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REARING OF *Cherax quadricarinatus* (Von Martens, 1868) JUVENILES USING FEED FOR STURGEONS

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Abstract

At present, the Australian red-clawed crayfish *Cherax quadricarinatus* (Von Martens, 1868) farming is not well-developed and is mainly limited to temperate and subtropical regions where the initial stages of growth occur under well controlled conditions. In Russia, *C. quadricarinatus* farming technologies are under development and the values of bioproducts are much more lower. Juveniles of crayfish are more demanding on feed and require at least a 30-50 % protein-based diet for rapid growth. Starter feed for sturgeon fish species has the appropriate indicators, which opens up prospects for its use in crayfish farming. In this work, for the first time, we submit data on feeding norms, growth rate, survival and hematological indicators of juvenile crayfish fed sturgeon feeds with a protein content of 46 %. Scientific research was aimed at studying the parameters of hemolymph and growth of juvenile Australian red-clawed crayfish that received mixed feed for sturgeons. The experiments were conducted at the Kuban State University. Equal-aged 480 juveniles of Australian red-clawed crayfish with an average weight of 150 mg were selected from three females, mixed, and distributed in three rearing tanks of 160 individuals each, according to feeding rates (group I — 9 %, group II — 6 %, group III — 3 %). The tnaks were mounted in a multi-tiered closed aquaculture system. The crayfish juveniles were fed twice a day (in the morning at 9^{00} and in the evening at 1800) with granulated feed Coppens vital (0.8-1.2 mm) (Alltech Coppens B.V., the Netherlands), a protein content of 46.0 %. Survival rates and growth rates were recorded every 8 days (July 21, July 29, August 6, August 14, and August 22). A dayly feeding rate was adjusted with respect to changes in survival and biomass of the groups. On day 32, 13 individuals weighing from 0.67 to 1.39 g were selected, boiled and weighed separately. The meat was separated from the carapace and other inedible parts and weighed. To determine the total hemocyte counting (THC) and the proportion of granulocytes in the hemolymph of crayfish, the cuticle was pierced at the base of the first pair of pleopods from the ventral side of the first segment of the abdomen and a small amount of hemolymph was removed with a micropipette. At the end of the experiment, the median length was 3.50 cm for groups I and II, 3.40 cm for group III; the median weight was 0.94 g, 0.98 g, and 0.89 g for groups I, II, and III, respectively. The differences between the groups were statistically insignificant. The final mortality was 57 individuals (35.6 %) for group I, 62 individuals (38.7 %) for group II, and 58 individuals (36.2 %) for group III. Differences between the groups in total hemocyte counts (THC) and percentage of granulocytes were statistically insignificant. The THC average values ranged from 1005 to 1073 cells/μl, granulocytes accounted for 20.1 to 21.1 %. The median THC was 965 cells/μl for group I, 840 cells/μl for roup II, and 1101 cells/μl for group III; the median percentage of granulocytes was 21.1 %, 20.1 %, 20.6 %for groups I, II, and III. The THC values at different daily feeding rates does not depend on the percentage of granulocytes (the correlation coefficients ranged from –0.02 to –0.08). The relative weight gain decreased from 99.8 to 17.6 % (group I), from 102.6 to 19.1 % (group II), and from 105.4 to 16.9 % (group III). The specific growth rate was from 8.6 to 2.0 % (group I), from 8.8 to 2.2 % (group II), and from 9.0 to 2.0 % (group III). The meat yield index of crayfish juveniles did not differ significantly between the groups. Average indicators ranged from 31.1 to 32.5 %. In group I, the feed cost was the highest, 2.00 vs. 1.47 in group II and 0.72 in group III. Low feed consumption (daily feeding rate 3 %) with similar values of growth rates, survival rates, average weight and length, and their medians indicate efficient assimilation of feed by *C. quadricarinatus* juveniles in group III and excessive feeding rate in other groups.

Keywords: *Cherax quadricarinatus*, Australian redclaw crayfish, juveniles, feeding, hemolymph, hemocytes, granulocytes, recirculating aquaculture system

The Australian red claw crayfish (*Cherax quadricarinatus*) belongs to the thermophilic aquaculture objects and has valuable consumer and economic qualities [1, 2]. The technology of industrial cultivation of Australian crayfish has not yet been sufficiently developed. Cultivation of this species is increasingly spreading in countries with a temperate and subtropical climate, where cultivation begins under controlled conditions and then continues in open water. In Russia, cultivation technologies for *C. quadricarinatus* are at the development stage and bioproduction indicators are much more modest [1, 3].

Cold climatic conditions require the obligatory use of closed systems for keeping spawners in winter, spawning, keeping females with eggs and juveniles, rearing juveniles [2, 4-6]. The most important element of this technology is the development of feeding. There are lines of specialized aquarium food on the market, which are disproportionately expensive and inapplicable for industrial breeding. Research and development of new methods and formulations of feeding met the physiological characteristics of crustaceans [7] is underway. These are the search for alternatives to traditional feed components [8, 9], the use of various additives [10-13] and various feeding regimes [14-17], but, as practice shows, it is long and expensive. The possibility of using already proven high-quality fish feeds in crayfish breeding has been poorly studied.

Young crayfish are more demanding on feed, and for its effective rapid growth, they must contain at least 30-50% protein [1, 18-20]. Starter feeds for sturgeon species meet the same requirements, which opens up prospects for their use in crayfish breeding. There have been attempts to explore the possibility of introducing these types of feeds in comparison with analogues [21], but different feeding regimens have not been sufficiently considered.

Malnutrition can lead to an inadequate balance of energy and material intake with macro- and micronutrient deficiencies, which is the most common cause of immunodeficiencies and is a risk factor in productive animals. In animal husbandry practice, violations of energy protein nutrition most often occur, which is accompanied by an increase in the sensitivity of individuals to infections due to suppression of innate and adaptive immunity [22, 23]. In this regard, when developing a diet, it is required to analyze indicators that characterize the state of the immune system. For crustaceans, these may be indicators of hemolymph. i.e., the total number of hemocytes (THN) and the proportion of granulocytes [24-28]. There are few studies that take these indicators into account when developing a diet for Australian red claw crayfish [15, 29].

In this work, for the first time, the feeding norms, growth rate, survival rate and hematological parameters of juvenile Australian red claw crayfish were established using specialized feed for sturgeon species with a protein content of 46%.

The purpose of the study was to study the effectiveness of the use of compound feed for sturgeon species and their effect on hemolymph parameters when growing juvenile Australian red claw crayfish.

Materials and methods. The experiment was carried out on the basis of the business incubator of the Kuban State University from July 21 to August 22, 2019. A multi-tiered recirculating water supply installation was 0.97 m in length, 0.70 m in width, 1.92 m in height. It consists of four nursery plastic containers with dimensions 78×56×18 cm (bottom 65.5×51 cm, area 0.334 m^2). Water treatment unit was divided into five compartments, the first for rough mechanical cleaning from sponge layers of different porosity, the second-fourth for floating polypropylene loading BioElements (RK Plast, Denmark) with a density of 0.93 g/cm3 and a specific surface area of 750 m^2/m^3. The fifth is a storage tank with a pump and a thermostat with a volume of 0.11 m^3; pump 14HF HyperFlow (RIO, Taiwan) 3.4 m^3/h; piston compressor Hailea Electrical Magnetic AC ACO-208 (Hailea, China) with atomizers for air supply to the biological treatment compartment; connecting polypropylene pipes and taps. The containers were installed on a metal frame. Three growing tanks were used for the experiment. Each was covered with a Styrofoam lid, which reduced water consumption by minimizing evaporation and reducing the likelihood of cancer coming out of the containers.

For experiments, coeval juveniles of the Australian red claw crayfish with an average weight of 150 mg (480 ind.) were selected from three females, then mixed and distributed over nursery tanks. A total of 160 individuals were stocked in nursery tanks.

To reduce the damage from cannibalism, we used multi-story shelters made of polycarbonate and plastic mesh that we designed. As the juveniles grew, the shelters were changed in accordance with the size characteristics. Shelters were designed to provide juvenile crayfish both with individual cells (with a margin), and to create an area on the floors necessary for safe molts, as well as served as an additional substrate for the fixation of nitrifying bacteria.

For the experiment, the juveniles were divided into three experimental groups with different daily feeding rate (as a percentage of biomass), 9% in group I, 6% in group II, and 3% in group III. Juveniles were fed twice a day, in the morning at 9.00 and in the evening at 18.00, with granulated feed for sturgeon species Coppens vital (0.8-1.2 mm) (Alltech Coppens B.V., Netherlands). The Coppens vital is 46.0% protein, 10.0% fat, 1.5% phosphorus, 14000 IU/kg vitamin A, 2140 IU/kg vitamin D, 280 mg/kg vitamin E, 500 mg/kg stable vitamin C: total energy is 19.4 MJ/kg.

During the experiment, the main hydrochemical indicators of water (NO_3, NO_2, NH_4/NH_3, pH) were within the limits of fish breeding standards, they were checked with colorimetric tests of the Sera brand (Germany) and Api (USA). Cleaning the bottom with a siphon and partial replacement of about 30% of water was carried out once every 4 days. The water temperature during the experiment varied from 27.1 to 29.5 °C, the average was 28.3 °C.

Every 8 days (July 21, July 29, August 6, August 14, August 22) the survival rate, individual weight, biomass growth were assessed and the actual daily feeding rate was corrected taking into account changes in the number and biomass of the experimental groups. The measurement was carried out with a ruler with a 1 mm accuracy. For weighing, an electronic balance MEM-EBS (Mercury, South Korea) with an accuracy of 0.01 g was used. The sample size was 50 ind. At the end of the experiment, all individuals were measured.

To determine the yield of meat at the end of the experiment (on day 32), 13 individuals weighing from 0.67 to 1.39 g were selected and boiled, and thes individually weighed. The meat was separated from the carapace and other inedible parts of the body and weighed.

Relative growth rate (ΔM, %) and specific growth rate (C_w, %) of biomass were calculated [30] as $\Delta M = (M_t - M_0)/M_0 \cdot 100$ %; $C_w = (\ln M_t - \ln M_0)/t \cdot 100\%$ where M_0, M_t is the biomass at the beginning and end of the period, g. Feed consuption (FC, g) per unit of weight gain was calculated as $FC = M_f/WG$, where M_f is the amount of feed consumed, g, WG is the weight gain, g.

The THN and the proportion of granulocytes in the cancer hemolymph were determined at the end of the experiment (on day 32). The hemolymph was collected as follows: the cuticle was pierced at the base of the first pair of pleopods on the ventral side of the first segment of the abdomen [31] and a small amount of hemolymph was removed with a micropipette.

Hemolymph samples were examined under a light microscope Mikromed-1 (Micromed, Russia) using the Goryaev chamber. The following formula was used to calculate the THN in 1 μl: THN = $N \times 10$ where N is the number of hemocytes in 25 large squares of the camera grid [32].

Mathematical data processing was carried out by standard methods of variation statistics. Mean values (M), standard deviations ($\underline{\pm\sigma}$), coefficients of variation ($\underline{Cv}$), medians (Me), 25th and 75th percentiles (Q1 and Q3) were calculated. Statistically significant differences between groups were identified using the Mann-Whitney U test and the Kruskal-Wallis test for non-parametric and independent groups. Calculations and graphic presentation of the obtained data were performed using Microsoft Excel and Statistica 12 software (StatSoft, Inc., USA).

Results. Figure 1 shows a multi-tiered closed water supply system which we used in the work.

Fig. 1. A multi-tier recirculating water supply facility used to rear juvenile Australian red-clawed crayfish (*Cherax quadricarinatus*).

As a result of the studies, the indicators of the dynamics of the average weights and biomass of juvenile Australian red claw crayfish during 32 days were obtained (Table 1). At the beginning of the experiment, the average weight of juveniles was 0.15 g. The average weight of juveniles at the end of the experiment was 1.06 g in group I, 1.01 g in group II, and 1.02 g group III. Differences between groups were not statistically significant.

The average weight in our experiment was comparable with that obtained by S.V. Sevasteev et al. [33]. In the authors' experiment, when feeding crayfish at the rate of 10% of the biomass with decapsulated brine shrimp, granules from brine shrimp, and brine shrimp "amber", juveniles weighed 1.11-1.54 g in 30 days vs. initial weight of 0.08-0.12 g.

The coefficient of body weight variation in juveniles in our experiment changed over time from 11.5-11.8 to 45.7-51.9%, and the differences between the groups were small. Such dynamics of variation in size and mass characteristics can be considered quite large for the Australian red claw crayfish, when compared with the few data of other works [2, 4, 5]. In our studies, this was most likely due to the greater variability of initial indicators and high stocking densities, which led to growth inhibition of initially lagging individuals. In the work of A.V. Zhigin et al. [6], the coefficient of variation in body weight changed from 8.51 to 14.17% when the weight stocking juveniles ranged within 0.44-0.57 g and an initial stocking density of $44.4/m^2$. In our case, juveniles had such a mass 16 days after the start of the experiment, and the stocking density was in the range of 385.1-$388.1/m^2$.

Medians (Fig. 2) as averages of samples are considered more objective for the analysis of results. The medians for length were 3.50 cm in groups I and II, 3.40 cm in group III; the medians for weight were 0.94 g in group I, 0.98 g in group II, and 0.89 g in group III. Differences in medians according to the Kruskal-Wallis test were not statistically significant. The minimum weight and length of juvenile Australian red claw crayfish at the end of the experiment in all groups were approximately the same and amounted to 0.33-0.40 g and 2.3-2.4 cm, respectively (see Fig. 2). The maximum indicators differed. In groups I and II, the values were greater, at 5.3 cm length of juveniles, the weight was 2.60 and 2.53 g, respectively, in group III, at 4.8 cm length, the weight averaged 2.34 g.

1. Weight of juvenile Australian red claw crayfish (*Cherax quadricarinatus*) fed Coppens vital (Alltech Coppens B.V., Netherlands) **granular feed for sturgeon species** (lab test, 2019)

Date	Weight (n = 50)	Group I	Group II	Group III
06/21 (the befininng of the test)	$M\pm\sigma$, g	0.15±0.017	0.15±0.017	0.15±0.018
	Cv, %	11.5	11.5	11.8
07/29	$M\pm\sigma$, g	0.34±0.059	0.34±0.062	0.34±0.060
	Cv, %	17.3	18.2	17.7
08/06	$M\pm\sigma$, g	0.56±0.161	0.57±0.173	0.60±0.169
	Cv, %	28.7	30.3	28.2
08/14	$M\pm\sigma$, g	0.81±0.432	0.72±0.310	0.76±0.361
	Cv, %	37.4	38.5	36.6
08/22 (the enf of the test)	$M\pm\sigma$, g	1.06±0.551	1.01±0.461	1.02±0.506
	Cv, %	51.9	45.7	49.7

N o t e. See the description of the experiments in the Materials anad methods section.

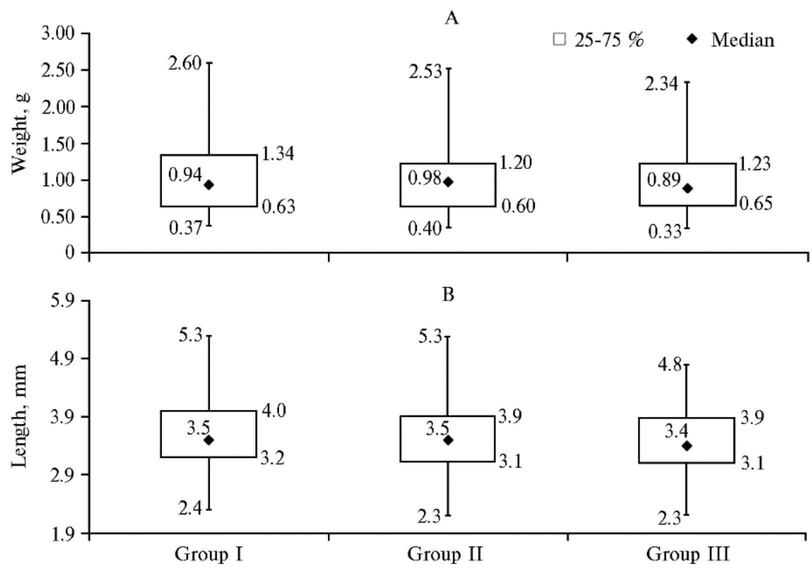

Fig. 2. Final weight (A) **and length** (B) **of juvenile Australian red claw crayfish (*Cherax quadricarinatus*) fed granular feed for sturgeon Coppens vital** (Alltech Coppens B.V., Netherlands) **on day 32 of the experiment** (lab test, 2019). See the description of the experiments in the Materials anad methods section.

Variation series were compiled to estimate the size structure of juveniles obtained at the end of the experiment (Fig. 3, 4). Weight was estimated according to 13 size classes with an interval of 0.2 g, length according to 10 classes with an interval of 0.3 cm. In all groups, the most representative individuals for weight and length were those of 0.40-1.39 g and 3.10-3.99 cm (see Fig. 3, 4). As the mass increases, one can notice a systematic decrease in the number of individuals in size groups.

The Australian red claw crayfish is characterized by high cannibalism, so the survival rate during the experiment (Table 2) was in the range of 61.3-64.4%. Mortality eventually amounted to 57 ind. (35.6%) in group I, 62 ind. (38.7%) in group II, and 58 ind. (36.2%) in group III.

The change in biomass during the experiment is indicative (see Table 2).

Initially, it was 24 g for each group. By the end of the experiment, group I was characterized by the largest actual increase in biomass of 85.5 g vs. 75.0 g in group II and 79.9 g in group III. This difference are not significant, since, given close average masses, it is due to greater survival in the group.

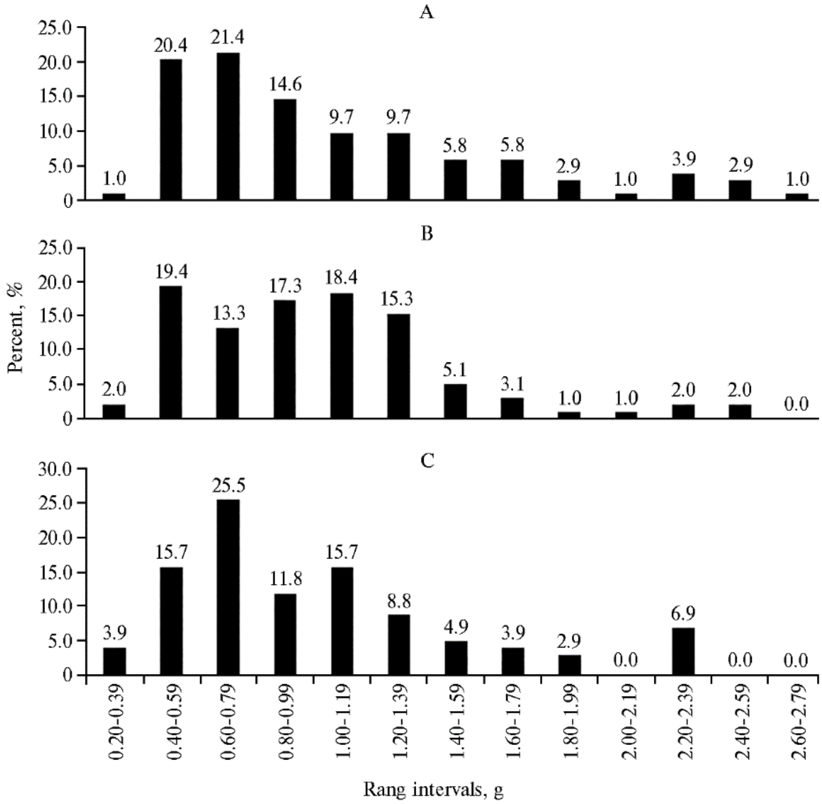

Fig. 3. Variation series of weight parameters in juvenile Australian red claw crayfish (*Cherax quadricarinatus*) fed granular feed for sturgeon Coppens vital (Alltech Coppens B.V., Netherlands) **on day 32 of the experiment:** A — group I, B — group II, C — group III (lab test, 2019). See the description of the experiments in the Materials anad methods section.

Since the daily feeding rate expressed as a percentage, increased in proportion to the growing biomass at each stage, it is incorrect to focus only on the above actual values. The description of the relative growth and specific growth rate can be considered decisive here, which decreased as they grew older in all groups. The relative increase in 32 days decreased from 99.8 to 17.6% in group I, from 102.6 to 19.1% in group II, and from 105.4 to 16.9 in group III. This is due to a natural decrease in metabolism as individuals mature and an increase in molt spacing in crustaceans, which is observed in many decapods. The specific growth rate ranged from 8.6 to 2.0% in group I, from 8.8 to 2.2% in group II, and from 9.0 to 2.0% in group III.

Malnutrition can lead to an inadequate ratio of energy and substance intake with a number of macro- and micronutrient deficiencies. It becomes the most common cause of immunodeficiencies and is a risk factor in productive animals. The red swamp crayfish (*Procambarus clarkii*) has been studied as an alternative to fish oil for feed [34]. Its complete replacement with beef showed potential harm to the health of crayfish, while partial replacement did not suppress growth and did not impair antioxidant capacity and innate immunity. An increase in hemolymph triglycerides and free fatty acids was observed compared to crayfish fed a complete traditional diet ($p < 0.05$) [34].

To some diets, various components (e.g., immunopotentiators, such as glycyrrhizic acid as an antiviral agent) are periodically or regularly added. F. Liu et al. [35] showed that crayfish in groups receiving the optimal dose of 50-150 mg/kg feed had increased final body weight, weight gain, specific growth rate, and reduced feed conversion rate compared to control ($p < 0.05$). The total number of hemocytes and the content of phenol oxidase in the hemolymph were increased, immune responses and expression of immunity-related genes were improved. The use of *Codonopsis pilosula* polysaccharides in the diet [36] gave similar results. The influence of the probiotic *Pediococcus acidilactici* [37], *Lactobacillus acidophilus*, *L. plantarum* [38] on the immunological parameters of hemolymph and the enzymatic system of juvenile *Astacus leptodactylus* and *Cherax cainii*, as well as chitosan on *Procambarus clarkii* [39] was studied. These approaches to varying degrees affected the hemogram of crustaceans and the general physiological state.

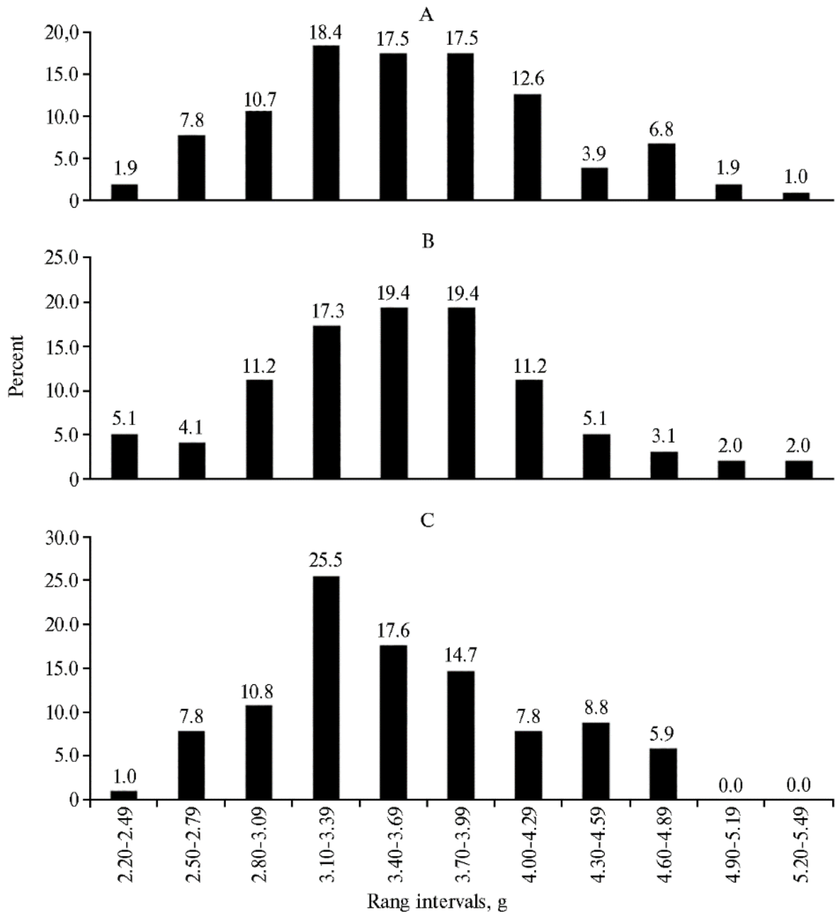

Fig. 4. Variation series of length parameters in juvenile Australian red claw crayfish (*Cherax quadricarinatus*) fed granular feed for sturgeon Coppens vital (Alltech Coppens B.V., Netherlands) **on day 32 of the experiment:** A — group I, B — group II, C — group III (lab test, 2019). See the description of the experiments in the Materials anad methods section.

2. Weight gain and survival of juvenile Australian red claw crayfish (*Cherax quadricarinatus*) fed Coppens vital (Alltech Coppens B.V., Netherlands) **granular feed for sturgeon species** (lab test, 2019)

Date	Group I	Group II	Group III
	Weigh, g		
07/21 (the befininng of the test)	24.0	24.0	24.0
08/22 (the enf of the test)	109.5	99.0	103.9

Continued Table 2

	Weigh gain, %		
07/29			
ΔM, %	99.8	102.6	105.4
Cw, %	8.6	8.8	9.0
08/06			
ΔM, %	50.7	52.4	57.0
Cw, %	5.1	5.3	5.6
08/14			
ΔM, %	28.9	12.1	14.8
Cw, %	3.2	1.4	1.7
08/22			
ΔM, %	17.6	19.1	16.9
Cw, %	2.0	2.2	2.0
	Survival, %		
07/21	100	100	100
07/29	88.1	89.4	90.6
08/06	80.6	81.3	80.6
08/14	71.9	72.5	73.1
08/22	64.4	61.3	63.8

N o t e. See the description of the experiments in the Materials anad methods section. ΔM — relative weigh gain, Cw — specific biomass growth rate.

In our experiments, there were no statistically significant differences in THN and the proportion of granulocytes between groups ($p > 0.05$). The average values of the THN in the groups ranged from 1005 to 1073 per 1 μl, the proportion of granulocytes was from 20.1 to 21.1% (Table 3).

3. Hematological parameters of juvenile Australian red claw crayfish (*Cherax quadricarinatus*) fed Coppens vital (Alltech Coppens B.V., Netherlands) **granular feed for sturgeon species** (lab test, 2019)

Parameter	Group I	Group II	Group III
Total hemocyres number/μl			
M±σ	1030±499	1005±493	1073±507
Cv, %	48.5	49.1	47.2
Granulocyte , %			
M±σ	21.1±5.97	20.2±5.50	20.1±5.48
Cv, %	28.3	27.3	27.2

N o t e. See the description of the experiments in the Materials anad methods section.

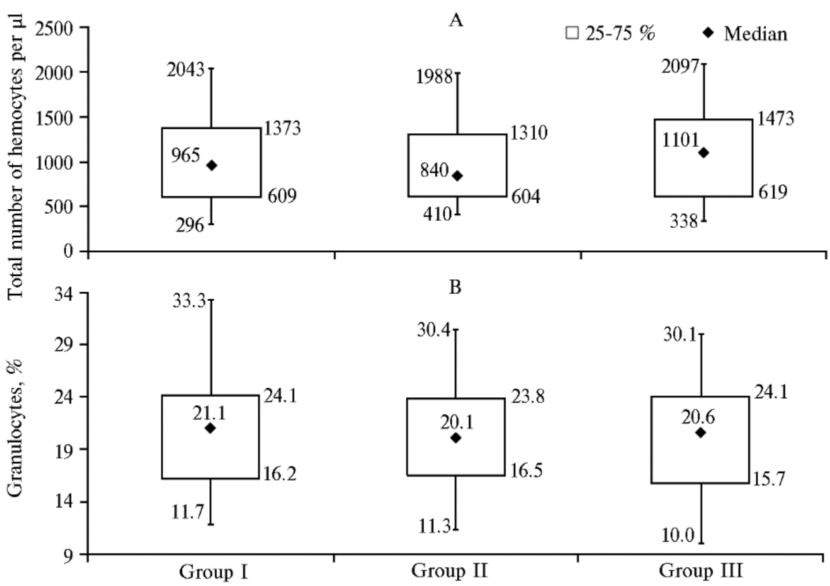

Fig. 5. Total hemocyres number (THN, A) **and granulocytes** (B) **in juvenile Australian red claw crayfish (*Cherax quadricarinatus*) fed granular feed for sturgeon Coppens vital** (Alltech Coppens B.V., Netherlands) **on day 32 of the experiment** (lab test, 2019). See the description of the experiments in the Materials anad methods section.

The medians (Fig. 5) for THN were 965 per 1 μl in group I, 840 per 1 μl in group II, and 1101 per 1 μl in group III. Granulocytes amounted to 21.1% in group I, 20.1% in group II, and 20.6% in group III.

The total number of hemocytes in crayfish at different daily feeding rates did not depend on the proportion of granulocytes ($p > 0.05$), the correlation coefficients ranged from -0.02 to -0.08 (Fig. 6).

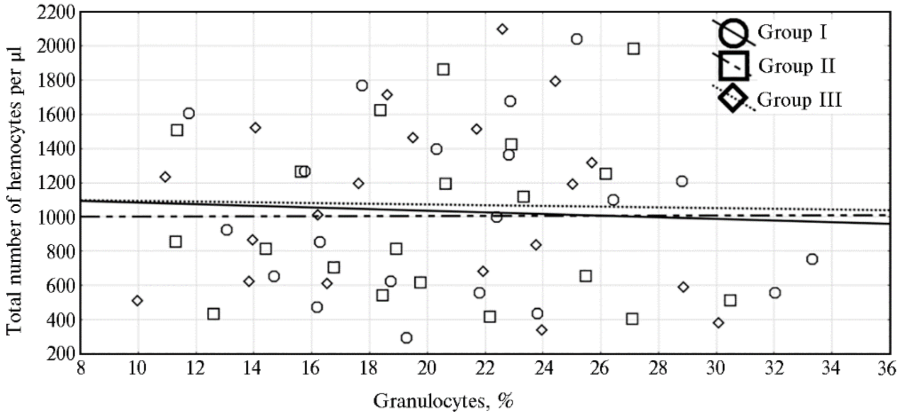

Fig. 6. The ratio of total hemocyres number (THN) **to granulocytes in juvenile Australian red claw crayfish (*Cherax quadricarinatus*) fed granular feed for sturgeon Coppens vital** (Alltech Coppens B.V., Netherlands) **on day 32 of the experiment** (lab test, 2019). The lines on the graph are straight lines of zero correlations of the experimental groups. See the description of the experiments in the Materials anad methods section.

4. Economic indicators of rearing juvenile Australian red claw crayfish (*Cherax quadricarinatus*) fed granular feed for sturgeon Coppens vital (Alltech Coppens B.V., Netherlands) (lab test, 2019)

Parameter	Group I	Group II	Group III
Initial stocking density, ind/m2	479	479	479
Feed consumption for the period, g:			
July 21-July 28	17.3	11.5	5.8
July 29-August 5	34.5	23.3	11.8
August 6-August 13	52.0	35.6	18.6
August 14-August 22	67.1	39.9	21.3
Total, g	170.9	110.3	57.5
Total weight gain, g	85.5	75.0	79.9
Feed consumption, units	2.00	1.47	0.72
Productivity, ind/m^2	308	293	305
Productivity, g/m^2	326.9	295.4	310.1
Cost (feed costs), rub/kg	421.4	309.7	151.7
Meat output			
Bodyweight before treatment, g			
$M \pm \sigma$	1.06±0.167	1.10±0.156	1.08±0.172
min-max	0.76-1.34	0.67-1.30	0.79-1.39
Bodyweight after treatment, g			
$M \pm \sigma$	0.95±0.146	0.92±0.136	0.97±0.149
min-max	0.68-1.16	0.66-1.15	0.72-1.21
Abdominal muscles, g			
$M \pm \sigma$	0.31±0.065	0.30±0.067	0.32±0.073
min-max	0.15-0.40	0.14-0.32	0.17-0.46
Output of meat from abdomen, %			
$M \pm \sigma$	32.5±3.85	31.1±2.99	32.0±3.90
min-max	22.1-37.6	21.9-37.0	22.9-36.9

Note. See the description of the experiments in the Materials anad methods section.

An important indicator of the nutrient assimilation in aquaculture is the yield of edible parts (in our case, muscle fiber, meat) from the total bodyweight. Since the mass of juvenile crayfish is small and it is not possible to remove the entire body meat, the amount contained only in the tail part was estimated. The remaining parts of the body were considered as inedible (Table 4).

The meat yield in the experimental groups in juvenile crayfish did not differ statistically significantly. The mean values ranged from 31.11% (group II) to 32.54% (group I). Close dvalues, the 30-32% of body weight which is characteristic of older individuals weighing from 22 to 86 g, were noted in *C. quadricarinatus* when grown in a recirculating water supply installation [2, 40], in other crayfish species these values amounted to 15-20% [40]. It should be noted that our work presents estimats for juveniles that other authors have not studied.

One of the indicators of growing efficiency in general is feed costs (see Table 4). For the entire experiment, the most feed was eaten in group I (170.9 g) where the highest feed costs (2.00 units) were also noted.

Low feed coefficients are shown in the work of S.V. Sevasteev et al. [33]. They reported thet, when feeding Artemia-based products, juveniles of close final sizes were obtained at similar times with a feed consumption of 0.5 to 1.6 units. Based on the OOO Pioneer Trade (Russia) price (1500 rubles/kg, 2018) of decapsulated Artemia offered by S.V. Sevasteev et al. [33] as a feeding option, the calculated cost of feed will be from 750 to 2400 rubles/kg, which is several times more expensive compared to feed for sturgeon species.

According to the price list dated February 21, 2019, at OOO AlpheusFeeds (the official Russian distributor of Coppens International B.V.—Alltech Coppens, the Netherlands), the cost of Coppens vital (0.8-1.2 mm) is 2.82 euros/kg, or 210.7 rubles/kg (at the exchange rate of 74.7 rubles prt euro in February 2019). With such cost of feed, the cost of juveniles in group III is minimal and amounts to 151.7 rubles/kg vs. 309.7 and 421.4 rubles/kg in groups I and II, respectively.

Thus, the low feed cost per unit of weigh gain of juvenile Australian red claw crayfish when fed Coppens vital granulated feed for sturgeon species at a daily feeding rate of 3% resulted in similar growth rates, survival, average weights, lengths, length medians and hematological status indicating effective feed assimilation and an excessive feeding rate in other groups. The daily feeding rate of more than 3% did not lead to an increase in the efficiency of rearing. When growing juveniles for 32 days from an average weight of 0.15 g to 0.89 g, the feed cost was 0.72 units. With an initial stocking density of 479 ind/m^2, 61-64% of crayfish survived with a productivity of 293-308 ind./m^2, or 295-327 g/m^2. For the first time, the yield of abdominal meat in young crayfish was estimate which ranges within 31-33%. An increase in the feeding rate did not affect the total number of hemocytes (1005-1073 per 1 μl) and the number of granulocytes (20-21%). Our trials confirmed the effectiveness of the feeding regimen for juvenile Australian red claw crayfish. Nevertgeless, more experimentation is needed to determine the minimum threshold for daily feeding both for the indicated age group of juvenile Australian red claws and for older ages, as metabolism, and with it the need for food, change with adulthood.

REFERENCES

1. Lagutkina L.Yu., Kuz'mina E.G., Taranina A.A., Akhmedzhanova A.B., Yasinskiy V.S., Ponomarev R.A. *Vestnik Astrakhanskogo gosudarstvennogo tekhnicheskogo universiteta. Seriya: Rybnoe khozyaystvo*, 2020, 2: 94-105 (doi: 10.24143/2073-5529-2020-2-94-105) (in Russ.).
2. Arystangalieva V.A. *Razrabotka tekhnologii vyrashchivaniya posadochnogo materiala avstraliyskogo krasnokleshnevogo raka (Cherax quadricarinatus) v ustanovke s zamknutym vodoispol'zovaniem. Kandidatskaya dissertatsiya* [Technology for the Australian red-clawed crayfish (*Cherax quadricarinatus*) stocking material production in an installation with closed water use. PhD Thesis]. Moscow, 2017 (in Russ.).
3. Lagutkina L.Yu., Kuz'mina E.G., Biryukova M.G., Pershina E.V. *Vestnik Astrakhanskogo gosudarstvennogo tekhnicheskogo universiteta. Seriya: Rybnoe khozyaystvo*, 2019, 4: 87-94 (doi: 10.24143/2073-5529-2019-4-87-94) (in Russ.).
4. Shumeyko D., Tsimbal N., Abramchuk A., Moskul G., Taranik A. Biotechnology of Australian red-claw crayfish (*Cherax quadricarinatus*) juvenile ongrowing in recirculating aquaculture system.

E3S Web of Conferences, 2020, 175: 02005 (doi: 10.1051/e3sconf/202017502005).
5. Shokasheva D.I. *Vestnik Astrakhanskogo gosudarstvennogo tekhnicheskogo universiteta. Seriya: Rybnoe khozyaystvo*, 2018, 2: 98-103 (doi: 10.24143/2073-5529-2018-2-98-103) (in Russ.).
6. Zhigin A.V., Borisov R.R., Kovacheva N.P., Zagorskaya D.S., Arystangalieva V.A. *Rybnoe khozyaystvo*, 2017, 1: 61-65 (in Russ.).
7. Cheng S., Wei Y.-c., Jia Y.-y., Li F., Chi M.-l., Liu S.-l., Zheng J.-b., Wang D.-l., Gu Z.-m. A study on primary diets for juveniles of red claw crayfish *Cherax quadricarinatus*. *Aquaculture Research*, 2021, 52(5): 2138-2145 (doi: 10.1111/are.15066).
8. Muzinic L., Thompson K., Morris A., Webster C., Rouse D., Manomaitis L. Partial and total replacement of fish meal with soybean meal and brewer's grains with yeast in practical diets for Australian red claw crayfish *Cherax quadricarinatus*. *Aquaculture*, 2004, 230(1-4): 359-376 (doi: 10.1016/S0044-8486(03)00420-4).
9. Qian D., Yang X., Xu C., Chen C., Jia Y., Gu Z., Li E. Growth and health status of the red claw crayfish, *Cherax quadricarinatus*, fed diets with four typical plant protein sources as a replacement for fish meal. *Aquaculture Nutrition*, 2021, 27(3): 795-806 (doi: 10.1111/anu.13224).
10. Foysal M.J., Chua E.G., Gupta S.K., Lamichhane B., Tay C.Y., Fotedar R. *Bacillus mycoides* supplemented diet modulates the health status, gut microbiota and innate immune response of freshwater crayfish marron (*Cherax cainii*). *Animal Feed Science and Technology*, 2020, 262: 114408 (doi: 10.1016/j.anifeedsci.2020.114408).
11. Lai Y., Luo M., Zhu F. Dietary *Bacillus amyloliquefaciens* enhance survival of white spot syndrome virus infected crayfish. *Fish & Shellfish Immunology*, 2020, 102: 161-168 (doi: 10.1016/j.fsi.2020.04.033).
12. Kong F., Zhu Y., Yu H., Wang X., Abouel Azm F.R., Yuan J., Tan Q. Effect of dietary vitamin C on the growth performance, nonspecific immunity and antioxidant ability of red swamp crayfish (*Procambarus clarkii*). *Aquaculture*, 2021, 541: 736785 (doi: 10.1016/j.aquaculture.2021.736785).
13. Xiao C., Zhang Y., Zhu F. Effect of dietary sodium butyrate on the innate immune response of *Procambarus clarkii* and disease resistance against white spot syndrome virus. *Aquaculture*, 2021, 541: 736784 (doi: 10.1016/j.aquaculture.2021.736784).
14. Stumpf L., Cárdenas P.N.S., Timpanaro S., Greco L.L. Feasibility of compensatory growth in early juveniles of «red claw» crayfish *Cherax quadricarinatus* under high density conditions. *Aquaculture*, 2019, 510: 302-310 (doi: 10.1016/j.aquaculture.2019.05.053).
15. Castillo Díaz F., Tropea C., Stumpf L., López Greco L.S. Effect of food restriction on female reproductive performance in the redclaw crayfish *Cherax quadricarinatus* (Parastacidae, Decapoda). *Aquaculture Research*, 48(8): 4228-4237 (doi: 10.1111/are.13244).
16. Luo S., Li X., Onchari M.M., Li W., Bu Y., Lek S., Zhang T., Wan Z., Jin S. High feeding level alters physiological status but does not improve feed conversion efficiency and growth performance of juvenile red swamp crayfish *Procambarus clarkii* (Girard, 1852). *Aquaculture*, 2021, 537: 736507 (doi: 10.1016/j.aquaculture.2021.736507).
17. Hou J., Wang X., Xu Q., Cao Y., Zhang D., Zhu J. Rice-crayfish systems are not a panacea for sustaining cleaner food production. *Environmental Science and Pollution Research*, 2021, 28(18): 22913-22926 (doi: 10.1007/s11356-021-12345-7).
18. Cortés-jacinto E., Villarreal-colmenares H., Civera-cerecedo R., Naranjo-páramo J. Effect of dietary protein level on the growth and survival of pre-adult freshwater crayfish *Cherax quadricarinatus* (von Martens) in monosex culture. *Aquaculture Research*, 2004, 35(1): 71-79 (doi: 10.1111/j.1365-2109.2004.00988.x).
19. Cortés-Jacinto E., Villarreal-Colmenares H., Cruz-Suárez L. E., Civera-Cerecedo R., Nolasco-Soria H., Hernández-Llamas A. Effect of different dietary protein and lipid levels on growth and survival of juvenile Australian redclaw crayfish, *Cherax quadricarinatus* (von Martens). *Aquaculture Nutrition,* 2005, 11(4): 283-291 (doi: 10.1111/j.1365-2095.2005.00353.x).
20. Cortés-Jacinto E., Villarreal-Colmenares H., Civera-Cerecedo R., Cruz-Suárez L.E. Studies on the nutrition of the freshwater crayfish *Cherax quadricarinatus* (von Martens): effect of the dietary protein level on growth of juveniles and pre-adults. *Freshwater Crayfish*, 2004, 14: 70-80.
21. Ankesheva B.M., Bedritskaya I.N., Pyatikopova O.V. *Rybovodstvo i rybnoe khozyaystvo*, 2021, 1: 70-79 (doi: 10.33920/sel-09-2101-06) (in Russ.).
22. Galochkin V.A., Ostrenko K.S., Galochkina V.P., Fedorova L.M. Interrelation of nervous, immune, endocrine systems and nutritional factors in the regulation of animal resistance and productivity (review). *Sel'skokhozyaistvennaya biologiya* [*Agricultural Biology*], 2018, 53(4): 673-686 (doi: 10.15389/agrobiology.2018.4.673rus).
23. Jolly C.A., Fernandes G. Protein-energy malnutrition and infectious disease. *Nutrition and immunology*. M.E. Gershwin, J.B. German, C.L. Keen (eds.). Humana Press, Totowa, NJ, 2000: 195-202 (doi: 10.1007/978-1-59259-709-3_16).
24. Sepici-Dinçel A., Alparslan Z.N., Benli A.Ç.K., Selvi M., Sarıkaya R., Özkul İ.A., Erkoç F. Hemolymph biochemical parameters reference intervals and total hemocyte counts of narrow clawed crayfish *Astacus leptodactylus* (Eschscholtz, 1823). *Ecological Indicators*, 2013, 24: 305-309 (doi: 10.1016/j.ecolind.2012.07.002).
25. Safari O., Paolucci M., Motlagh H.A. Effects of synbiotics on immunity and disease resistance of

narrow-clawed crayfish, *Astacus leptodactylus leptodactylus* (Eschscholtz, 1823). *Fish & Shellfish Immunology*, 2017, 64: 392-400 (doi: 10.1016/j.fsi.2017.03.049).
26. Lu X., Peng D., Chen X., Wu F., Jiang M., Tian J., Wei K. Effects of dietary protein levels on growth, muscle composition, digestive enzymes activities, hemolymph biochemical indices and ovary development of pre-adult red swamp crayfish (*Procambarus clarkii*). *Aquaculture Reports*, 2020, 18: 100542 (doi: 10.1016/j.aqrep.2020.100542).
27. Safari O., Paolucci M. Effects of dietary onion (*Allium cepa*) powder on growth performance, hemolymph indices and fillet organoleptic properties of juvenile narrow-clawed crayfish, *Astacus leptodactylus leptodactylus* Eschscholtz, 1823. *Aquaculture Nutrition*, 2017, 23(6): 1418-1428 (doi: 10.1111/anu.12517).
28. Huang Y., Ren Q. Research progress in innate immunity of freshwater crustaceans. *Developmental & Comparative Immunology*, 2019, 104: 103569 (doi: 10.1016/j.dci.2019.103569).
29. Lagutkina L.Yu., Evgrafova E.M., Kuz'mina E.G., Mazlov A.M. *Vestnik Astrakhanskogo gosudarstvennogo tekhnicheskogo universiteta. Seriya: Rybnoe khozyaystvo*, 2021, 2: 134-143 (doi: 10.24143/2073-5529-2021-2-134-143) (in Russ.).
30. Shcherbina M.A., Gamygin E.A. *Kormlenie ryb v presnovodnoy akvakul'ture* [Fish feeding in freshwater aquaculture]. Moscow, 2006 (in Russ.).
31. Kovacheva N.P., Aleksandrova E.N. *Gematologicheskie pokazateli kak indikatory fiziologicheskogo sostoyaniya dekapod: kamchatskogo kraba Paralithodes camtschaticus i rechnykh rakov rodov Astacus i Pontastacus* [Hematological parameters as indicators of the physiological state of decapods, the Kamchatka crab *Paralithodes camtschaticus* and river crayfish genera *Astacus* and *Pontastacus*]. Moscow, 2010 (in Russ.).
32. Ivanov A.A., Pronina G.I., Koryagina N.Yu. *Fiziologiya gidrobiontov* [Physiology of hydrobionts]. St. Petersburg, 2021 (in Russ.).
33. Sevasteev S.V., Asanova A.V., Litosh T.A. V sbornike: *Sbornik III natsional'noy (vserossiyskoy) nauchnoy konferentsii «Teoriya i praktika sovremennoy agrarnoy nauki»* [In: Collection of the III Scientific Conference «Theory and practice of modern agricultural science»]. Novosibirsk, 2020, 2: 705-709 (in Russ.).
34. Gao F., Liu M., Tang J., Wang A., Tian H., Wen C., Chi C., Jiang G., Li X., Liu W., Zhang D. Partial replacement of dietary fish oil by beef tallow does not impair antioxidant capacity and innate immunity of red swamp crayfish, *Procambarus clarkii. Aquaculture Research*, 2021, 52(7): 3310-3321 (doi: 10.1111/are.15176).
35. Liu F., Shao G.-Y., Tian Q.-Q., Cheng B.-X., Shen C., Wang A.-M., Zhang J.-H., Tian H.-Y., Yang W.-P., Yu Y.-B. Enhanced growth performance, immune responses, immune-related gene expression and disease resistance of red swamp crayfish (*Procambarus clarkii*) fed dietary glycyrrhizic acid. *Aquaculture*, 2021, 533: 736202 (doi: 10.1016/j.aquaculture.2020.736202).
36. Liu F., Geng C., Qu Y.-K., Cheng B.-X., Zhang Y., Wang A.-M., Zhang J.-H., Liu B., Tian H. Y., Yang W.-P., Yu Y.-B., Chen Z.-B. The feeding of dietary *Codonopsis pilosula* polysaccharide enhances the immune responses, the expression of immune-related genes and the growth performance of red swamp crayfish (*Procambarus clarkii*). *Fish & Shellfish Immunology*, 2020, 103: 321-331 (doi: 10.1016/j.fsi.2020.05.034).
37. Vaezi M., Esmaeili Feridooni A., Manaffar R., Amini K. Effects of probiotic (*Pediococcus acidilactici*) on heamatological parameters, immunological responses and digestive enzymes of *Astacus leptodactylus* juveniles. *Aquatics Physiology and Biotechnology*, 2018, 6(3): 35-60 (doi: 10.22124/japb.2018.8702.1197).
38. Foysal M.J., Fotedar R., Siddik M.A.B., Tay A. *Lactobacillus acidophilus* and *L. plantarum* improve health status, modulate gut microbiota and innate immune response of marron (*Cherax cainii*). *Scientific Reports*, 2020, 10(1): 5916 (doi: 10.1038/s41598-020-62655-y).
39. Sun B., Quan H., Zhu F. Dietary chitosan nanoparticles protect crayfish *Procambarus clarkii* against white spot syndrome virus (WSSV) infection. *Fish & Shellfish Immunology*, 2016, 54: 241-246 (doi: 10.1016/j.fsi.2016.04.009).
40. Lagutkina L.Yu., Ponomarev S.V. *Estestvennye nauki*, 2010, 4 (33): 64-68 (in Russ.).