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Oxygen uptake in relation to body weight in freshwater fish Tilapia *Oreochromis niloticus*

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Abstract
This study shows the oxygen uptake rates of *Tilapia* (*Oreochromis niloticus*), in relation to body weight during two distinct seasonal temperature conditions: winter (20±1°C) and summer (30±1°C). The relationship between oxygen consumption (mlo_2/hr) and body weight was analyzed using the equation $y=a.W^b$, where (a) is the intercept and (b) is the regression coefficient. In winter, the regression coefficient (b) was 0.7038, with a correlation coefficient (r) of 0.9972 ($p<0.01$), and the antilog of the intercept (a) was 0.375. Oxygen uptake rates varied inversely with weight, with values of 0.2898 (mlO_2/g/hr), 0.1981(mlO_2/g/hr), 0.1570 (mlO_2/g/hr) for 2g, 9g, and 17g, respectively. During summer, the regression coefficient (b) increased to 0.8028, with a correlation coefficient (r) of 0.9937 ($p<0.01$) and the antilog of the intercept was 0.551. Oxygen uptake rates similarly decreased with weight, ranging from 0.5542 (mlO_2/g/hr), 0.3374 (mlO_2/g/hr), and 0.3230 (mlO_2/g/hr) for 2g, 10g and 19g fish, respectively.

Keywords: Oxygen consumption, respiration, seasonal temperature, summer and winter

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Introduction

Oxygen uptake is a fundamental physiological process in fish, directly reflecting their metabolic demands and energy requirements. It is influenced by several factors, including body size, water temperature, and environmental conditions. Temperature, in particular, plays a critical role in regulating metabolic activity, as fish are ectothermic organisms whose physiological processes are largely dictated by external temperature (Brett, 1971). Seasonal temperature changes can therefore result in significant variations in oxygen uptake, impacting growth, reproduction, and survival.

Research has shown that oxygen uptake generally increases with temperature due to elevated metabolic activity. For example, (Brett, 1971) demonstrated a marked increase in oxygen consumption in salmonids at higher temperatures, while (Bhattacharya and Subba, 2006) observed similar trends in the flying barb *(Esomus dandricus*). Conversely, colder temperatures are associated with reduced metabolic rates and lower oxygen demands, as observed in snow trout *(Schizothorax richardsonii*) (Kamalam *et al*., 2019).

Body size is another critical factor influencing oxygen uptake. Smaller fish typically exhibit higher mass-specific metabolic rates than larger ones due to their greater surface area-to-volume ratios, facilitating faster gas exchange (Clarke and Johnston, 1999). This relationship has been observed in various species, including Zebrafish (*Danio rerio*) (Barrionuevo and Burggren, 1999) and Rainbow trout (*Oncorhynchus mykiss*) (Farrell, 2002). Munshi *et al.* (1976) measured oxygen consumption through gills and skin in *Clarias batrachus,* demonstrating a positive correlation between oxygen uptake and body weight. The finding indicates that weight-specific oxygen consumption decreases with increasing body weight, highlighting the significance of gill and skin respiration in fish size.

Beamish (1964) examined seasonal variations in the standard metabolic rate of the brook and brown trout, revealing that oxygen consumption rates fluctuate with seasonal changes, potentially due to reproductive activities and environmental factors. Elevated water temperatures, a consequence of global warming, significantly impact the physiological functions of fish, including Nile tilapia (*O. niloticus*).

Islam *et al*. (2022) demonstrated that acclimatization to extremely warm ambient temperatures leads to increased oxygen consumption and notable alterations in gill morphology in Nile tilapia. Khater *et al*. (2021) developed a mathematical model to predict oxygen concentration in tilapia fish farms. The model considered factors such as fish respiration, biofiltration, and water temperature. It was observed that oxygen consumption by fish respiration ranged from 12.04 to 47.53 g O_2 m^{-3} h^{-1}, with variations influenced by water temperature and individual fish weight.

Tilapia *(O. niloticus)* are freshwater fish belonging to the family Cichlidae, which includes numerous species that inhabit rivers, lakes, and streams, primarily in Africa. They are naturally distributed across tropical and subtropical regions but have been introduced to other parts of the world for aquaculture. These fish are adaptable and can tolerate a range of salinities, from freshwater to brackish water, making them highly versatile. The present paper is an attempt to ascertain the effect of seasonal temperature and size on the routine oxygen consumption of the Tilapia *(O. niloticus*).

Materials and methods

To measure oxygen uptake, 30 live specimens of *O. niloticus* of different sizes and weight were collected from Regional Agricultural Research Station, Tarahara, Sunsari. Live specimens were acclimatized in an aquarium under controlled environmental conditions. Water temperature was maintained at seasonal ranges (e.g., in winter (20±1°C) and (30±1°C) in summer), with neutral pH (7.0). The fish were fed daily Optimum highly nutritious fish food. For experimentation, individuals of specific sizes were sorted, starved for 24 hours to standardize metabolic conditions, and placed in rectangular aquaria. Oxygen consumption was measured using dissolved oxygen probes over a fixed period, ensuring stable environmental conditions to avoid stress-induced variability.

Oxygen uptake was determined using a cylindrical glass respirometer measuring 24cm in length and 7cm in diameter, with a total volume of 722ml. One end of the respirometer was attached to a reservoir that maintained a constant water level. The reservoir outlet was linked to two conical flasks arranged in series to capture the discharged water.

The experimental fish was weighed and carefully placed in a respirometer filled with water and closed the mouth with a suitable rubber cork having a delivery tube inserted. To ensure the fish remained stress-free and showed no signs of suffocation, the flow of water from the reservoir to the respirometer was adjusted appropriately. To minimize disturbances, the respirometer was covered with a black cloth, leaving a small opening for observation. Before commencing the experiment, the fish was allowed to acclimate for an hour. Water samples were collected from the conical flasks connected at the inlet (representing the inspired water) and the outlet of the respirometer (representing the expired water).

The dissolved oxygen concentration in these water samples was measured using a Lutron DO 5509. Dissolved Oxygen Monitor. Oxygen consumption by the fish was calculated both per unit time (mlO_2/hr) and per unit body weight ($mlO_2/kg/hr$) by analyzing the differences in oxygen levels between the incoming and outgoing water, along with the water flow rate and the fish's weight. Regression analysis, incorporating logarithmic transformations, was performed to examine the relationship between oxygen uptake rates and the fish's body parameters.

Results

The oxygen consumption measurements (VO_2) for 12 different weight groups of fish, along with the results of regression analysis evaluating the relationship between VO_2 and body weight, are presented in tables 1-4.

Relation between oxygen consumption to body weight during summer 30 ± 1°C

During the summer at 30±1°C, the oxygen consumption through gills in *O. niloticus* was found to correlate strongly with body weight. The uptake of oxygen through gills in summer ranged from1.1084 to 6.1377 ml/hr within the weight range of 2 to 19g (Table 1). The regression equation that represents the relationship between oxygen uptake (mlO_2/hr) and body weight is:

$VO_2= aW^b$

Where, VO_2= oxygen uptake

a = rate of oxygen uptake

W = body weight
b = slope of the regression coefficient
Therefore, substituting the values:
$VO_2 = 0.551W^{0.8028}$ Or, $\log VO_2 = -0.2588 + 0.8028 \log W$

A slope (b) value of 0.8028 indicates the degree of increase in oxygen uptake with body weight. The log-log plot of oxygen uptake versus body weight produced a straight line (Figs. 1-2), with a very high correlation coefficient ($r=0.9937$, $p<0.01$), signifying a positive correlation between body weight and oxygen uptake in Tilapia during summer.

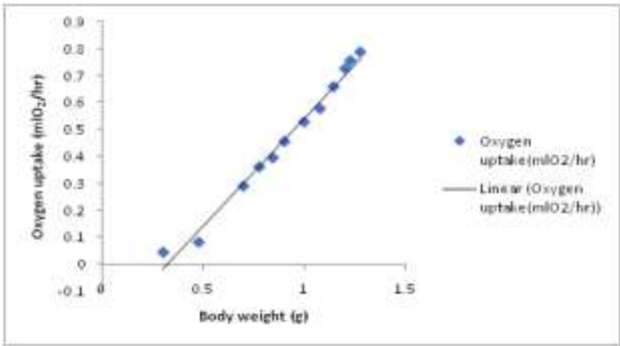

Figure 1. Log/log plots showing the relationship between oxygen uptake and body weight (ml O_2/hr) at 30±1°C temperature in *O. niloticus.*

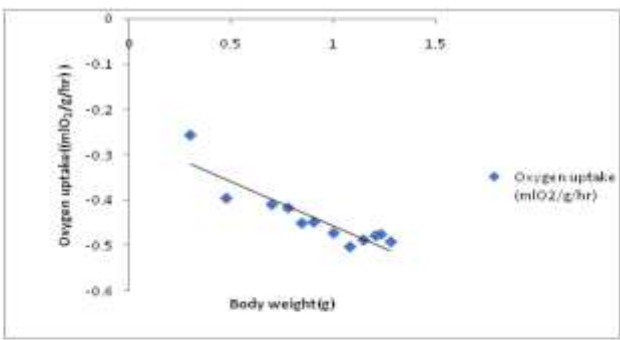

Figure 2. Log/log plots showing the relationship between body weight and weight-specific oxygen consumption (mlO_2/g/hr) at 30±1°C temperature in *O. niloticus.*

This means that as the body weight of the fish increases, the oxygen consumption also increases, but at a decreasing rate due to the non-linear relationship between these two variables.

From the data, the oxygen uptake values were estimated for several body weights: for a 2g fish, the oxygen consumption was 0.5542 mlO_2/g/hr; for a 10g fish, it decreased to 0.3374 mlO_2/g/hr, for a 19g fish, it further dropped to 0.3230 mlO_2/g/hr. The trend indicates that as the body weight of the fish increases, the weight-specific oxygen uptake decreases, likely because larger fish require less oxygen per gram of body weight compared to smaller fish.

The results also emphasize the biological significance of the correlation ($r=0.9937$), which reflects a very strong and statistically significant relationship between body weight and oxygen consumption. The equation and correlation further provide a predictive model to estimate oxygen consumption across different body weights in *O. niloticus* under similar conditions.

Relation between oxygen consumption to body weight in during winter 20 ± 1°C

In *O. niloticus*, the relationship between oxygen consumption and body weight during winter (20 ± 1°C) shows a clear negative correlation between weight-specific oxygen uptake and body size. The uptake of oxygen through gills in winter ranged from 0.5797 to 2.6698 ml/hr within the weight range of 2 to 17g (Table 3). The regression equation that represents the relationship between oxygen uptake (mlO_2/hr) and body weight is: $VO_2 = aW^b$
Where, VO_2= oxygen uptake
a = rate of oxygen uptake
W = body weight
b = slope of the regression coefficient

During winter, the regression coefficient (b) was found to be 0.7038, with a high correlation coefficient (r) of 0.9972 ($p<0.01$), indicating a very strong positive linear relationship.
Therefore, substituting the values:
$VO_2 = 0.375W^{0.7038}$
$\log VO_2 = -0.9808 + 0.7038 \log W$

Using this relationship, the oxygen uptake rates for different weights were calculated. For instance, a 2g fish had an oxygen uptake of 0.2898 mlO_2/g/hr, while a 9g fish had a rate of 0.1981 mlO_2/g/hr, and a 17g fish exhibited a rate of 0.1570 mlO_2/g/hr. The log-log plot of oxygen uptake versus body weight produced a straight line (Figs. 3-4).

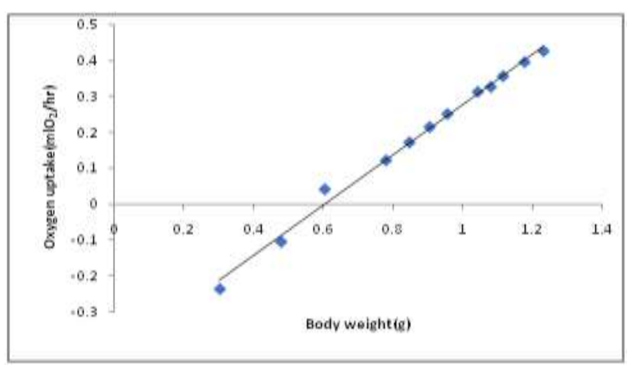

Figure 3. Log/log plots showing the relationship between oxygen uptake and body weight (mlO_2/hr) at 20±1°C temperature in *O. niloticus.*

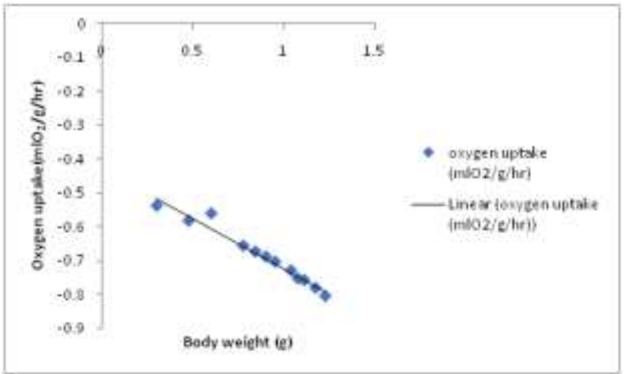

Figure 4. Log/log plots showing the relationship between oxygen uptake and body weight (mlO_2/g/hr) at 20±1°C temperature in *O. niloticus.*

Table 1. Oxygen uptake in relation to body weight in summer

Body Weight (g)	Atm. Tempe. (°C)	Ambient Tempe. (°C)	Opercular Frequency (min)	Oxygen uptake mlO_2/hr	mlO_2/g/hr	mlO_2/kg/hr
2g	30	29	90	1.1084	0.5542	554.2
3g	30	29	89	1.2084	0.4028	405.8
5g	29	29	88	1.9503	0.3900	390
6g	30	30	86	2.2997	0.3832	383.2
7g	30	30	85	2.4855	0.3550	355
8g	30	29	84	2.8562	0.3570	357
10g	29	29	83	3.3744	0.3374	337.4
12g	30	30	83	3.7823	0.3151	315.1
14g	30	29	82	4.5621	0.3258	325.8
16g	31	31	81	5.3307	0.3331	333.1
17g	31	30	80	5.7003	0.3353	335.3
19g	31	30	80	6.1377	0.3230	323
Avg=9.9	30.0	29.58	84.25	3.3996	0.3676	340.75

Table 2. Summary of oxygen uptake showing intercept (a), slope(b) and correlation(r) in summer

Body wt. (w) vs. O_2 Consumption (r)	Intercept (a)	Slobe(b)	Correlation coefficient
VO_2(mlO_2/hr)	0.551	0.8028	0.9937
VO_2(mlO_2/g/hr)	0.550	-0.1968	-0.9086

Table 3. O_2 uptake in relation to body weight in Winter

Body Weight (g)	Atm. Tempe. (°C)	Ambient Tempe. (°C)	Opercular Frequency (min)	Oxygen uptake mlO_2/hr	mlO_2/g/hr	mlO_2/kg/hr
2g	22	21	73	0.5797	0.2898	289.8
3g	22	21	72	0.7850	0.2616	261.6
4g	22	22	72	1.1002	0.2750	275
6g	21	21	70	1.3244	0.2207	220.7
7g	20	20	69	1.4854	0.2122	212.2
8g	20	20	67	1.6403	0.2050	205
9g	20	20	65	1.7835	0.1981	198.1
11g	20	20	64	2.0541	0.1867	186.7
12g	20	19	63	2.1215	0.1767	176.7
13g	21	20	61	2.2728	0.1748	174.8
15g	20	20	61	2.4876	0.1658	165.8
17g	20	20	60	2.6698	0.1570	157
Avg=7.91	20.66	20	66	1.6920	0.2102	210.28

Table 4. Summary of oxygen uptake showing intercept (a), slope (b), and correlation(r) in winter

Body wt. (w) vs. O_2 Consumption (r)	Intercept (a)	Slobe(b)	Correlation coefficient
VO_2(mlO_2/hr)	0.375	0.7038	0.9972
VO_2(mlO_2/g/hr)	0.354	-0.2667	-0.1124

As body weight increased, the oxygen uptake rate per gram of fish consistently decreased, illustrating the typical inverse relationship between body size and weight specific oxygen consumption. These findings suggest that as Tilapia grow in size during the cooler winter months, their metabolic rate decreases relative to their body weight, resulting in lower oxygen consumption per unit of body weight.

Conclusion

The oxygen uptake of Tilapia was evaluated in both winter (20±1°C) and summer (30±1°C) conditions, revealing distinct differences in metabolic rates across seasons:

Winter (20± 1 °C):

- Regression Coefficient (b) = 0.7038; Correlation coefficient (r) = 0.9972 ($p<0.01$)
- Smaller fish showed higher oxygen uptake per gram compared to larger fish, with values ranging from 0.2898 mlO_2/g/hr (2g) to 0.1570 mlO_2/g/hr (17g)

Summer (30±1°C):

- Regression Coefficient (b) = 0.8028; Correlation coefficient (r) = 0.9937 ($p<0.01$)
- Oxygen uptake was significantly higher at this temperature, with values ranging from 0.5542 mlO_2/g/hr (2g) to 0.3230 mlO_2/g/hr (19g).
- Overall oxygen uptake decreased with increasing body weight in both seasons but was higher in summer due to the increased metabolic demand.

Discussion

Oxygen uptake in fish, especially in *O. niloticus*, is influenced by a variety of factors, with body size and environmental temperature being two of the most significant. Our results align with prior studies that have highlighted the inverse relationship between fish weight and specific oxygen uptake. In large fish, the metabolic rate per unit of body weight tends to decrease, a phenomenon commonly referred to as allometric scaling. This is because large fish have lower surface-area-to-volume ratios, leading to less efficient oxygen exchange relative to their overall mass. This relationship was evident in our study, where the smallest fish (2g) had the highest oxygen uptake per gram, and the largest fish (19g) exhibited the lowest oxygen uptake rate.

This trend reflects metabolic scaling principles that are commonly observed in ectothermic animals, where smaller individuals require more oxygen per gram to maintain physiological functions due to higher relative metabolic rates.

Several studies have also explored the temperature dependency of oxygen consumption in fish. Our results show an increase in oxygen uptake at higher temperatures (30±1°C) compared to cooler temperatures (20±1°C). This aligns with findings from previous research suggesting that fish generally increase their metabolic rate in response to warmer water, as higher temperatures accelerate biochemical reactions in the body. However, the effect of temperature on oxygen uptake may be subject to a thermal tolerance limit for the species. As water temperature rises beyond a species optimal range, oxygen uptake may no longer increase proportionally due to reduced oxygen availability in the water and metabolic constraints (Fry, 1970).

Studies on various fish species have shown that oxygen uptake decreases significantly in cooler water as metabolic processes slow down. Kutty (1968) observed reduced oxygen consumption in the goldfish (*Carassius auratus)* at low temperatures, attributing this to a metabolic rate depression as part of a seasonal acclimatization strategy. In contrast, during summer, the higher temperatures elevate fish metabolism due to increased enzymatic activity and energy demands. Brett (1971) demonstrated that salmonids exhibit a significant rise in oxygen uptake with increasing temperature, reflecting higher metabolic costs associated with warmer water.

Clarke and Johnston (1999) noted that smaller fish have proportionally higher metabolic rates due to their greater surface area-to-volume ratios, which facilitate faster oxygen exchange. Farrell (2002) studied oxygen uptake in rainbow trout across different temperatures, showing higher metabolic rates during warmer conditions but reduced performance at extreme temperatures due to thermal stress.

Zebrafish demonstrated a marked increase in oxygen uptake when exposed to higher temperatures, supporting the notion of temperature-dependent metabolic scaling (Barrionuevo and Burggren, 1999). Bhattacharya and Subba (2006) observed that smaller *Esomus dandricus* had higher oxygen uptake per gram of body weight than larger ones.

Similarly, Kamalam *et al*. (2019) studied the snow trout (*Schizothorax richardsonii*) and found that seasonal changes in water temperature significantly affected their metabolic rates, with higher oxygen consumption observed during warmer periods. When compared to other fish, tilapia displayed moderate oxygen uptake rates. Species like Rainbow trout (*Oncorhynchus mykiss*) and Flying barb (*Esomus dandricus)* showed higher oxygen demands under similar conditions.

While Snow trout *(Schizothorax richardsonii*) had lower rates, highlighting their adaptation to colder environments. (Subba and Gosh, 2011) examined the relationship between oxygen uptake and body weight in the hill-stream fish (*Glyptothorax telchitta)*.

They found that as body weight increased, the total oxygen uptake per unit of time also increased, following an allometric relationship. Specifically, the oxygen uptake rate (VO_2) increased with body weight raised to the power of 0.930, indicating a less-than-proportional increase relative to body size.

Conversely, weight-specific oxygen uptake (mlO_2/kg/hr) decreased with increasing body weight, following a negative correlation with body weight raised to the power of -0.070. This suggests that smaller fish have higher metabolic rates per unit body weight compared to larger individuals.

This study emphasizes the need for temperature and size-specific strategies to optimize fish health and productivity, especially in the context of changing environmental conditions and seasonal variability.

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