%)	*As. niger* (12.0%) *As. flavus* (8.0%) *Saprolegnia* sp. (6.0%) *C. albicans* (8.0%)	*As. niger* (14.0%) *As. flavus* (6.0%) *Saprolegnia* sp. (10.0%) *S. cerevisiae* (8.0%) *C. albicans* (10.0%)	*As. niger* (16.0%) *As. flavus* (6.0%) *Penicillium* sp. (6.0%) *C. albicans* (6.0%)	*As. niger* (22.0%) *As. flavus* (6.0%) *As. fumigatus* (8.0%) *C. albicans* (16.0%)

Incidence was calculated in relation to the examined samples / season for each fish source (n=50)

Discussion

Global climate change has direct or indirect altering effects on aquatic ecosystems through rising water temperatures, changing flow patterns, ocean acidification, deoxygenation, and more extreme weather events. These changes disrupt fish habitats, reduce fish productivity, nutritive value, and cause biodiversity loss, threatening fisheries and aquaculture sustainability. In addition, microbiological quality is also affected as warmer temperatures and poorer water conditions favor the proliferation of opportunistic pathogens, affecting fish health and safety of aquaculture products **(Maulu *et al.*, 2021 and Aroyehun and Henri-Ukoha, 2025).**

Water quality analysis

In the current study, pH, temperature, dissolved oxygen (DO), salinity %, and ammonia levels were determined in water samples that were collected from wild Nile River and aquaculture fish ponds during winter and summer season.

Regarding the obtained data**, Table (1)** shows slight variation in the pH values of the examined water samples, even more obviously observed in Nile water wild stream samples; where the mean pH values were 7.62 and 7.96 for wild stream water samples, whereas were 8.06 and 8.14 for aquaculture pond water samples during winter and summer seasons, re-

spectively. However, pH still within optimum range for ecosystem stability and fish activity. Recorded results revealed that pH of aquaculture pond's water samples tends to be higher than those of wild stream water samples; while, slightly higher pH values were recorded in summer season than the winter one. pH mean values were 7.62 and 7.96 for wild stream water samples; while were 8.06 and 8.14 for aquaculture pond's water samples during winter and summer seasons, respectively.
Although slight fluctuations were recorded in the pH of both wild and aquaculture water samples in relation to the season of collection i.e. temperature of water, it still tends to alkaline pH that is preferable for fish metabolism and activity (7.3-8.5). Slight lower pH values were recorded in wild Nile water samples in winter season than in the summer that may be attributed to increase photosynthesis, reducing dissolved CO_2 and raising pH during warmer conditions **(Badr *et al.*, 2013).** While, aquaculture ponds kept minimum pH fluctuation because of being under control of water irrigation, inlet filtration and proper ventilation.
Recorded results came in consistent with the recorded findings of **Badr *et al.* (2013)**, and **Ramadan *et al.* (2024)** who documented that pH of the examined water samples ranged from 7.8-8.5 in different seasons and sites of collection.

Referring to the recorded water temperature **(Table, 2),** pond's temperature was kept under control either with under-water heaters in winter or aquarium fans in summer; where the mean pond temperature ranged from 27.5-27.6^{o}C and from 28.8-29.7^{o}C during winter and summer seasons, respectively; with minimum fluctuation that may be attributed to using heaters during winter season and fans with higher water irrigation rate during summer season. For wild stream, significant variations in water temperature were recorded between different time and seasons of measuring; where it ranged from 12.72-15.58 and 24.3-31.1^{o}C during winter and summer seasons, respectively, where 6:00 am revealed the lowest recorded temperatures; but 12:00 pm revealed the highest temperature.
The recorded temperatures came in line with those of **Hassaan *et al.* (2019) and Abd El-Hack *et al.* (2022)** who recorded an average ranged from 20-30^{o}C in adaptive fish ponds. Additionally, results came in line with **Younis *et al.* (2024)** who found that the mean temperature on wild Nile water was 30.8 and 15.4^{o}C in summer and winter seasons, respectively.
Water temperature plays a critical role in influencing key water quality parameters such as dissolved oxygen (DO), ammonia, and salinity, which in turn affect fish health and growth. As temperature rises, the solubility of oxygen in water decreases, leading to lower DO levels despite increased metabolic oxygen demand by fish and microorganisms **(EPA, 2024)**. Concurrently, higher temperatures elevate ammonia production and the proportion of toxic unionized ammonia (NH3) due to accelerated metabolic and microbial activity, posing toxicity risks if not properly managed **(Edwards *et al.*, 2024)** Additionally, increased water temperature can enhance evaporation rates, concentrating salts and thus increasing salinity, especially in closed or poorly replenished systems; elevated salinity combined with high temperatures can further stress fish and promote disease outbreaks **(Elnady *et al.*, 2021)**.
Regarding the recorded salinity % of the current study **(Table, 3)**, non-significant increase in the salinity % of wild stream water samples during summer season (0.04±0.01) was recorded that may be attributed to large water volume and constant flow, natural hydrological cycle including seasonal rainfall and upstream freshwater input balance, and minimal direct human intervention **(Musie and Gonfa, 2023)**, that came in line with the recorded results of **Younis *et al.* (2024)**; while significant increase salinity % in aquaculture ponds in summer season (0.05 ± 0.01) that may be attributed to limited water volume and retention, high water evaporation particularly in summer season, and poor irrigation and water addition practices that may contain dissolved salts **(Ozaki *et al.*, 2021).** The results came in line with the recorded results of **(Elnady *et al.*, 2021).**

As a consequence of temperature fluctuation, significant decrease in the DO levels was recorded in the collected water samples either

from wild stream or aquaculture ponds in summer season; while still within optimum requirement for fish growth and activity. It is worth noted that lower DO levels were recorded in wild stream samples (11.52 and 10.58 mg/L) than those from aquaculture ponds (13.76 and 11.7 mg/L) during winter and summer seasons, respectively **(Table, 4).**

Results came in line with the records of **Badr *et al.* (2006), Badr *et al.* (2013), Abd El-Hady *et al.* (2015), and Ibrahim (2016)** who estimated DO levels in Nile river during summer and winter seasons in different times, where it ranged from 6-9 mg/L during winter season, while lower values were recorded in summer season; while higher DO values were recorded by **Younis *et al.* (2024)** that may be attributed to lower water temperature, during winter season that enhance oxygen solubility, while higher temperature during summer season increases biological activity that play a role in lowering oxygen availability. All the recorded studies confirmed negative correlations between water temperature and DO.

Ammonia concentrations in the Nile River exhibit noticeable seasonal variation influenced by temperature, hydrological dynamics, and biological activities. Studies report generally low ammonia levels throughout the year, but slightly elevated concentrations tend to occur during warmer months such as summer and autumn due to increased water temperature accelerating organic matter decomposition and fish metabolism, thus releasing more ammonia into the water. Conversely, ammonia levels often decrease in winter when lower temperatures slow down microbial and biochemical processes. The seasonal shifts also correlate with water flow patterns; during low-flow or drought periods, reduced dilution can lead to local concentration increases, particularly in closed aquaculture fish ponds **(Ali *et al.*, 2014).**

Regarding the obtained results of ammonia levels (µg/L) in **Table (5),** ammonia levels were obviously higher in summer season (13.2 and 15.2) than winter season (7.1 and 12.66) for wild and aquaculture fish samples with significant statistical difference, respectively. In addition, although ammonia levels raised in winter season it still optimum for tilapia performance (50 µg/L). Moreover, higher ammonia levels in the summer collected samples than wild stream collected samples during winter season may be attributed to the direct relationship with water temperature, and rate of water irrigation especially in fish culture ponds; where higher water temperature with lower rate of water irrigation significantly increase the ammonia levels **(Hargreaves and Tucker, 2004 and Lembang *et al*., 2025)**.

The obtained results came consistent with **Ali *et al.* (2014)** and **Younis *et al.* (2024)** with some variations that can be referred to difference in the site of collection, season of collection and technique of detection.

Fish sample's quality

In the present study, fish samples were examined for their gross characters regarding growth rate represented by weight average and overall appearance **(Table, 6),** nutritive value regarding the percentage of protein, fat, ash, moisture and carbohydrate content **(Table, 7),** keeping quality regarding musculature pH, total volatile nitrogen (TVN) and thiobarbituric acid (TBA) **(Table, 8)**, and microbiological quality regarding the aerobic plate count (APC) as an hygienic indicator, Enterobacteriaceae and fungal populations **(Table, 9).**

Regarding gross characterization of the collected fish samples **(Table, 6)**, significant variation in the body weight was recorded between wild fish and aquaculture fish samples, particularly in winter season that may be attributed to the availability of feed stuff, fish activity and tolerability to the climatic changes; where aquaculture fish samples had higher body weight (134.6 and 174.4 g during winter and summer seasons, respectively), and overall acceptability scores (8.78 and 9.38 during winter and summer seasons, respectively), referring to its eye, operculum, scales, fins, coloration, body conditions and deformities scoring, than wild fish samples during winter and summer seasons, respectively.

The weight loss observed in wild Nile Tilapia during winter, unlike cultured Tilapia, primarily results from their limited ability to tolerate low temperatures, which slows their metabolism and shifts energy allocation from growth to basic physiological maintenance. Wild Ti-

lapia is exposed directly to natural seasonal temperature drops, often experiencing water temperatures falling below 16°C, which significantly reduces their feeding activity and digestion efficiency. This leads to decreased nutrient absorption and eventually weight loss. Additionally, wild fish face increased stress and disease susceptibility due to cold temperatures, further compromising their condition. In contrast, cultured Tilapia benefit from controlled environments where temperature management helps maintain optimal conditions (usually 25–30°C), preserving feeding behavior and growth rates during winter **(Abd El-Hack *et al.*, 2022)**.

Higher acceptability scores and body weight of either wild or cultured fish samples during summer season may be attributed to the higher availability of feeding, more suitable ecosystem for fish activity, metabolism with higher immunity and health conditions **(Volkoff and Rønnestad, 2020).**

Several previous studies have estimated the body weight of Nile Tilapia (*Oreochromis niloticus*) during summer and winter seasons, highlighting seasonal growth variations influenced by temperature and environmental conditions such as **Khallaf *et al.* (2020)** who reported that the highest length-weight slope values occurred in summer and slightly lower in winter, suggesting slightly higher growth rate in warm season. Another study found that Nile Tilapia fingerlings grew better at deeper water depths during the cold season, indicating that factors like water depth and temperature regulate growth rate and fish performance **(Ali *et al.*, 2013)**. On the other hand, research on nutritional interventions to mitigate winter thermal stress also showed that Tilapia can maintain or improve growth rates in cold water (16–19 °C) with dietary supplements, particularly in controlled aquaculture fish ponds, despite the natural slowing of metabolism in winter **(Hassaan *et al.*, 2019)**.

Consequently, seasonal body composition analysis findings **(Table, 7)** came consistent with that recorded by **(Younis *et al.*, 2015 and Rakib *et al.*, 2021)** who recorded that protein content generally tends to be higher in winter, with wild samples reaching approximately 19–20%, while decreasing to around 13–16% during summer. Cultured Tilapia exhibits similar seasonal trends but maintain comparatively higher and more stable protein levels due to controlled feeding regimes. Fat content, on the other hand, increases significantly in summer, sometimes reaching up to 9–10% in wild fish, reflecting metabolic shifts that favor lipid accumulation in warmer temperatures, whereas fat levels decline during winter. Carbohydrate levels are relatively low overall but show a summer increase correlating with higher fat and moisture contents. Moisture content typically peaks in summer, often reaching about 82%, and decreases to around 79–80% in winter, showing an inverse relationship with fat content. Ash content, representing mineral accumulation, usually increases in winter and decreases in summer, likely influenced by changes in diet and physiological processes. In addition, **El-Sherif *et al.* (2023)** reported that the values (%) of moisture, protein, lipid, ash and carbohydrate of Tilapia fish ranged from 78.24-79.11, 16.5-18.2, 2.12-2.87, 1.25-1.46, and 0.06-0.19; where authors concluded that lipid and protein ratio of fish feeding formulas in fish farms significantly affect the nutritional composition of Tilapia musculature.

The present obtained results of body composition can be attributed to seasonal variations that are mainly influenced by environmental factors such as water temperature, which affects fish metabolism: higher temperatures accelerate metabolic rates leading to increased fat deposition and moisture content but reduce protein synthesis and mineral retention. In contrast, cooler winter temperatures slow metabolism, favoring protein and mineral accumulation while lowering fat stores that tends to be metabolized for energy maintenance. Differences in feeding practices further contribute, as cultured Tilapia are provided with consistent and nutritionally balanced diets, resulting in reduced seasonal fluctuation compared to wild fish that depend on variable natural food sources. The reproductive cycle also affects body composition, as energy reserves like fat are mobilized during spawning periods often coinciding with warmer months. Additionally, thermal stress from elevated summer temperatures can promote lipid storage as an energy reserve, whereas the colder conditions in winter can suppress appetite and growth, impact-

ing nutrient profiles **(Vollenweider *et al.*, 2011; Saeed, 2013, Volkoff and Rønnestad, 2020)**.

Based on the present results **(Table, 8)**, the estimated pH, Total Volatile Nitrogen (TVN), and Thiobarbituric Acid (TBA) values of wild and cultured Nile Tilapia vary between summer and winter seasons due to environmental and physiological factors. Generally, the pH of fresh Tilapia muscle tends to be slightly higher in winter (around 6.3–6.8) compared to summer (6.2–6.6), reflecting better freshness and slower biochemical degradation during cooler months. TVN values, an indicator of protein breakdown and spoilage, were lower in winter (8–14 mg N/100g) and increase significantly in summer (15.0-18.5 mg N/100g). Similarly, TBA values, measuring lipid oxidation, showed lower levels in winter (0.4–0.9 mg MDA/kg fish) and rise in summer (0.7–1.2 mg MDA/kg), indicating that oxidative rancidity is more pronounced in warmer conditions. On the other hand, cultured Tilapia samples consistently exhibit better freshness indexes (lower TVN and TBA) than wild samples.

These findings can be attributed to the influence of seasonal temperature variations on fish muscle biochemical processes: higher temperatures in summer accelerate spoilage and oxidative reactions, whereas cooler winter temperatures slow down these deteriorative processes. Additionally, cultured fish benefit from stable rearing conditions, leading to enhanced microbiological and chemical stability in their flesh throughout the year **(Jiang *et al.*, 2021)**.

The present obtained results indicated that the tested fresh fish samples of high keeping quality, in a result that coincides with that of **Buchtová (2011)** who assessed that fresh fish muscle is associated with pH value most frequently in the range of 6.0 to 6.5. The pH value in this study was in accordance with that obtained by **Mohamed (2018)**, **El-Sherif *et al.* (2023) and Kourany *et al.* (2024)** who recorded that the pH value was 6.40, 6.28, and 6.18, respectively for fresh caught Tilapia fish samples.

TVN is considered a marker of the quality and freshness of fish flesh, and it is a group of nitrogen-containing compounds, including NH3 and amines, originated from protein degraded by bacteria and enzymes' activities **(Rathod and Pagarkar, 2013).**

Based on the aforementioned findings, it could be noticed that, the TVN content in Tilapia samples is less than the acceptability limit (35 mg/100g) stated by **(EOS, 2020),** however, higher TVN values were recorded in fish samples collected during summer season. Therefore, the present recorded TVN values of investigated fish samples (mg N/100g) were much lower than the maximum permissible levels, and have a high freshness level and did not reach hazardous levels for the final consumer. This finding concurs with that of **Talab *et al.* (2016)** who reported that the ranges of TVN of the Nile Tilapia fish were 16.04–19.24mg N/100g, **El-Sherif *et al.* (2023)** (10.72-12.04 mg N/100 g), and **Kourany *et al.* (2024)** (12.72-15.04 mg N/100 g); while lower values were recorded by **Mohamed (2018) (**8.68mg N/ 100 g).

Thiobarbituric acid (TBA) is widely used as a biochemical indicator to measure lipid oxidation in fish flesh, specifically by quantifying malonaldehyde (MDA), a secondary product of lipid peroxidation. Referring to the obtained result, it was (0.4-0.9 mg MDA/kg) much lower than MPLs (4.5 MDA/kg) as recommended by the Egyptian Standard Specifications **(EOS, 2020)** indicating high freshness and keeping quality although higher values were recorded in summer season collected samples.

The current results are in consistent with those of **El-Sherif *et al.* (2016)** (0.75 mg MDA/Kg), and **Kourany *et al.* (2024)** (0.77 mg MDA/ Kg); but, higher than those determined by **Mohamed (2018)** (0.17 MDA/kg for Tilapia fish from the Fayoum fish farms), and **El-Sherif *et al.* (2023)** (ranged from 0.31 to 0.57 mg MDA/ Kg based on the source of harvesting).

Referring to the obtained results of APC (3.5, 3.7, 4.6 and 4.7 log CFU/g for wild and aquaculture tilapia samples during winter and summer seasons, respectively), it came within the recommended permissible limits by **EOS (2020)** (<6 log CFU/g). however, it came lower than those recorded by **Sabae and Mohamed (2015)** who demonstrated the bacterial load values in Tilapia spp. at 5.26 log CFU/g, 5.16 log CFU/g and 5.18 log CFU/g in the eastern, middle and western parts of the Lake

Qarun, respectively, and **Ahmed (2019)** (5.6 log CFU/g). Remarkably, the present values are somewhat agreeing with those recorded by **El Sherif *et al.* (2016)** who found that APC was 3.39 log CFU/g for the raw Nile Tilapia fish obtained from Wadi El-Rayan Lake, and **El-Sherif *et al.* (2023)** (3.85 log CFU/g).

Enterobacteriaceae especially food poisoning members represent a major and important group of microorganisms because of their frequent occurrence and activities that may have a negative impact on seafood quality, or even has a potential food poisoning **(Cortés-Sánchez *et al.*, 2025).**

Referring to the obtained results of Enterobacteriaceae prevalence and strains identification of the examined fish samples of the current study i.e. 80 and 88% during winter; 94 and 96% during summer season in wild and aquaculture samples, respectively. Moreover, *E. coli*, *C. freundii,* Klabsiella spp. and Enterobacter spp. were detected in various prevalence; where summer season revealed higher rate of contamination; beside that, aquaculture examined fish samples showed higher rate of bacterial contamination **(Table, 9).**

The obtained results agreed with the records of **Rawash *et al.* (2019)** who detected Enterobacteriaceae in 94.0% of the examined Tilapia samples; besides that, authors recorded detection of *Citrobacter freundii, E. coli, Enterobacter aerogenes, Enterobacter cloacae, Klebsiella oxytoca, Proteus mirabilis, Proteus vulgaris* in different ratios, where *E. coli* had the highest ratio among the detected strains. On the other hand, higher prevalence of Enterobacteriaceae in examined Tilapia samples was recorded by **Saad *et al.* (2018),** where it was detected in all of the examined samples (100%). In addition, **Ahmed (2019)** recorded determination of different food poisoning bacteria, where *E. coli* was the most significant identified bacteria. It is worth noted that lower contamination levels in wild fish samples may be attributed to continuous runny water stream that may, also, be affected by site of collection and its distance from industrial waste disposal sources.

Fungal contamination of Nile Tilapia flesh is a significant concern in aquaculture particularly where the contaminated feed is the primary source of contamination, while, wild fish may be incorporating fungal contamination from contaminated site of rearing with sewage and drainage. Fungal contamination, primarily caused by molds and yeasts, can impair fish health and product safety **(Mohamed *et al.*, 2017)**.

Regarding the obtained data **(Table, 9)**, higher prevalence of fungal detection was recorded in winter season (48 and 50% for wild and aquaculture fish samples), where, cultured fish samples revealed higher prevalence of contamination (50%). Higher fungal contamination of Tilapia flesh in winter compared to summer (24-30%) is primarily caused by environmental and physiological factors linked to seasonal temperature changes. During winter, lower water temperatures—often below 15°C—create favorable conditions for fungal pathogens such as Saprolegnia spp. and various Aspergillus species, which thrive in cooler, moist environments **(Abdel Razek *et al.*, 2021)**. Additionally, sudden temperature fluctuations and cold stress suppress the immune system of Tilapia, increasing their susceptibility to fungal invasion and proliferation **(Abdul Kari, 2025)**. In contrast, warmer summer temperatures can inhibit certain fungal growth due to higher metabolic rates and fish immune activity, though thermotolerant fungi like *A. niger* may still persist. Furthermore, poor water quality, high organic load, and inadequate hygiene during capture and handling, which may worsen in winter due to slower decomposition and limited water exchange, also contribute to increased fungal contamination **(Garcia-Solache and Casadevall, 2010)**.

The obtained results came somewhat agree with the records of **Yehia and Aman (2003)** who detected mould contamination in 44.4 and 50.0% of the collected samples from El-Gharbia and Kafr El-Sheikh governorates, respectively; where, Candida sp. and Aspergillus sp. the major detected fungi from the examined samples with the prevalence of 16.67 and 22.22 for El-Gharbia samples, 24.44 and 12.22 for Kafr El-Sheikh samples, respectively; and **Eid *et al.* (2017)** who recorded that Saprolegnia sp. and A. niger were the most detected mould strains in winter and summer seasons, respectively, and **Abdel Razek *et al.* (2021)**

who reported detection of Saprolegnia sp., Penicillium sp., *A. niger., A. flavus* and other fungal strains in the examined Tilapia samples collected during the period of December 2018 to May 2019, while in lower prevalence rate (76.0-92.0% based of the site of collection).
Although, relatively high microbial prevalence in the examined fish samples either of wild or aquaculture sources, fish samples kept their apparently acceptability that may be attributed to the low microbial population; where microbial virulence, environmental conditions and fish immunity play a cruciate role in the body conditions **(Amillano-Cisneros *et al.*, 2025).**
Overall, these findings demonstrate that both environmental seasonality, rearing system, and water quality strongly influence the nutritional, keeping and microbiological quality of Nile Tilapia, with cultured fish generally showing higher and more consistent nutrient levels than their wild counterparts.

Conclusion

Seasonal variations notably affect the water quality of both wild Nile environments and aquaculture ponds, which in turn influence the keeping quality, nutritional value, and microbiological status of Nile Tilapia. Summer season lead to higher water temperatures, decreased dissolved oxygen, and increased levels of ammonia and salinity %. This often causes reduced protein content, increased fat and moisture levels, and elevated microbial contamination, negatively impacting fish freshness and shelf life.

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