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The Energy Metabolism in *Tilapia nilotica*
II. Active metabolism at 20° and 26°C

Samir. Y. MISHRIGI* and Tatsuro KUBO*

Abstract

Active metabolism experiments for *Tilapia nilotica* of the size range 2.5–198 g fish were studied at 20°C and 26°C, applying water velocities at 18 and 35 cm/sec. The results suggested that these velocities were enough particularly for maturing and matured sizes under 20°C to express the scope of activity. At this temperature a general decrease in the metabolic expansibility with size (3–2.6) was observed at both velocities, while at 26°C a gradual increase (4–5.9) with size occurred with the same both velocities. The increase in the metabolic expansibility under 26°C resulted from a proportional increase in the metabolic rate with applied velocity, while there was a failure of the same under 20°C. This is a new evidence for a normal level of metabolism at 26°C and possibly higher temperatures than 20°C.

The weight exponents of the equations related to the active metabolic rate with size were found to have small variations compared to the same for standard metabolism. Hence, a possible but less pronounced role of maturity state on active metabolism could not be ruled out.

Introduction

The relation of weight to metabolic rate of fishes received considerable attention, particularly for resting or standard rates of metabolism[1-5]. However only a few experiments have dealt with the influence of weight on active metabolism [6-7]. Since standard metabolism relates to the maintenance costs of a non-feeding, nonactive fish, studies on active metabolism is of importance to recognize a large variation in overall metabolic rates encountered in ordinary non-basal states. Moreover, since fish are neither continuously resting nor persistently active, the determination of the metabolic cost in relation to defined but gradual levels of activity is needed to establish the objective and quantitative relationship between activity and metabolic rate.

For *Tilapia nilotica* the relation of standard metabolism and weight with reference to temperature (20° and 26°C) has already been studied[8]. The present study on the relation of active metabolism to size with reference to the same temperatures is to determine quantitatively the relation between activity and metabolic rate. This is necessary for a full understanding of the energy metabolism and how different energy pathways are related to each other and to environmental conditions. This in turn leads to a better understanding of how the fish could be a success and why it is a failure under particular culture conditions.

* *Nanae Fish Culture Experimental Station, Faculty of Fisheries, Hokkaido University*
(北海道大学水産学部付属七飯養魚実習施設)
(北海道大学水産学部付属七飯養魚実習施設業績第9号)

Material and Methods

Tilapia nilotica used in the present study were obtained as a result of nursing, rearing and growing hatchlings in the same manner described in the previous paper[8]. Sex and maturity were determined using also the same criteria mentioned previously. The fish were acclimatized to the test temperature for about one month before the start of experiments. Fish of different but successive sizes of both sexes were experimented as much as possible to facilitate comparison.

The respirometer consisted of acryl cylinders of different lengths and diameters depending on the size of the fish to be experimented. Each cylinder has two rubber stoppers one at each end through which pass two tubes. One of the tubes at the inlet stopper allows saturated water which comes by means of a pump from a specially designed aquarium equipped with heaters and an air pump. The water finds its way out the respirometer through a homologous tube in the outlet stopper and back to the original aquarium. Water samples for oxygen determination for water leaving the respirometer were collected through this way.

To ensure full saturation before the start of the experiment and a steady level during the experiment, the water was left under aeration overnight as well as until the end of each experiment. This was also efficient to eliminate chlorine which might render it unsuitable for the maintenance of fish to measure the active metabolism. The quantity of water which must enter the respirometer was adjusted by a "T" shaped glass tube fixed between the pump and the inlet tube. The unneeded quantity of water after filling up the respirometer requirements was restored by the aquarium. This was also used to collect water samples for oxygen determinations for water before entering the bottle.

The other prementioned two tubes in the inlet and outlet stoppers were used to carry water from the respirometer to a bigger capacity pump (50 *l*/sec) which allows the water to circulate at a required velocity. A by-pass circuit was designed to adjust the circulation velocity. This was done by opening or closing valves in the circuit. The current inside the respirometer was determined by a flow meter fitted outside the respirometer.

Since the characteristics of the velocity profile of water in the bottle are important in the consideration of the swimming velocity, a laminar flow is not desirable. For this reason a plastic funnel-shaped piece with perforations was fixed in the inlet tube from inside to allow the entering water to get distributed evenly in all directions, thus creating a regular flow of the same strength through the whole volume of the respirometer. The diameter of the funnel and the size of its perforations were subject to change to match the diameter of the bottle in use.

Unlike the case of studying standard metabolisn, the length of the bottle allowed always enough space for the fish to take position and perform swimming movements. This was determined by trials before starting real experiments; a bottle of about one and a half the length of the fish was generally found satisfactory.

To avoid fluctuations in the temperature of circulating water, the whole respirometer was fixed in position inside a separate aquarium containing water at a desired temperature. The whole water surface of this aquarium was covered with a thin blue plastic sheet to avoid exciting the fish, yet without preventing the observation of swimming behaviour. Test fish transferred to the respirometer

were kept in a water flow at a velocity lower than 5–7 cm/sec for about one hour before the test velocity was applied. This was also found to be necessary to avoid the effect of handling which stimulates oxygen consumption at a proportionally high rate.

Two different velocities 18 cm/sec and 35 cm/sec were applied. For deciding the appropriate swimming period which allows for the maximum performance possible under each velocity and with each size at both temperatures, a limited number of experiments were conducted with selected sizes (small, medium and big sizes) to trace when fatigue starts as indicated from the pattern of oxygen consumption with time. This was found to differ with both applied velocities and temperatures. On the average, 15 and 25 minutes of swimming periods at 20° and 26°C, respectively, were found satisfactory to induce maximum swimming without the effect of fatigue. On the other hand, while conducting the real experiments at least 3 samples were always collected within the prescribed periods to ensure the exact values of oxygen uptake. Fish which was left to swim for a longer period was observed to change its position from swimming against the current to swimming with the current, then turned on its sides and practically stopped swimming.

Moreover, the pattern of applying velocities was found to affect oxygen consumption; i.e., applying both used velocities in a successive manner resulted in consuming comparatively lower values at the higher velocity. For this reason the fish were allowed a one hour period of rest before applying the next higher velocity. This was also helpful to counter any possible effect of oxygen debt which might result from burst swimming as was the case with small sizes at 26°C under the lower velocity of 18 cm/sec.

At each instance two water samples were taken, one before entering the oxygen bottle and the other after leaving the bottle. The oxygen content was determined by the unmodified Winkler method. By knowing the rate of flow and the difference in oxygen content between the two samples, the consumed oxygen was calculated as volume per fish per hour.

Results and Discussion

The results of the experiments with fish of different weights are shown in table 1 (20°C) and table 2 (26°C). The standard metabolism, the cost of maintenance of non-active fish as determined in the previous study[8], is considered here as the base line for comparison with other levels of activity as a result of subjecting the fish to different velocities[7].

Observations of the behaviour at 20°C showed that the fish sculls with the pectoral fins and propulsion with the caudal fin for a few minutes after introduction in the bottle and then learns to maintain the same position. When applying velocity the fish continues to swim in the same way though in a restless manner. At 26°C, the swimming behaviour differed with velocities, i.e. under the velocity of 18 cm/sec the fish continued to swim in spurts with many side ways, while under the speed of 35 cm/sec, the dorsal and pectoral fins were laid flat against the body and only the tail and the caudal fin provided a steady thrust to maintain a regular and smooth swimming.

Table 1. *Active metabolism as indicated from oxygen consumption at 20°C*

Length (cm)	Weight (g)	Sex and maturity	18 cm/sec velocity	35 cm/sec velocity
			cc/fish/hr	cc/fish/hr
5.5	2.5	Im.	0.8	1.4
6	3.9	Im.	0.9	1.5
7.6	6.9	Im.	1.9	2.3
8.9	11	Im.	2.6	3.6
12.5	29.8	♀ Resorption	4.1	5.2
13	34.5	♂ Resorption	4.6	5.9
13	37	♂ Resorption	4.8	6.1
14	38.4	♀ Resorption	4.8	6
16	60	♂ Resorption	6.2	7.8
15	63	♀ Resorption	6.6	7.6
16.5	67	♂ Resorption	6.8	7.9
17	80	♂ Resorption	7.4	8.5
17.5	81	♀ Resorption	7.2	8.3
18.5	104.5	♂ Resorption	8.7	9.3
20.5	134	♂ Resorption	9.9	10.6
20.5	137	♀ Resorption	10.2	10.4
21.5	152	♂ Resorption	11.1	11.7
22	170	♀ Resorption	11.7	11.7
22	180	♂ Resorption	11.7	11.2
22	198.5	♂ Resorption	12.2	12.3

Table 2. *Active metabolism as indicated from oxygen consumption at 26°C.*

Length (cm)	Weight (g)	Sex and maturity	18 cm/sec velocity	35 cm/sec velocity
			cc/fish/hr	cc/fish/hr
6.5	3.9	Im.	1.6	2.7
7.5	5.8	Im.	2.2	3.6
8.5	8.6	Im.	3.3	5.4
9.4	11.4	Im.	4.2	6.3
9.4	13.7	Im.	4.9	7.4
10.5	18	Im.	6.4	9.2
11	19.2	♂ III	6.7	9.5
11.5	20	♀ III	6.5	9.6
12.5	27	♂ III	7.9	10.1
12	29	♂ V	7.9	10.6
12.5	32.2	♀ III	7.7	10.5
14.5	48	♀ V	9.3	12
16	56.4	♀ V	10.8	13.8
15.5	59	♂ Oozing	10.9	13.6
16.5	70	♂ Oozing	12.6	15.8
16.5	72	♀ Oozing	12.4	15.8
17.5	83	♀ Oozing	14.2	18.8
18	100	♂ Oozing	16.6	20.2
18.5	107	♀ Ozoing	17.6	22.4
19.5	122	♂ Oozing	19.7	25
21.5	149.5	♂ Oozing	24.6	29.5
22	167.4	♀ Oozing	27.2	32.6

When the general equation of Winberg[2] relating metabolic rate to weight was applied using the least square method to determine each equation for standard[8] and active metabolic rates (Table 1 & 2), the weight exponents and the level of metabolism could be computed as shown in Table 3. At 20°C, the weight exponents approximate a 0.4 value; i.e. 0.44 with fish in a non-active state, 0.43 under 18 cm/sec velocity and 0.42 under 35 cm/sec velocity. The level of metabolism accordingly increased from –0.37 to 0.08 to 0.11 respectively. At 26°C we find a different trend for the weight exponent; a 0.53 value with a non-active fish decreased to 0.41 when applying a velocity of 18 cm/sec and then increased to 0.59 with a 35 cm/sec velocity. Accordingly, the level of metabolism increased from –0.42 to 0.47 and then decreased to 0.15 respectively.

Table 3. *Equations relating metabolic rate (T) and weight (W) at different temperatures under different levels of activity.*

Level of activity	Temperature	
	20°C	26°C
Standard metabolism	Log T=–0.37+0.44 Log W	Log T=–0.42+0.53 Log W
Active metabolism 18 cm/sec	Log T= 0.08+0.43 Log W	Log T= 0.47+0.41 Log W
Active metabolism 35 cm/sec	Log T= 0.11+0.42 Log W	Log T= 0.15+0.59 Log W

The relationships between the oxygen uptake and weight at 20°C and 26°C are graphed in Figs 1 and 2, respectively. These were fitted in accordance with the determined equations (Table 3). Values of oxygen uptake for selected sizes are given in Table 4 and 5. These values lie on the heavy line which is the best fit, other shown points are located visually. From both graphs we observe that though the oxygen consumption is in general higher at 26°C than at 20°C, a curvilinear nature of the relation is almost the same for non-active fish and for fish under different activity levels.

It is of importance to observe that at 20°C under each activity level there is a proportional decrease in the elevation of oxygen uptake with size. This trend continues until a size of about 180 g, where the oxygen consumption reaches a plateau and the fish bigger than 180 g consume almost the same amount of oxygen regardless of the velocity applied (Table 4 and Fig. 1). On the other hand, the standard metabolism continued to show a slight decrease with size and as a result the metabolic expansibility dropped from 3 with a fish of 20 g and less, to 2.6 with fish of one kilogram and bigger.

At 26°C, the active metabolism is found to follow a different trend. Under the lower velocity of 18 cm/sec, a 5 g fish consumed 1140 cc/kg/hr of oxygen, while at a higher velocity of 35 cm/sec the same sized fish consumed only 740 cc/kg/hr. The apparent lack of relationship between the imposed velocity and metabolic

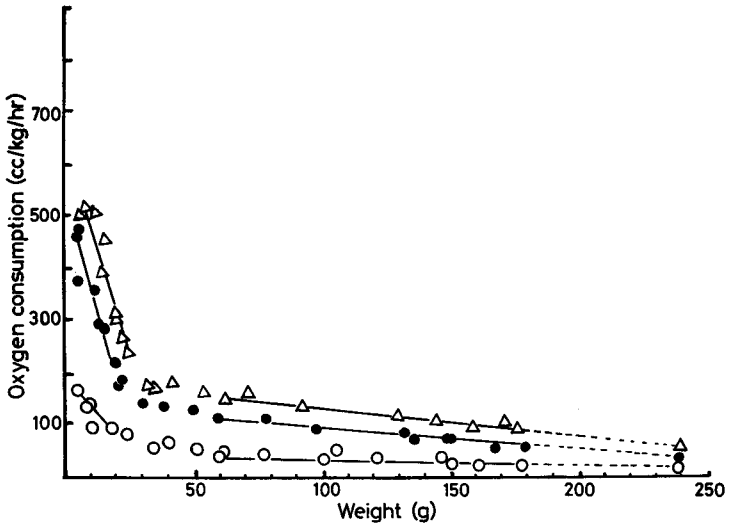

Fig. 1. Relation between oxygen consumption and size for different levels of activity at 20°C. Open circles, non-active fish; dots, at 18 cm/sec velocity; triangles, at 35 cm/sec velocity. Points other than those on heavy lines (best fits) located visually, dotted lines calculated values.

Table 4. *Oxygen consumption at different levels of activity for selected sizes at 20°C as calculated from determined metabolic equations.*

Weight (g)	Oxygen consumption			Metabolic expansibility 35 cm/sec
	Standard cc/kg/hr	Active 18 cm/sec cc/kg/hr	Active 35 cm/sec cc/kg/hr	
5	172	480	540	3.1
20	80	215	240	3.0
40	55	145	152.5	2.8
60	43.3	115	125	2.9
180	23.3	62.2	63.3	2.7
240	17.3	46.3	47.3	2.7
1000	8.9	23.3	23.5	2.6
3000	4.8	12.4	12.4	2.6

rate continued until a fish of about 50 g. This seems to be due to an excitement of the fish as indicated from the observed swimming behaviour in the bottle already described. Similar results were mentioned also by Brett[7] and Smit[9]. However, this effect tends to be abolished with size, and a fish of about 60 g starts to show a proportional relation between the imposed velocity and oxygen consumption as indicated from the intersection of the corresponding curves (Fig. 2). This continued with bigger fish and a relative decrease in the elevation of oxygen uptake with size was observed to be related to the velocity in action.

Moreover, we find that the plateau observed at 20°C disappeared at 26°C,

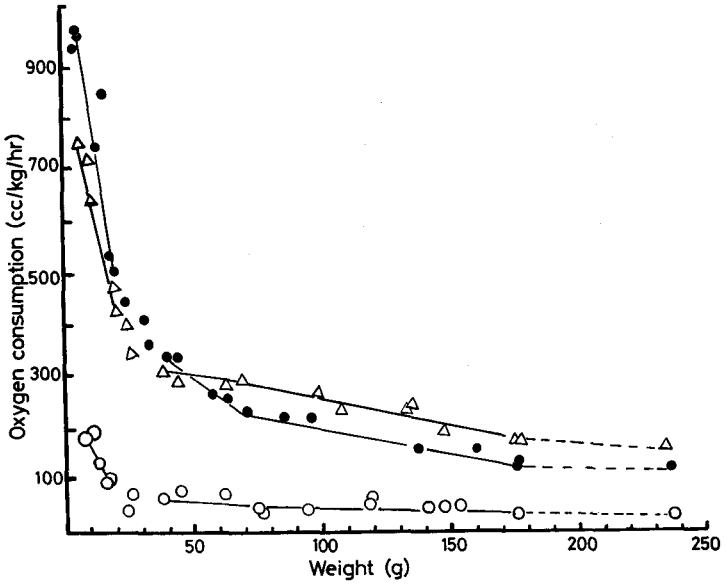

Fig. 2. Relation between oxygen consumption and size for different levels of activity at 26°C. Open circles, non-active fish; dots, at 18 cm/sec velocity; triangles, at 35 cm/sec velocity. Points other than those on heavy lines (best fits) located visually, dotted lines calculated values.

Table 5. *Oxygen consumption at different levels of activity for selected sizes at 26°C as calculated from determined metabolic equations.*

Weight (g)	Oxygen consumption			Metabolic expansbility 35 cm/sec
	Standard cc/kg/hr	Active 18 cm/sec cc/kg/hr	Active 35 cm/sec cc/kg/hr	
5	180	1140	740	4.1
20	90	504	415	4.6
40	67.5	335	312.5	4.6
60	56.7	263.5	263.7	4.7
180	33	137.8	169.5	5.1
240	29.2	116.7	150	5.1
1000	15	60	85	5.7
3000	9	26	53.4	5.9

hence oxygen uptake does not show equal values at any size. Fish of one kilogram and bigger at 20°C do not consume different amounts of oxygen under both velocities. At 26°C, values of oxygen uptake for the same sizes differ, i.e. for a one kilogram fish, oxygen consumption is 60 and 80 cc/kg/hr at 18 and 35 cm/sec velocities respectively, and for a three kilogram fish the corresponding values are 26 and 53 cc/kg/hr. Accordingly, the metabolic expansibility at 26°C ranged from 4.1 with fish of 5 g and unlike the case at 20°C (Fig. 3), continued to increase up to a value of 5.9 with three kilogram fish.

Although it could not be claimed that a full measure of active metabolism was obtained as only two different velocities were applied, it is clear that at 20°C and for big sizes (180 g and bigger), this has been attained. These sizes seemed not to respond to any increase in the velocities applied, which means that the almost 2.6 value for metabolic expansibility is also the same value for the scope of activity. On the other hand, we observe that the small sizes at 20°C behaved differently from those at 26°C, because it was not possible to trace any excitement effect. Therefore the incapability of these sizes for a more elevation in oxygen uptake under higher velocities may be ruled out.

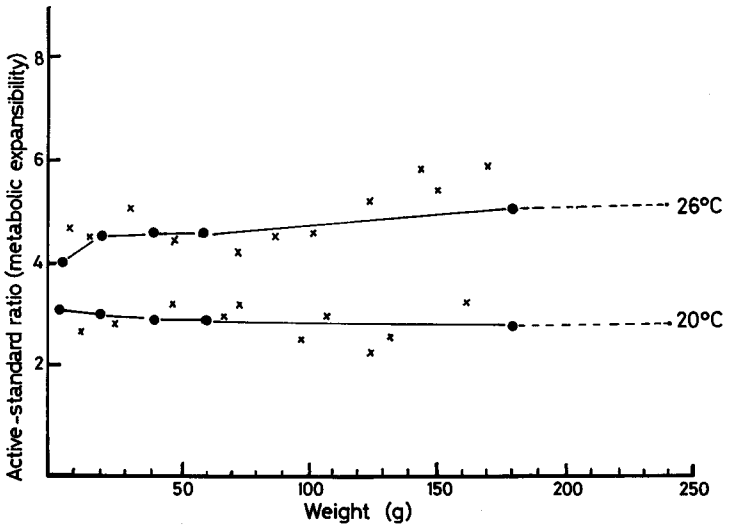

Fig. 3. Ratio of active to standard metabolic rate (metabolic expansibility) in relation to weight at 20°C and 26°C. Small crosses located visually-dotted lines calculated values.

The fish at 26°C, however, seemed to be still capable of elevating the oxygen uptake for different sizes. This was indicated from the parallel trend of the curves relating oxygen consumption with velocity. The expressed metabolic expansibility in this case may only be looked upon as a parameter for the metabolic scope.

Job[4] found that the scope for activity of speckled trout *Salvelinus fontinalis* under various environmental conditions such as temperature is not the same for all sizes, and that the smaller fish are better able to withstand the effects of higher temperature. Therefore, the better capability of small sized tilapias as a warm water fish under a temperature of 20°C, as indicated from their higher metabolic expansibility compared to the bigger sizes, is in agreement with previous results.

Moreover, the curvilinear relationship of the metabolic rate to size in case of tilapia and the linear relationship with most of the species studied[7], suggest a different metabolic rate temperature relationship for small sizes compared to the same for big sized fish. This is justified when based on a possible role for the

maturity state in tilapia which makes small immature fish to show a different level of metabolism characterized by the convex part of the curves. The effect of the maturity state on active metabolism is also traced from the slight increase of weight exponents in the metabolic equations for the active fish under both temperatures compared with that for standard metabolism.

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