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ENERGY BUDGET OF ROACH (*Rutilus rutilus* L.) LARVAE AT THE BEGINNING OF EXOGENOUS FEEDING

Jarosław Żelepień, Andrzej Karpiński

The Stanisław Sakowicz Inland Fisheries Institute in Olsztyn

A B S T R A C T. Daily energy requirement of roach larvae in various developmental stages were calculated according to the bioenergetic model. Metabolic level and amount of excreted faeces were measured experimentally. Daily energy requirement of roach larvae was related to fish age and ranged from 3.67 to 5.36 $J \cdot ind.^{-1}$. Over 80% of energy was used by the fish for the metabolic processes and activity.

Key words: ROACH, LARVAE, ENERGY BUDGET

INTRODUCTION

Larval development, and particularly the beginning of exogenous feeding, is a critical period in fish life (Stevens et al. 1985). At that time high mortality occurs, caused by a reduction of food availability. Thus, it is necessary to assess energy requirement of larval stages and of possible ways of energy supply under variable trophic conditions (Keckeis, Schiemer 1990, 1992). Many methods are used to evaluate food requirements (Vlymen 1977). One of them is based on Winberg's model applying the 1st principle of thermodynamics (Ney 1993). The model assumes that energy supplied with food is used by an organism for growth and metabolism, and excreted with faeces:

$$C = G + R + W$$

where: **C**- energetic value of ingested food

G – energy used for growth

R – energy used for metabolism:

- Basal metabolism (the minimal amount of energy to maintain vital body functions while fasting and at total rest).
- Routine metabolism involving spontaneous activity (without stress and locomotive hyperactivity).

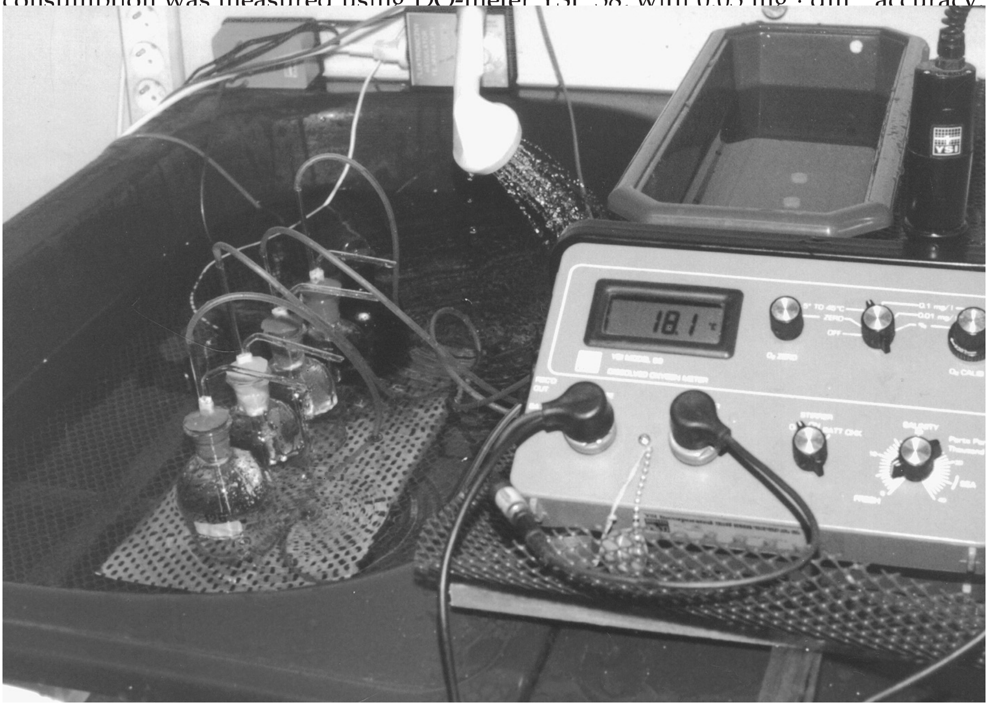
- Active metabolism involving food search and escape reaction.
- SDA – specific, dynamic action of food.

W – energy excreted with faeces (excrements and metabolic by-products).

The aim of the present study was to evaluate energy requirements of early stages of roach: resting larvae (2d), at the beginning of exogenous feeding (5d), and intensely feeding larvae (15d).

MATERIAL AND METHODS

Bottle respirometers of 300 cm^3 were used in the experiment (phot. 1). They were supplied with water of 12°C (±1.07), 16°C (±0.54), and 19°C (±0.66). The fish were fed brine shrimp (*Artemia salina*) nauplii at the rate of 50 ind. · cm^{-3}. Another group of fish were starving. In starving fish, basal metabolic rate was measured (2 days old larvae), and then – routine metabolic rate in 5 and 15 days old fish. Active metabolic rate, SDA, and excreted ammonia were evaluated in fed 5 and 15 days old larvae. Oxygen consumption was measured using DO-meter YSI®58, with 0.05 mg · dm^{-3} accuracy.



Phot. 1. Botle respirometers used in the experiment

TABLE 1

Characteristics of roach larvae

Age (days)	2d	5d	15d
Number of fish	450	314	164
Length Lt (mm)	6.16	7.22	8.53
SD +/-	0.543	0.556	0.756
Mean dry weight - SM (g)	0.00008	0.00014	0.00027
SD +/-	0.000005	0.000016	0.000080
Fish numbers in respirometer	200	100	50

Ammonia content was measured using the colorimetric salicylate-hypochlorite method, at wavelength 652 nm, immediately after sampling. Control respirometers contained water without fish, and water with brine shrimp nauplii only, in the same number as in the experimental vessels. During the experiment, pH was monitored to evaluate amount of toxic un-ionized ammonia. pH value ranged from 7.15 to 8.20. Maximum ammonia concentration equal to 9.11 ìg · dm^{-3} was noted at 16°C in the respirometer with fed fish. However, it remained within the range considered safe for salmonid fishes (up to 12 μg · dm^{-3}, Waters, Pratt 1977). The experiment was discontinued when DO dropped below 4 mg · dm^{-3}. Oxygen concentration was measured every 4 h, and ammonia – only once, 8 h after the beginning of the experiment. After sampling for ammonia measurement, the respirometers were refilled, and DO measured again. Stocking rates depended on fish size (tab. 1). After the end of the experiment, the larvae were dried at 60°C for 24 h and weighed with 0.0001 g accuracy.

The relationship between energy budget factors, body mass and water temperature was described with the formula (Bevelhimer et al. 1985):

$$X = a \cdot DM^{b} \cdot exp(c \cdot T)$$

where:

X – energy budget factor (mg · g-1 · h-1) (tab. 2)

DM – dry mass of larvae (g)

T – temperature (°C)

a, b, c – coefficients

Spontaneous activity of 5 and 15 days old larvae was calculated subtracting the extrapolated value of basal metabolic rate of 2d larvae from the routine metabolic

TABLE 2

Schemat doświadczenia i średnie wartości uzyskane z pomiarów konsumpcji tlenu i usuwania amoniaku

Age of larvae	2d	5d	15d	5d	15d
Conditions	without food			with food	
Oxygen consumption (mg g^{-1} h^{-1})					
Metabolism:	basal	routine		active + SDA	
12°C	6.84	16.96	8.45	26.32	15.52
16°C	16.99	23.50	18.10	36.08	27.27
19°C	22.52	38.92	38.54	49.08	39.67
12-19°C	15.45	26.46	21.70	37.16	27.49
Ammonie removal (mg g^{-1} h^{-1})					
excretion			faeces + excretion		
12°C	0.51	0.36	0.51	2.02	2.41
16°C	0.93	1.11	1.40	2.99	3.88
19°C	1.16	0.81	-	2.58	-
12-19°C	0.86	0.76	0.96	2.53	3.15

rate. Feeding activity and SDA were calculated as the difference between active and routine metabolic rates.

Energy requirement of roach larvae (C=G+R+W) was expressed in $J \cdot g^{-1} \cdot d^{-1}$, assuming the following conversion coefficients:

- Energetic value of oxygen 19.4 $J \cdot mg^{-1}$ (Meng 1993)
- Energetic value of ammonia 24.9 $J \cdot mg^{-1}$ (Carter, Brafield 1992)
- Energetic value of roach larvae 26610 $J \cdot g^{-1}$ (Keckeis, Schiemer 1992)

RESULTS

Basal and routine metabolic rates correlated with temperature and body mass of the larvae (tab. 2). Temperature increase by 7°C caused over 3 fold increase of oxygen consumption by 2 d larvae (from 6.8 at 12°C to 22.5 $mg \cdot g^{-1} \cdot h^{-1}$ at 19°C) (tab. 3). In 5 d larvae, the routine metabolic rate increased slower, from 17.0 $mg \cdot g^{-1} \cdot h^{-1}$ at 12°C to 38.9 $mg \cdot g^{-1} \cdot h^{-1}$ at 19°C. In 15 d fish, the metabolic rate increased 4 times, from 8.5 to 38.5 $mg \cdot g^{-1} \cdot h^{-1}$. Oxygen consumption was inversely proportional to body mass. Five days old larvae consumed more oxygen per unit of weight (26.5 $mg \cdot g^{-1} \cdot h^{-1}$) than 15 d larvae (21.7 $mg \cdot g^{-1} \cdot h^{-1}$).

TABLE 3

Parameters of the model $X=aSM^{b}+e^{cT}$ (explanations in the text)

Components of energy balance	a	b	c	r^2
Basal metabolism	0.000035	-1.090549	0.172878	0.8932
Routine metabolism	0.002106	-0.736604	0.177650	0.9858
Active metabolism +SDA	0.438885	-0.262720	0.127686	0.9214
Ammonia excretion	0.552776	0.127528	0.101924	0.7589

TABLE 4

Components of energy balance C= G+R+W roach larvae

Age	2d	5d	15d
Production			
G	-	2265.6	1242.5
Metabolism:			
Basal metabolism	9218.1	5644.8	2776.6
Spontantaneous activity	-	10142.6	10169.7
Feeding activity +SDA	-	6382.3	3452.7
R	9218.1	22169.8	16399.0
By-products			
Ammonia excretion	514.8	453.6	570.0
Ammonia in faeces		1507.4	1877.2
W	514.8	1961.0	2447.2
Daily energetic requirement			
C	9732.9	26396.4	20088.7

Among fed fish, the lowest metabolic rate occurred at 12°C – 26.3 mg · $g^{-1} \cdot h^{-1}$ (5 d larvae), and 15.5 mg · $g^{-1} \cdot h^{-1}$ (15 d larvae) (tab. 3). Temperature increase to 19°C resulted in an increase of oxygen consumption: in 5d larvae to 49.1 mg · $g^{-1} \cdot h^{-1}$, and in 15 d fish to 39.7 mg · $g^{-1} \cdot h^{-1}$. Active metabolic rate with SDA was also inversely proportional to body weight. Younger larvae consumed more oxygen (37.2 mg · $g^{-1} \cdot h^{-1}$) than older ones (27.5 mg · $g^{-1} \cdot h^{-1}$).

Amount of excreted ammonia increased with temperature and was the highest at 19°C – 1.2 mg · $g^{-1} \cdot h^{-1}$. Fish 5 and 15 days old excreted large amounts of ammonia at 16°C: 1.1 and 1.4 mg · $g^{-1} \cdot h^{-1}$, respectively. Average level of ammonia excretion within the range 12-19°C was, however, similar in all fish groups, irrespective of body mass (tab. 3).

The level of ammonia excreted by fed fish was the highest at 16°C being equal to 3.0 mg · $g^{-1} \cdot h^{-1}$ in 5d larvae, and 3.9 mg · $g^{-1} \cdot h^{-1}$ in 15 d larvae.

TABLE 5

Coefficients of energy transformations

Age	2d	5d	15d
(Ma+SDA)/Mr*	-	1.4	1.3
R/C %	94.7	84.0	81.6
W/C %	5.3	7.4	12.2
G/C %	-	8.6	6.2
C (%SM)	-	138	105
SGR**	-	8.5	4.7

**Ma+SDA - active metabolism +SDA, Mr - routine metabolism*
***SGR - specific growth rate in %SM * d-1*

Metabolic rate and ammonia excretion were related to the temperature and fish body weight according to the models shown in tab 2. Larvae used large amounts of energy for metabolism (tab. 4 and 5). For basal metabolism, spontaneous activity, feeding activity and SDA, 5 d fish used 22169.8 $J \cdot g^{-1} \cdot d^{-1}$, and 15 d fish – 16399.0 $J \cdot g^{-1} \cdot d^{-1}$. Energy requirement of the smallest, resting larvae was the least – 9218.1 $J \cdot g^{-1} \cdot d^{-1}$. Energetic value of wastes was related to body weight, and equal to 514.8-2447.18 $J \cdot g^{-1} \cdot d^{-1}$, including 453.6-570.0 $J \cdot g^{-1} \cdot d^{-1}$ in metabolic excretions and 1507.4-1877.2 $J \cdot g^{-1} \cdot d^{-1}$ in faeces (tab. 4). Fish also used 2265.6 $J \cdot g^{-1} \cdot d^{-1}$ (5 d larvae), and 20088.7 $J \cdot g^{-1} \cdot d^{-1}$ (15 d larvae) for growth (tab. 4). Daily energy requirement of newly hatched roach larvae was equal to 9732.9 $J \cdot g^{-1} \cdot d^{-1}$. The requirements of 5 d and 15 d old larvae were almost 3 times higher: 26396.4 and 20088.7 $J \cdot g^{-1} \cdot d^{-1}$ to support spontaneous and feeding activity, SDA and growth (fig. 1).

DISCUSSION

Early larval stages of roach need a lot of energy, mainly for metabolic processes (81.6-94.7%) (tab.5). Newly hatched larvae used about 9218 $J \cdot g^{-1} \cdot d^{-1}$ for basal metabolism, while 5 d and 15 d old fish 5644.8 and 2776.6 $J \cdot g^{-1} \cdot d^{-1}$ respectively. Both groups of swimming larvae needed similar amounts of energy for spontaneous activity – 10150 $J \cdot g^{-1} \cdot d^{-1}$, but for feeding activity + SDA 5 d old larvae used almost twice as much energy as 15 d larvae (6382.3 and 3452.7 $J \cdot g^{-1} \cdot d^{-1}$ respectively) (fig. 1). Higher energy needs of smaller larvae were caused by their energy-consuming way of food search and capture, observed also by Meng (1993). Thus, it seems that feeding strategy changes with fish growth and locomotion ability improvement, and energetic ef-

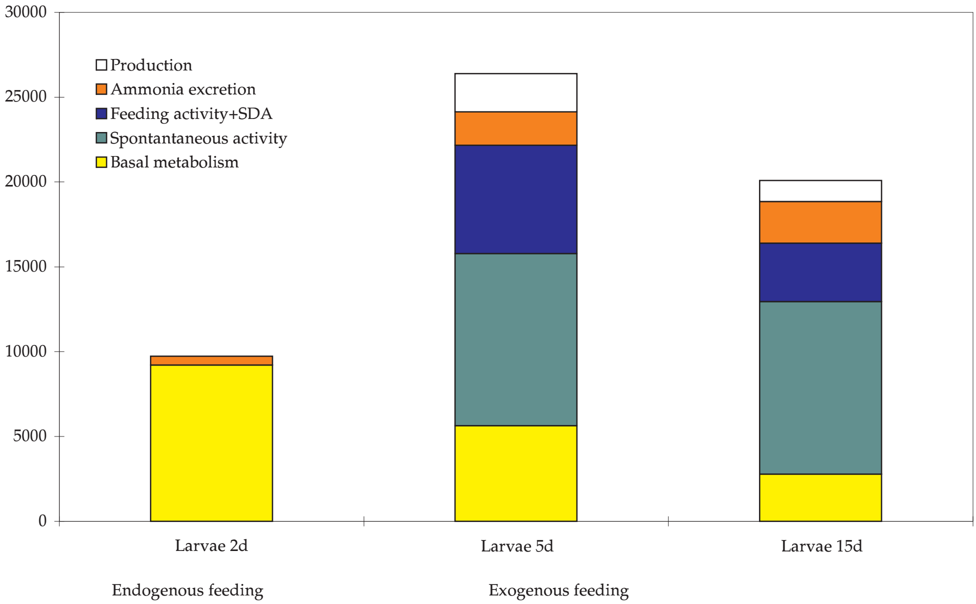


Fig. 1. Energetic budget of roach larvae depending on age

ficiency of the organism increases. In both age groups of larvae, despite differences in spontaneous and feeding activity, ratios of active and routine metabolic levels were similar and ranged from 1.3 to 1.4 (tab. 5). Similar result was obtained by Meng (1993). Other authors measured only routine oxygen consumption rate (Eldridge et al. 1977, Keckeis, Schiemer 1990, 1992). Active metabolic rate was usually estimated, according to Ware (1975), as routine metabolic rate multiplied by 2.5.

Both age groups of roach larvae showed very low growth efficiency coefficients (described as the ratio of the amount of energy used for growth to energetic value of the consumed food, $G \cdot C^{-1}$). They were equal to 8.6 and 6.2% for 5 d and 15 d old fish respectively (tab. 5). Poor growth was related to high metabolic rate of the fish. Despite this, specific growth rate (SGR) was equal to 8.5% DM $\cdot$ d^{-1} (5d) and 4.7% DM $\cdot$ d^{-1} (15 d). These values fit the range calculated by Kickeis, Schiemer (1992) for roach larvae of body weight 0.0006 g reared under optimum food conditions.

Daily energy requirements per individual were equal to 3.67 J (5 d larvae) and 5.36 J (15 d larvae), which makes 87 and 127 individuals of brine shrimp per fish respectively. The requirements were equal to 138 and 105% of DM and were consistent with food consumption level of roach larvae determined by Marmull and Rösch (1990). Increase of W/C value with fish growth (tab. 5) was probably related to higher waste production (W) by 15 d fish, resulting from higher food intake (assuming equal digesting efficiency and no histological differences in digestive tracts between the groups of larvae).

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STRESZCZENIE

BUDŻET ENERGETYCZNY LARW PŁOCI (*Rutilus rutilus* L.) W OKRESIE PRZEJŚCIA NA POKARM EGZOGENNY

W niniejszej pracy podjęto próbę określenia dziennego zapotrzebowania energetycznego wczesnych stadiów rozwojowych płoci (tab.1). W tym celu przeprowadzono doświadczenie z respiracją larw w różnych temperaturach i wariantach żywieniowych oraz badano ilość wydzielanego i wydalanego amoniaku (tab. 2 i 3). Dzienne zapotrzebowanie energetyczne larw płoci wynosiło w zależności od wieku od 9732,9 $J \cdot g^{-1} \cdot d^{-1}$ do 26396,4 $J \cdot g^{-1} \cdot d^{-1}$ (tab.4). Znaczną część konsumowanej energii (80 %) larwy płoci przeznaczały na procesy metaboliczne i aktywność (tab. 5, rys. 1)

ADRES AUTORÓW:

Mgr inż. Jarosław Żelepień
Dr Andrzej Karpiński

Instytut Rybactwa Śródlądowego
10-719 Olsztyn, ul. Oczapowskiego 10