**Ukrainian Journal of Veterinary and Agricultural Sciences**
http://ujvas.com.ua


The Stepan Gzhytskyi National University of Veterinary Medicine and Biotechnologies Lviv

Volume 8
Number 3

**original article** | UDC 597.551.2:591.43 | **doi: 10.32718/ujvas8-3.11**

# Features of the morphology of the respiratory organs of Clarias gariepinus (Burchell, 1822) of the catfish family

L. P. Horalskyi[1], I. V. Tsanko[1], B. V. Gutyj[2], Yu. V. Loboiko[2], O. G. Rud[3], L.V. Shevchenko[4]

[1]*Zhytomyr Ivan Franko State University, V. Berdychivska Str., 40, Zhytomyr, 10002, Ukraine*
[2]*Stepan Gzhytskyi National University of Veterinary Medicine and Biotechnologies, Pekarska Str., 50, Lviv, 79010, Ukraine*
[3]*Rivne State University for the Humanities, Str. Plastova, 29-a, Rivne, 33028, Ukraine*
[4]*National University of Life and Environmental Sciences of Ukraine, Heroiv Oborony Str., 15, Kyiv, 03041, Ukraine*

*Article info*
*Received 11.09.2025*
*Received in revised form 14.10.2025*
*Accepted 15.10.2025*

*Correspondence author*
*Leonid Horalskyi*
*Tel.: +38-098-878-58-66*
*E-mail: goralsky@ukr.net*



*Contents*



**Abstract**

Fish farming plays a significant role in ensuring the global food supply. For achieving maximum yields in the global production of edible fish products, aquaculture has become the most dynamically developing sector. Within this context, the cultivation of Clarias catfish (*Clarias gariepinus*) holds particular importance due to its biological advantages in terms of growth and development when compared to other artificially cultured fish species under aquaculture conditions. This article presents findings on the morphological structure of the respiratory organs (gills and lungs) of the Clarias catfish, obtained using macroscopic, morphometric, and statistical research methods. Observations revealed distinctive features in the structure of respiratory organs in air-breathing (bimodal) fish, of which the Clarias catfish is a representative. It was shown that during the phylogenetic development of air-breathing fish, modifications occur in their gas exchange and circulatory systems–specifically, the development of a double circulatory loop–like that observed in amphibians. In these animals, paired lungs form in addition to gills, enabling them to breathe atmospheric air. Thus, in the evolutionary development of the respiratory organs of air-breathing fish such as the Clarias catfish, structural adaptations are observed compared to fish that rely solely on gill respiration. These changes ensure efficient gas exchange between the animal's body and the surrounding environment. Such adaptations are characterized by the improvement of respiratory structures typical of amphibians, in which paired lungs form alongside gills, allowing the organism to utilize atmospheric oxygen. In unfavorable aquatic conditions, Clarias catfish can migrate to alternative water bodies. In Clarias catfish, the gills are in the pharyngeal region on the gill arches, with two rows of gill filaments attached to their outer edges. A dense network of fine blood capillaries is found within these filaments. The lungs (right and left) of the Clarias catfish are composed of branched anatomical structures situated on the second and fourth gill arches. These are paired hollow sacs with alveolate walls, connected to the esophagus and adapted for aerial respiration. The lungs originate from the gill cavities and branches in a tree-like manner to form the parabrachial organ, which includes both the right and left lungs. Each lung comprises medial and lateral lobes. Morphologically, the lungs exhibit three surfaces: dorsal (facing the dorsal part of the trunk), ventral (facing the ventral side), and mediastinal (facing the midline). The lungs also possess distinct cranial, caudal, and lateral borders. According to the results of morphometric analysis, the absolute lung mass in Clarias catfish is 5.24 ± 0.09 g, and the relative lung mass is 0.33 ± 0.02 %. The absolute mass of the left lung is 2.52 ± 0.17 g (48.13 ± 2.71 %), while the right lung weighs 2.72 ± 0.16 g (51.87 ± 2.71 %). Among the lung lobes, the medial lobes are more developed, while the lateral lobes are less developed. Specifically, the absolute mass of the medial lobe of the left lung is 2.16 ± 0.12 g (41.46 ± 2.94 %), and the lateral lobe is 0.36 ± 0.11 g (6.68 ± 1.84 %). The absolute mass of the medial lobe of the right lung is 2.24 ± 0.11 g (42.83 ± 1.5 %), while the lateral lobe weighs 0.48 ± 0.1 g (9.03 ± 1.7 %). Based on linear measurements the length of the medial lobe of the right lung is 21.0 ± 0.78 mm, the width is 32.2 ± 1.0 mm, and the thickness is 12.8 ± 0.33 mm, the lateral lobe of the right lung measures 11.2 ± 0.25 mm in length, 17.5 ± 0.4 mm in width, and 6.0 ± 0.48 mm in thickness, the medial lobe of the left lung measures 20.2 ± 0.45 mm in length, 31.4 ± 0.63 mm in width, and 12.0 ± 0.6 mm in thickness, the lateral lobe of the left lung measures 10.9 ± 0.73 mm in length, 17.3 ± 0.68 mm in width, and 5.8 ± 0.35 mm in thickness. According to the lung development index (length-to-width ratio), which is 64 %, the lungs of the Clarias catfish are classified as the expanded-shortened type.

**Keywords**: vertebrate animals; gills; lungs; morphometry.

**Citation:**
Horalskyi, L. P., Tsanko, I. V., Gutyj, B. V., Loboiko, Yu. V., Rud, O. G., & Shevchenko, L.V. (2025). Features of the morphology of the respiratory organs of Clarias gariepinus (Burchell, 1822) of the catfish family. *Ukrainian Journal of Veterinary and Agricultural Sciences*, 8(3), 84–90.

## 1. Introduction

Fish farming plays a significant role in ensuring food security both in Ukraine and globally. According to fish product monitoring data, the cultivation of aquatic organisms–mainly edible species–already accounts for nearly half of the global demand for fish products, and projections suggest this figure may rise to 60–70 % by 2030 (Subasinghe et al., 2009). To achieve the highest yields in global food fish production, aquaculture remains the most dynamically growing sector.

Within this sector, particular attention is given to the cultivation of *Clarias* catfish due to its biological advantages in growth and development compared to other fish species reared under artificial conditions. These advantages include low environmental requirements, disease resistance, rapid growth rates, high stocking density tolerance, omnivorous feeding habits, and more – all of which are of exceptional economic importance in reducing production costs (Baßmann et al., 2017; Lawal et al., 2017; Ukagwu et al., 2017; Juin et al., 2017; Strauch et al., 2020).

The African *Clarias* catfish, also known as the marbled *Clarias* or Nile catfish (*Clarias gariepinus*), is naturally distributed throughout Africa, including Saharan water bodies, the Jordan River basin, and regions of South and Southeast Asia. It inhabits freshwater lakes, swamps, river mouths, rivers, irrigation canals, ponds, and floodplain waters–even those that periodically dry up (Hecht et al., 1996; Hildebrand et al., 2023). This species is air-breathing, omnivorous, freshwater-dwelling, and thermophilic, capable of breathing atmospheric air in addition to utilizing gill respiration (Tsaryk et al., 2018).

Optimal development of this fish species requires a specific temperature regime in the aquatic environment–ranging from 20 °C to 30 °C (Hogendorn & Vismans, 1980; Britz & Hecht, 1987; Huisman & Richter, 1987). *Clarias* catfish can tolerate water temperatures as low as 8 °C (Zadorozhnii & Bekh, 2024) and are also moderately tolerant of low salinity levels (Clay, 1977; Chervinski, 1984).

Considering the species' tolerance for intensive stocking, capacity for reproduction under artificial conditions, and low sensitivity to water quality parameters, *Clarias* catfish farming is regarded as a promising direction in aquaculture in many countries (Hogendorn, 1979; Hogendorn, 1980; Viveen et al., 1985; Bovendeur et al., 1987; De Graaf & Janssen, 1996; Eding & Kamstra, 2002), including Ukraine. The cultivation of *Clarias* catfish under controlled conditions is a relatively new and developing area in the Ukrainian aquaculture industry (Zadorozhnii, 2023; Zadorozhnii & Bekh, 2024).

For the successful development of aquaculture, improvement of productivity traits and disease prevention must be addressed not only through management strategies, but also through comprehensive biological studies of the organism, including macro- and microscopic examination of organs and systems. A particularly relevant aspect is the study of structural and functional characteristics of the respiratory system at the species level and under the influence of anthropogenic environmental factors (Horalskyi et al., 2022).

This has not only theoretical importance for morphologists but also serves as a foundation for ichthyologists and fish farmers to prevent diseases caused by stress and adverse environmental conditions during fish cultivation in aquaculture systems.

In vertebrates, the respiratory organs perform essential life-sustaining functions (Prokushenkova, 2009). In all terrestrial vertebrates, the respiratory system includes air-conducting pathways and gas-exchange organs–lungs. Pulmonary respiration is characteristic of all terrestrial vertebrates, including adult amphibians, reptiles, birds, and mammals. Unlike diffusive, gill, or tracheal respiration, pulmonary respiration is a more advanced form of gas exchange, providing for external respiration-i.e., the exchange of gases between air and blood. Through this process, oxygen enters the organism and carbon dioxide is expelled (Horalskyi et al., 2020; 2022; 2023).

In fish, respiration is primarily gill-based, and lungs are generally absent. However, in air-breathing (bimodal) fish such as *Clarias* catfish, the respiratory system includes paired lungs in addition to gills. As a result, these fish can perform pulmonary respiration and breathe atmospheric air (Aleksiienko, 2007; Melnyk et al., 2008; Sherman et al., 2009; Tsaryk et al., 2018).

Therefore, the *Clarias* catfish exhibits specific morphological features in its respiratory organs and a distinct physiological respiratory mechanism. This formed the basis for our study.

Consequently, we conducted a comparative morphological and morphometric evaluation of the gill and lung structures in the air-breathing catfish *Clarias gariepinus*.

## 2. Materials and methods

The study was conducted in accordance with the international principles of the European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes (Strasbourg, 1986) and the Rules for Conducting Work with the Use of Experimental Animals approved by Order No. 281 of the Ministry of Health of Ukraine dated November 1, 2000, "On Measures for Further Improvement of Organizational Forms of Work with Experimental Animals," as well as the Law of Ukraine "On the Protection of Animals from Cruelty" (No. 3447-IV of February 21, 2006, Kyiv).

The research complied with the general rules of Good Laboratory Practice (GLP, 1981) and the provisions of the "General Ethical Principles of Animal Experiments", approved by the First National Congress on Bioethics (Kyiv, 2001).

The object of the study was the gills and lungs of the African catfish (*Clarias gariepinus*), a species of air-breathing vertebrate (*Chordata*), class *Actinopterygii*, family *Clariidae*.

The cultivation and maintenance of *Clarias gariepinus* (Burchell, 1822) were carried out under controlled domestic conditions using artificially created ecosystems with appropriate environmental parameters, including optimal water temperature, acidity, and salinity, to ensure comfortable living conditions.

For this purpose, aquaria with a volume of up to 500 liters were used. These were equipped with technical devices and filtration systems for mechanical, biological, and bacteriological treatment–Eheim Professional 3 1200XL filters and Resun UV-08 24W external ultraviolet sterilizers. Oxygenation of the water was maintained by Resun ACO-001 air compressors.

Water temperature (maintained at 25–28 °C) was controlled using JBL ProTemp e500 external heaters with a capacity of 500 W. The quality of water and fish stocking density complied with the recommended standards for the cultivation of *Clarias gariepinus* (Hecht et al., 1996). Tap water, previously dechlorinated by settling and heated to tank temperature, was used for water supply and replenished daily in an amount equivalent to 10 % of the total volume.

Hydrochemical monitoring of the water was performed once daily, including measurements of pH, temperature, $NH_3$, $NH_4^+$, $NO_2^-$, and $NO_3^-$ levels. The pH level was measured using an SX-620 laboratory pH meter; temperature was recorded with an electronic thermometer; concentrations of $NH_3$, $NH_4^+$, $NO_2^-$, and $NO_3^-$ were assessed using Ptero water quality test kits.

The room where the tanks were located was dimmed during daylight hours. The fish were fed compound feed twice daily–morning and evening. General clinical assessment of the fish was performed via daily visual observation, focusing on their mobility, general behavior (activity), appetite, etc.

Morphological, morphometric, and statistical research methods were employed. The study was conducted on five specimens of *Clarias gariepinus* (n = 5). Clinical examination of freshly caught specimens and assessment of external (appearance, body weight) and internal (linear dimensions, absolute and relative organ mass) parameters after anatomical dissection were performed in accordance with ichthyological (Pylypenko et al., 2006) and morphological (Horalskyi et al., 2020) guidelines. To minimize the impact of stress factors, fish were anesthetized with a hypnodil solution (5–10 ml/L) prior to dissection.

Body weight was determined using VTD-3/0.1FD "Dneprovyes" scales, accurate to 0.1 g. The absolute mass of lungs and their structural components was measured with electronic scales of 0.1 g precision. Relative organ mass (RM) was calculated as: RM = absolute organ mass / body mass × 100.

Linear parameters (length, width, thickness) of the lungs were measured directly using a caliper. The lung development index was determined as the ratio of their total length to width, according to the formula:

Lung Development Index = (lung length / lung width) × 100.

Morphological terminology for lung structures was provided according to the International Nomina Anatomica Veterinaria and Nomina Histologica Veterinaria.

The digital processing of the study results was carried out using Statistica 7.0 software (StatSoft Inc., Tulsa, USA). Statistical differences between values were evaluated using ANOVA. Differences were considered statistically significant at $P < 0.05$, considering Bonferroni correction.

## 3. Results and discussion

### 3.1 Results

According to our research, the gills of *Clarias gariepinus* are in the pharyngeal region and are supported by four pairs of vertical bony branchial (gill) arches. Attached to the outer margin of each gill arch are two rows of red-colored gill filaments (Fig. 1). Inside these filaments are thin-walled blood vessels that branch into a dense network of fine capillaries. Gas exchange occurs through the walls of these capillaries-oxygen is absorbed from the water, and carbon dioxide is released.

Water flows between the gill filaments due to the rhythmic contractions of the pharyngeal musculature and the movement of the opercular (gill cover) flaps. Along the inner edge of each gill arch are gill rakers, which function to filter out foreign particles and food debris, preventing them from entering and damaging the delicate gill tissues (Fig. 1).

Our findings confirm that the African catfish possesses four pairs of gill slits, each formed by the corresponding gill arches (Fig. 1).

**Fig. 1.** Macroscopic structure of the respiratory organs in African catfish (*Clarias gariepinus*) in dorsal position: 1 – gills; 2 – gill filaments; 3 – gill arches; 4 – opercular covers; 5 – esophagus; 6 – right lung; 7 – left lung; 8 – lung attachment to gill arches; 9 – dorsal surface of the lungs; 10 – cranial lung margin; 11 – caudal lung margin; 12 – lateral lung margin. Macroscopic specimen

The lungs of *Clarias gariepinus* are located in the right and left halves of the cranial part of the trunk, positioned laterally to the mediastinum. Dorsally, the lungs are situated on either side of the cartilaginous notochord, which runs centrally along the body in the form of a dorsal tube. The lungs lie within well-developed paired suprabranchial cavities (right and left), which are shaped as convex, finger-like oval recesses located in the dorsal wall of the cranial cavity of the anterior trunk region, formed by a robust bony shield (Fig. 2).


**Fig. 2.** Cranial part of the trunk of *Clarias gariepinus* (ventral view): 1 – cartilaginous notochord; 2 – right suprabranchial cavity; 3 – left suprabranchial cavity. Macroscopic specimen

Ventrally, the right and left lungs of *Clarias gariepinus* – a representative of dipnoan or air-breathing fish–are located at the base of the pharynx on either side of the esophagus. By connecting to the esophagus, they form a highly specialized organ for aerial respiration (Fig. 3). Morphologically, the lungs of *Clarias gariepinus* appear as paired hollow sacs with alveolated walls, which open into the esophagus and enable atmospheric breathing (Fig. 3).

The lungs originate from the gill cavities and then branch in a tree-like manner to form the suprabranchial organ–comprising the right and left lungs (Fig. 3). They attach to the caudal portion of the gill arches (Fig. 1). Due to the arborized branching penetrated by numerous blood vessels, and the trabeculae projecting into the pulmonary cavity, the respiratory surface area of the lungs is significantly increased.

This anatomical feature allows *Clarias gariepinus* to survive for extended periods (up to 48 hours) outside water or in turbid, oxygen-depleted aquatic environments, and even to move over land surfaces.

Each lung is formed by branched structures located on the second and fourth gill arches (Fig. 1) and is largely covered with vascularized tissue (Fig. 3), facilitating oxygen exchange between the body and the external environment. The suprabranchial cavity that receives air connects with both the pharynx and gill arches.

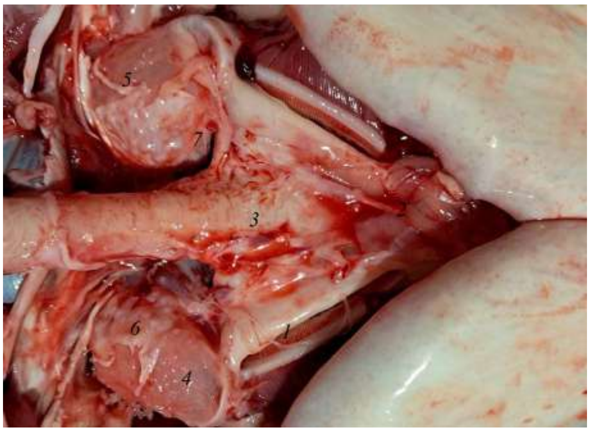


**Fig. 3.** Cranial part of the trunk of *Clarias gariepinus* (ventral view): 1 – gill arches; 2 – base of the pharynx; 3 – esophagus; 4 – left lung; 5 – right lung; 6 – vascularized tissue; 7 – connection of the lung with the esophagus. Macroscopic specimen

The lungs of *Clarias gariepinus* are pale pink in color. According to our morphological analysis, three surfaces can be distinguished: dorsal, ventral, and mediastinal. The dorsal surface faces the dorsal side of the body, the ventral surface is oriented toward the ventral part, and the mediastinal surface faces the midline (mediastinum). Anatomically, the lungs also have distinct cranial, caudal, and lateral borders (Fig. 1).

In vertebrates (*Chordata*), class *Actinopterygii*, family *Clariidae*, species *Clarias gariepinus*, according to our research, the right and left lungs consist of a medial (large) lobe and a lateral (small) lobe (Fig. 4).

The medial lobes of the lungs are in the cranial part of the trunk, respectively on the right and left sides of the esophagus. The lateral lobe adjoins the dorsal surfaces of the medial lobes and lies laterally adjacent to the fourth gill arch, contacting the operculum (Fig. 4). Cranially, the lateral lobe borders the gill arches.


**Fig. 4.** Macroscopic structure of the respiratory organs of *Clarias gariepinus*: 1 – gills; 2 – gill filaments; 3 – gill arches; 4 – medial lobe of the right lung; 5 – lateral lobe of the right lung; 6 – medial lobe of the left lung; 7 – lateral lobe of the left lung. Macroscopic specimen

The right and left lungs originate from the gill arches as a trunk that branches in a tree-like manner, forming morphological structures similar to the bronchial and alveolar trees observed in mammals, thereby creating the right and left lungs. The main trunk of the medial lung lobe branches into four large branches, which further divide into medium and small branches, forming a tree-like structure. The lateral lung lobe has a separate trunk that is not connected to the medial lobe of the lung (Fig. 5).

*a*


*b*


**Fig. 5**. Lateral lobe: *a* – of the left lung; *b* – of the right lung:
1 – main trunk; 2 – medium branch; 3 – small branch; 4 – pulmonary vesicles. Macroscopic specimen

The small branches of both the right and left lungs branch into even smaller twigs, which terminate blindly in thick-walled vesicles (Fig. 5), thereby forming alveolar tree-like structures similar to those found in mammals. In the walls of the large, medium, and small branches, blood vessels originating from the efferent branchial arteries extend into the lungs of these air-breathing fish. These vessels further divide into smaller branches, forming a microcirculatory network within the thick-walled vesicles, where gas exchange likely occurs.

According to our morphometric data, the length of the medial lobe of the right lung measures 21.0 ± 0.8 mm, width – 32.2 ± 1.0 mm, and thickness – 12.8 ± 0.4 mm. Corresponding values for the lateral lobe of the right lung are: length – 11.2 ± 0.3 mm, width – 17.5 ± 0.4 mm, and thickness – 6.0 ± 0.5 mm.

The medial lobe of the left lung measures 20.2 ± 0.5 mm in length, 31.4 ± 0.6 mm in width, and 12.0 ± 0.6 mm in thickness. The lateral lobe of the left lung has a length of 10.9 ± 0.7 mm, width – 17.3 ± 0.7 mm, and thickness – 5.8 ± 0.4 mm.

Based on these linear measurements and the ratio of lung length to width, the lung development index in the African sharptooth catfish (*Clarias gariepinus*) averages 64 %, including: medial lobe of the right lung: 65 %; medial lobe of the left lung: 64 %; lateral lobe of the left lung: 63 %; lateral lobe of the right lung: 64 %.

Therefore, the lungs of *Clarias gariepinus* are classified as expanded-shortened in type.

According to the organometric analysis, the absolute lung mass in *Clarias gariepinus* is 5.24 ± 0.09 g, while the relative mass accounts for 0.33 ± 0.02 % of body weight. The absolute mass of the left lung is 2.52 ± 0.17 g (48.1 ± 2.7 %), while that of the right lung is 2.72 ± 0.16 g (51.9 ± 2.7 %), which is 1.08 times greater than the left lung (Table 1).

Based on morphometric data, the absolute mass of the medial lobe of the left lung averages 2.16 ± 0.12 g (41.5 ± 2.9 %), and the lateral lobe – 0.36 ± 0.11 g (6.68 ± 1.84 %). The absolute mass of the medial lobe of the right lung is 2.24 ± 0.11 g (42.8 ± 1.5 %), and the lateral lobe – 0.48 ± 0.10 g (9.03 ± 1.75 %) (Table 1).

Thus, in Clarias gariepinus, the medial lobes of both lungs are more developed, whereas the lateral lobes are significantly less developed ($P < 0.001$) (Table 1).

**Table 1**
Absolute and Relative Mass of the Lungs in African Sharptooth Catfish (Clarias gariepinus)

| Parts of the lungs | Left lung | | Right lung | | Both lungs | |
|---|---|---|---|---|---|---|
| | Absolute mass (g) | Relative mass (%) | Absolute mass (g) | Relative mass (%) | Absolute mass (g) | Relative mass (%) |
| Medial lobe | 2,16 ± 0,12[b] | 41,5 ± 2,9[b] | 2,24 ± 0,11[b] | 42,8 ± 1,5[b] | 4,41 ± 0,15[b] | 84,3 ± 2,9[b] |
| Lateral lobe | 0,36 ± 0,11[a] | 6,68 ± 1,84[a] | 0,48 ± 0,12[a] | 9,03 ± 1,75[a] | 0,84 ± 0,16[a] | 15,7± 2,9[a] |

*Note*: letters indicate significant differences between the subgroups within one line ($P < 0.05$) according to the Tukey's test

Thus, in the structure of the respiratory organs of air-breathing fishes, represented by the African sharptooth catfish (*Clarias gariepinus*), evolutionary changes can be observed compared to fish that rely solely on gill respiration. These changes are reflected in the development of a respiratory system that ensures efficient gas exchange between the organism and the external environment. Such adaptations manifest in the morphological improvement of the respiratory apparatus, resembling that of amphibians, in which, in addition to gills, paired lungs are formed. This allows the animals to breathe atmospheric air. As a result, when the aquatic environment becomes unsuitable for survival, *Clarias* catfish can migrate across land to reach a more favorable aquatic habitat.

### 3.2 Discussion

The gills are the primary respiratory organs in bony fishes. They are formed by numerous filaments attached proximally to the gill arches. In cartilaginous fishes, in contrast to bony fishes, gill lamellae are attached on one side to the intrabronchial septum. The gill surface area in bony fishes is significantly larger than in cartilaginous fishes, which enables a more advanced mechanism of inhalation and exhalation. Moreover, a considerable amount of gas exchange in fish (up to 10 %) occurs through the skin. Additionally, the swim bladder and certain parts of the intestine may also participate in gas exchange (Melnyk et al., 2008; Tsaryk et al., 2018).

In air-breathing (dipnoan) fishes, in addition to gill respiration, pulmonary respiration also occurs. In such cases, a large, alveolated swim bladder is transformed into one or two lungs that enable the breathing of atmospheric air (Mel'chenkov et al., 2011). According to Mel'chenkov E. A., Pryzov V. V., and Tansykbaev N. N. (2011), lungs in the African sharptooth catfish (*Clarias gariepinus*) are even more essential for survival than the gills (Mel'chenkov et al., 2011).

Based on a literature review, including scientific publications (Mel'chenkov et al., 2011), textbooks and manuals on vertebrate zoology (Aleksiienko, 2007; Melnyk et al., 2008; Sherman et al., 2009; Tsaryk et al., 2018), available information on the morphological structure of the respiratory organs in fishes is fragmentary and primarily illustrated only by schematic diagrams.

Therefore, we conducted a detailed morphological study of the gills and lungs, as well as their morphometric characteristics, in air-breathing fishes using Clarias gariepinus as a model organism.

According to I.S. Tsaryk and others (Tsaryk et al., 2018), the gills are the main respiratory organs in bony fishes and are located on the first to fourth gill arches. Paired gill filaments are attached at their bases along the bony arches. Along these arches run gill arteries that branch into the filaments, forming a capillary network. The filaments have thin transverse lamellae–up to 15 per millimeter–on their surface, which greatly increases their area (typically 1–3 $cm^2$ per 1 g of fish body mass). The distal ends of the filaments interlock during water flow, creating a vaulted structure. Blood in the capillaries flows in the opposite direction to the water stream. This structural adaptation enables the fish to extract 46–82 % of the dissolved oxygen in water and remove over 90 % of the carbon dioxide from the blood (Tsaryk et al., 2018).

Due to this specialized gill structure, fish draw water into the oral cavity and, with the help of gill cover movements, direct it through the pharynx where it washes over the gill filaments and exits through gill openings (respiratory apertures). The presence of gill slits is characteristic of cartilaginous fishes (sharks, rays), most of which have 5 pairs of gill slits, while some species have 6 or 7 pairs. In contrast, bony fishes have only one gill opening, which is covered by an operculum (Tsaryk et al., 2018).

In dipnoan fishes, in addition to gills, one or two lungs are present. These are hollow sacs connected to the esophagus. These paired, alveolate sacs have capillary networks connected to the last pair of branchial arteries. The duct connecting the lungs to the esophagus arises from the ventral side of the esophagus and remains functional throughout the fish's life. Usually, the lungs serve as auxiliary respiratory organs, especially when water bodies dry up (Tsaryk et al., 2018).

Our research has shown that *Clarias gariepinus*, an air-breathing fish species, possesses a specialized pair of lungs (right and left) in addition to gills, which enable breathing of atmospheric air.

Morphometric studies in morphology allow for better understanding of growth and development processes of organs and systems and help monitor the growth and differentiation of cells in comparative and species-specific contexts. Such systematic quantitative analysis of tissue architecture, structural organization, and interrelationships provides compelling data to support morpho functional changes that occur during ontogeny and phylogeny (Horalskyi et al., 2015).

In vertebrate mammals, based on the lung development index (LDI), the lungs in most species are categorized as moderately elongated (LDI = 121–130 %) or elongated (LDI = 131–140 %) (Horalskyi et al., 2022).

Based on our results, the lung asymmetry coefficient in *Clarias gariepinus* is 1:1.08, indicating an absence of significant asymmetry between the right and left lungs. In contrast, the lung asymmetry index in mammals (i.e., the ratio of the absolute mass of the right lung to the left) is much higher than in *Clarias*, for example: in rabbits – 1:1.30, dogs – 1:1.33, sheep – 1:1.37, pigs – 1:1.34, cattle – 1:1.37, and horses – 1:1.2. This indicates pronounced asymmetry between the right and left lungs in these species.

## 4. Conclusion

In *Clarias gariepinus* (the African sharptooth catfish), in addition to gill respiration, pulmonary respiration is also present. The gills are located in the pharyngeal region on the gill arches, which consist of four pairs of vertical bony arches. On the outer edge of each gill arch, there are two rows of red-colored gill filaments, inside which blood vessels are found, branching into a significant number of fine blood capillaries. Each lung of *Clarias gariepinus* is formed by branched structures located on the second and fourth gill arches. These are paired hollow sacs with alveolated walls, which connect to the esophagus and provide for atmospheric respiration. Topographically, the lungs originate from the gill cavities and, branching in a tree-like manner, form a suprabranchial organ—comprising the right and left lungs. Each lung consists of medial and lateral lobes. Morphologically, the lungs have dorsal (directed towards the dorsal part of the body), ventral (directed towards the ventral part of the body), and mediastinal (directed towards the mediastinum) surfaces. Anatomically, the lungs are distinguished into cranial, caudal, and lateral borders.

The absolute mass of the lungs in the *Clarias* catfish is 5.24 ± 0.09 g, and the relative mass is 0.33 ± 0.02%. The absolute mass of the left lung is 2.52 ± 0.17 g, and the right lung is 2.72 ± 0.16 g. The absolute mass of the medial lobe of the left lung is 2.16 ± 0.12 g, and the lateral lobe is 0.36 ± 0.11 g. The absolute mass of the medial lobe of the right lung is 2.24 ± 0.11 g, and the lateral lobe is 0.48 ± 0.10 g. The length of the medial lobe of the right lung is 21.0 ± 0.78 mm, the width is 32.2 ± 1.0 mm, and the thickness is 12.8 ± 0.33 mm. The length of the medial lobe of the left lung is 20.2 ± 0.45 mm, the width is 31.4 ± 0.63 mm, and the thickness is 12.0 ± 0.6 mm; for the lateral lobe, the length is 10.9 ± 0.7 mm, the width is 17.3 ± 0.7 mm, and the thickness is 5.8 ± 0.35 mm. According to the lung development index (the ratio of lung length to width), which is 64 %, the lungs of the *Clarias* catfish belong to the expanded-shortened type.

**Conflict of interest**

The authors of this study declare no conflict of interest.

## References


Aleksiienko, V. R. (2007). Ikhtiolohiia. Posibnyk dlia studentiv biolohichnykh fakultetiv [Ichthyology. A guide for students of biological faculties]. Kyiv: Ukrainskyi fitosotsiolohichnyi tsentr (in Ukrainian).
[Google Scholar]

Baßmann, B., Brenner, M., & Palm, H. W. (2017). Stress and welfare of african catfish (clarias gariepinus Burchell, 1822) in a coupled aquaponic system. *Water*, 9(7), 504.
[Crossref] [Google Scholar]

Bovendeur, J., Eding, E. H., & Henken, A. M. (1987). Design and performance of water recirculation system for high-density culture of the african catfish, clarias gariepinus (Burchell 1822). *Aquaculture*, 63(1-4), 329–353.
[Crossref] [Google Scholar]

Britz, P. J., & Hecht, T. (1987). Temperature preferences and optimum temperature for growth of african sharptooth catfish (clarias gariepinus) larvae and postlarvae. *Aquaculture*, 63(1-4), 205–214.
[Crossref] [Google Scholar]

Chervinski, J. (1984). Salinity tolerance of young catfish, Clarias lazera (Burchell). *Journal of Fish Biology,* 25(2), 147–149.
[Crossref] [Google Scholar]

Clay, D. (1977). Preliminary observations on salinity tolerance Clarias lazera, Israel. *Bamidgeh*, 29(3), 102–109.
[Abstract] [Google Scholar]

De Graaf, G. J., & Janssen, H. (1996). Artificial reproduction and pond rearing of the African catfish Clarias gariepinus in Sub-Saharan Africa – a handbook. FAO Fisheries Technical Paper No. 362, FAO, Rome, Italy.
[Abstract] [Google Scholar]

Eding, E., & Kamstra, A. (2002). Netherlands farm tune recirculation systems to productin of varied species. *Global Aquaculture Advocate*, 5, 52–54.
[Abstract] [Google Scholar]

Hecht, T., Oellermann, L., & Verheust, L. (1996). Perspectives on clarid culture in Africa. *Aquatic Living Resources,* 9, 197–206.
[Crossref] [Google Scholar]

Hildebrand, M.-C., Rebl, A., Nguinkal, J. A., Palm, H. W., & Baßmann, B. (2023). Effects of Fe-DTPA on health and welfare of the african catfish clarias gariepinus (Burchell, 1822). *Water*, 15(2), 299.
[Crossref] [Google Scholar]

Hogendorn, H. (1979). Controlled propagation of the African catfish Clarias lazera (C. & V.). I. Reproductive Biology and Field Experiments. *Aquaculture*, 17(4), 323–333.
[Crossref] [Google Scholar]

Hogendorn, H. (1980). Controlled propagation of the African catfish Clarias lazera (C. & V.). III. Feeding and growth of fry. *Aquaculture*, 21(3), 233–241.
[Crossref] [Google Scholar]

Hogendorn, H., & Vismans, M. M. (1980). Controlled propagation of the Africa Clarias lazera (C.&V.). II. Artificial reproduction. *Aquaculture*, 21(1), 39–53.
[Crossref] [Google Scholar]

Horalskyi, L. P., Demus, N. V., Sokulskyi, I. M., Gutyj, B. V., Kolesnik, N. L., Pavliuchenko, O. V., & Horalska, I. Y. (2023). Species specifics of morphology of the liver of the fishes of the Cyprinidae family. *Regulatory Mechanisms in Biosystems,* 14(2), 234–241.
[Crossref] [Google Scholar]

Horalskyi, L. P., Hlukhova, N. M., & Sokulskyi, I. M. (2020). Morfolohichni osoblyvosti leheniv krolia [Morphological features of rabbit lungs]. *Naukovi horyzonty,* 08(93), 180–188 (in Ukrainian).
[Abstract] [Google Scholar]

Horalskyi, L. P., Hlukhova, N., Sokulskyi, I. M., & Kolesnik, N. L. (2022). Morphological features and morphometric parameters of the lungs of sexually mature horses (Equus Ferus Caballus L., 1758). *Ukrainian Journal of Veterinary Sciences,* 13(1), 25–33.
[Crossref] [Google Scholar]

Horalskyi, L. P., Khomych, V. T. & Kononskyi, O. I. (2015). Osnovy histolohichnoi tekhniky i morfofunktsionalni metody doslidzhennia u normi ta pry patolohii [Basics of histological technique and morphofunctional methods of research in normal and pathology]. Zhytomyr: Polissia (in Ukrainian).
[Abstract] [Google Scholar]

Horalskyi, L. P., Ragulya, M. R., Glukhova, N. M., Sokulskiy, I. M., Kolesnik, N. L., Dunaievska, O. F., Gutyj, B. V., & Goralska, I. Y. (2022). Morphology and specifics of morphometry of lungs and myocardium of heart ventricles of cattle, sheep and horses. *Regulatory Mechanisms in Biosystems,* 13(1), 53–59.
[Crossref] [Google Scholar]

Huisman, E. A., & Richter, C. J. J. (1987). Reproduction, growth, health control and aquacultural potential of the african catfish, clarias gariepinus (Burchell 1822). *Aquaculture*, 63(1-4), 1–14.
[Crossref] [Google Scholar]

Juin, S. K., Sarkar, S., Maitra, S., & Nath, P. (2017). Effect of fish vitellogenin on the growth of juvenile catfish, Clarias gariepinus (Burchell, 1822). *Aquaculture Reports*, 7, 16–26.
[Crossref] [Google Scholar]

Lawal, B. M., Adewole, H. A., & Olaleye, V. F. (2017). Digestibility study and nutrient re-evaluation in clarias gariepinus fed blood meal-rumen digesta blend diet. *Notulae Scientia Biologicae,* 9(3), 344–349.
[Crossref] [Google Scholar]

Mel'chenkov, E. A., Priz, V. V., & Tansykbaev, N. N. (2011). Features of cultivation of African catfish Clarias gariepinus (Burcell, 1822) in the first fish farming zone. *Tavriiskyi Naukovyi Visnyk,* 76, 247–251.
[Google Scholar]

Melnyk, O. P., Kostiuk, V. V., & Shevchenko, P. H. (2008). Anatomiia ryb [Fish anatomy]. Kyiv: Tsentr uchbovoi literatury (in Ukrainian).
[Google Scholar]

Prokushenkova, O. H. (2009). Morfolohiia lehen tsutseniat sobak Neonatalnoho periodu [Lung morphology of puppies of dogs of the Neonatal period]. Scientific Messenger of LNU of Veterinary Medicine and Biotechnologies. Series: Veterinary Sciences, 2(41/4), 244–247 (in Ukrainian).
[Google Scholar]

Pylypenko, Y. V., Rylov, V. H., Korniienko, V. O., & Prudko, N. O. (2006). Morfolohichni doslidzhennia ryb: metodychni rekomendatsii [Morphological studies of fish: methodological recommendations]. Kherson: RVTs KhDAU "Kolos" (in Ukrainian).

Sherman, I. M., Pylypenko, Y. V., & Shevchenko, P. H. (2009). Zahalna ikhtiolohiia: pidruchnyk [General ichthyology: textbook]. Kyiv: Ahrarna osvita (in Ukrainian).
[Google Scholar]

Strauch, S. M., Wenzel, L. C., Bischoff, A., Dellwig, O., Klein, J., Schüch, A., Wasenitz, B., & Palm, H. W. (2020). Commercial african catfish (Clarias gariepinus) recirculating aquaculture systems: assessment of element and energy pathways with special focus on the phosphorus cycle. *Water*, 12(5), 1386.
[Crossref] [Google Scholar]

Subasinghe, R., Soto, D., & Jia, J. (2009). Global aquaculture and its role in sustainable development. *Reviews in Aquaculture,* 1(1), 2–9.
[Crossref] [Google Scholar]

Tsaryk, Y. V., Khamar, I. S., & Dykyi, I. V. (2018). Zoolohiia khordovykh: pidruchnyk [Chordate Zoology: Textbook] Lviv: Lvivskyi natsionadbnyi universytet imeni Ivana Franka (in Ukrainian).

Ukagwu, J. I., Anyanwu, D. C., Offor, J. I., & Nduka, C. O. (2017). Comparative studies of nutrient composition of wild caught and pond reared african catfish, Clarias gariepinus. *International Journal of Research in Applied, Natural and Social Sciences*, 5(7), 63–68.
[Abstract] [Google Scholar]

Viveen, W. J. A. R., Richter, C. J. J., van Oordt, P. G. W. J., Janssen, J. A. L., & Huisman, E. A. (1985). Practical manual for the culture of the African catfish (Clariasgariepinus). Published by: Directorate General International Cooperation of the Ministry of Foreign Affair, The Hague, the Netherlands; Research Grup for Comparative Endocrinology, Dept. of Zoology of the University of Utrecht, the Netherlands.
[Abstract] [Google Scholar]

Zadorozhnii, M. V. (2023). Osoblyvosti zahartuvannia molodi klariievoho soma (Clarias gariepinus) dlia vyroshchuvannia u pryrodnikh umovakh Pivnochi Ukrainy [Features of hardening of young Clarias gariepinus for cultivation in natural conditions of Northern Ukraine]. *Tavriiskyi Naukovyi Visnyk*, 132, 352–357 (in Ukrainian).
[Crossref] [Google Scholar]

Zadorozhnii, M. V., & Bekh, V. V. (2024). Minimalno dopustymi temperatury pry vyroshchuvanni afrykanskoho klariievoho soma (Slarias gariepinus) [Minimum permissible temperatures for growing African Clarias catfish (Clarias gariepinus)]. *Tavriiskyi Naukovyi Visnyk*, 135, 232–238 (in Ukrainian).
[Crossref] [Google Scholar]

Zadorozhnii, M., & Bekh, V. (2024). First experience of cultivating african catfish (Clarias gariepinus Burchell, 1822) under natural temperature conditions in water bodies of Polissiya of Ukraine. *Ribogospodars'ka Nauka Ukraini,* 1(67), 74–88.
[Crossref] [Google Scholar]