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COMPARATIVE CHARACTERISTICS OF PHYSICOCHEMICAL PARAMETERS OF MEAT AND BIOCHEMICAL COMPOSITION OF HEMOLYMPH IN THREE SPECIES OF CRAYFISHES

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Background. Crayfish farming is a promising direction in the development of aquaculture. Compared with marine crustacean species, freshwater crayfish require lower cultivation costs, while their meat is regarded as an additive dietary delicacy with a high nutritional value. The aim of this study was to compare the morphological and physiological data (slaughter yield, taste quality, physicochemical composition of meat, and some biochemical indexes of hemolymph) of three species of adult crayfishes, i.e. Australian red claw crayfish (*Cherax quadricarinatus*), narrow-clawed crayfish (*Astacus leptodactylus*), and marbled crayfish (*Procambarus fallax forma virginalis*)*, which were* cultivated in a recirculating aquaculture system.

Materials and Methods. Organoleptic and physicochemical methods were used to assess meat quality, while biochemical methods were applied to determine hemolymph parameters in the abovementioned crayfish species.

Results. The results showed that the edible portion relative to live weight was 15.16 ± 0.20 % in the Australian redclaw crayfish, 12.16 ± 0,21 % in the Marbled crayfish, and 9.40 ± 0,19 % in the Narrow-clawed crayfish. The highest protein content in meat was observed in marbled crayfish (17.4 ± 0.84 %). The highest fat content was registered in Australian redclaw crayfish (0.95 ± 0.024 %); for the marble crayfish, this value was 0.9 ± 0.03 %, and for the narrow-clawed crayfish, it was 0.9 ± 0.35 %. No differences were found in carbohydrate content among the studied species; the value of this parameter was approximately 1.2 ± 0.02 % in all the crayfish species. The meat of Australian redclaw crayfish exhibited the highest energy value (76.1 ± 3.12 kcal/100 g), exceeding that of the other species by 1.3 – 2.2 kcal/100 g, marbled crayfish – 74.8 ± 3.69 kcal/100 g, and narrow-clawed crayfish – 73.9 ± 3.52 kcal/100 g, respectively. In terms of hemolymph protein content, Australian redclaw crayfish showed the highest level (77.1 ± 2.87 g/L), for the narrow-clawed crayfish, this value was (64.9 ± 2.90 g/L), and for the marbled crayfish, it was (57.2 ± 2.41 g/L).

The highest calcium concentration in hemolymph was observed in narrow-clawed crayfish (9.52 ± 0.212 mmol/L), while comparable levels were recorded in Australian redclaw (7.99 ± 0.215 mmol/L) and marbled crayfish (7.42 ± 0.292 mmol/L). Differences in all studied indicators were considered statistically significant at $p \le 0.05$.

Conclusions. The study results obtained for Australian red claw crayfish, narrow-clawed crayfish and marbled crayfish allow us to evaluate their productivity and meat nutritional validity, as well as to propose the reference ranges of key indexes which can be used in optimizing aquaculture technologies and production of high-quality delicacies or supporting food products.

Keywords: crayfish aquaculture, Australian red claw crayfish (*Cherax quadricarinatus*), narrow-clawed crayfish (*Astacus leptodactylus*), marbled crayfish (*Procambarus fallax* forma *virginalis*), slaughter yield, meat productivity, hemolymph, reference indexes

INTRODUCTION

In recent years, aquaculture has been actively developing worldwide, increasing its share in the industrial production of hydrobionts. The range of delicacy species of aquatic organisms, particularly crustaceans, has been expanding. Crayfish products are a source of high-quality protein, fat, vitamins, and mineral elements. As of 2022, crustaceans accounted for 10 % of global aquaculture production, while the overall increase in crustacean populations from 2000 to 2022 amounted to +140 % (Crandall *et al*., 2007; FAO, 2024). The meat of certain crustacean species competes with "seafood delicacies", while the growing global demand for it gives impetus for the development of industrial aquaculture production in Ukraine (Sharylo *et al*., 2020; Hrynevych *et al*., 2022).

The most common crayfish species in Ukraine include the European noble crayfish (*Astacus astacus*), the narrow-clawed crayfish *(Astacus leptodactylus*), the Australian red claw crayfish (*Cherax quadricarinatus*), the Florida white and red swamp crayfish (*Procambarus clarkii*), and the marbled crayfish (*Procambarus fallax* forma *virginalis*) (Dammannagoda, 2015; Hrynevych *et al*., 2022).

For many decades, crustacean aquaculture was based on the cultivation of native river crayfish species, mainly the European noble crayfish (*Astacus astacus*) and the narrow-clawed crayfish (*Astacus leptodactylus*). The narrow-clawed crayfish (*Astacus leptodactylus*) is distributed in stagnant freshwater bodies of Eastern and Central Europe and is most commonly found in waters with dense vegetation. This crayfish species is sensitive to sudden changes in water quality and quickly dies in the presence of chemical pollution; however, it is tolerant of reduced oxygen levels in water to below 5 mg/L, which is critical for the Australian redclaw and the noble crayfish species. *Astacus leptodactylus* is characterized by high fecundity, is nocturnal, and feeds on both decaying and fresh plant material as well as animal-based food (detritus and small fish). In sexually mature individuals, moulting occurs once a year (Rida, 2020; Slusar *et al*., 2023).

The breeding period of the narrow-clawed crayfish lasts from early September to late October. A few days after fertilization, the female lays 100–200 eggs, of which about 40 % survive. The eggs are attached to the female's pleopods (on the underside of the abdomen). Incubation lasts about six months. Narrow-clawed crayfish reach sexual maturity at the age of three years. Adult individuals grow to 20–25 cm in length and reach a live weight of about 80–90 g. The lifespan of narrow-clawed crayfish is approximately 25 years (Muzaffer *et al*., 2018).

The Australian redclaw crayfish (*Cherax quadricarinatus*), as an aquaculture and aquarium species, has only recently appeared in Ukraine. It is a large freshwater crayfish with a body length of about 20–25 cm. Under natural conditions, males can reach a live weight of up to 500 g, while females reach about 400 g. Individuals reach sexual maturity at the age of 5–8 months when their body length is approximately 6–10 cm. Their body coloration is greenish-blue (depending on water acidity). Males of this species are distinguished by the bright red coloration on the outer side of the claw (Lawrence *et al*., 2002).

The natural range of this species includes freshwater bodies in the northern part of the Australian continent as well as in south-eastern Papua New Guinea (Holthuis, 1986). *Cherax quadricarinatus* prefers waters with high turbidity, weak currents, and stagnant areas. During the monsoon season, water flows can carry crayfish downstream. As a result, the Australian redclaw crayfish tends to migrate upstream; this behaviour also allows it to avoid water bodies that become shallow or dry out during the dry season. In nature, the red claw crayfish feeds on both animal and plant-based food. Since the late 1980s, this species has been cultivated in aquaculture (Lawrence *et al*., 2002; Yahkoub, 2019).

Compared with other crustaceans, the Australian redclaw crayfish is characterized by a high growth rate, low demands regarding rearing conditions, and relatively low levels of aggression and cannibalism (Huner, 1990; Volpe *et al*., 2015). Two main approaches are used in its cultivation: in ponds, cages, and tanks in the warm waters of energy facilities during the summer, and in recirculating aquaculture systems (RAS) throughout the year. In both cultivation methods, RAS are used during winter to maintain brood stock, conduct spawning, incubation, and rear juveniles (Azhar *et al*., 2020).

The marbled crayfish (*Procambarus fallax forma virginalis*) remains insufficiently studied in many aspects of aquaculture, although it has become an invasive species in natural conditions. The origin of this species is not reliably known. Previously, in the international literature it was referred to as the Cuban crayfish and considered a mutated (triploid) form of *Procambarus fallax* from the family *Cambaridae*, described in 2010. Its main distinction from other crustaceans is the ability to reproduce through parthenogenesis (development of eggs in the adult organism without fertilization) (Vogt *et al*., 2019). The population consists entirely of females, as males are absent. Because this species reproduces rapidly and displaces other crayfish species from natural habitats, it has been recognized as invasive within the European Union (Jackson *et al*., 2019). In natural biogeocenoses, it occurs in water bodies in Germany, Sweden, the Czech Republic, Croatia, the Netherlands, Romania, Slovakia, Hungary, Ukraine, Italy, and

Japan. During the winter period, the female lays several dozen eggs (about 30 in young individuals and up to 300 in adults), which are attached to the pleopods (Ziegera, 2013). Incubation lasts 3–6 weeks. Throughout the incubation period, the female remains in shelter without feeding. During incubation, the eggs change colour (Slusar *et al*., 2023).

Although this species is omnivorous, plant-based food constitutes the main component of its diet. These crayfish are well adapted to life under various conditions and are not demanding regarding water quality. The body length of adult individuals ranges from 5 to 15 cm, and their live weight from 15 to 40 g. The carapace of this crustacean is beige with a dark brown marbled pattern. In water with higher acidity, the coloration often becomes bluish. The lifespan of the marbled crayfish is about two years (Kaldre, 2016).

Crayfish meat has been recognized as an edible product with good taste qualities. It has high nutritional and biological value due to its easy digestibility, efficient utilization of proteins by the human body, and a high content of essential amino acids (El-Sherif *et al*., 2016). In terms of its caloric value, crayfish meat is comparable to fish meat, while its fat content exceeds that of non-predatory fish species (Iwar, 2021).

In general, crayfish meat is distinguished by a high protein content of about 18–20 %, a relatively low fat content (0.14–1.69 %), and a balanced fatty acid composition, being rich in omega-3 fatty acids. Comprehensive literature reviews reveal that only a limited number of scientific studies have addressed this issue (Ben Yahkoub, 2019; Śmietana *et al*., 2021). Therefore, the available literature provides insufficient data fully describing the nutritional and food value of crayfish cultivated in RAS, which is a prerequisite for their introduction as a new product to the consumer market. In addition, when farming crayfish in RAS, it is critically important to assess indicators of their physiological state, particularly hemolymph parameters, which serve as indicators of their health status and enable the early diagnosis of stress and disease development, monitoring of the moulting process, and adjustment of feeding regimes (Rida *et al*., 2021).

In aquaculture, the range of cultivated crustacean species is continuously expanding. However, technologies for their production under artificial conditions are still under development, and research on their physiological, biochemical, and productivity indicators remains a relevant task. In view of the above and considering that in recent years the food industry has increasingly faced the issue of alternative sources of raw materials of animal origin, our study aimed to update research data on the nutritional properties of meat and the biochemical composition of hemolymph in the crayfish *Cherax quadricarinatus*, *Astacus leptodactylus*, and *Procambarus fallax forma virginalis* cultivated in recirculating aquaculture systems.

MATERIALS AND METHODS

The study was conducted at LLC "First Investment Agrarian Company", (Ukraine, Zhytomyr region) which specializes in the cultivation of hydrobionts. The objects of the study were sexually mature individuals of the crayfish *Cherax quadricarinatus, Astacus leptodactylus*, and *Procambarus fallax forma virginalis*. The experimental crayfish were maintained in three tanks with a volume of 0.3 m^3 each. The water temperature was 25 °C, the pH was 7, and the dissolved oxygen content was 7 mg/L. The diet was uniform and consisted of 70 % of plant-based feed (rice, wheat, oak leaves) and 30 % of animal-based feed (Aller feed additive, pellet diameter 3 mm, lean fish meat, and larvae of the buzzer midge *Chironomus plumosus*), provided at a rate of 2.5 % of the total crayfish biomass per day.

To determine slaughter and morphometric parameters, as well as the chemical composition and caloric value of crayfish meat, 10 individuals of each species were selected from the tanks. The specimens were individually weighed, after which the meat was separated from the exoskeleton and other inedible body parts (**Fig. 1**).

Fig. 1. Crayfish meat separation and weighing

For physicochemical analysis of the meat, three composite samples were prepared from all experimental individuals of each crayfish species. The assessment of organoleptic and physicochemical parameters of the meat was carried out at the Zhytomyr Regional State Laboratory of the State Service of Ukraine on Food Safety and Consumer Protection.

Organoleptic evaluation was conducted following the conventional methods specified in DSTU 8451:2015 "Fish and fish products. Methods for determination of organoleptic characteristics". For a more comprehensive assessment of the slaughter qualities of crayfish, physicochemical analyses of the meat were performed according to the following parameters: mass fraction of moisture (%), mass fraction of ash (%), fats (g), proteins (g), carbohydrates (g), and energy value (kcal). The moisture content was determined in accordance with DSTU ISO 1442:2005, ash content according to DSTU 8718:2017, and fat, protein, and carbohydrate contents in accordance with methodological guidelines MB No 1-40/3805.

The biochemical composition of hemolymph was analyzed at the Educational and Scientific Clinical and Diagnostic Laboratory of the Faculty of Veterinary Medicine, Polissia National University. To determine biochemical parameters, hemolymph samples were collected from the pericardial sinus of 10 individuals of each studied species using an insulin syringe, following preliminary dissection of the exoskeleton (**Fig. 2**).

For biochemical analysis, hemolymph samples were collected into sterile Vacutainer-type tubes with a separating gel. To obtain serum, the samples were centrifuged at

4500 rpm for 4 min using a Hermle Z 300 centrifuge. The separated serum (500 μL) was transferred using a single-channel pipette (Sartorius, 100–1000 μL) into sterile disposable Eppendorf microtubes with a volume of 1.5 mL. The serum was analyzed on the day of preparation; therefore, no preservation was applied.

The concentrations of protein fractions, lipids, and macroelements in hemolymph serum were determined using a semi-automatic analyzer Chem-7 (Erba, the Czech Republic) and reagents from DAC (Moldova), by performing biochemical assays in accordance with the manufacturer's standard instructions, without modification. Specifically, total protein was determined by the photometric biuret method; albumin by the photometric method using bromocresol green; globulin content was calculated automatically by the analyzer based on total protein and albumin values; urea by the kinetic photometric method; triglycerides by the enzymatic photometric method; alanine aminotransferase by the kinetic UV method; calcium by the photometric method using cresolphthalein; and potassium by the turbidimetric method without deproteinization using a tetraphenylborate reagent.

Fig. 2. Hemolymph sample collection

The experimental studies were conducted in accordance with modern methodological approaches and in compliance with relevant requirements and standards, including DSTU ISO/IEC 17025:2005 (2006), the Law of Ukraine "On Protection of Animals from Cruel Treatment," the Regulations governing the use of animals in scientific experiments, and ethical standards in accordance with Directive 2010/63/EU of the European Parliament and of the Council of 22 September 2010 on the protection of animals used for scientific purposes. The study was conducted in compliance with bioethical requirements for research involving sexually mature individuals of *Cherax quadricarinatus*, *Astacus lep-*

todactylus, and *Procambarus fallax forma virginalis* cultured in a recirculating aquaculture system (Protocol No. 1 dated October 6, 2025, of the Commission on Bioethical Expertise and Ethics of Scientific Research of the Zhytomyr Ivan Franko State University).

Statistical analysis. The obtained data were processed using methods of variation statistics. For each parameter, the arithmetic mean and the standard error of the mean (M±m) were calculated. The significance of differences between parameters was assessed using Tukey's post-hoc test following one-way analysis of variance (ANOVA); differences were considered statistically significant at $p < 0.05$. Calculations were performed using Microsoft Excel 2021 (Microsoft, USA).

Results and Discussion. In terms of texture and aroma, the meat of Australian red claw crayfish is similar to that of marine crustaceans (lobsters), which allows it to be positioned as a delicacy species. Compared to narrow-clawed crayfish, Australian red claw crayfish exhibits a less intense red coloration after cooking, with a darker pattern. The meat is primarily concentrated in the abdominal part of the body and has a more delicate consistency compared to that of freshwater crayfish. Marbled crayfish is characterized by a denser meat texture, similar to that of the Black Sea shrimp.

The results of the control slaughter demonstrate differences in morphometric and slaughter characteristics among the studied species (**Table 1**).

Table 1. **Morphometric and slaughter parameters (g) of the studied crayfish species: Australian redclaw, marbled, and narrow-clawed, (x ± SE, n = 10)**

Parameter, g	Australian redclaw crayfish		Marbled crayfish		Narrow-clawed crayfish	
	x ± SE	Cv, %	x ± SE	Cv, %	x ± SE	Cv, %
Live weight, g	67.6 ± 2.10	26.0	16.4 ± 0.25***	12.7	27.6 ± 0.55***	16.8
Abdomen weight, g	19.0 ± 0.51	22.5	4.2 ± 0.06***	12.3	5.5 ± 0.07***	10.2
Cephalothorax weight, g	34.4 ± 0.98	23.3	9.4 ± 0.19***	16.7	16.9 ± 0.54***	26.1
Appendage weight, g	14.2 ± 0.78	43.8	2.8 ± 0.08***	23.6	5.2 ± 0.17***	25.9
Meat weight, g	10.2 ± 0.35	26.7	2.0 ± 0.04***	14.7	2.6 ± 0.06***	18.9

Note: statistical significance of differences is indicated according to Tukey's test relative to the Australian redclaw crayfish taken as the reference species: P < 0.05 (*); P < 0.01 (**); P < 0.001 (***)

Thus, the highest live weight was observed in the Australian redclaw crayfish (67.6 g), while the lowest was recorded in the marbled crayfish (16.4 g), with narrow-clawed crayfish occupying an intermediate position (27.6 g). It should be noted that Australian redclaw crayfish are relatively large in terms of their morphological characteristics, reaching a body weight of up to 35 g by the age of 6 months, whereas individuals of the narrow-clawed and marbled species reach only 16 g and 15 g, respectively. Accordingly, the weight of the abdomen (19.0 g), cephalothorax (34.4 g), appendages (14.2 g), and edible meat (10.2 g) in Australian red claw crayfish was significantly higher (P < 0.001) compared to the corresponding values in the other two species: in marbled crayfish by 14.8 g, 25.0 g, 11.4 g, and 8.2 g, and in narrow-clawed crayfish by 13.5 g, 17.5 g, 9.0 g, and 7.6 g, respectively.

The physicochemical parameters of the crayfish meat from the studied species are presented in **Table 2**.

The lowest moisture content was observed in the meat of the marbled crayfish, at 79.4 %, which was significantly lower than in the Australian redclaw cray fish by 1.9 % and in narrow-clawed crayfish by 2.3 % ($P < 0.05$ in both cases). Accordingly, the meat of the marbled crayfish contained the highest level of dry matter and, therefore, the highest ash content (1.02 %); however, their advantage over the other two species in this parameter was not statistically significant (**Table 2**).

Among the key indicators of crayfish meat quality are the contents of fat, protein, and carbohydrates. The highest fat content was recorded in the meat of the Australian red claw crayfish (0.95 %), while slightly lower values (by 0.05 %) were observed in the marbled and narrow-clawed crayfish. In contrast, the highest protein content was found in the marbled crayfish (17.4 %). In this respect, this species significantly exceeded narrow-clawed crayfish by 2.2 % ($P < 0.05$) and non-significantly – the Australian red claw crayfish by 1.8 %.

Table 2. **Physicochemical parameters of meat of crayfish species: Australian redclaw, marbled, and narrow-clawed, (x ± SE, n = 10)**

Parameter, units of measurement	Australian redclaw crayfish		Marbled crayfish		Narrow-clawed crayfish	
	x ± SE	Cv, %	x ± SE	Cv, %	x ± SE	Cv, %
Mass fraction of moisture, %	81.3 ± 0.48	1.1	79.4 ± 0.61*	1.3	81.7 ± 0.61	1.3
Mass fraction of ash, %	0.87 ± 0.111	22.2	1.02 ± 0.121	20.8	0.95 ± 0.113	20.7
Fat, %	0.95 ± 0.024	4.4	0.9 ± 0.03	5.9	0.9 ± 0.35	4.1
Protein, %	15.6 ± 0.92	10.3	17.4 ± 0.84*	8.4	15.2 ± 0.39	11.2
Carbohydrates, %	1.2 ± 0.02	3.8	1.2 ± 0.02	4.0	1.2 ± 0.02	4.0
Energy value (caloric content) per kcal/100 g	76.1 ± 3.12	7.1	74.8 ± 3.69	8.6	73.9 ± 3.52	8.3

Note: statistical significance of differences is indicated according to Tukey's test relative to the Australian redclaw crayfish taken as the reference species: $P < 0.05$ (*); $P < 0.01$ (**); $P < 0.001$ (***)

No differences were observed in carbohydrate content among the studied species, with this parameter being 1.2 % in all cases. The highest energy value was characteristic of the Australian red claw crayfish meat (76.1 kcal), whereas in the marbled crayfish it was 74.8 kcal and 73.9 kcal in the narrow-clawed crayfish.

The biochemical composition of hemolymph reflects the intensity of metabolic processes and the physiological state of hydrobionts; however, it remains insufficiently studied. Therefore, a series of investigations was conducted to establish reference values for a range of biochemical parameters of hemolymph in the three studied crustacean species (**Table 3**).

The total protein content in hemolymph is one of the most important indicators characterizing the physiological condition of an organism. The study results showed that the highest total protein content was observed in the Australian red claw crayfish (77.1 g/L), exceeding that of the marbled crayfish by 25.81 % and the narrow-clawed crayfish by 15.82 %. In terms of albumin content, Australian redclaw crayfish significantly exceeded marbled crayfish by 11.9 g/L and narrow-clawed crayfish by 9.3 g/L. No significant differences were observed regarding globulin content; however, the highest level was recorded in the Australian redclaw crayfish (35.1 g/L), while the lowest was in the marbled crayfish (27.1 g/L), with the narrow-clawed crayfish showing an intermediate value (32.2 g/L). The intensity of protein metabolism, particularly protein degradation, is indicated by urea concentration, which is the end product of protein catabolism. The highest urea level was found in the narrow-clawed crayfish (17.27 mmol/L), followed by the Australian red claw crayfish (12.41 mmol/L), while the lowest value was observed in the marbled crayfish (11.92 mmol/L).

The functional state of the hepatopancreas is reflected by the activity of alanine aminotransferase. In hemolymph serum, the highest activity of this enzyme was recorded in the Australian red claw crayfish (67.0 U/L), which was lower by 14.1 U/L in the narrow-clawed crayfish and by 19.6 U/L in the marbled crayfish. According to the data presented in **Table 3**, the highest triglyceride level was observed in the marbled crayfish (111.2 mmol/L), followed by the narrow-clawed crayfish (81.9 mmol/L), while the lowest value was recorded in the Australian redclaw crayfish (79.4 mmol/L).

Table 3. **Biochemical parameters of hemolymph of crayfish species: Australian redclaw, marbled*,* and narrow-clawed, (x ± SE, n = 10)**

Parameter	Australian redclaw crayfish		Marbled crayfish		Narrow-clawed crayfish	
	x ± SE	Cv, %	X ± SE	Cv, %	X ± SE	Cv, %
Total protein (g/L)	77.1 ± 2.87	6.5	57.2 ± 2.41***	7.3	64.9 ± 2.90*	7.7
Albumins (g/L)	42.0 ± 2.70	11.2	30.1 ± 2.42**	14.0	32.7 ± 2.22**	11.8
Globulins (g/L)	35.1 ± 0.40	2.0	27.1±0.17***	1,1	32.2 ± 0.26***	1.4
Urea (mmol/L)	12.41 ± 2.228	3.2	11.92 ± 0.217	3.2	17.27 ± 0.232***	2.3
Triglycerides (mmol/L)	79.4 ± 2.86	6.3	111.2 ± 2.17***	3.4	81.9 ± 2.19	4.7
Na (mmol/L)	203 ± 3.4	2.9	209 ± 3.6	3.0	211 ± 3.3	2.7
K (mmol/L)	6.52 ± 0.229	6.1	9.51 ± 0.210***	3.8	7.44 ± 0.219*	5.1
Ca (mmol/L)	7.99 ± 0.215	4.7	7.42 ± 0.292	6.8	9.52 ± 0.212***	3.9
Cl (mmol/L)	144 ± 12.2	14.7	197 ± 11.6**	10.2	182 ± 12.6*	12.0
ALT (U/L)	67.0 ± 1,9	5.1	47.4 ± 1,14***	4.2	52.9 ± 1,95*	6.4

Note: statistical significance of differences is indicated according to Tukey's test relative to the Australian redclaw crayfish taken as the reference species: P < 0.05 (*); P < 0.01 (**); P < 0.001 (***)

The calcium content in the hemolymph serum did not differ significantly among the studied species and ranged from 7.42 to 9.52 mmol/L, while the potassium concentration showed a wider range, from 6.52 mmol/L in the Australian red claw crayfish to 9.51 mmol/L in the marbled crayfish (**Table 3**). The concentrations of sodium and chloride in hemolymph were the lowest in the Australian red claw crayfish, amounting to 203 mmol/L and 144 mmol/L, respectively. In the narrow-clawed crayfish , the sodium level was 211 mmol/L, whereas the lowest sodium concentration (209 mmol/L) was observed in marbled crayfish. In contrast, the lowest chloride content was recorded in the narrow-clawed crayfish (182 mmol/L), while in the marbled crayfish it was at an intermediate level (182 mmol/L).

The study of meat yield and nutritional value in crayfish is important in the context of growing demand for alternative protein sources, as this indicator directly affects production profitability. In addition, the physicochemical properties of the meat justify its use in human nutrition and the development of balanced feeds for aquatic organisms. Although the chemical composition and nutritional value of crustaceans depend on species diversity, rearing conditions and diet (Romano & Sinha, 2020), our results demonstrate that the Australian red-clawed crayfish exhibits the highest potential among the studied species. Indeed, the meat yield of the Australian red clawed crayfish (15.16 %) significantly exceeded that of the marbled crayfish (12.6 %) and the native narrow-clawed crayfish (9.4 %). The observed pattern of a higher proportion of meat in the abdomen (77.1 %) and claws (19.9 %) in the Australian red claw crayfish not only confirms its high meat yield compared to other species but also correlates with its rapid growth under controlled conditions in recirculating aquaculture systems. Thus, from a practical standpoint, it is the aquaculture of the Australian red claw crayfish that ensures the highest level of profitability and produces raw material with optimal physicochemical properties.

According to studies by J. Lazarević *et al*. (2022) conducted on spiny-cheek crayfish (*Faxonius limosus*), their meat has high nutritional value, with protein content around 18 %, and the predominant minerals include potassium, sodium, calcium, phosphorus, and magnesium (Lazarević *et al*., 2022). According to N. F. Zaglol *et al*. (2009) and M. Harlıoğlu *et al*. (2012), the energy value of crayfish meat is approximately 76 kcal (Zaglol *et al*., 2009; Harlioğlu *et al*., 2012). Other studies (Stanek *et al*., 2011; Iwar *et al*., 2021) have shown that crayfish meat is a source of essential minerals such as potassium, calcium, sodium, copper, zinc, magnesium, and iron.

At the same time, E. Fedorovych *et al*. (2022) report that crayfish meat exhibits the highest nutritional value and best sensory qualities during the inter-moult period (anecdysis). During this period, the content of proteins, fats, and carbohydrates is significantly higher than during the moulting phases (proecdysis, ecdysis, and metecdysis) (Fedorovych *et al*., 2022). A number of studies also show that the protein content in a crayfish organism, including crude protein, increases from 20.70 % to 41.12 % with an increase in dietary protein, and begins to decline when the protein content in the diet reaches 44.64 % (Lu *et al*., 2020).

The crustacean circulatory system is of the open type. The circulating fluid, hemolymph, which moves through vessels and intercellular spaces, accounts for approximately 26.5 % of total body volume and consists of plasma and hemocytes. Plasma primarily performs a transport function, carrying nutrients, hormones, and toxic substances. Hemocytes play an important protective role, including the phagocytosis of pathogens and activation of coagulation mechanisms, thereby preventing hemolymph loss following tissue damage. Hemocyanin is the dominant protein in hemolymph, accounting for over 90% of the total protein fraction and functioning as the primary oxygen carrier. The remaining protein fraction comprises clotting proteins and immune-related components. In particular, hemolymph is rich in complex glycoproteins, as well as catalytic and regulatory proteins involved in respiratory, regulatory, hemostatic, protective, and excretory functions. During the moulting period, these components additionally contribute to the strengthening of the exoskeleton (Soares *et al*., 2022). R. Anbuchezhian *et al*. (2009) and S. Schainost (2016) maintain that the level of total protein in hemolymph can be used to assess the physiological condition of crustaceans and to obtain reliable data on the status of their immune system (Anbuchezhian *et al*., 2009; Schainost, 2016).

Previous studies by M. Soares *et al*. (2022) examined glucose levels in the hemolymph of crayfish maintained under both field and laboratory conditions, identifying this parameter as a reliable indicator of stress in *Procambarus clarkii* (Soares *et al*., 2022). Studies on the East European narrow-clawed crayfish (*Astacus leptodactylus Eschscholtz*), reared under natural conditions, reported the following average values of hemolymph biochemical parameters: glucose – 4.8 mg/dL; calcium – 38.07 mg/dL; potassium – 4.795 mEq/L; sodium – 190.3 mEq/L; and total protein – 2.578 g/dL (Sepici-Dinçel *et al*., 2013).

CONCLUSION

Crayfish of the species *Cherax quadricarinatus, Astacus leptodactylus,* and *Procambarus fallax forma virginalis* differed in slaughter characteristics, chemical composition, and caloric value. Among the studied species, Australian redclaw crayfish (*Cherax quadricarinatus*) were the most massive, and their meat exhibited the highest energy value. In terms of protein content, marbled crayfish (*Procambarus fallax forma virginalis*) showed the highest values. No significant differences were observed in fat and carbohydrate content; however, the highest moisture content was recorded in narrow-clawed crayfish (*Astacus leptodactylus*), whereas the highest ash content was found in marbled crayfish (*Procambarus fallax* forma *virginalis*).

Regarding hemolymph biochemical parameters, *Cherax quadricarinatus* exhibited the highest levels of total protein (77.1 g/L), albumin (42.0 g/L), globulins (35.1 g/L), and alanine aminotransferase activity (67.0 U/L). Higher levels of urea (17.27 mmol/L), sodium (211 mmol/L), and calcium (9.52 mmol/L) were observed in narrow-clawed crayfish. In contrast, marbled crayfish were characterized by higher levels of triglycerides (111.2 mmol/L), potassium (9.51 mmol/L), and chloride (197 mmol/L). The obtained results provide essential reference values for the studied crayfish species under aquaculture conditions.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest: the authors declare that research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Animal studies: All international, national and institutional guidelines for the care and use of laboratory animals were followed.

AUTHOR CONTRIBUTIONS

Conceptualization, [F.E.; S.M.; M.A.]; methodology, [F.E.; M.A.; S.M.; K.I.]; validation, [M.V.; S.M.; I.O.]; formal analysis, [S.M.; M.A].; investigation, [S.M.; M.V.; K.I.]; resources, [M.A.; S.M.; I.O.]; data curation, [M.V.]; writing – original draft preparation, [K.I.; M.A.; F.E.]; writing – review and editing, [K.I.]; visualization, [S.M.; I.O.] supervision, [S.M.; K.I.]; project administration, [K.I.; S.M.]; funding acquisition, [S.M.; M.A.; K.I.; F.E.; M.V.; S.M.; I.O.].

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REFERENCES

Anbuchezhian, R. M., Ravichandran, S., Rameshkumar, G., & Ajithkumar, T. T. (2009). Influence of crab haemolymph on clinical pathogens. *Advances in Biological Research*, 3(3-4), 104–109.
Google Scholar

Azhar, M. H., Suciyono, S., Budi, D. S., Ulkhaq, M. F., Anugrahwati, M., & Ekasari, J. (2020). Biofloc-based co-culture systems of Nile tilapia (*Oreochromis niloticus*) and redclaw crayfish (*Cherax quadricarinatus*) with different carbon–nitrogen ratios. *Aquaculture International*, 28(3), 1293–1304. doi:10.1007/s10499-020-00526-z
Crossref ● Google Scholar

Ben Yahkoub, Y., Fekhaoui, M., El Qoraychy, I., & Yahyaoui, A. (2019). Current state of knowledge on Louisiana crawfish (*Procambarus clarkii* Girard, 1852) in Morocco. *Aquaculture, Aquarium, Conservation & Legislation*, 12(2), 618–628. https://bioflux.com.ro/docs/2019.618-628.pdf
Google Scholar

Crandall, K. A., & Buhay, J. E. (2007). Global diversity of crayfish (Astacidae, Cambaridae, and Parastacidae – Decapoda) in freshwater. In E. V. Balian, C. Lévêque, H. Segers, & K. Martens (Eds.), *Freshwater animal diversity assessment* (Developments in Hydrobiology, Vol. 198, pp. 295–301). Springer. doi:10.1007/978-1-4020-8259-7_32
Crossref ● Google Scholar

Dammannagoda, L. K., Pavasovic, A., Hurwood, D. A., & Mather, P. B. (2013). Effects of soluble dietary cellulose on specific growth rate, survival and digestive enzyme activities in three freshwater crayfish (*Cherax*) species. *Aquaculture Research*, 46(3), 626–636. doi:10.1111/are.12209
Crossref ● Google Scholar

El-Sherif, S. A. & Abd El-Ghafour, S. (2016). Investigation of the quality properties and nutritional values of four fish species from Lake Qaroun, Egypt. *International Journal of ChemTech Research,* 9(4), 16–26.
Google Scholar

Fedorovych, E. I., Muzhenko, A. V., Slusar, N. V., & Kovalchuk, I. I. (2022). Characteristics of the moulting process of different crayfish species. *Taurian Scientific Herald*, (126), 230–237. doi:10.32851/2226-0099.2022.126.32 (In Ukrainian)
Crossref ● Google Scholar

Food and Agriculture Organization of the United Nations (FAO). (2024). *World food and agriculture – Statistical yearbook 2024*. doi.org/10.4060/cd2971en
Crossref ● Google Scholar

Harlioğlu, M. M., Köprücü, K., Harlioğlu, A. G., Yilmaz, Ö., Aydin, S., Mişe Yonar, S., Çakmak Duran, T., & Özcan, S. (2012). The effects of dietary n-3 series fatty acid on the fatty acid composition, cholesterol and fat-soluble vitamins of pleopodal eggs and stage 1 juveniles in a freshwater crayfish, *Astacus leptodactylus* (Eschscholtz). *Aquaculture*, 356-357, 310–316. doi:10.1016/j.aquaculture.2012.05.001
Crossref ● Google Scholar

Holthuis, L. B. (1986). The freshwater crayfish of New Guinea. *Freshwater Crayfish*, 6(1), 48–56.
Google Scholar

Hrynevych, N. E., Zharchynska, V. S., Svitelskyi, M. M., Khomiak, O. A., & Sliusarenko, A. O. (2022). Promising object of aquaculture of crustaceans *Cherax quadricarinatus* (von Martens, 1868): biology, technology (review). *Water Bioresources and Aquaculture,* 1, 47–62. doi:10.32851/wba.2022.1.4 (In Ukrainian)
Crossref ● Google Scholar

Huner, V., & Romaire, R. (1990). Crawfish culture in the Southeastern USA. *World Aquaculture*, 21(4), 58–65.
Google Scholar

Iwar, M., & Amu, C. M. (2021). Nutrient and anti-nutrient composition of processed crayfish (*Atya gabonensis)* from river Benue, Nigeria. *Sustainability, Agri, Food and Environmental Research*, 9(1), 205–215. doi:10.7770/safer-v9n2-art2257
Crossref ● Google Scholar

Jackson, C., & van Staaden, M. (2019). Characterization of locomotor response to psychostimulants in the parthenogenetic marbled crayfish (*Procambarus fallax* forma *virginalis*): a promising model for studying the neural and molecular mechanisms of drug addiction. *Behavioural Brain Research*, 361, 131–138. doi:10.1016/j.bbr.2018.12.024
Crossref ● PubMed ● Google Scholar

Kaldre, K., Meženin, A., Paaver, T., & Kawai, T. (2015). A preliminary study on the tolerance of marble crayfish *Procambarus fallax* f. *virginalis* to low temperature in nordic climate. In T. Kawai, Z. Faulkes, & G. Scholtz (Eds.), *Freshwater crayfish. A global overview* (pp. 54–62). CRC Press. doi:10.1201/b18723-6
Crossref ● Google Scholar

Lawrence, C., & Jones, C. (2002). Cherax. In D. M. Holdich (Ed.), *Biology of freshwater crayfish* (pp. 635–669). Blackwell Science.
Google Scholar

Lazarević, J., Čabarkapa, I., Rakita, S., Banjac, M., Tomičić, Z., Škrobot, D., Radivojević, G., Kalenjuk Pivarski, B., & Tešanović, D. (2022). Invasive crayfish *Faxonius limosus*: meat safety, nutritional quality and sensory profile. *International Journal of Environmental Research and Public Health*, 19(24), 16819. doi:10.3390/ijerph192416819
Crossref ● PubMed ● PMC ● Google Scholar

Lu, X., Peng, D., Chen, X., Wu, F., Jiang, M., Tian, J., Liu, W., Yu, L., Wen, H., & Wei, K. (2020). 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*, 18, 100542. doi:10.1016/j.aqrep.2020.100542
Crossref ● Google Scholar

Rida, R., Zein-Eddine, R., Kreydiyyeh, S., Garza de Yta, A., & Saoud, I. P. (2020). Influence of salinity on survival, growth, hemolymph osmolality, gill sodium potassium ATPase activity, and sodium potassium chloride co-transporter expression in the redclaw crayfish *Cherax quadricarinatus. Journal of the World Aquaculture Society*, 52(2), 466–474. doi:10.1111/jwas.12762
Crossref ● Google Scholar

Romano, N., & Sinha, A. K. (2020). Husbandry of aquatic animals in closed aquaculture systems. In F. S. B. Kibenge & M. D. Powell (Eds.), *Aquaculture health management: design and operation approaches* (pp. 17–73). Academic Press. doi:10.1016/b978-0-12-813359-0.00002-6
Crossref ● Google Scholar

Schainost, S. C. (2016). *The crayfish of Nebraska*. Nebraska Game and Parks Commission. https://digitalcommons.unl.edu/nebgamewhitepap/69
Google Scholar

Sepici-Dinçel, A., Alparslan, Z. N., Benli, A. Ç. K., Selvi, M., Sarıkaya, R., Özkul, İ. A., & Erkoç, F. (2013). Hemolymph biochemical parameters reference intervals and total hemocyte counts of narrow clawed crayfish *Astacus leptodactylus* (Eschscholtz, 1823). *Ecological Indicators*, 24, 305–309. doi:10.1016/j.ecolind.2012.07.002
Crossref • Google Scholar

Sharylo, Yu. Ye., Vdovenko, N. M., Gherasymchuk, V. V., Poplavska, O. S., Fedorenko, M. O., Makhyboroda, K. V., Neboha, H. I., Dmytryshyn, R. A., Misar, M. O., Mykhalchychyna, L. H., Sinenok, I. O., Dombrovska, T. O., Yefimenko, O. A., & Shepeliev, S. S. (2020). *Zbirnyk tekhnolohii vyrobnytstva riznykh vydiv ryb z vykorystanniam instrumentiv vplyvu na popyt ta propozytsiiu ryby, inshykh vodnykh zhyvykh resursiv dlia zabezpechennia konkurentnykh perevah rybnoho hospodarstva* [Collection of technologies for the production of various fish species using tools to influence the demand and supply of fish and other aquatic living resources to ensure competitive advantages in the fisheries sector]. NUBiP. https://dglib.nubip.edu.ua/items/4d2d3583-8db1-4d22-8f93-dde67ed20a90 (In Ukrainian)
Google Scholar

Slusar, M., Muzhenko, A., Kovalchuk, I., Borshchenko, V., & Verbelchuk, T. (2023). Study of the embryonic period of female crayfish egg development in different species. *Scientific Horizons*, 26(12), 22–31. doi:10.48077/scihor12.2023.22
Crossref • Google Scholar

Śmietana, N., Panicz, R., Sobczak, M., Śmietana, P., & Nędzarek, A. (2020). Spiny-cheek crayfish, *Faxonius limosus* (Rafinesque, 1817), as an alternative food source. *Animals*, 11(1), 59. doi:10.3390/ani11010059
Crossref • PubMed • PMC • Google Scholar

Soares, M. C., Banha, F., Cardoso, S., Gama, M., Xavier, R., Ribeiro, L., & Anastácio, P. (2022). Haemolymph glycaemia as an environmental stress biomarker in the invasive red swamp crayfish (*Procambarus clarkii*). *Physiological and Biochemical Zoology*, 95(3), 265–277. doi:10.1086/719857
Crossref • PubMed • Google Scholar

Stanek, M., Borejszo, Z., Dąbrowski, J., & Janicki, B. (2011). Fat and cholesterol content and fatty acid profiles in edible tissues of spiny-cheek crayfish, *Orconectes limosus* (Raf.) from Lake Gopło (Poland). *Archives of Polish Fisheries*, 19(4), 241–248. doi:10.2478/v10086-011-0030-7
Crossref • Google Scholar

Vogt, G., Dorn, N. J., Pfeiffer, M., Lukhaup, C., Williams, B. W., Schulz, R., & Schrimpf, A. (2019). The dimension of biological change caused by autotriploidy: a meta-analysis with triploid crayfish *Procambarus virginalis* and its diploid parent *Procambarus fallax*. *Zoologischer Anzeiger*, 281, 53–67. doi:10.1016/j.jcz.2019.06.006
Crossref • Google Scholar

Volpe, M. G., Santagata, G., Coccia, E., Di Stasio, M., Malinconico, M., & Paolucci, M. (2014). Pectin-based pellets for crayfish aquaculture: structural and functional characteristics and effects on redclaw *Cherax quadricarinatus* performances. *Aquaculture Nutrition*, 21(6), 814–823. doi:10.1111/anu.12204
Crossref • Google Scholar

Zaglol, N. F., & Eltadawy, F. (2009). Study on chemical quality and nutrition value of fresh water cray fish (*Procambarus clarkii*). *Journal of the Arabian Aquaculture Society*, 4(1), 1–18. http://arabaqs.org/journal/vol_4/1/Text%2009%20-%2001.pdf
Google Scholar

ПОРІВНЯЛЬНА ХАРАКТЕРИСТИКА ФІЗИКО-ХІМІЧНИХ ПОКАЗНИКІВ М'ЯСА ТА БІОХІМІЧНОГО СКЛАДУ ГЕМОЛІМФИ РАКІВ РІЗНИХ ВИДІВ

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Обґрунтування. Розведення раків є перспективним напрямом розвитку аквакультури. Порівняно з морськими видами ракоподібних, прісноводні раки потребують менших витрат на вирощування, а їхнє м'ясо вважається корисним делікатесом із високою харчовою цінністю. Мета цього дослідження – порівняти морфологічні та фізіологічні дані (вихід м'яса, смакові якості, фізико-хімічний склад м'яса, біохімічні показники гемолімфи) трьох видів статевозрілих раків, а саме: австралійського червоноклешневого рака (*Cherax quadricarinatus*), довгопалого рака (*Astacus leptodactylus*), мармурового рака (*Procambarus fallax forma virginalis*), яких вирощували в рециркуляційній системі водопостачання.

Матеріали та методи. У роботі використано органолептичні та фізико-хімічні методи досліджень м'яса і біохімічні методи дослідження показників гемолімфи.

Результати. Результати показують, що маса їстівної частини від живої маси раків у відсотковому співвідношенні становила 15,16 ± 0,20 % для червоноклешневого, 12,16 ± 0,21 % для мармурового та 9,40 ± 0,19 % для довгопалого рака відповідно. Найвищий вміст білка був у м'ясі особин мармурового виду (17.4 ± 0,84 %). Найвищим вмістом жиру в м'ясі характеризувалися особини австралійського червоноклешневого виду (0.95 ± 0,024 %), для мармурового рака цей показник був на рівні 0,9 ± 0,03 %, а для довгопалого рака – 0,9 ± 0,35 %. За вмістом вуглеводів у м'ясі раків досліджуваних видів різниці не спостерігали, цей показник був на рівні 1,2 ± 0,02 %. Найкалорійнішим було м'ясо австралійського червоноклешневого виду (76,1 ± 3,12 ккал/100 г), що перевищувало показники інших досліджуваних видів у межах 1,3–2.2 ккал/100 г, зокрема, м'ясо мармурового рака – 74,8 ± 3,69 ккал/100 г, м'ясо довгопалого рака – 73,9 ± 3,52 ккал/100 г відповідно. За показниками білка в гемолімфі переважав австралійський червоноклешневий рак (77,1 ± 2,87 г/л), для довгопалого рака це значення становило 64,9 ± 2,90 г/л, а для мармурового рака – 57,2 ± 2,41 г/л. Найвищу концентрацію кальцію в гемолімфі зафіксовано у річкового довгопалого рака (9,52 ± 0,212 ммоль/л), майже на одному рівні цей показник був у австралійського червоноклешневого рака (7,99 ± 0,215 ммоль/л) та мармурового рака (7,42 ± 0,292 ммоль/л). Різницю вважали статистично значущою за $p \le 0{,}05$.

Висновки. Дані досліджень австралійського червоноклешневого, довгопалого та мармурового раків дають змогу оцінити їхню продуктивність, харчову цінність м'яса і визначити референтні діапазони досліджених показників, які можна

використати для оптимізації технологій аквакультури та виробництва високоякісних делікатесних або супутніх харчових продуктів.

Ключові слова: вирощування раків, австралійський червоноклешневий рак (*Cherax quadricarinatus*), довгопалий рак (*Astacus leptodactylus*), мармуровий рак (*Procambarus fallax* forma *virginalis*), вихід м'яса, м'ясна продуктивність, гемолімфа, референтні значення

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