EFFECTS OF TEMPERATURE AND pH ON THE OXYGEN CONSUMPTION RATE OF *Sudanonautes* (*Convexonautes aubryi*) *floweri* (DE MAN) (CRUSTACEA: DECAPODA)

INYANG, Nicholas Mathias and NWANKWO, Enyinnaya Lewechi
Department of Zoology, University of Nigeria, Nsukka. Enugu State, Nigeria.

Corresponding author: INYANG, Nicholas Mathias, Department of Zoology, University of Nigeria, Nsukka. Enugu State, Nigeria.

ABSTRACT

The oxygen consumption rate of a freshwater sub-terrestrial crab, Sudanonautes floweri in relation to different temperatures and pH was investigated. The average temperature and pH of the crab's peaty stream habitat were 29.5^{0}C and 7.5 respectively. The lethal temperatures at pH 7.0 recorded for the species were 14.5^{0}C and 34.5^{0}C respectively. The oxygen consumption rate (Q) within the temperature range of 21^{0}C – 31^{0}C increased with temperature but decreased in the zones of temperature stress ($\leq$ 16^{0}C and $\geq$ 31^{0}C). There was no significant difference (P>0.05) between weight specific oxygen consumption (QW^{-1}) of the male and female crabs. The oxygen consumption rate was positively correlated with the body weight of the crabs (r = 1.0); but was inversely related to the unit weight of the crab per hour (r = -0.95). The average oxygen consumption of the animal at 30 ^{0}C and pH 7.0 was 53.1 $\mu g\ O_2\ g^{-1}\ h^{-1}$.

Key words: Temperature, pH, Oxygen consumption, *Sudanonautes floweri*

INTRODUCTION

Factors affecting the metabolic rate of invertebrates can be either endogenous (body size, respiratory surfaces, activity, nutritional status and state of reproductive cycle (Newell *et al.,* 1979) or exogenous (temperature, salinity, hydrogen ion concentration (pH), photoperiod and oxygen concentration among others). These factors affect the life pattern and activities of animals in a particular ecosystem. Temperature is a measure of "hotness" and "coldness" in an animal's body. It is usually a function of the rate of molecular agitation which is controlled to a large extent by the rate of physico-chemical reactions in the body of the animal (Hardy, 1979). Since crabs are poikilotherms, it is expected that temperature will grossly affect their metabolic rates. Though metabolic rate of an animal tends to increase with increasing temperature, Aldrich (1975) noted that because of the complex interactions of environmental, demographic and physiological factors it may not be surprising to notice individual variability of oxygen consumption rates in some crustaceans. Lagler *et al.* (1977) stated that there is similarity of effects of oxygen carrying capacity of the blood by carbon (IV) oxide (CO_2) tension and pH. Thus, respiratory rate is generally expected to increase with increasing hydrogen ion concentration.

Bell *et al.* (1970) defines metabolism as the total chemical changes occurring in the cell or in the body. Metabolic rate in an animal can be quantified from the rate of food consumption, energy released as heat or the amount of oxygen consumed in its oxidation processes to obtain energy. Of these three methods, the third is more widely used because it is easy and technically accurate. Thus, metabolic rate conventionally means or represents the rate of oxygen consumption.

Information on the metabolic rates of animals is of basic importance in defining the energy budget of animals. Such information is useful for the establishment of aquaculture facilities and for the evaluation of the aquaculture perspectives of the species involved (Buesa, 1979).

The relationship between oxygen consumption (Q) and the unit body weight oxygen requirement (QW^{-1}) is a well documented phenomenon in the animal kingdom and is most evident in animals weighing from one gram (1 g) to 1000 grams (1 kg). Though metabolism in poikilotherms generally varies with the environmental temperature, it is also influenced by size (Bell *et al.,* 1970). So for strict quantitative purposes

metabolic rates expressed by the rate of oxygen consumption are satisfactory only when individuals of one species population and of about the same sizes are compared (WolveKamp and Waterman, 1969).

While a number of studies have been done on the ecology and aspects of the biology of macruran – Natantia crustaceans in Nigeria, particularly on the important commercial species (Adetayo, 1980, 1983; Ajayi and Adetayo, 1980; Powell, 1982; Marioghae, 1982; Inyang, 1984) not much attention has been given to the brachyuran crustaceans in spite of the fact that many crabs are used as food condiment in some parts of Nigeria, especially along the coast and the riverine areas. In some places crabs are fermented and used as spice in special Nigerian dishes (Inyang, pers. comm.). Crabs also occupy a strategic position in maintaining the ecological balance between the wet – land and aquatic ecosystem. They are also good bioindicators in drilling and exploitation of minerals on the soil-water interphase.

Out of about 42 species of crabs so far identified in Nigeria (Egborge, 1993), *Sudanonautes* species are the most common in freshwaters. *Sudanonautes floweri (= Convexonautes aubryi)* (De Man) is a sub-terrestrial crab that lives in burrows in river banks and crawls out slowly from its burrow only making brisk dashes either to grab a prey or avoid a predator. They are subject to temperature and pH variations in their natural environment.

Information on the biology of freshwater crabs of South Eastern Nigeria are few (Ejike, 1972; Okafor, 1988; Okpala, 1998; Oputa, 1998). The present study is to investigate the effect of temperature and pH variations on the oxygen consumption rate of *S. floweri* in the laboratory as a contribution to the biology of the species.

MATERIALS AND METHODS

Collection and Acclimation of Crabs: About 70 crabs (*S. floweri)* with average weight of 25.5 g, carapace width of 4 - 6 cm were collected from the banks of a peaty stream at Lokpanta, Okigwe, Imo State, Nigeria, during the months of April and May, 1998. At collection, the average temperature, pH and percentage oxygen saturation of the stream were recorded. The crabs were transported immediately after collection to the laboratory at the University of Nigeria, Nsukka in baskets. They were acclimated for eight days in an aquarium (70 x 30 x 30 cm) under laboratory temperature (26^0C – 28^0C). In the aquarium, rocks and stages on which the crabs could climb and stay out of water were provided. The water in the aquarium was changed every other day. The crabs were fed daily on small and immature grasshoppers before the water was changed. The aquarium water was aerated with an air pump continuously.

Experimental Set Up: The modern method of determining the rate of respiration in aquatic animals is by the use of continuous flow recording respirometer (Brown, 1954) which has the advantage of taking readings for a long period without adding an extra environmental stress (low oxygen tension) to the system. In the absence of such a facility a modification of Gilchrist (1959) respiratory chambers were used for short periods (60 minutes) of recordings. Six respiratory chambers (10 X 10 X 10 cm) (A – F) in the water – bath (70 X 40 X 20 cm) with a thermostatically set temperature control (0^0C – 120^0C) were used. The chambers were filled with water and left open until their temperature equilibrised with the thermostatically set temperature of the water bath.

Temperature Experiment: Based on a test-run of the lower and upper lethal temperatures, the selected temperatures of the experiment were 16^0C, 21^0C, 26^0C, 31^0C and 32^0C. At the required temperature at a constant pH 7.0, water sample was siphoned from chamber A (control chamber) into an oxygen bottle and fixed for oxygen determination. The mean value of the oxygen so obtained was taken as the initial oxygen concentration for all the respiratory chambers. The crabs were then removed from the acclimation aquarium, weighed (g), sexed and introduced into the respective chambers (B – F). The water-bath was then closed, making the chambers air-tight and bubble-free. After 60 minutes (1 hour), water samples were siphoned from each of the chambers and fixed for oxygen determination. The difference between the value obtained after 60 minutes and the initial value of oxygen in control chamber was regarded as the amount of oxygen consumed by the crabs per hour (Q = mg O_2 $crab^{-1}$ h^{-1}), while the weight-specific oxygen consumption (QW^{-1} = μg O_2 g^{-1} h^{-1}) was calculated as the amount of oxygen consumed by a unit body weight of the crab per hour. Each temperature trial had two replicates.

Effect of size/weight on oxygen consumption: Different sizes and weight of crabs ranging from 44.0 – 110.0 g respectively were subjected to the same treatment as in the temperature experiment at 30 ^{o}C and pH 7.0. The experiment was replicated with crabs of approximately the same size and weight.

Hydrogen Ion Concentration (pH) Experiment: The pH values used were 4, 6, 8 and 10 at a constant temperature of 28 ^{0}C. The pH values were altered by adding some drops of 1.0 M citric acid or 0.5 M potassium hydroxide (KOH) solution along with a buffer solution of 0.5 M sodium hydrogen phosphate ($NaH_2 PO_4. H_2O$). The values of the pH were cross-checked with a pH meter. The experimental procedure was the same as in temperature experiment. Each pH value trial had two replicates.

Lethal Temperature and pH: The determination of the lower and upper lethal temperatures was a modification of those described by Evans (1948). Young specimens were used for this experiment. Temperature of the respiratory chambers was varied by 1 ^{0}C every two minutes from 10 ^{0}C – 35 ^{0}C by setting the temperature of the bath to the required temperature. Ice water was added to lower the temperature when necessary. The specimens were observed for 60 minutes at each temperature. The time and temperature at which death occurred in all the crabs were noted. The pH values were altered every 5 minutes by adding some drops of 1.0 M citric acid or 0.5 M potassium hydroxide solution along with a buffer solution of 0.5 M sodium hydrogen phosphate ($NaH_2PO_4.H_2O$) to the chambers. A pH meter was used to monitor the pH values. The pH values used were 3, 4, 6, 8, 10 and 12. Specimens in the various pH values were observed, and the time and the pH at which death occurred were noted.

Oxygen Determination: The oxygen concentration of the water sample was determined titrimetrically (Winkler's method) according to Stainton *et al.* (1977) and expressed as mg O_2 h^{-1}.

Analysis of Data: A sample t-test was used to compare the data where necessary (Bailey, 1974).

RESULTS

The temperature and pH of the crab's peaty stream habitat were 29.5^{0}C and 7.5 respectively. The percentage oxygen saturation of the stream was 98.7%.

Lethal Temperatures and pH: At 14.5^{0} C the crabs fell into stupor and died after 30 minutes. They started to float in the water after 45 minutes. Heat coma which preceded death occurred at 34.5^{0}C and actual death of the crabs occurred after 25 minutes later. Prior to the heat coma, the crabs became restless and erratic in behaviour with uncoordinated movements.

At a pH of 3.5, the crabs also became restless after 30 minutes and death occurred later after 80 minutes. The upper lethal pH value was 11, at which all the crabs died after 2 ½ hours.

Effect of temperature on the rate (Q) and weight-specific oxygen consumption (QW^{-1}) of *S. floweri:* Table 1 shows the rate of oxygen consumption (Q) and the weight-specific oxygen consumption (QW^{-1}) of the crabs. The rate of oxygen consumption by the crabs decreased from 1.62 $\pm$ 04 at 16 ^{0}C to 1.22 $\pm$ 0.03 mg O_2h^{-1} at 21 ^{0} C. It then rose sharply to 3.27 $\pm$ 0.03 at 26 ^{0}C reaching a peak (3.88 $\pm$ 0.02) at 31.0 ^{0}C. At 32.0 ^{0}C the rate of oxygen consumption fell to 3.22 $\pm$ 0.01 mg O_2h^{-1} (Table 1).

The weight-specific oxygen consumption followed the same trend as Q with a peak also at 26 ^{0}C (84.3 $\pm$ 0.77 μg O_2 g^{-1} h^{-1}). The QW^{-1} dropped sharply to 56.9 $\pm$ 0.22 at 31 ^{0}C before rising again to 72.6 $\pm$ 0.30 μg O_2 g^{-1} h^{-1} at 32 ^{0}C (Table 1). Death of the crabs occurred at 34.5 ^{0}C.

Sex influence on the oxygen consumption of the crabs: Weight-specific oxygen consumption per hour (QW^{-1}) was used to compare the oxygen consumption of the male and female *S. floweri* at different temperatures. The result is shown in Table 2. The rate of oxygen consumption (metabolic rate) within the temperature range of 21 ^{0}C – 26 ^{0} C was slightly higher in the female than in the male. The reverse was the case at the zones of thermal stress (16 ^{0} C and $\geq$ 31 ^{0} C). However, there was no significant difference ($P > 0.05$) in the overall oxygen consumption of the male and female specimens ($t = 0.096 < t_{0.05} = 2.77$).

Table 1: Influence of temperature on the rate of oxygen consumption (Q) and weight-specific oxygen consumption (QW^{-1}) of *S. floweri* (n = 60, mean weight = 25.5 ± 10.59 g)

Temperature (^{0}C)	Q ($mg\ O_2\ h^{-1}$)	QW^{-1} ($\mu g\ O_2\ g^{-1}\ h^{-1}$)
16	1.62 ± 0.04	32.6 ± 0.81
21	1.22 ± 0.03	25.5 ± 0.59
26	3.27 ± 0.03	84.3 ± 0.77
31	3.88 ± 0.02	56.9 ± 0.22
32	3.22 ± 0.01	72.6 ± 0.30

Table 2: Influence of sex on oxygen consumption at different temperatures

	QW^{-1} ($\mu g\ O_2\ g^{-1}\ h^{-1}$)	
Temperature (^{0}C)	Male	Female
16	38.7	30.5
21	34.0	37.0
26	60.6	62.0
31	60.0	57.5
32	67.7	62.2
N	Mean weight (g)	Weight range
Male 22	25.0 ± 0.70	(24 – 26g)
Female 14	24.5 ± 5.16	(15 – 30 g)

Table 3: Influence of size/weight on oxygen consumption at 30 ^{0}C

Wet weight (g)	*Q* ($mg\ O_2\ h^{-1}$)	*QW^{-1}* ($\mu g\ O_2\ g^{-1}\ h^{-1}$)
44	2.90	65.9
50	3.03	60.6
60	3.20	53.3
80	3.98	49.8
90	4.15	46.1
110	4.73	43.0
Average	3.66	53.10
Correlation coefficient (r)	1.01	-0.95

Table 4: Effect of pH on oxygen consumption of *S. floweri (n = 14, weight range = 24.0 – 27.0 g, mean weight = 25.1 ± 1.0 g)*

pH	Q ($mg\ O_2\ h^{-1}$)	QW^{-1} ($\mu g\ O_2\ g^{-1}\ h^{-1}$)
4	3.08 ± 0.02	57.0 ± 0.31
6	4.51 ± 0.01	92.1 ± 0.25
7	3.79 ± 0.03	75.7 ± 0.49
8	3.05 ± 0.01	61.0 ± 0.04
10	2.63 ± 0.01	54.8 ± 0.27

Effect of size/weight on oxygen consumption of *S. floweri:* The rate (Q) and weight-specific oxygen consumption (QW^{-1}) of crabs of different weight at 30 ^{0}C are shown in Table 3. While the rate of oxygen consumption increased with increase in weight and size of the crabs, the weight-specific oxygen consumption decreased with weight (Table 3). The rate of oxygen consumption was strongly and positively correlated with the weight of the crabs (r = 1.01). A negative inverse relationship (r = -0.95) between the rate of oxygen consumption and the unit weight of the crabs was obtained. A regression analysis of the relationship between the oxygen consumption and the weight of the crabs gave the following equation:

$O_2 = -0.308W^{0.469}$ (O_2 = oxygen consumption; W = weight (g)). The average oxygen consumption per unit weight (g) per hour was 53.1 μg O_2 g^{-1} h^{-1}.

Effect of pH on oxygen consumption: The rate of oxygen consumption increased sharply from 3.08 ± 0.02 mg O_2 h^{-1} at pH 4 to 4.51 ± 0.01 at pH 6. It then decreased to 3.79 ± 0.03 at pH 7 and to 3.05 ± 0.01 and 2.63 ± 0.01 at pH 8 and 10 respectively. Death occurred at pH 11.5 after 30 minutes.

The weight-specific oxygen consumption (QW^{-1}) followed the same trend as Q with a peak value of 92.1 ± 0.25 μg O_2 g^{-1} h^{-1} also at pH 6 (Table 4).

DISCUSSION

It is well known that poikilothermous animals survive within definite temperature ranges. For *S. floweri* the survival temperature range was between > 14.5 ^{0}C and < 34.5 ^{0}C. Thermal death occurred at 14.5 ^{0}C and 34.5 ^{0}C respectively. Thermal death according to Schmidth-Nielson (1977) could be because of inactivation of enzymes at rates exceeding their formation rate or the depletion or accumulation of certain intermediary metabolic products whose formation and transport are temperature dependent. Wolvekamp and Waterman (1969) also stated that high temperature reduces the binding capacity of copper containing blood pigment (haemocyanin), thus depriving the animals of sufficient oxygen to survive. It is therefore possible that death at the upper lethal temperature (34.5^{0}C) could have been due to asphyxiation. Death at the lower thermal temperature (≤ 14.5^{0}C) could be due to the inactivation of enzymes and accumulation of toxic metabolic products in the body of the animal, making it impossible for the crabs to survive.

Effect of Temperature: The metabolic rate of crustaceans depends on a number of internal and external variables. Temperature is one of the external factors that influences the life pattern of poikilothermous animals. It influences the animals directly and indirectly. Johnson *et al*. (1954) interprets the direct effect of temperature on organisms in terms of activation energies of key biochemical reactions. Te mperature affects the organisms indirectly through its effect on the metabolic rate of the organism. A change of external temperature results in a change of oxygen consumption (metabolic rate). In *S. floweri* oxygen consumption was positively correlated with temperatures between 16 ^{0}C and 31 ^{0}C. At 31 ^{0}C the oxygen consumption was about 2.4 times greater than at 16 ^{0}C. The relationship between oxygen consumption and temperature has been attributed to the physiological processes and reactions taking place in the animal's body. Mc Mohon *et al.* (1978) also explained the pattern of increase of metabolic rate with temperature as a result of branchial water flow to supply extra oxygen demand in the crab, *Cancer magister.*

The average temperature coefficient (Q_{10}) of 1.0 recorded at 30 ^{0}C for *S. floweri* was less than those of other tropical crabs studied: *Sesarma ricordi* (1.6 – 2.2) and *Uca mordax* (2.0 – 2.5) at 25^{0}C – 35^{0}C respectively (Scholander *et al.,* 1953). This may be due to the habitats of the crabs, since according to Ayers (1938) the rate of oxygen consumption in several estuarine crabs studied increased as the habitat became more terrestrial. While *Sesarma recordi* is a terrestrial crab, *Sudanonautes floweri* is a sub-terrestrial freshwater crab and *U. mordax* is an estuarine/marine crab. Husain and Alikhan (1979) explained that the higher rate of oxygen consumption in terrestrial species may be a reflection of the increased energy required to carry the mass of the animal in a less buoyant medium.

Oxygen Consumption and Body Weight: The dependence of the rate of oxygen uptake upon animal size is well documented in crustaceans (Zeuthen, 1953; Bertalanffy, 1957; Hart, 1980). The oxygen consumption of *S. floweri* conformed to the general rule of metabolism in poikilotherms which stipulates that metabolism increases with size (Table 3). The oxygen uptake per unit time by crustaceans as in other animal groups can be expressed as $O_2 = aW^b$, where a and b are coefficients in the logarithmic expression. For most crustaceans the b value is generally between 0.67 and 1.0 (Wolvekamp and Waterman, 1969). In *S. floweri* the b value obtained was 0.45. According to Ellenby (1951), body shape of an animal can change the value of b from the Rubner's 0.67 rule. This probably accounted for the deviation of our result from the 0.67 - 1.0 rule.

Sex Influence: The oxygen consumption rate of the male crabs was not significantly different from that by the female. The result agrees with

what Husain and Alikhan (1979) observed for *Porcellio laevis.*

pH Effect: Increase in pH value increases the rate of oxygen consumption in animals. The maximum oxygen consumption rate for *S. floweri* at 30 ^{0}C was at pH 6, beyond which the oxygen consumption decreased. The increase and decrease in the oxygen consumption of the crabs with almost equal gradients on either side of pH 6 (pH 4-6 and pH 6-8) is a consequence of the alteration of the partial pressure of oxygen reducing the half-saturation (P = 50 % saturation) of the haemocyanin with oxygen. At pH values lower or higher than the optimum value, the mucus in the gills become coagulated and this may account for the reduction in the oxygen consumption (Cameron and Randall, 1972) as the gills cannot function properly.

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