Thermal acclimation of teleost **Oreochromis niloticus** *(Pisces, Cichlidae)*

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ABSTRACT

Rates thermal acclimation of Oreochromis niloticus *to different temperatures were measured by following the changes in metabolic rate (oxygen uptake-$mgO_2.kg^{-1}.h^{-1}$) over a timed period (days). Fish previously acclimated to 20 °C and 25 °C respectively were transferred to 30 °C and 35 °C. In both cases the animals displayed a 3 fold higher metabolic rate within the first 24 hours. This was followed by a decrease which reached a stable and constant level after 4 days for fish transferred from 20 °C to 30 °C and 5 days for fish transferred from 25 °C to 35°C. The rates of thermal acclimation were estimated as 2.5 °C.day^{-1} and 2.0 °C.day^{-1} respectively. The reverse direction of acclimation (35 °C to 25 °C and 30 °C to 20 °C) consisted of a slower process, presenting a 2-3 fold lower metabolic rate during the initial 24 hours. This attained a stable level after 6-7 days for fish transferred from 35 °C to 25 °C and 14 days for fish transferred from 30 °C to 20 °C. A time course of acclimation of fishes to 15 °C could not be determined although a sample of fish survived for a short period of time at that temperature. The species presented a low adaptation to cool temperatures (15 °C) and below.*

KEY WORDS : Temperature — Adaptation — Metabolic rate — *Oreochromis niloticus.*

RÉSUMÉ

ACCLIMATATION THERMIQUE D'*Oreochromis niloticus* (PISCES, CICHLIDAE)

*Les taux d'acclimatation thermique d'*Oreochromis niloticus *à différentes températures ont été mesurés en suivant l'évolution du taux métabolique (consommation de l'oxygène-$mgO_2.kg^{-1}.h^{-1}$) en fonction du temps (jours) après le transfert à nouvelle température. Les poissons ont été acclimatés d'abord à 20 °C et 25 °C et ensuite transportés à 30 °C et 35 °C respectivement. Dans les deux cas les poissons ont présenté un taux métabolique 3 fois supérieur dans les premières 24 heures. Ensuite ce taux a diminué jusqu'à un niveau stable et constant après 4 jours (poissons transportés de 20 °C à 30 °C) et 5 jours (poissons transportés de 25 °C à 35 °C) et les taux d'acclimatation thermique ont été estimés à 2,5 °C.$jours^{-1}$ et 2,0 °C.$jours^{-1}$ respectivement. L'acclimatation dans le sens contraire (de 35 °C à 25 °C et de 30 °C à 20 °C) fut un processus lent qui a présenté un taux métabolique 2 à 3 fois plus faible pendant les premières 24 heures. Ce taux a augmenté jusqu'à atteindre des niveaux stables après 6 à 7 jours (poissons transportés de 35 °C à 25 °C) et 14 jours (poissons transportés de 30 °C à 20 °C) d'exposition à la nouvelle situation thermique. Il n'a pas été possible d'acclimater les poissons à 15 °C, bien qu'un groupe ait survécu à cette température pendant une courte période.*

MOTS-CLÉS : Température — Adaptation — Taux métabolique — *Oreochromis niloticus.*

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INTRODUCTION

The effect of temperature on fishes has been the subject of important research over the last four decades. Reviews and classical studies have reported the effects of temperature on the thermal tolerance, metabolism, performance, growth rate and reproduction of these ectothermic organisms (BRETT, 1970, 1979; FRY 1947, 1964, 1971; FRY *et al.*, 1942; SYLVESTER, 1972; HAZEL and PROSSER, 1974)

The existence of thermal adaptation and changes in metabolism as a result of alterations in the thermal environment is a well established phenomenon in nature (BRETT, 1944). Fishes and other ectothermic organisms, show metabolic acclimation after transference from one temperature to another. This results in changes in their lethal temperatures (DOUDOROFF, 1942; BRETT, 1944) and biochemical mechanisms (SIDELL *et al*, 1973; HOCHACHKA and SOMERO, 1973). Metabolic alterations were also investigated as an index measure of temperature acclimation (SUMMER and DOUDOROFF, 1938; SCHULTZE, 1965; GRAHAM, 1972; CAMPBELL and DAVIES, 1975). Nevertheless, most studies were done with animals which had reached a new steady state at the altered temperature, and little is known about the change in metabolic rate as the fish goes from one level up to a compensating one.

The African cichlid, *Oreochromis niloticus* is widely distributed around the world where temperatures are suitable for its growth and reproduction. In many countries it was introduced for vegetation control, pond culture, recreational and commercial fishing (because of its excellent aquaculture potential), fast growth, omnivorous feeding habit and tolerance to low water quality (CHERVINSKI, 1982). *O niloticus*, like many other cichlids, is also known for its tolerance of temperature variations and its occurrence in different thermal regimes. However, from the physiological, ecological and economical points of view, important aspects like the rate of thermal acclimation (time required to adapt to an altered thermal condition), the range of temperature acclimation, critical temperatures and lethal limits of temperature, still remain to be studied

The main purpose of the present study is to determine the rate of acclimation of *Oreochromis niloticus* cultivated in Brazil, to different temperatures, and the physiological and ecological implications of this aspect

MATERIAL AND METHODS

Adult specimens of *Oreochromis niloticus* (14 to 30 g) were obtained from the Fish Culture Division of the Promissão Hydroelectric Powerplant-CESP-São Paulo State, Brazil.

Groups of 5 fishes were kept under constant temperature in 250 l tanks with filtered running water, continuous aeration and 12/12 h photoperiod. The animals were daily fed on commercial fish food but were starved for 48 h prior to, and during, the experimental periods.

Two chambers of 250 l, fitted with cooling and heating systems (RANTIN, 1983) and controlled by a FAC-207 Temp. Control. thermostat (precision $\pm$ 1.0 °C) were used to acclimatize the fishes.

The rate of thermal acclimation was determined by following the changes in metabolic rate (oxygen consumption/weight/hour — $\dot{M}O_2$ — $mgO_2.kg^{-1}.h^{-1}$), after transference of fishes from the temperature of previous acclimation (at least 4 weeks of exposure) to another one 10 °C above or below (from 20 to 30 °C; 30 to 20 °C; 25 to 35 °C and 35 to 25 °C). The transference from one temperature to another generally took about 1 hour.

The oxygen consumption was obtained by means of flow-through respirometry (glass respirometer, flow = 6 $l.h^{-1}$, under artificial light condition) and the oxygen content of the water was determined by modified Winkler's method (HOAR and HICKMAN, 1967). Before each experiment the animals were left for 24 to 48 hours to adapt to the respirometer.

During the acclimation process and experiments the water oxygen tension was kept around 100 % of saturation.

RESULTS

Figure 1.a shows the metabolic rate of a group of 5 fishes acclimated for 4 weeks at 20 °C and transferred to 30 °C. The metabolic rate increased abruptly. It was about 3 fold higher for the first 24 h after transference and decreased, in the following days to a steady level after 4 days of exposure to the new thermal condition. The rate of acclimation was estimated to be 2.5 $°C.day^{-1}$.

Similar results were obtained with the group acclimated at 25 °C and transferred to 35 °C (fig. 1.b). A 3 fold higher metabolic rate was displayed initially by the fishes at 35 °C with a subsequent reduction to constant values around the 5th day. The rate of acclimation was 2.0 $°C.day^{-1}$.

The time course of thermal acclimation in the reverse direction (30 to 20 °C) was slower. When transferred from 30 °C to 20 °C, the metabolic rate dropped by half after the first days of exposure, and returned to constant levels after about 2 weeks at this temperature (fig. 2.a). The rate of acclimation was 0.7 $°C.day^{-1}$.

Figure 2.b illustrates the changes in metabolic rate of the group of fishes transferred from 35 to 25 °C. Initially the metabolic rate fell 3 fold but

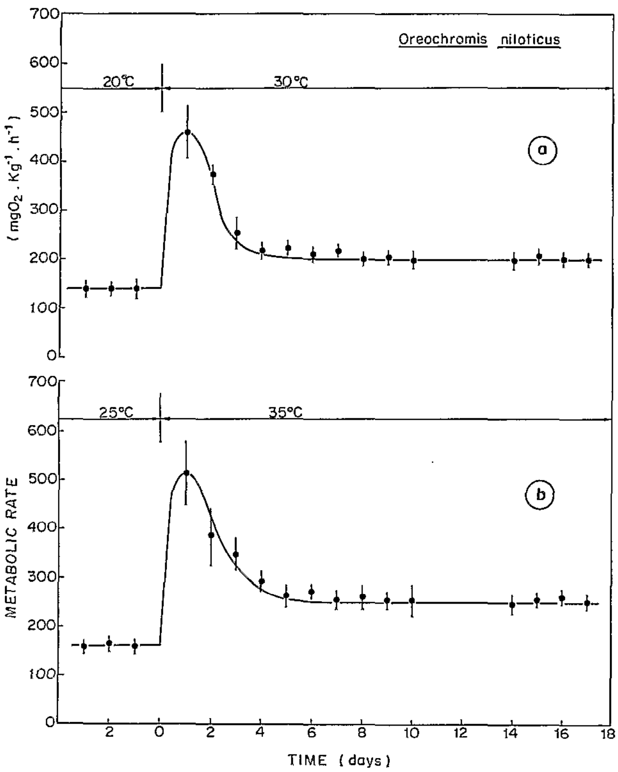

FIG. 1. — Variations in the metabolic rate of *Oreochromis niloticus* before and after transference from 20 °C to 30 °C (a) and 25 °C to 35 °C (b). (Mean ± 1 standard deviation.)

*Variation du taux métabolique d'*Oreochromis niloticus *avant et après le transfert de 20 °C à 30 °C (a) et de 25 °C à 35 °C (b). Les points représentent la moyenne (± 1 écart-type).*

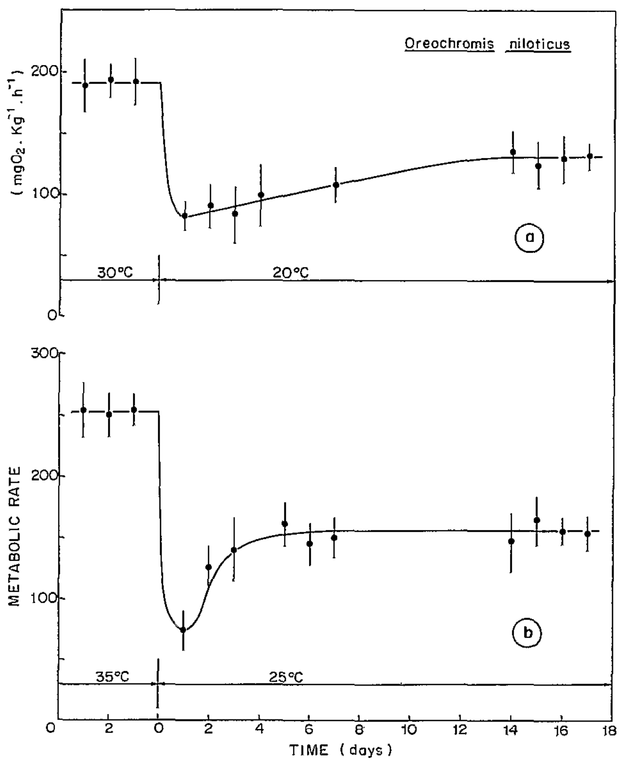

FIG. 2. — Variations in the metabolic rate of *Oreochromis niloticus* before and after transference from 30 °C to 20 °C (a) and 35 °C to 25 °C (b). (Mean ± 1 standard deviation.)

*Variation du taux métabolique d'*Oreochromis niloticus *avant et après le transfert de 30 °C à 20 °C (a) et de 35 °C à 25 °C (b). Les points représentent la moyenne (± 1 écart-type).*

was followed by a gradual return to higher constant values after 6-7 days, resulting in a rate of acclimation of 1.5 °C.day^{-1}.

Fish transferred from 25 to 15 °C started to die one week after the temperature change, apparently without any other symptom than that shown by low temperature coma. These facts indicated the inability of *Oreochromis niloticus*, at least in laboratory conditions, to acclimate at such a low temperature.

DISCUSSION

A brusque alteration in metabolism immediately following thermal stress of fish was previously reported by BULLOCK (1955) in trout. As postulated by BRETT (1970), and observed in the present study on *Oreochromis niloticus*, the acclimation to a new temperature, measured by alterations in metabolism, is less dependent on the direction of temperature change. An overshoot (or undershoot, in the reverse situation) of the metabolic rate for the first 24 hours, accompanied by responses of lesser magnitude during the next few days was observed either above or below the acclimation temperature (fig. 1 and 2). The times necessary for complete acclimation to higher temperatures were 4 days (20 to 30 °C) and 5 days (25 to 35 °C) respectively. To acclimate to lower temperatures 7 days (35 to 25 °C) to 14 days (30 to 20 °C) were required. This shows a close dependence on the initial acclimation temperature.

For some species, e.g. *Salmo salar* and *Blennius pholis*, the time required for full acclimation has been shown to be about 2 or 3 weeks regardless of the direction of temperature changes (PETERSON and ANDERSON, 1969, CAMPBELL and DAVIES, 1975). Nevertheless, other species in which thermal acclim-

TABLE I

Comparison among the time course of thermal acclimation of *Oreochromis niloticus* and other species already studied.
Comparaison de l'acclimatation thermique d'Oreochromis niloticus *avec d'autres espèces de Téléostéens déjà étudiées.*

Species	Family	Temperature Change (°C)	Acclimation Time (days)	Temperature Change (°C)	Acclimation Time (days)	References
Girella nigricans	Kiphosidae	14 to 26	1	26 to 14	>25	Doudoroff, 1942
Carassius auratus	Cyprinidae	4 to 12	16	-	-	Brett, 1946
		20 to 28	3	-	-	Brett, 1946
Apogon dovii	Apogonidae	-	-	23-30 to 17	7	Graham, 1972
Rypticus nigripinis	Grammistidae	-	-	23-30 to 17	17	Graham, 1972
Bathygobius ramosus	Gobiidae	-	-	23-30 to 17	42	Graham, 1972
Mugil cephalus	Mugilidae	25 to 27	7	25 to 23	11	Sylvester, 1974
		25 to 29	9	25 to 15	9	Sylvester, 1974
Hoplias malabaricus	Erythrinidae	25 to 35	2	35 to 25	11-13	Rantin *et al.*, 1985
		20 to 30	4-5	-	-	Rantin *et al.*, 1985
		15 to 25	6-7	25 to 15	20	Rantin *et al.*, 1985
Oreochromis mossambicus	Cichlidae	25 to 30	1	25 to 15	>20	Allanson & Noble, 1964
		24 to 30	2	30 to 24	>14	Chung, 1983
Geophagus brasiliensis	Cichlidae	-	-	20 to 15	21	Rantin, 1978
Oreochromis niloticus	Cichlidae	25 to 35	5	35 to 25	7	present work
		20 to 30	4	30 to 20	14	present work

ation has been determined by changes in lethal temperatures (BRETT, 1946; RANTIN, 1978), or compensatory alterations of certain enzymes involved in the mechanisms of thermal adaptation (SIDELL *et al.*, 1973) showed results similar to ours. In most cases, the adjustement to higher temperatures is faster than to lower ones. A comparison of time courses of acclimation of *O. niloticus* and other species to new temperatures is presented in table I.

There is little information about the time necessary for thermal acclimation of cichlids. One or two days were necessary for *Oreochromis mossambicus* to reach full acclimation when transferred from 20 to 25 °C. However the reverse direction of acclimation (25 to 20 °C) demanded more than 20 days (ALLANSON and NOBLE, 1964; CHUNG, 1983). The South American cichlid, *Geophagus brasiliensis*, required 21 days when the temperature was changed from 20 to 15 °C (RANTIN, 1978). *Oreochromis niloticus* exhibited a high capacity for acclimation at 20, 25, 30 and 35 °C. The time required was similar to that found for most of the teleosts already studied. It is necessary to emphasize the ability of *Oreochromis niloticus* to acclimate to temperatures over 35 °C (FERNANDES and RANTIN, 1986), which is uncommon for tropical species. According to VERHEYEN *et al.*, (1985), the blood-oxygen affinity of *O. niloticus* suggests an important adaptative strategy to high temperature and low oxygen levels. The acclimation of *O. niloticus* took place rapidly when transferred from 35 to 25 °C. This is particularly interesting as 25 °C is a common water temperature during the colder months.

Oreochromis niloticus, brought from the Ivory Coast, Africa, was introduced in the state of Ceará, in Northeastern Brazil, in 1971 (LOVSHIN, 1975). The climatic conditions were very similar to those found in the original habitat. The fish became widely distributed in the country, including the southern regions where the aquatic environments normally have lower temperatures in the winter. It adapted completely to 20 °C (2 weeks) although it would rarely be exposed to such conditions in tropical waters. The ability of *O. niloticus* to adapt to such temperatures, the rate at which this process takes place and the concomitant increase in cold tolerance (FERNANDES and RANTIN, 1986) is particularly important. In agreement with CAULTON (1982) our results suggest that temperatures as low as 20 °C are not limiting for *O. niloticus*. Thus it could be cultivated in environments subjected to this temperature over long periods.

The inability of *O. niloticus* to acclimate to 15 °C makes it difficult to culture in cooler regions such as Southern Brazil during the winter (about 12 °C). FERNANDES and RANTIN (1983) observed that over 70 % of *O. niloticus* exposed to 15 °C died during the first and second week of exposure and only about 30 % became acclimated at that temperature. A high mortality was observed during June 1985 in the fish culture division of the Federal University of

São Carlos-SP, Brazil, when the water temperature remained below 15 °C for 2 weeks. From the economic point of view, these observation and our results lead to the conclusion that cultivation of *O. niloticus* in the southern regions of Brazil and South America must be preceded by studies of climatic conditions in order to avoid mass mortality of fish during the colder months. Research on the effect of temperature on other life parameters such as growth rate, sexual maturation, reproduction, etc., as well as genetical and biochemical mechanisms involved in the thermal adaptation of *Oreochromis niloticus* would also shed more light on the ecology and possibilities for commercial utilization of this important species.

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