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GROWTH, MORPHOMETRIC AND HEMATOBIOCHEMICAL PARAMETERS OF AFRICAN CATFISH (*Clarias gariepinus*) AT DIFFERENT ARGININE-TO-LYSINE RATIOS IN COMPOUND FEEDS

SUMMARY

The aim of this study was to determine the effect of different arginine-to-lysine (Arg:Lys) ratios in compound feeds on the growth, morphometric parameters and hematobiochemical status of African catfish (*Clarias gariepinus*) under commercial recirculating aquaculture system (RAS) conditions. The study was carried out as a production-scale (on-farm) trial lasting 84 days and comprising two consecutive rearing periods, during which fish grew from an initial body weight of about 183 g to marketable size. Three groups were formed by the principle of analogues and fed isonitrogenous and isoenergetic extruded compound feeds formulated to provide analysed Arg:Lys ratios of 66% (first, control group), 100% (second group) and 134% (third group); crystalline L-arginine (98.5%) was added at 0, 1.441 and 2.846% of the diet and compensated by a stepwise reduction of blood meal and an increase of wheat grain, so that crude protein, gross energy and the remaining analysed nutrients remained practically identical. Each dietary treatment was represented by a single tank, so that the results are descriptive and hypothesis-generating rather than confirmatory. Among the three ratios tested, 100% was the most favourable: on day 84 the mean body weight of the second group was 4.9% higher than that of the control, the absolute weight gain was 10.9% higher, and the fillet yield of females exceeded the control by 17.6% in absolute terms and by 3.8 percentage points in relative terms. The narrowest ratio (66% of lysine) was associated with the lowest growth and the lowest yield of edible carcass parts, whereas the widest ratio (134%) provided no growth advantage over the control and was accompanied by the highest blood creatinine content. Hemoglobin concentration

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and erythrocyte count increased numerically with increasing arginine level, but these differences did not exceed the variation among individual fish. These observations indicate that an Arg:Lys ratio of about 100% may be a promising formulation target for African catfish, and require confirmation in a replicated trial covering a wider range of ratios.

Keywords: feeding, African catfish, arginine, lysine, arginine-to-lysine ratio, growth, fillet yield, blood parameters, recirculating aquaculture system

INTRODUCTION

African (sharp-tooth) catfish (*Clarias gariepinus*) is one of the most promising species of freshwater aquaculture owing to its high growth rate, resistance to unfavorable environmental conditions, ability to breathe atmospheric air, and tolerance of high stocking densities, which makes it particularly suitable for rearing in recirculating aquaculture systems (RAS). Intensification of the production of this species imposes increased requirements on the nutritional completeness of compound feeds, primarily on their amino acid composition, since the balance of essential amino acids largely determines the realization of the genetic growth potential, feed utilization efficiency, and product quality.

Among the essential amino acids, lysine and arginine occupy a special place. Lysine is traditionally used as the reference amino acid in the ideal protein concept, since it is one of the first limiting amino acids in plant-based diets and plays a key role in the synthesis of muscle proteins and in the formation of meat productivity of animals (Feng *et al.*, 2021; Dou *et al.*, 2023; Ilchuk *et al.*, 2026). Arginine is an essential amino acid for fish, which have a limited ability for its endogenous synthesis due to an incomplete ornithine cycle; this amino acid participates in protein synthesis via the TOR signaling pathway, regulates energy metabolism, is a precursor of nitric oxide, polyamines and creatine, and also performs immunomodulatory and antioxidant functions (Wang *et al.*, 2021; Salamanca *et al.*, 2025). It should be emphasised at the outset that the absolute dietary requirement for arginine, the absolute dietary requirement for lysine, and the balance (ratio) between the two are related but conceptually distinct nutritional questions. The first two define the minimum dietary inclusion at which growth ceases to be limited by the respective amino acid and are conventionally established in dose–response trials with graded levels of a single amino acid. The third describes the extent to which these two amino acids interfere with each other once both are supplied at nominally adequate levels, and it cannot be derived from the two requirement values taken separately. The present study addresses the third of these questions.

The use of the arginine-to-lysine ratio rather than of two absolute levels is biologically and nutritionally justified. Arginine and lysine are both dibasic (cationic) amino acids that share the same γ^+ transport systems in the intestinal brush border and in the renal tubule, so that an excess of one competitively suppresses the absorption and reabsorption of the other; in addition, lysine modifies arginine catabolism through its effect on hepatic and renal arginase

activity. This mutual interference is known as the arginine–lysine antagonism. In practical terms it means that a diet may satisfy the tabulated absolute requirements for both amino acids and still support suboptimal growth if the balance between them is unfavourable – a situation created routinely by the supplementation of plant-based aquafeeds with crystalline L-lysine without a corresponding correction of arginine. Formulating to a ratio therefore captures an aspect of amino acid nutrition that formulating to two independent minima does not.

The arginine and lysine requirements of fish have been studied for a number of species, including Nile tilapia (Furuya *et al.*, 2012; Furuya *et al.*, 2023), dorado *Salminus brasiliensis* (Dairiki *et al.*, 2013), yellow catfish *Pelteobagrus fulvidraco* (Chen *et al.*, 2016; Cao *et al.*, 2024), gibel carp (Li *et al.*, 2024) and swamp eel (Huo *et al.*, 2023). Across these species, both a deficiency and an excess of these amino acids have been reported to depress weight gain and to impair feed conversion. Dietary arginine has additionally been reported to modify body and carcass composition, digestive enzyme activity, serum biochemical indices, haematological parameters, and antioxidant and immune responses (Chen *et al.*, 2016; Huo *et al.*, 2023; Li *et al.*, 2024; Cao *et al.*, 2024), and an optimal arginine level has been shown to increase flesh percentage, muscle protein content and muscle firmness in Pacific white shrimp (Li *et al.*, 2022). Conversely, supra-optimal arginine has been associated with altered plasma and liver metabolomic profiles without any additional growth benefit (Andersen *et al.*, 2016). Studies that address the arginine-to-lysine ratio as such, rather than the two requirements separately, remain far less numerous: in Nile tilapia the lysine requirement has been determined against a background of diets balanced at an Arg:Lys ratio of about 1.3:1 (Furuya *et al.*, 2012), and in fast-growing broiler chickens graded Arg:Lys ratios have been shown to affect productivity, meat quality and the metabolomic profile of plasma and muscle at an unchanged crude protein level (Zampiga *et al.*, 2018).

For African catfish specifically, the available information is considerably more limited. Published recommendations for *C. gariepinus* concern mainly the overall levels of crude protein and digestible energy and the protein-to-energy ratio, while the amino acid data available refer predominantly to early life stages and to absolute requirement values rather than to amino acid balance (Langi *et al.*, 2024). What remains insufficiently studied is therefore not African catfish nutrition in general, which has been reviewed in detail, but the Arg:Lys balance in this species during the on-growing phase from about 180 g to marketable weight under RAS conditions – the production stage that accounts for the largest share of total feed intake and hence of feed cost. It is in this specific sense that we state below that data on the optimal arginine-to-lysine ratio for African catfish are practically absent.

These two amino acids therefore have to be considered jointly rather than independently. A change in their balance affects productivity, meat quality and the metabolomic profile of plasma and muscles even at an unchanged level of

crude protein (Zampiga *et al.*, 2018). Previously, we established the effect of different levels and ratios of arginine and lysine on the productivity and slaughter traits of broiler chickens (Sychoy *et al.*, 2022; Zasukha *et al.*, 2022), as well as on the growth of rainbow trout fingerlings (Kondratiuk *et al.*, 2023), which confirms the relevance of optimizing this ratio for both poultry and fish.

Given the growing interest in the use of alternative protein sources, in particular high-protein sunflower concentrate instead of soybean meal (Shkarban and Sychoy, 2025; Sychoy *et al.*, 2025), the precise balancing of the amino acid profile of feeds is becoming increasingly important for the sustainable development of aquaculture. Despite considerable progress in the study of amino acid nutrition of fish, data on the optimal arginine-to-lysine ratio for African catfish reared to marketable weight under RAS conditions are practically absent.

In this regard, the aim of this study was to determine the effect of different arginine-to-lysine ratios (66, 100 and 134%) in isonitrogenous and isoenergetic compound feeds on the growth, morphometric parameters (body composition and fillet yield) and hematobiochemical status of African catfish (*Clarias gariepinus*) during the rearing period from about 180 g to marketable weight under commercial RAS conditions.

We tested the hypothesis that, at a constant level of crude protein, gross energy and lysine, an arginine-to-lysine ratio close to 100% would support a higher growth rate and a higher fillet yield than a narrower ratio, whereas widening the ratio beyond 100% would yield no further improvement in growth and would raise indicators of arginine catabolism. The three ratios were selected to represent parity between the two amino acids (100%) and an approximately symmetrical relative arginine deficiency and excess around it (−34 and +34%, i.e. 66 and 134%); the narrowest ratio corresponds to a diet supplemented with crystalline L-lysine but not with L-arginine, which is the common commercial situation, while the widest ratio was chosen to test whether the growth response continues beyond parity.

MATERIAL AND METHODS

The study of the effect of different arginine levels in compound feeds for African catfish (*Clarias gariepinus*) was carried out in 2026 at Aquafarm LLC (Vasylkiv, Kyiv region, Ukraine) as a production-scale (on-farm) trial under commercial recirculating aquaculture system (RAS) conditions.

The studied factor was the arginine-to-lysine ratio in the compound feed, which according to the analysed amino acid composition of the feeds (Table 3) was 0.66 (first, control group), 1.00 (second group) and 1.34 (third group). The trial lasted 84 days and consisted of two consecutive rearing periods, from an initial body weight of about 183 g to marketable weight: the first period (days 0–56) and the second period (days 57–84). The experimental design is presented in Table 1.

Table 1. Experimental design

Parameter	Group		
	1 control	experimental	
		2	3
Arginine content in the feed relative to lysine, %	66	100	134
Number of fish in the trial, ind.:			
first period of the trial (days 0–56)	1150	1150	1150
second period of the trial (days 57–84)	650	650	650

Notes: 1150 fish per tank were kept in the first period and 650 fish per tank in the second period.

In the first period of the trial, 1150 fish with an initial body weight of 182.83–183.39 g were allocated to each group by the principle of analogues. Each group was held in one circular tank with a working volume of 3 m³, i.e. one tank per dietary treatment and three tanks in total; the tank was thus the experimental unit of the study and the number of independent experimental units per treatment was one. The stocking density at the beginning of the period was 70.09–70.30 kg/m³, and at the end (day 56) 247.56–260.21 kg/m³. Fish survival during the first period was 96.52–97.74%. The three tanks were structurally identical, were positioned adjacent to one another and were served by the same water treatment loop. They were assigned to the dietary treatments at random, by drawing lots.

At the end of the first period the fish of each tank were graded by size, and 650 fish per group were retained for the second period in order to bring the stocking density to a level compatible with the final rearing phase. Grading was carried out within each tank separately, using the same target weight range for all three groups, so that the initial body weight of the retained fish was equalised between the groups (683.54–687.27 g). As a consequence of grading, the mean body weight of the retained subsample was 3.3% above the corresponding day-56 tank mean in the control group and 0.9–1.0% below the tank mean in the second and third groups, while the standard deviation of body weight was reduced approximately twofold relative to the ungraded populations. The retained fish were kept in the same tanks as during the first period; fish were neither transferred between tanks nor mixed between groups at any point of the trial. The stocking density at the beginning of the second period was 148.10–148.91 kg/m³, and at the end (day 84) 246.99–262.34 kg/m³. Fish survival during the second period was 96.46–98.92%. Because of this grading step, the two rearing periods should be regarded as two consecutive, partly independent observation periods rather than as a single continuous 84-day growth trajectory of one unselected population; the growth data of the two periods are therefore presented and interpreted separately.

The experimental fish were reared in a recirculating aquaculture system (RAS) consisting of three circular tanks 2.5 m in diameter and 0.75 m in height (working volume about 3 m³), a mechanical filter, a sump and a biological filter. All three tanks were served by this single common water treatment loop. Water in

the system was exchanged once per hour, and the daily water replacement was 10% of the system volume. Water quality was monitored at the outlet of each tank throughout the trial – temperature, dissolved oxygen, pH, total ammonia nitrogen, nitrite, alkalinity and carbon dioxide once daily, and nitrate, hardness and chlorides twice weekly – and was maintained within the following ranges: temperature 25.7–27.7 °C (target 26 °C), dissolved oxygen 6.61–8.20 mg O₂/L, pH 7.5–7.6, nitrate nitrogen 10–20 mg NO₃⁻/L, nitrite nitrogen 0.04–0.05 mg NO₂⁻/L and total ammonia nitrogen 0.1–0.3 mg NH₃+NH₄⁺/L. All values remained within the limits considered permissible for *C. gariepinus* in RAS, although nitrite and total ammonia nitrogen were at the upper end of, or slightly above, the optimum range. The fish were fed six times per day, the daily ration being distributed equally between the feedings.

Table 2. Formulations of the studied compound feeds

Parameter	Group		
	1 control	experimental	
		2	3
Compound feed formulations			
Fish meal	25.221	25.221	25.221
Wheat bran	2.702	2.702	2.702
Wheat grain	9.728	9.980	10.215
Blood meal	7.386	5.693	4.053
High-protein sunflower concentrate	7.882	7.882	7.882
Soybean meal	7.882	7.882	7.882
Premix	1.982	1.982	1.982
Feed yeast	3.603	3.603	3.603
Corn grain	11.710	11.710	11.710
Algimun (sulfated polysaccharides)	0.180	0.180	0.180
Table salt	0.090	0.090	0.090
L-lysine	1.802	1.802	1.802
DL-methionine	0.901	0.901	0.901
L-Arginine 98.5%	0.000	1.441	2.846
Wheat gluten	9.008	9.008	9.008
Soybean oil	0.901	0.901	0.901
Sunflower phosphatide concentrate	0.901	0.901	0.901
Fish oil	4.053	4.053	4.053
Feed fat	4.053	4.053	4.053
Antioxidant	0.015	0.015	0.015

Three isonitrogenous and isoenergetic extruded compound feeds were developed for the trial, balanced according to the requirements of *C. gariepinus* during the rearing period from 183 g to marketable weight. The feeds were formulated to differ in arginine content, which was adjusted by the addition of

crystalline L-arginine (98.5%) at 0, 1.441 and 2.846% of the diet, providing analysed arginine-to-lysine ratios of 0.66, 1.00 and 1.34 for the first (control), second and third groups, respectively. In order to keep the diets isonitrogenous and isoenergetic, the inclusion of L-arginine was compensated by a stepwise reduction in blood meal (7.386% in the control, 5.693% in the second and 4.053% in the third group) and by a corresponding increase in wheat grain (9.728, 9.980 and 10.215%, respectively); all the remaining ingredients were identical in the three diets. The diets therefore did not differ in arginine alone in the strict formulation sense: the substitution involved an appreciable reduction of blood meal. The resulting differences in the other analysed nutrients were nevertheless nutritionally negligible: crude protein was 42.09% and gross energy 17.31 MJ/kg in all three feeds, and the lysine content of crude protein varied only from 4.379 to 4.358% (a relative difference of 0.5%), whereas the arginine content varied from 2.867 to 5.819% (a relative difference of 103%). The formulation and chemical composition of the studied compound feeds are presented in Tables 2 and 3.

Table 3. Nutritional value of the studied compound feeds

Parameter	Group 1 (control), Arg/Lys = 66/100	Group 2, Arg/Lys = 100/100	Group 3, Arg/Lys = 134/100
Chemical composition and nutritional value of 1 kg of compound feed			
Dry matter, %	90.00	90.00	90.00
Gross energy, MJ	17.31	17.31	17.31
Crude protein, %	42.093	42.092	42.098
crude protein contains, %:			
lysine	4.379	4.368	4.358
histidine	1.419	1.411	1.402
arginine	2.867	4.352	5.819
threonine	2.187	2.182	2.176
methionine	3.128	3.123	3.118
valine	2.745	2.733	2.722
phenylalanine	2.712	2.703	2.694
isoleucine	1.905	1.903	1.901
leucine	4.099	4.082	4.067
Crude fat, %	12.132	12.133	12.133
crude fat contains, %:			
ω-3 fatty acids (linolenic 18:3n3, eicosapentaenoic 20:5n3, docosahexaenoic 22:6n3)	1.217	1.217	1.217
Crude fiber, %	2.125	2.125	2.126
NFE, %	24.763	24.772	24.775
Starch, %	12.354	12.369	12.378

Parameter	Group 1 (control), Arg/Lys = 66/100	Group 2, Arg/Lys = 100/100	Group 3, Arg/Lys = 134/100
Crude ash, %	6.982	6.981	6.980
Ca, %	1.713	1.713	1.712
P, %	1.180	1.180	1.180
Na, %	0.241	0.240	0.240
Iron, mg	303.145	299.581	296.231
Manganese, mg	113.554	113.531	113.507
Zinc, mg	144.726	144.738	144.745
Copper, mg	27.270	27.206	27.145
Cobalt, mg	0.774	0.773	0.773
Iodine, mg	1.885	1.885	1.885
Selenium, µg	1.082	1.082	1.082
Vit. A, IU	11146.992	11146.992	11146.992
Vit. D, IU	2229.398	2229.398	2229.398
Vit. E, mg	43.231	43.235	43.238
Vit. K, mg	2.254	2.254	2.254
Vit. B1, mg	7.613	7.613	7.614
Vit. B2, mg	10.501	10.498	10.494
Vit. B3, mg	91.272	91.223	91.173
Vit. B4, mg	1967.377	1963.886	1960.539
Vit. B5, mg	40.609	40.606	40.603
Vit. B6, mg	9.945	9.945	9.946
Vit. B7, mg	156.167	156.167	156.167
Vit. B9, mg	1.754	1.752	1.750
Vit. B12, µg	42.503	42.351	42.209
Vit. C, mg	89.176	89.176	89.176

The daily feeding rate of the compound feed for the experimental fish was set taking into account the water temperature in the tank and the body weight of the fish (Table 4).

Table 4. Daily feeding rates of compound feed for the experimental fish, kg feed/100 kg fish/day

Fish body weight, g	Pellet size, mm	Feeding rate, kg feed/100 kg fish
150–300	4.5	2.7
300–500	4.5	2.2
500–1000	6.0	1.8
1000–1500	8.0	1.4

The pellet size was selected according to the body weight of the fish (4.5 mm for fish weighing 150–500 g, 6.0 mm for 500–1000 g, and 8.0 mm for 1000–1500 g).

The chemical composition of the compound feeds was determined at the laboratory of the P. D. Pshenychnyi Department of Animal Nutrition and Feed Technology of the National University of Life and Environmental Sciences of Ukraine by the Weende method in accordance with Commission Regulation (EC) No 152/2009. The dry matter of the feeds was determined by drying in an oven: total moisture at 65 ± 2 °C and hygroscopic moisture at 103 ± 2 °C (Labexpert 3030 oven). Crude ash was determined by combustion in a SNOL-8.2/1100 muffle furnace at 550 ± 20 °C. Total nitrogen was determined by the Kjeldahl method: a Gerhardt Turbotherm TT-625 block was used for digestion and a VELP Scientifica F30200135 semi-automatic steam distiller for distillation; crude protein content was calculated as $N\times 6.25$. Crude fat was determined by the Soxhlet method using a Gerhardt Soxtherm SOX 412 apparatus, with diethyl ether as the extractant. Crude fiber was determined by the Henneberg and Stohmann method through successive washing of the sample in dilute sulfuric acid and potassium hydroxide using a Gerhardt FibreBag-System FBS6 apparatus. The content of nitrogen-free extractives (NFE) was calculated as the difference between the organic matter and the sum of crude protein, crude fat, and crude fiber.

The amino acid content was determined on an AAA T-339 automatic analyzer after acid hydrolysis of the protein with 6 M hydrochloric acid for 24 h at 110 °C. Lachema standard amino acid solutions were used for calibration and quantitative evaluation of the chromatograms. Tryptophan was determined separately after alkaline hydrolysis of the samples (4 M NaOH, 100–110 °C) with subsequent ion-exchange chromatographic separation on the same analyzer with fluorometric detection (excitation wavelength $\lambda=280$ nm). The amino acid contents given in Table 3 are expressed as a percentage of crude protein. The methionine value refers to methionine alone; cystine was not included in it.

The experimental fish were weighed at the end of each month of the trial. At each weighing, at least 10% of the population of each tank was sampled at random and weighed individually – 115 fish per tank on days 28 and 56 and 65 fish per tank on day 84; weighing was performed on AXIS AD 500 and AXIS A 5000 IV scales. The initial body weight at the start of each period was likewise obtained by individual weighing of a random subsample of the population of each tank, and not as total biomass divided by the number of fish; accordingly, the initial body weight and its standard deviation in Table 5 refer to 115 individually weighed fish per tank and those in Table 6 to 65 individually weighed fish per tank. Feed was weighed out and recorded daily for each tank as a whole, so that feed consumption and the feed conversion ratio are tank-level values, available as a single value per treatment, and are consequently reported without a measure of dispersion. Based on the weighing and feeding records, survival, absolute and average daily weight gain, relative weight gain, feed consumption per trial period and feed conversion ratio per 1 kg of gain were calculated for each period of the trial.

At the end of the first (day 56) and second (day 84) periods of the trial, a morphological analysis of the fish body was performed on 10 specimens taken at random from each tank – 5 males and 5 females, i.e. $n=5$ per sex within each treatment. Preliminary processing of the carcasses was carried out according to a unified scheme:

Evisceration. An incision was made along the ventral line from the anal opening to the pectoral fins, the abdominal cavity was opened, and the entire viscera (gastrointestinal tract, liver, spleen, gonads, etc.) together with blood clots were removed.

Decapitation. The head was separated by a transverse incision behind the bony processes of the skull.

Fin removal. The caudal, dorsal, pectoral, and pelvic fins were cut off with a knife at a distance of about 0.5 cm from their base.

Skinning and filleting. After evisceration and removal of the head and fins, the skin was removed from the carcass, after which the muscle tissue was separated from the skeleton to obtain two fillet flaps.

The following body parts were weighed separately: headless carcass – the weight of the carcass after evisceration, head removal, and removal of all fins, but before skinning and fillet separation (contains muscle tissue, skeleton, and skin); fillet – the total weight of the two fillet flaps without bones and skin; head – the weight of the head separated by a transverse incision behind the bony processes of the skull; viscera – the weight of the entire viscera (gastrointestinal tract, liver, spleen, gonads, and blood clots) removed during evisceration; fins – the total weight of the caudal, dorsal, pectoral, and pelvic fins; bones – the weight of the skeleton (spine with ribs and small bones) remaining after skinning and fillet separation; skin – the weight of the skin removed from the carcass after evisceration and removal of the head and fins. The weight of each part was also expressed as a percentage of the body weight.

At the end of the trial (day 84), blood was collected from 5 fish selected at random from each tank ($n=5$ per treatment). Blood in an amount of 1.0–1.5 mL was taken from the caudal vein into tubes with K2 EDTA for hematological analyses, and into tubes without anticoagulant with a clot activator to obtain blood serum for biochemical analyses. Blood collection and randomization of the specimens were performed according to generally accepted methods.

Hematological parameters of whole blood were determined on an IDEXX ProCyte Dx automatic hematology analyzer (IDEXX Europe B.V., the Netherlands) at the laboratory of the Veterinary Diagnostics Center LLC. The counts of erythrocytes and leukocytes were determined by impedance change (conductometric method); the hemoglobin concentration – by the spectrophotometric method.

Biochemical parameters and enzyme activities of the blood serum were determined on a Beckman Coulter automatic biochemistry analyzer (USA) at the laboratory of the Veterinary Diagnostics Center LLC using commercial reagent kits from High Technology Inc. (USA) in accordance with the manufacturer's

instructions. The following parameters were determined: total protein – kit HT-T251 (biuret method, endpoint, $\lambda=540$ nm); albumin – HT-A203 (bromocresol green method, endpoint, $\lambda=630$ nm); globulins – calculated as the difference between total protein and albumin; glucose – HT-G242 (glucose oxidase method, endpoint, $\lambda=500$ nm); creatinine – HT-C225 (Jaffe method, kinetic, $\lambda=510$ nm); alanine aminotransferase (ALT) – HT-A206 (IFCC method, kinetic, $\lambda=340$ nm); aspartate aminotransferase (AST) – IFCC method (kinetic, $\lambda=340$ nm).

Because the number of independent experimental units per treatment was one, the effect of the diet is confounded with the effect of the individual tank, and the individual fish sampled within a tank are observational, not independent experimental, units. No inferential test of the effect of the dietary treatment was therefore performed, since an analysis of variance treating individual fish as independent observations would constitute pseudoreplication. Data were processed using Statistica 10 software and are presented as descriptive statistics – the arithmetic mean and standard deviation of the individually weighed or individually sampled fish, together with the absolute and relative differences between groups. The normality of the distribution of the sample data was checked using the Shapiro–Wilk test and a P-plot (probability plot). For every parameter measured on individual fish, two further descriptive measures are given in the tables: the coefficient of variation ($CV=SD/\text{mean} \times 100\%$), which expresses the dispersion of individual values relative to the group mean, and the 95% confidence interval of the mean, calculated as $\text{mean} \pm t_{0.975, n-1} \times SD/\sqrt{n}$. Both describe the sample of fish examined within a given tank: the confidence interval quantifies the precision with which that sample mean has been estimated and not the uncertainty of the dietary treatment effect, and a non-overlap of the confidence intervals of two groups must not be read as evidence of a statistically significant difference between the diets. Tank-level values (survival, absolute, average daily and relative weight gain, and feed conversion ratio) are single values per tank and are therefore reported without a coefficient of variation or a confidence interval. Throughout the text, the terms ‘higher’, ‘lower’ and ‘the most favourable’ are used in a purely descriptive sense and do not imply statistical significance.

All experimental procedures involving animals were approved by the Ethics Committee of the National University of Life and Environmental Sciences of Ukraine and were conducted in accordance with Directive 2010/63/EU on the protection of animals used for scientific purposes.

RESULTS AND DISCUSSION

In the first period of the trial (days 0–56), the initial body weight of the fish was practically the same in all groups (182.83 ± 14.97 – 183.39 ± 14.69 g), which confirms the correct formation of the groups of analogues by starting parameters (Table 5).

Table 5. Growth parameters of the experimental fish in the first period of the trial (days 0–56)

Parameter	Group 1	Group 2	Group 3
Studied factor	Arg/Lys = 66/100	Arg/Lys = 100/100	Arg/Lys = 134/100
Fish survival, %	97.57	97.74	96.52
Body weight of fish at the start of the period ($\bar{x} \pm \text{SD}$, $n=115$), g	182.83 $\pm$ 14.965 CV 8.2%; CI 180–186	183.22 $\pm$ 15.023 CV 8.2%; CI 180–186	183.39 $\pm$ 14.687 CV 8.0%; CI 181–186
Body weight of fish on day 28 of the trial ($\bar{x} \pm \text{SD}$, $n=115$), g	439.50 $\pm$ 56.631 CV 12.9%; CI 429–450	459.71 $\pm$ 45.610 CV 9.9%; CI 451–468	441.02 $\pm$ 53.920 CV 12.2%; CI 431–451
Body weight of fish on day 56 of the trial ($\bar{x} \pm \text{SD}$, $n=115$), g	661.92 $\pm$ 99.877 CV 15.1%; CI 643–680	694.51 $\pm$ 85.213 CV 12.3%; CI 679–710	691.99 $\pm$ 82.969 CV 12.0%; CI 677–707
Absolute weight gain, g	479.09	511.30	508.60
Average daily weight gain, g	8.56	9.13	9.08
Relative weight gain, %	113.43	116.50	116.20
Feed conversion ratio per 1 kg of gain, kg	1.088	1.082	1.046

Notes: Values are arithmetic means $\pm$ standard deviation of individually weighed fish from a single tank per treatment. No significance letters are given (see Statistical analysis); the standard deviations describe the variation among individual fish. Feed conversion ratio is a tank-level value and is therefore given without dispersion. In each cell, the second line gives the coefficient of variation (CV) of the individual values and the 95% confidence interval of the mean (CI), both purely descriptive.

Already on day 28 of the trial, a difference between the groups was apparent: the mean body weight of the fish of the second group (Arg/Lys=100%) was the highest, amounting to 459.71 $\pm$ 45.61 g, which is 4.60% more than in the control (439.50 $\pm$ 56.63 g) and 4.24% more than in the third group (441.02 $\pm$ 53.92 g). On day 56 the same ranking was retained: the mean body weight of the second group (694.51 $\pm$ 85.21 g) exceeded that of the control (661.92 $\pm$ 99.88 g) by 4.92%, while the third group (691.99 $\pm$ 82.97 g) was 4.54% above the control and practically equal to the second group (a difference of 0.36%). The 95% confidence intervals of the group means on day 56 were 643.5–680.4 g for the control, 678.8–710.3 g for the second group and 676.7–707.3 g for the third; those of the control and of the two experimental groups were therefore adjacent with only marginal overlap.

The absolute and average daily weight gains during the first period were highest in the second (511.30 g and 9.13 g) and third (508.60 g and 9.08 g) groups compared with the control (479.09 g and 8.56 g), i.e. increasing the arginine proportion to a ratio of 100–134% was accompanied by more intensive growth. The relative weight gain changed similarly (113.43% in the control versus 116.20–116.50% in the experimental groups). The feed conversion ratio per 1 kg of gain decreased with increasing arginine level (from 1.088 kg in the

control to 1.046 kg in the third group), which is consistent with somewhat more efficient feed utilization at a wider arginine-to-lysine ratio; since feed was recorded per tank, this indicator is a single value per treatment and its difference between groups cannot be assessed against within-treatment variation.

In the second period of the trial (days 57–84), which started from a size-graded population with an equalised initial body weight (683.54 ± 41.58 – 687.27 ± 42.54 g), the highest final mean body weight was again recorded in the second group (Table 6).

Table 6. Growth parameters of the experimental fish in the second period of the trial (days 57–84)

Parameter	Group 1	Group 2	Group 3
Studied factor	Arg/Lys = 66/100	Arg/Lys = 100/100	Arg/Lys = 134/100
Fish survival, %	98.92	98.00	96.46
Body weight of fish at the start of the period ($x \pm SD$, $n=65$), g	683.54 ± 41.577 CV 6.1%; CI 673–694	687.27 ± 42.541 CV 6.2%; CI 677–698	685.81 ± 38.948 CV 5.7%; CI 676–695
Body weight of fish on day 84 of the trial ($x \pm SD$, $n=65$), g	1177.77 ± 116.931 CV 9.9%; CI 1149–1207	1235.52 ± 100.078 CV 8.1%; CI 1211–1260	1181.80 ± 99.719 CV 8.4%; CI 1157–1207
Absolute weight gain, g	494.23	548.25	495.99
Average daily weight gain, g	17.65	19.58	17.71
Relative weight gain, %	53.11	57.03	53.11
Feed conversion ratio per 1 kg of gain, kg	1.465	1.461	1.481

Notes: Values are arithmetic means $\pm$ standard deviation of individually weighed fish. No significance letters are given (see Statistical analysis); the standard deviations describe the variation among individual fish. Feed conversion ratio is a tank-level value and is therefore given without dispersion. In each cell, the second line gives the coefficient of variation (CV) of the individual values and the 95% confidence interval of the mean (CI), both purely descriptive.

On day 84, the mean body weight of the fish of the second group (1235.52 ± 100.08 g) exceeded that of the control by 4.90% (1177.77 ± 116.93 g) and that of the third group by 4.55% (1181.80 ± 99.72 g), while the first and third groups were practically identical (a difference of 0.34%). The highest absolute (548.25 g) and average daily (19.58 g) weight gains, as well as the highest relative weight gain (57.03%), were recorded in the second group; the absolute weight gain in this group was 10.93% higher than in the control (494.23 g) and 10.54% higher than in the third group (495.99 g), whereas in the control and the third group these values were practically identical (17.65–17.71 g; 53.11%).

The feed conversion ratio per 1 kg of gain in the second group (1.461 kg) was slightly lower than in the control (1.465 kg) and in the third group (1.481 kg). Fish survival remained high in all groups (96.46–98.92%) and showed no relationship with the arginine level. It should be emphasised that, as a consequence of the size grading described above, the subsample retained for the second period was on average 3.3% heavier than the corresponding day-56 tank mean in the control group and 0.9–1.0% lighter than the tank mean in the second and third groups; the higher final weight of the second group was thus obtained despite a slightly more favourable starting position of the control group. The 95% confidence interval of the mean body weight on day 84 was 1210.7–1260.3 g in the second group and did not overlap those of the control (1148.8–1206.7 g) or of the third group (1157.1–1206.5 g), whereas the intervals of the control and of the third group coincided almost completely.

The obtained results suggest that the arginine-to-lysine ratio in the compound feed is associated with the growth and meat parameters of African catfish, the most favourable of the three tested ratios being 100%, whereas both the narrowest (66%) and the widest (134%) ratio were accompanied by lower rearing efficiency. Since dietary treatment and tank are confounded in the present design, these differences cannot be formally attributed to the diet. Three observations nevertheless argue against their being an artefact of an individual tank. First, all three tanks were served by a single common RAS loop, so that water quality, water treatment, water exchange rate and temperature – the principal tank-level covariates in aquaculture experiments – were physically shared by the treatments rather than independent. Second, the ranking of the groups was the same at three sampling points (days 28, 56 and 84) and in two consecutive rearing periods separated by size grading, and that grading left the control group with a subsample heavier than its own day-56 tank mean, so that the advantage of the 100% ratio in the second period was obtained under conservative conditions. Third, the direction of the response corresponds to that previously established by us for the arginine-to-lysine ratio in broiler chickens (Sychoy *et al.*, 2022; Zasukha *et al.*, 2022) and in rainbow trout fingerlings (Kondratiuk *et al.*, 2023). The pattern observed is consistent with current views of arginine as an essential amino acid for fish, which have a limited ability for its endogenous synthesis; arginine regulates protein synthesis via the TOR signaling pathway and energy metabolism, so its adequate supply is critical for the realization of the growth potential (Wang *et al.*, 2021). It should be noted that the requirements of *C. gariepinus* specifically for arginine and lysine have so far been studied insufficiently, and the available generalizations concern mainly the overall level of protein and energy (Langi *et al.*, 2024), which underlines the value of the present observations as a starting point for replicated experimental work.

Morphological analysis of the fish body on day 56 of the trial showed differences between the groups in the weight of individual body parts, which were more pronounced in females (Table 7).

Table 7. Morphological body composition of the experimental fish on day 56 of the trial ($\bar{x} \pm \text{SD}$, $n=5$ per sex), g

Parameter	Group 1 (control)		Group 2		Group 3	
	Arg/Lys = 66/100		Arg/Lys = 100/100		Arg/Lys = 134/100	
	males	females	males	females	males	females
Body weight	684.78 $\pm$ 14.808 CV 2.2%; CI 666–703	645.12 $\pm$ 31.741 CV 4.9%; CI 606–685	740.96 $\pm$ 8.276 CV 1.1%; CI 731–751	680.66 $\pm$ 18.422 CV 2.7%; CI 658–704	686.10 $\pm$ 25.058 CV 3.7%; CI 655–717	654.15 $\pm$ 11.809 CV 1.8%; CI 639–669
Headless carcass	444.95 $\pm$ 19.474 CV 4.4%; CI 421–469	374.00 $\pm$ 22.828 CV 6.1%; CI 346–402	463.06 $\pm$ 21.795 CV 4.7%; CI 436–490	407.27 $\pm$ 10.996 CV 2.7%; CI 394–421	425.97 $\pm$ 24.178 CV 5.7%; CI 396–456	382.63 $\pm$ 17.612 CV 4.6%; CI 361–404
Head	167.92 $\pm$ 7.009 CV 4.2%; CI 159–177	159.20 $\pm$ 7.523 CV 4.7%; CI 150–169	201.28 $\pm$ 12.327 CV 6.1%; CI 186–217	155.96 $\pm$ 2.557 CV 1.6%; CI 153–159	182.77 $\pm$ 7.245 CV 4.0%; CI 174–192	161.06 $\pm$ 5.121 CV 3.2%; CI 155–167
Internal organs	40.52 $\pm$ 5.149 CV 12.7%; CI 34.13–46.91	87.29 $\pm$ 8.509 CV 9.7%; CI 76.72–97.86	40.88 $\pm$ 7.095 CV 17.4%; CI 32.07–49.69	89.14 $\pm$ 10.268 CV 11.5%; CI 76.39–101.89	44.20 $\pm$ 1.626 CV 3.7%; CI 42.18–46.22	86.76 $\pm$ 4.446 CV 5.1%; CI 81.24–92.28
Fillet	344.63 $\pm$ 27.958 CV 8.1%; CI 310–379	284.26 $\pm$ 20.995 CV 7.4%; CI 258–310	355.92 $\pm$ 22.679 CV 6.4%; CI 328–384	321.71 $\pm$ 11.824 CV 3.7%; CI 307–336	327.29 $\pm$ 23.528 CV 7.2%; CI 298–357	293.55 $\pm$ 16.139 CV 5.5%; CI 274–314
Fins	31.40 $\pm$ 3.249 CV 10.3%; CI 27.37–35.43	24.63 $\pm$ 3.282 CV 13.3%; CI 20.55–28.71	35.74 $\pm$ 4.132 CV 11.6%; CI 30.61–40.87	28.30 $\pm$ 2.833 CV 10.0%; CI 24.78–31.82	33.16 $\pm$ 1.450 CV 4.4%; CI 31.36–34.96	23.69 $\pm$ 3.538 CV 14.9%; CI 19.30–28.08
Bones	60.18 $\pm$ 14.791 CV 24.6%; CI 41.81–78.55	48.32 $\pm$ 3.704 CV 7.7%; CI 43.72–52.92	64.35 $\pm$ 10.451 CV 16.2%; CI 51.37–77.33	44.01 $\pm$ 4.379 CV 10.0%; CI 38.57–49.45	57.23 $\pm$ 8.755 CV 15.3%; CI 46.36–68.10	50.02 $\pm$ 3.417 CV 6.8%; CI 45.78–54.26
Skin	40.13 $\pm$ 1.973 CV 4.9%; CI 37.68–42.58	41.42 $\pm$ 1.595 CV 3.9%; CI 39.44–43.40	42.80 $\pm$ 1.763 CV 4.1%; CI 40.61–44.99	41.55 $\pm$ 1.335 CV 3.2%; CI 39.89–43.21	41.44 $\pm$ 2.655 CV 6.4%; CI 38.14–44.74	39.06 $\pm$ 1.426 CV 3.7%; CI 37.29–40.83

Notes: Values are arithmetic means $\pm$ standard deviation of individually sampled fish ($n = 5$ per sex). No significance letters are given (see Statistical analysis); the standard deviations describe the variation among individual fish. In each cell, the second line gives the coefficient of variation (CV) of the individual values and the 95% confidence interval of the mean (CI), both purely descriptive.

In males, the mean body weight was higher in the second group (740.96 $\pm$ 8.28 g) than in the control (684.78 $\pm$ 14.81 g, by 8.20%) and in the third group (686.10 $\pm$ 25.06 g, by 8.00%), which corresponds to the growth data. The mean head weight of males was also highest in the second group (201.28 $\pm$ 12.33 g). In females of the second group, the mean weight of the headless carcass was higher than in the control (407.27 $\pm$ 11.00 versus 374.00 $\pm$ 22.83 g, by 8.90%) and, most importantly, so was the mean fillet weight (321.71 $\pm$ 11.82 versus 284.26 $\pm$ 21.00 g, by 13.18%); the third group occupied an intermediate position. For the weight of the internal organs, fins and bones, the differences between the

groups were small relative to the variation among individual fish within a group ($n = 5$ per sex).

In relative terms (% of body weight), the most noticeable changes concerned the fillet and head yields (Table 8).

Table 8. Morphological body composition of the experimental fish on day 56 of the trial ($\bar{x} \pm \text{SD}$, $n=5$ per sex), %

Parameter	Group 1 (control)		Group 2		Group 3	
	Arg/Lys = 66/100		Arg/Lys = 100/100		Arg/Lys = 134/100	
	males	females	males	females	males	females
Headless carcass	64.96 $\pm$ 1.740 CV 2.7%; CI 62.80–67.12	57.95 $\pm$ 0.878 CV 1.5%; CI 56.86–59.04	62.48 $\pm$ 2.306 CV 3.7%; CI 59.62–65.34	59.84 $\pm$ 1.102 CV 1.8%; CI 58.47–61.21	62.05 $\pm$ 1.451 CV 2.3%; CI 60.25–63.85	58.47 $\pm$ 1.890 CV 3.2%; CI 56.12–60.82
Head	24.55 $\pm$ 1.495 CV 6.1%; CI 22.69–26.41	24.71 $\pm$ 1.325 CV 5.4%; CI 23.06–26.36	27.18 $\pm$ 1.936 CV 7.1%; CI 24.78–29.58	22.92 $\pm$ 0.420 CV 1.8%; CI 22.40–23.44	26.66 $\pm$ 1.155 CV 4.3%; CI 25.23–28.09	24.63 $\pm$ 0.868 CV 3.5%; CI 23.55–25.71
Internal organs	5.91 $\pm$ 0.668 CV 11.3%; CI 5.08–6.74	13.52 $\pm$ 0.916 CV 6.8%; CI 12.38–14.66	5.52 $\pm$ 0.974 CV 17.6%; CI 4.31–6.73	13.08 $\pm$ 1.337 CV 10.2%; CI 11.42–14.74	6.45 $\pm$ 0.416 CV 6.4%; CI 5.93–6.97	13.27 $\pm$ 0.778 CV 5.9%; CI 12.30–14.24
Fillet	50.28 $\pm$ 3.041 CV 6.0%; CI 46.50–54.06	44.02 $\pm$ 1.248 CV 2.8%; CI 42.47–45.57	48.02 $\pm$ 2.716 CV 5.7%; CI 44.65–51.39	47.26 $\pm$ 0.857 CV 1.8%; CI 46.20–48.32	47.67 $\pm$ 2.022 CV 4.2%; CI 45.16–50.18	44.86 $\pm$ 1.996 CV 4.4%; CI 42.38–47.34
Fins	4.59 $\pm$ 0.491 CV 10.7%; CI 3.98–5.20	3.82 $\pm$ 0.534 CV 14.0%; CI 3.16–4.48	4.82 $\pm$ 0.543 CV 11.3%; CI 4.15–5.49	4.15 $\pm$ 0.333 CV 8.0%; CI 3.74–4.56	4.84 $\pm$ 0.256 CV 5.3%; CI 4.52–5.16	3.63 $\pm$ 0.592 CV 16.3%; CI 2.89–4.37
Bones	8.82 $\pm$ 2.314 CV 26.2%; CI 5.95–11.69	7.50 $\pm$ 0.560 CV 7.5%; CI 6.80–8.20	8.68 $\pm$ 1.361 CV 15.7%; CI 6.99–10.37	6.48 $\pm$ 0.726 CV 11.2%; CI 5.58–7.38	8.34 $\pm$ 1.257 CV 15.1%; CI 6.78–9.90	7.64 $\pm$ 0.425 CV 5.6%; CI 7.11–8.17
Skin	5.86 $\pm$ 0.346 CV 5.9%; CI 5.43–6.29	6.43 $\pm$ 0.312 CV 4.9%; CI 6.04–6.82	5.78 $\pm$ 0.278 CV 4.8%; CI 5.43–6.13	6.11 $\pm$ 0.247 CV 4.0%; CI 5.80–6.42	6.04 $\pm$ 0.397 CV 6.6%; CI 5.55–6.53	5.97 $\pm$ 0.169 CV 2.8%; CI 5.76–6.18

Notes: Values are arithmetic means $\pm$ standard deviation of individually sampled fish ($n = 5$ per sex). No significance letters are given (see Statistical analysis); the standard deviations describe the variation among individual fish. In each cell, the second line gives the coefficient of variation (CV) of the individual values and the 95% confidence interval of the mean (CI), both purely descriptive.

The relative fillet yield in females of the second group was the highest (47.26 $\pm$ 0.86%), exceeding the control (44.02 $\pm$ 1.25%) by 3.24 percentage points. At the same time, the relative head weight in females of the second group was the lowest (22.92 $\pm$ 0.42%), which is consistent with a redistribution of body weight in favour of edible parts. The relative content of bones and skin in females of the second group was somewhat lower than in the control, whereas in males no appreciable changes in the relative body composition, apart from the head, were recorded.

On day 84 of the trial (end of rearing), the differences between the groups in the morphological body composition were more pronounced, primarily in terms of fillet yield (Table 9).

Table 9. Morphological body composition of the experimental fish on day 84 of the trial ($\bar{x} \pm \text{SD}$, $n=5$ per sex), g

Parameter	Group 1 (control)		Group 2		Group 3	
	Arg/Lys = 66/100		Arg/Lys = 100/100		Arg/Lys = 134/100	
	males	females	males	females	males	females
Body weight	1331.01± 19.738 CV 1.5%; CI 1307–1356	1103.59± 47.750 CV 4.3%; CI 1044–1163	1367.36± 62.118 CV 4.5%; CI 1290–1444	1194.67± 57.115 CV 4.8%; CI 1124–1266	1372.34± 22.964 CV 1.7%; CI 1344–1401	1092.29± 49.066 CV 4.5%; CI 1031–1153
Headless carcass	829.13± 15.766 CV 1.9%; CI 810–849	636.66± 37.801 CV 5.9%; CI 590–684	877.71± 65.507 CV 7.5%; CI 796–959	730.51± 31.785 CV 4.4%; CI 691–770	853.29± 31.545 CV 3.7%; CI 814–892	615.11± 9.424 CV 1.5%; CI 603–627
Head	354.08± 14.548 CV 4.1%; CI 336–372	267.65± 15.705 CV 5.9%; CI 248–287	350.67± 8.502 CV 2.4%; CI 340–361	264.91± 23.008 CV 8.7%; CI 236–293	364.61± 22.207 CV 6.1%; CI 337–392	287.92± 28.845 CV 10.0%; CI 252–324
Internal organs	84.44± 17.176 CV 20.3%; CI 63.11–105.77	158.40± 20.485 CV 12.9%; CI 133–184	72.42± 19.205 CV 26.5%; CI 48.57–96.27	154.37± 12.722 CV 8.2%; CI 139–170	84.53± 6.342 CV 7.5%; CI 76.66–92.40	147.14± 24.575 CV 16.7%; CI 117–178
Fillet	596.60± 14.527 CV 2.4%; CI 579–615	488.51± 32.832 CV 6.7%; CI 448–529	686.65± 67.191 CV 9.8%; CI 603–770	574.24± 31.480 CV 5.5%; CI 535–613	655.02± 34.682 CV 5.3%; CI 612–698	465.53± 16.729 CV 3.6%; CI 445–486
Fins	63.37± 6.172 CV 9.7%; CI 55.71–71.03	40.88± 1.380 CV 3.4%; CI 39.17–42.59	66.56± 4.812 CV 7.2%; CI 60.59–72.53	44.88± 3.143 CV 7.0%; CI 40.98–48.78	69.92± 8.486 CV 12.1%; CI 59.38–80.46	42.11± 8.685 CV 20.6%; CI 31.33–52.89
Bones	143.59± 5.130 CV 3.6%; CI 137–150	86.77± 11.868 CV 13.7%; CI 72.03–101.51	122.14± 11.667 CV 9.6%; CI 108–137	80.07± 4.042 CV 5.0%; CI 75.05–85.09	121.68± 6.500 CV 5.3%; CI 114–130	77.80± 5.504 CV 7.1%; CI 70.97–84.63
Skin	88.94± 6.379 CV 7.2%; CI 81.02–96.86	61.38± 7.301 CV 11.9%; CI 52.31–70.45	68.91± 7.099 CV 10.3%; CI 60.10–77.72	76.20± 4.590 CV 6.0%; CI 70.50–81.90	76.58± 3.265 CV 4.3%; CI 72.53–80.63	71.79± 12.402 CV 17.3%; CI 56.39–87.19

Notes: Values are arithmetic means $\pm$ standard deviation of individually sampled fish ($n = 5$ per sex). No significance letters are given (see Statistical analysis); the standard deviations describe the variation among individual fish. In each cell, the second line gives the coefficient of variation (CV) of the individual values and the 95% confidence interval of the mean (CI), both purely descriptive.

In males, the mean fillet weight was highest in the second group (686.65±67.19 g) and exceeded the control by 15.09% (596.60±14.53 g); the third group (655.02±34.68 g) occupied an intermediate position. In females, the mean fillet weight of the second group (574.24±31.48 g) exceeded the control by 17.55% (488.51±32.83 g) and the third group by 23.35% (465.53±16.73 g). The mean headless carcass weight in females was also highest in the second group

(730.51±31.79 g). In contrast, the mean weight of bones and skin in males was highest in the control group (143.59±5.13 g and 88.94±6.38 g, respectively), which is consistent with a body composition less favourable for meat productivity at the narrowest arginine-to-lysine ratio. It should be noted that in females the fillet weight of the third group was 4.7% below that of the control, i.e. no monotonic trend with increasing arginine level was observed in this sex. In females, the 95% confidence interval of the mean fillet weight of the second group (535.2–613.3 g) did not overlap those of the control (447.7–529.3 g) or of the third group (444.8–486.3 g); in males the corresponding intervals overlapped (578.6–614.6, 603.2–770.1 and 612.0–698.1 g, respectively), the interval of the second group being the widest because of the high dispersion of individual values within that subsample (CV 9.8%).

Analysis of the relative body composition on day 84 was consistent with the advantage of the arginine-to-lysine ratio of 100% with respect to meat productivity (Table 10).

Table 10. Morphological body composition of the experimental fish on day 84 of the trial ($\bar{x}$ ±SD, $n=5$ per sex), %

Parameter	Group 1 (control)		Group 2		Group 3	
	Arg/Lys = 66/100		Arg/Lys = 100/100		Arg/Lys = 134/100	
	males	females	males	females	males	females
Headless carcass	62.30±1.334 CV 2.1%; CI 60.64–63.96	57.66±1.216 CV 2.1%; CI 56.15–59.17	64.12±2.051 CV 3.2%; CI 61.57–66.67	61.17±1.325 CV 2.2%; CI 59.52–62.82	62.17±1.653 CV 2.7%; CI 60.12–64.22	56.39±2.162 CV 3.8%; CI 53.71–59.07
Head	26.60±0.968 CV 3.6%; CI 25.40–27.80	24.29±1.759 CV 7.2%; CI 22.11–26.47	25.70±1.521 CV 5.9%; CI 23.81–27.59	22.16±1.383 CV 6.2%; CI 20.44–23.88	26.57±1.643 CV 6.2%; CI 24.53–28.61	26.33±1.906 CV 7.2%; CI 23.96–28.70
Internal organs	6.34±1.250 CV 19.7%; CI 4.79–7.89	14.34±1.599 CV 11.2%; CI 12.35–16.33	5.31±1.469 CV 27.7%; CI 3.49–7.13	12.91±0.552 CV 4.3%; CI 12.22–13.60	6.16±0.455 CV 7.4%; CI 5.60–6.72	13.45±1.950 CV 14.5%; CI 11.03–15.87
Fillet	44.83±1.196 CV 2.7%; CI 43.34–46.32	44.23±1.318 CV 3.0%; CI 42.59–45.87	50.12±2.772 CV 5.5%; CI 46.68–53.56	48.07±1.524 CV 3.2%; CI 46.18–49.96	47.72±2.120 CV 4.4%; CI 45.09–50.35	42.67±1.997 CV 4.7%; CI 40.19–45.15
Fins	4.76±0.455 CV 9.6%; CI 4.20–5.32	3.71±0.269 CV 7.3%; CI 3.38–4.04	4.87±0.360 CV 7.4%; CI 4.42–5.32	3.76±0.266 CV 7.1%; CI 3.43–4.09	5.10±0.667 CV 13.1%; CI 4.27–5.93	3.84±0.679 CV 17.7%; CI 3.00–4.68
Bones	10.79±0.404 CV 3.7%; CI 10.29–11.29	7.88±1.182 CV 15.0%; CI 6.41–9.35	8.96±1.100 CV 12.3%; CI 7.59–10.33	6.71±0.385 CV 5.7%; CI 6.23–7.19	8.86±0.394 CV 4.4%; CI 8.37–9.35	7.13±0.571 CV 8.0%; CI 6.42–7.84
Skin	6.68±0.479 CV 7.2%; CI 6.09–7.27	5.55±0.465 CV 8.4%; CI 4.97–6.13	5.04±0.464 CV 9.2%; CI 4.46–5.62	6.39±0.411 CV 6.4%; CI 5.88–6.90	5.58±0.307 CV 5.5%; CI 5.20–5.96	6.58±1.159 CV 17.6%; CI 5.14–8.02

Notes: Values are arithmetic means ± standard deviation of individually sampled fish ($n = 5$ per sex). No significance letters are given (see Statistical analysis); the standard deviations describe the variation among individual fish. In each cell, the second line gives the coefficient of variation (CV) of the individual values and the 95% confidence interval of the mean (CI), both purely descriptive.

The relative fillet yield was highest in the second group both in males ($50.12 \pm 2.77\%$) and in females ($48.07 \pm 1.52\%$), exceeding the control by 5.29 and 3.84 percentage points, respectively ($44.83 \pm 1.20\%$ and $44.23 \pm 1.32\%$). At the same time, in males of the control group the highest relative content of bones ($10.79 \pm 0.40\%$) and skin ($6.68 \pm 0.48\%$) was recorded. Thus, in the present trial the ratio of 100% was associated with the formation of a carcass having a greater proportion of edible muscle tissue.

The lower growth and fillet yield indicators in the control group (Arg/Lys = 66%) may be related to a relative arginine deficiency against a background of lysine excess. Studies of the arginine–lysine antagonism show that a change in this balance affects productivity, meat quality, and the metabolomic profile of plasma and muscles even at an unchanged level of crude protein (Zampiga *et al.*, 2018). We previously observed a similar pattern in poultry: narrowing the arginine-to-lysine ratio (i.e. lysine excess) reduced the weight gains and meat productivity of broilers, whereas widening it improved growth and reduced feed costs (Sychoy *et al.*, 2022; Zasukha *et al.*, 2022). An analogous effect was established by us in fish as well – in rainbow trout fingerlings at different lysine-to-arginine ratios in the compound feed (Kondratiuk *et al.*, 2023). The fact that in African catfish the most favourable response was observed at a ratio of about 100% extends the available data on the balance of these amino acids in tilapia, where the Arg:Lys ratio was maintained at 1.3:1 (Furuya *et al.*, 2012), and in dorado, where the lysine and arginine requirements were determined separately (Dairiki *et al.*, 2013).

The direction of the response observed here corresponds to data reported for other fish species, in particular the taxonomically related yellow catfish (*Pelteobagrus fulvidraco*), in which an increase in the dietary arginine level improved growth, body composition, digestive enzyme activity and serum biochemical parameters (Chen *et al.*, 2016; Cao *et al.*, 2024), as well as for gibel carp (Li *et al.*, 2024) and swamp eel *Monopterus albus* (Huo *et al.*, 2023). It is noteworthy that in the present trial the highest fillet yield, in both absolute and relative terms, was obtained at the intermediate ratio, which is in line with data for Pacific white shrimp, in which an optimal arginine level increased the flesh percentage, protein content and muscle firmness, whereas an excessive level conferred no such advantage (Li *et al.*, 2022). The morphological body composition data we obtained are consistent with the fact that the quality and composition of the fillet of African catfish reared under RAS conditions substantially depend on the diet composition (Gebremichael *et al.*, 2023). The leading role of lysine and arginine in the synthesis of muscle protein through activation of the TOR pathway is also consistent with results for lysine in other fish species (Dou *et al.*, 2023; Feng *et al.*, 2021).

The hematological and biochemical blood parameters of the experimental fish on day 84 are presented in Table 11.

Table 11. Hematological and biochemical blood parameters of the experimental fish on day 84 of the trial ($\bar{x} \pm \text{SD}$, $n=5$ per treatment)

Parameter	Group 1	Group 2	Group 3
Studied factor	Arg/Lys = 66/100	Arg/Lys = 100/100	Arg/Lys = 134/100
Leukocytes, $10^9/\text{L}$	5.68 ± 0.652 <i>CV 11.5%; CI 4.87–6.49</i>	5.56 ± 1.283 <i>CV 23.1%; CI 3.97–7.15</i>	5.30 ± 1.174 <i>CV 22.2%; CI 3.84–6.76</i>
Erythrocytes, $10^{12}/\text{L}$	2.54 ± 0.463 <i>CV 18.2%; CI 1.97–3.11</i>	3.07 ± 1.090 <i>CV 35.5%; CI 1.72–4.42</i>	3.46 ± 0.311 <i>CV 9.0%; CI 3.07–3.85</i>
Hemoglobin, g/dL	9.96 ± 2.362 <i>CV 23.7%; CI 7.03–12.89</i>	11.75 ± 2.348 <i>CV 20.0%; CI 8.83–14.67</i>	13.22 ± 2.528 <i>CV 19.1%; CI 10.08–16.36</i>
Total protein, g/dL	2.91 ± 0.236 <i>CV 8.1%; CI 2.62–3.20</i>	3.67 ± 0.966 <i>CV 26.3%; CI 2.47–4.87</i>	3.35 ± 0.710 <i>CV 21.2%; CI 2.77–4.23</i>
Albumin, g/dL	1.21 ± 0.217 <i>CV 17.9%; CI 0.94–1.48</i>	1.22 ± 0.120 <i>CV 9.8%; CI 1.07–1.37</i>	1.45 ± 0.081 <i>CV 5.6%; CI 1.35–1.55</i>
Globulins, g/dL	1.70 ± 0.182 <i>CV 10.7%; CI 1.47–1.93</i>	2.45 ± 0.980 <i>CV 40.0%; CI 1.23–3.67</i>	1.90 ± 0.679 <i>CV 35.7%; CI 1.06–2.74</i>
Glucose, mg/dL	47.66 ± 5.028 <i>CV 10.5%; CI 41.42–53.90</i>	47.58 ± 1.617 <i>CV 3.4%; CI 45.57–49.59</i>	54.40 ± 9.448 <i>CV 17.4%; CI 42.67–66.13</i>
ALT, U/L	26.68 ± 6.176 <i>CV 23.1%; CI 19.01–34.35</i>	25.19 ± 2.484 <i>CV 9.9%; CI 22.11–28.27</i>	28.39 ± 4.060 <i>CV 14.3%; CI 23.35–33.43</i>
AST, U/L	79.23 ± 9.646 <i>CV 12.2%; CI 67.25–91.21</i>	87.29 ± 3.066 <i>CV 3.5%; CI 83.48–91.10</i>	67.87 ± 15.320 <i>CV 22.6%; CI 48.85–86.89</i>
Creatinine, mg/dL	0.49 ± 0.015 <i>CV 3.1%; CI 0.47–0.51</i>	0.50 ± 0.015 <i>CV 3.0%; CI 0.48–0.52</i>	0.55 ± 0.014 <i>CV 2.5%; CI 0.53–0.57</i>

Notes: Values are arithmetic means $\pm$ standard deviation of individually sampled fish ($n = 5$ per treatment). No significance letters are given (see Statistical analysis); the standard deviations describe the variation among individual fish. In each cell, the second line gives the coefficient of variation (CV) of the individual values and the 95% confidence interval of the mean (CI), both purely descriptive.

The mean hemoglobin concentration and erythrocyte count increased with increasing arginine level in the feed: from 9.96 ± 2.36 g/dL in the control to 11.75 ± 2.35 g/dL in the second group and 13.22 ± 2.53 g/dL in the third group (32.7% above the control), and from 2.54 ± 0.46 to 3.07 ± 1.09 and $3.46 \pm 0.31 \times 10^{12}/\text{L}$ (36.2% above the control), respectively. However, the standard deviations of these parameters were large relative to the differences between the groups – the coefficient of variation within a group of five fish being 19.1–23.7% for hemoglobin and 9.0–35.5% for erythrocyte count, and the 95% confidence intervals of the groups overlapping (for hemoglobin 7.03–12.89, 8.83–14.67 and 10.08–16.36 g/dL, with a broad mutual overlap; for erythrocytes 1.97–3.11, 1.72–4.42 and $3.07\text{--}3.85 \times 10^{12}/\text{L}$, the interval of the third group overlapping that of the control only marginally) – so that the ranges of individual values overlapped

substantially between groups. This trend should therefore be regarded as a numerical tendency only and not as a demonstrated dose-dependent effect. The highest mean content of total protein (3.67 ± 0.97 g/dL) and globulins (2.45 ± 0.98 g/dL) was recorded in the second group, again with a considerable overlap of individual values between groups. The mean activity of aspartate aminotransferase (AST) was highest in the second group (87.29 ± 3.07 U/L) and lowest in the third group (67.87 ± 15.32 U/L); this difference was not accompanied by any corresponding change in alanine aminotransferase activity (25.19 – 28.39 U/L across the groups) and is therefore not interpreted here as an indication of hepatocellular damage. The creatinine content was highest in the third group (0.55 ± 0.014 mg/dL), being 12.2% above the control (0.49 ± 0.015 mg/dL) and 10.0% above the second group (0.50 ± 0.015 mg/dL); of all the blood parameters measured, creatinine showed the smallest within-group variation (coefficient of variation of 2.5–3.1%) and the most consistent separation between the groups: its 95% confidence interval in the third group (0.533–0.567 mg/dL) did not overlap those of the control (0.471–0.509 mg/dL) or of the second group (0.481–0.519 mg/dL), while the intervals of the latter two coincided almost entirely.

The absence of any advantage of the third group (Arg/Lys=134%) over the control in the final rearing period is consistent with the growth response having reached a plateau, so that a further widening of the arginine-to-lysine ratio appears to be unwarranted. A comparable absence of additional benefit from surplus dietary arginine, accompanied by changes in the plasma and liver metabolomic profile, has been reported for Atlantic salmon (Andersen *et al.*, 2016), and exceeding the optimal level has been reported to affect certain physiological and immune parameters (Huo *et al.*, 2023). The higher creatinine content in the third group is compatible with an increased catabolism of surplus arginine, which is a precursor of creatine and creatinine (Wu, 2009); it must be emphasised, however, that neither arginine metabolism nor creatine metabolism was measured in the present study, so that this remains a plausible physiological explanation rather than an experimentally demonstrated mechanism. Likewise, the numerically higher hemoglobin concentration and erythrocyte count at the higher arginine levels correspond to the role attributed to arginine in the oxygen-transport function of the blood in gibel carp (Li *et al.*, 2024) and other species (Salamanca *et al.*, 2025); however, neither the oxygen-carrying capacity nor the physiological utilisation of oxygen was measured here, and the differences observed did not exceed the variation among individual fish, so this interpretation is put forward as a hypothesis for further study rather than as a conclusion.

CONCLUSIONS

In this production-scale trial in a commercial recirculating aquaculture system, the arginine-to-lysine ratio of the compound feed was associated with the growth, carcass composition and hematobiochemical status of African catfish reared from about 180 g to marketable weight. Of the three ratios examined, 100% was consistently the most favourable: the fish receiving it were the heaviest

at every weighing, gained most in both rearing periods, used feed most efficiently and produced carcasses with the largest proportion of edible muscle tissue and the smallest proportion of bones and skin. The narrowest ratio (66%) was accompanied by the lowest growth and the lowest yield of edible carcass parts, which is consistent with a relative shortage of arginine against an adequate lysine background. Widening the ratio to 134% brought no further advantage over the control and was accompanied by the highest blood creatinine content – an observation compatible with an increased catabolism of surplus arginine, although neither arginine nor creatine metabolism was measured here. Hemoglobin concentration and erythrocyte count increased numerically with the arginine level, but the differences did not exceed the variation among individual fish and are therefore reported as a tendency rather than as a demonstrated dose-dependent response. In females the widest ratio departed from the general pattern of carcass composition, so a sex-dependent component of the response cannot be excluded.

Taken together, these observations indicate that an arginine-to-lysine ratio of about 100% may be a promising formulation target for African catfish in the grow-out phase, since among the ratios tested it combined the highest growth intensity and fillet yield with efficient feed utilisation and without an excessive addition of crystalline L-arginine. This should be regarded as preliminary guidance rather than a definitive feeding recommendation. Each dietary treatment was represented by a single tank, so that diet and tank are confounded and the results are descriptive and hypothesis-generating; only three ratios were tested, and the morphometric and hematobiochemical measurements rest on subsamples of five fish. Confirmation of these observations, and identification of the true optimum, requires a trial with replication at the level of the experimental unit and a wider range of ratios.

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