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MORFOMETRI STRUKTUR INSANG DAN ARBORESCENT *Clarias gariepinus* (Burchell, 1822) PADA BERBAGAI TAHAP PERKEMBANGAN

MORPHOMETRY OF THE GILL AND ARBORESCENT STRUCTURES OF Clarias gariepinus (Burchell, 1822) AT DIFFERENT DEVELOPMENTAL STAGES

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ABSTRAK

Ikan lele merupakan salah satu komoditas perikanan unggulan di Indonesia. Ikan ini memiliki mekanisme adaptif pada struktur insangnya yang dikenal sebagai *arborescent*, yang memungkinkan bertahan hidup di lingkungan dengan kadar oksigen rendah. Penelitian ini bertujuan untuk mengkaji morfometri struktur insang dan *arborescent* pada ikan lele mutiara pada berbagai tahap perkembangan. Parameter morfometri yang diamati mencakup struktur insang dan struktur *arborescent.* Struktur insang diukur berdasarkan rasio berat insang kanan dan kiri terhadap berat dan panjang total ikan. Struktur insang dibagi menjadi tiga bagian utama: jumlah rakers per cm, filamen insang, dan *branchiospinalis*. Lengkung insang diamati melalui rasio panjang lengkung terhadap panjang total ikan. Bagian filamen insang meliputi rata-rata jumlah filamen per lengkung, kerapatan filamen (filamen/cm), dan rasio panjang filamen terhadap panjang lengkung. Bagian *branchiospinalis* mencakup rata-rata jumlah branchiospinalis per lengkung dan kerapatannya. Struktur *arborescent* diamati berdasarkan rasio relatif berat *arborescent* (kanan dan kiri) terhadap berat total ikan, serta rasio jumlah cabang *arborescent* terhadap berat total *arborescent*. Ikan lele diamati pada tiga tahap perkembangan: larva (1–14 hari), juvenil (15–21 hari), dan pascajuvenil hingga pra-dewasa (22–90 hari). Analisis statistik dilakukan menggunakan perangkat lunak SPSS versi 22. Hasil penelitian menunjukkan bahwa pada tahap pascajuvenil hingga pra-dewasa, ikan lele mutiara memiliki berat relatif insang dan *arborescent* yang lebih besar dibandingkan tahap juvenil dan larva, serta menunjukkan struktur insang dan *arborescent* yang lebih berkembang pada tahap ini.

Kata kunci: Arborescent; Insang; Morfometri; Lele Mutiara; Respirasi

ABSTRACT

Catfish is one of Indonesia's top fishery commodities. These fish have an adaptive mechanism in their gill structure, known as arborescent, which allows them to survive in low-oxygen environments. This study focuses on the gill and arborescent morphometry of Mutiara catfish at different developmental stages. The morphometric parameters include the gill and arborescent structures. The gill structure is measured by the ratio of the right and left gill weight to the fish's total weight and length. The gill is divided into three main parts: rakers/cm, branchial filaments, and branchiospinalis. The branchial arch is observed by the ratio of its length to the total length of the fish. The branchial filaments section measures the average number of filaments per arch, filament density (filaments/cm), and the ratio of filament length to arch length. The branchiospinalis section includes the average number of branchiospinalis per arch and its density. The arborescent

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structure consists of the relative weight ratio of arborescent (right and left) to total fish weight and the ratio of the number of arborescent branches to total arborescent weight. Catfish were sampled from larval (1–14 days), juvenile (15–21 days), and post-juvenile to pre-adult (22–90 days) stages. Statistical analysis was conducted using SPSS 22 software. The results show that the post-juvenile to pre-adult stage Mutiara catfish have higher relative gill and arborescent weights compared to the juvenile and larval stages, with more developed gill and arborescent structures at this stage.

KEYWORDS: Arborescent, Gills, Morphometry, Mutiara Catfish, Respiration

INTRODUCTION

Mutiara catfish (*Clarias gariepinus*) (Burchell, 1822)) is one of the leading commodities in Indonesian aquaculture (Ministry of Maritime Affairs and Fisheries of Indonesia, 2022). This species offers several advantages, including relatively easy and efficient maintenance. Furthermore, it has significant consumption potential due to its high protein content, reaching up to 17.26% (Gunawan, 2018; Pyz-Lukasik & Paszkiewicz, 2018; Shadieva et al., 2020). To support their survival, catfish possess an adaptive mechanism in their respiratory system. The respiration process in organisms, including fish, requires adequate oxygen intake from the environment (Lefevre, 2014; Maina, 2018; Fernandes & Moron, 2020). The environment is a dynamic factor that naturally causes fluctuations in temperature and oxygen availability (Baudron et al., 2014). Oxygen is a crucial factor in maintaining the stability of metabolic processes, which is why several fish species have developed additional air-breathing organ (ABO) structures (Lefevre, 2014; Mbanga, 2018; Maina, 2021).

This additional structure in catfish is known as the arborescent, an extension of the second and fourth-gill arches (Karlina & Luthfi, 2017; Zaccone et al., 2018). Catfish typically inhabit oxygen-poor environments, such as muddy swamps, where the arborescent structure enables them to extract oxygen directly from the air. This ability to take up atmospheric oxygen ensures a sufficient oxygen supply (Mbanga, 2018; Maina, 2021). Adequate oxygen levels in the environment are essential for maintaining normal respiratory processes in catfish and supporting their growth and development (Lefevre, 2014; Karlina & Luthfi, 2017; Mbanga, 2018; Maina, 2021). Previous studies by Amalia & Budijastuti (2022) and Delfita (2014) have shown that dissolved oxygen in the water is absorbed by the gill capillaries and distributed throughout the fish's body. Therefore, changes in the aquatic environment can affect the structure of the respiratory system, including both the gills and the arborescent.

Gills and arborescent structures can be identified using morphological traits, one of which is morphometric measurements (Ernita et al., 2020; Amalia & Budijastuti, 2022). Morphometry is a method used to measure body size or the external surface area of organs, serving as a basis for comparing fish sizes (Suryana et al., 2015; Islam et al., 2020). Morphometric studies are crucial because environmental factors can influence changes or differences in morphometric characteristics. Abumandour & El-Bakary (2017) reported that environmental factors and food availability influence alterations in morphometric traits in fish. Water quality parameters, such as dissolved oxygen, carbon dioxide, acidity, alkalinity, nitrates, and phosphates, can affect food intake. Poor water quality makes it difficult for fish to meet their daily needs, ultimately impacting their morphometric characteristics (Amalia & Budijastuti, 2022; Lahnsteiner, 2024).

Studies on the comparative anatomical structure of the gills of Keureling fish (*Tor tambroides*) and goldfish (*Cyprinus carpio*) by Ernita et al. (2020) reported that goldfish have a greater relative gill weight than Keureling fish. This difference is thought to be one of the factors influencing their ability to adapt to fluctuations in dissolved oxygen levels in water. The relative gill weight can serve as an initial indicator of the adaptability of a fish's respiratory system to its environment (Cruz & Fernandes, 2016). Fast-swimming fish, such as skipjack tuna (*Katsuwonus pelamis*), typically have larger gill sizes with a shorter diffusion distance. In contrast, fish that are more sedentary and inhabit slow-moving waters, such as *Clarias gariepinus*, tend to have a smaller gill size proportion with shorter filament lengths (Cruz & Fernandes, 2016; Chen et al., 2019). These findings demonstrate that fish gill morphometrics vary depending on species, habitat, and environmental factors.

Mbanga (2018) reported that the morphometrics of the arborescent organ in *Clarias mossambicus* revealed an average surface area of the labyrinth organ per unit body weight of 4.65 ± 1.6 mm²/g. Additionally, the average thickness of the alveolar-capillary membrane (tissue barrier) of the arborescent organ was 0.287 µm, and the specific morphometric diffusion capacity was 0.07 mL/min/mmHg/kg.

This value represents approximately 50% of the total diffusion capacity of the respiratory organs. However, further research on other morphometric characteristics of the arborescent organ in catfish has not yet been conducted. To date, no studies have examined the gill and arborescent morphometric characteristics of catfish, particularly mutiara catfish, across various developmental stages (larvae, juveniles, and pre-adults).

MATERIALS AND METHODS

Preparing larval, juvenile, and post-juvenile rearing ponds for Mutiara catfish (*Clarias gariepinus* (Burchell, 1822))

For the larval stage, a 50 x 30 x 30 cm³ aquarium pond was used, while for the post-larval to pre-adult stages, an 80-liter cultivation bucket was employed. The water used for rearing was allowed to stand for approximately 24 hours (or overnight) to allow dissolved substances to precipitate. Afterward, the water was filled to a height of 15 cm in the aquarium and aerated using an Airpump (WP-AP-2000) aerator to increase oxygen levels (Indonesian National Standardization Agency, 2011; Gunawan, 2016; Indonesian National Standardization Agency, 2018).

Selection of Mutiara catfish (*Clarias gariepinus* (Burchell, 1822)) larvae

Larvae were obtained from the Aquaculture Technology Development Center (BPTPBA), Yogyakarta, Indonesia. The fish used ranged from the larval stage (1 day old) to pre-adult (90 days). Samples were collected from each developmental stage, larvae, juveniles, and post-juveniles to pre-adults, three times each. The sampling time was at the larval stage on the 1st, 7th, and 14th days. Juvenile stage on the 15th, 18th, and 21st days. Post-juvenile stage to pre-adult on the 22nd, 56th, and 90th days. Each sample was captured using a camera (Canon EOS 1500D Kit (EF-S 18-55 IS II)) for morphological analysis. The quality of the larvae was selected based on the following criteria: blackish-brown coloration, agile movement, and no visible body defects (Indonesian National Standardization Agency, 2014). One hundred larvae, aged 1 to 20 days, were placed in a glass aquarium, after which they were transferred to a plastic cultivation bucket pond for further growth from 21 to 90 days.

Feed provision and management for the larval, juvenile, and post-juvenile stages of Mutiara catfish (*Clarias gariepinus* (Burchell, 1822))

Feeding method: feeding is conducted using three methods, based on the fish's developmental stages-larvae, juveniles, and post-juveniles to pre-adulthood (harvest). These methods include ad-libitum, biomass measurements to determine the daily feed amount, and satiation (Rarassari et al., 2021). Ad-libitum method (Rarassari et al., 2021): larvae (1st to 14th days) were fed dry Artemia EG Inve using this method, with a feeding frequency of three times a day (7–8 AM, 1–2 PM, and 7–8 PM), providing 2 g per feeding (Kitagawa et al., 2015). Biomass method (Elesho et al., 2021): juveniles (aged 15 to 21 days) were fed PF 1000, while post-juveniles to pre-adults were fed Feng Li–2A, Feng Li–3S, Feng Li–3M, and Feng Li–3L. Feeding occurred twice a day (7–8 AM and 7–8 PM). Fish were weighed periodically (every 10 days) to assess feed conversion at each daily feeding frequency. The feed dosage was determined according to Andi et al. (2023), using the following formula: daily feed amount (g) = average weight of fish (g) × number of fish stocked × 3%. Satiation method (Elesho et al., 2021): this method is employed after the ad-libitum and biomass feeding methods. Once the feed is evenly distributed in the pond, the fish are left to feed for 30 minutes to 1 hour. Any remaining feed is then removed using an Artemia net. This method is applied as needed when excess feed remains.

Management and control of water quality and temperature in Mutiara catfish (*Clarias gariepinus* (Burchell, 1822)) rearing

Monitoring of fish-rearing water parameters was conducted every 3 days, both in the morning (7–8 AM) and afternoon (4–5 PM), with three repetitions. Water temperature (26–30°C) was measured using a TDS meter (TDS-3 PPM hydroponic). The pH (6.5–8.5) was measured with a digital automatic calibration pH meter (Mediatech P-2Z | B1900126). Ammonia levels (maximum 0.01/0.1 mg/L) were assessed using Sper Scientific ammonia test strips. Dissolved oxygen (DO) (minimum 3 mg/L or > 2 mg/L) was measured using an DO meter (OHAUS® ST20D). Chemical oxygen demand (COD) (< 40 mg/L) and biochemical oxygen demand (BOD) (< 25 mg/L) were measured every 10 days. Fish-rearing water samples were sent to the Health and Calibration Laboratory Center in Yogyakarta, Indonesia, for analysis. Quality standards for COD and BOD testing were determined according to the Indonesian National Standard/SNI 6989 72-2009 and APHA 23rd Edition, 5220-C, 2017 (Indonesian National Standardization Agency, 2018; American Public Health Association, American Water Works Association, & Water Environment Federation, 2023).

Table 1. Morphometrics and ratios of gill and arborescent structures of Mutiara catfish at different developmental stages

Parameters	Larval stage (1-14 days old)	Juvenile stage (15-21 days old)	Post-adolescent to pre-adult stage (22-90 days old)
Relative gill weight (%)	0.01 ± 0.01a	0.04 ± 0.00a	0.50 ± 0.46a
Ratio of branchial arch length to total length	2.10 ± 2.32a	5.90 ± 1.69a	18.85 ± 8.61a
Ratio of branchial filament length to branchial arch length (%)	0.47 ± 0.45a	1.18 ± 0.30a	2.03 ± 0.84a
Average number of branchial filaments per branchial arch	20.11 ± 19.43a	39.44 ± 11.64a	53.83 ± 17.84a
Average branchial filament density (filaments/cm)	0.18 ± 0.20a	0.10 ± 0.00a	0.10 ± 0.00a
Average number of branchiospinalis per branchial arch	7.58 ± 6.34a	16.91 ± 2.70a	28.80 ± 8.77a
Average branchiospinalis density (rakers/cm)	0.13 ± 0.00a	0.23 ± 5.79a	0.24 ± 0.04a
Relative arborescent weight (%)	-*	-*	0.11 ± 0.08a
Average number of arborescent branches	-*	-*	171.11 ± 34.44a

Note:

* = At the larval and juvenile stages, the arborescent structure has not yet appeared

a = The same superscript letter in the same row indicates no significant difference ($p > 0.05$).

Control of pests and diseases of Mutiara catfish *Clarias gariepinus*) (Burchell, 1822))

Pest and disease control was carried out by maintaining water quality parameters, managing excess feed, keeping the pond clean, and administering antibiotics and fish salt. Pond cleanliness was ensured by removing leftover food and fish waste from the bottom of the pond using an Aquarium Yamano Sand Cleaner Pump one hour after feeding. Antibiotics were provided through the use of EM4 fisheries fermentation, produced by PT. Songgolangit Persada (SLP), along with cane molasses. For the fermentation process, 500 L of reverse osmosis (RO) water was mixed with 100 mL of EM4 Fisheries and 100 mL of molasses, then fermented for 3 days. The resulting mixture was applied to the pond at a rate of 1 mL per liter of pond water daily. Fish salt was administered at a dose of approximately 0.1 grams per liter of pond water volume (Gunawan, 2016; Delima et al., 2021).

Measurement of gill and arborescent morphometry in Mutiara catfish (*Clarias gariepinus* (Burchell, 1822))

Morphometric characters measured included relative fish weight (%), relative total fish length (%), relative gill weight (%) for both the right and left sides, relative arborescent weight (%) for both the right and left sides, the ratio of branchial arch length to total length (%), the ratio of the length of the branchial filaments to the length of the branchial arches (%), the average number of branchial filaments per branchial arch, the average density of branchial filaments (filaments/cm), the average number of branchial spines per branchial arch, and the average density of branchial spines (rakers/cm) (Ernita et al., 2016). Sampling was conducted at three stages of fish development: larvae (1st to 14th days), juveniles (15th to 21st days), and post-juvenile to pre-adult or harvest stage (22nd to 90th days). Sampling was carried out at the beginning, middle, and end of each developmental stage. Larvae were sampled on the 1st, 7th, and 14th days; post-larvae on the 15th, 18th, and 21st days; and post-juveniles to pre-adults (harvest) on the 22nd, 56th, and 90th days. Measurements were taken using the digital caliper (Bison K21520) and fish weight was measured using a digital jewelry scale (8028-series) (Kutner et al., 2004; Yuda, 2013; Yuliara, 2016).

Statistical analysis

The experiment was conducted with five replications (n = 3), and the data are presented as the mean ± standard deviation. Morphometric data for each parameter were analyzed using a one-way analysis of variance (ANOVA). Statistical significance was determined at the

Table 2. Measurement of general parameters of water quality for Mutiara catfish maintenance

No	Sampling to-/time	Fish age (days)	Time	Parameters	Repetition I	Repetition II	Repetition III	Average
1.	1st/ Tuesday, January 23, 2024 (acclimatization)	0	a.m.	Temperature (oC)	27.10	27.00	27.20	27.10
				Ammonia (ppm)	0.25	0.25	0.25	0.25
				pH	7.60	7.50	7.60	7.57
				DO (mg/L)	7.50	7.40	7.50	7.47
			p.m.	Temperature (oC)	28.50	28.60	28.40	28.50
				Ammonia (ppm)	0.25	0.25	0.25	0.25
				pH	7.60	7.90	7.60	7.70
				DO (mg/L)	7.60	7.40	7.60	7.53
2.	2nd/ Thursday,February 1, 2024	9	a.m.	Temperature (oC)	27.80	27.70	27.60	27.70
				Ammonia (ppm)	1.00	0.50	0.50	0.67
				pH	7.00	7.10	1.10	5.07
				DO (mg/L)	4.50	4.00	4.40	4.30
			p.m.	Temperature (oC)	28.70	27.60	27.50	27.93
				Ammonia (ppm)	0.25	0.25	0.25	0.25
				pH	7.60	7.50	7.50	7.53
				DO (mg/L)	6.40	6.50	6.60	6.50
3.	3rd/ Saturday, February 10, 2024	18	a.m.	Temperature (oC)	28.00	27.70	27.70	27.80
				Ammonia (ppm)	1.00	0.50	0.50	0.67
				pH	7.60	7.50	7.40	7.50
				DO (mg/L)	4.50	4.80	4.70	4.67
			p.m.	Temperature (oC)	27.70	27.50	27.50	27.57
				Ammonia (ppm)	0.25	0.25	0.25	0.25
				pH	7.80	7.50	7.60	7.63
				DO (mg/L)	7.10	7.00	6.90	7.00
4.	4th/ Monday, February 19, 2024	27	a.m.	Temperature (oC)	28.00	28.80	28.80	28.53
				Ammonia (ppm)	1.00	0.50	0.50	0.67
				pH	7.50	7.40	7.40	7.43
				DO (mg/L)	4.70	5.00	5.20	4.97
			p.m.	Temperature (oC)	27.90	27.90	28.00	27.93
				Ammonia (ppm)	0.25	0.25	0.25	0.25
				pH	7.20	7.70	7.80	7.57
				DO (mg/L)	6.00	7.20	7.10	6.77
5.	5th/ Wed-nesday, February 28, 2024	36	a.m.	Temperature (oC)	28.20	28.10	28.20	28.17
				Ammonia (ppm)	0.50	0.50	0.50	0.50
				pH	8.80	9.00	9.00	8.93
				DO (mg/L)	3.10	3.00	3.00	3.03
			p.m.	Temperature (oC)	29.40	29.50	29.50	29.47
				Ammonia (ppm)	0.25	0.25	0.25	0.25
				pH	7.80	8.00	7.90	7.90
				DO (mg/L)	4.50	4.80	4.60	4.63
6.	6th/ Friday, March 8, 2024	45	a.m.	Temperature (oC)	27.80	27.90	27.80	27.83
				Ammonia (ppm)	0.50	0.50	0.50	0.50
				pH	9.00	9.10	8.90	9.00
				DO (mg/L)	3.10	3.20	3.10	3.13
			p.m.	Temperature (oC)	29.00	29.00	29.30	29.10
				Ammonia (ppm)	0.25	0.25	0.25	0.25
				pH	7.80	8.00	8.00	7.93
				DO (mg/L)	4.70	4.50	4.50	4.57

Table 2. Measurement of general parameters of water quality for Mutiara catfish maintenance (Cont.)

No	Sampling to-/time	Fish age (days)	Time	Parameters	Repetition I	Repetition II	Repetition III	Average
7.	7th/ Sunday, March 17, 2024	54	a.m.	Temperature (oC)	28.30	28.20	28.00	28.17
				Ammonia (ppm)	0.50	0.50	0.50	0.50
				pH	8.90	9.00	9.00	8.97
				DO (mg/L)	3.00	3.10	3.20	3.10
			p.m.	Temperature (oC)	29.40	29.00	29.50	29.30
				Ammonia (ppm)	0.25	0.25	0.25	0.25
				pH	8.00	8.00	8.00	8.00
				DO (mg/L)	4.20	4.40	4.50	4.37
8.	8th/ Tuesday, March 26, 2024	63	a.m.	Temperature (oC)	27.80	27.80	28.00	27.87
				Ammonia (ppm)	0.50	0.50	0.50	0.50
				pH	9.30	9.20	9.00	9.17
				DO (mg/L)	3.00	3.00	3.10	3.03
			p.m.	Temperature (oC)	29.10	29.30	29.30	29.23
				Ammonia (ppm)	0.25	0.25	0.25	0.25
				pH	8.00	8.00	8.00	8.00
				DO (mg/L)	4.60	4.80	4.80	4.73
9.	9th/ Thursday, April 4, 2024	72	a.m.	Temperature (oC)	27.60	27.90	28.00	27.83
				Ammonia (ppm)	0.50	0.50	0.50	0.50
				pH	8.90	9.00	9.00	8.97
				DO (mg/L)	3.00	3.00	3.20	3.07
			p.m.	Temperature (oC)	29.50	29.40	29.40	29.43
				Ammonia (ppm)	0.25	0.25	0.25	0.25
				pH	8.00	8.00	8.00	8.00
				DO (mg/L)	4.60	4.70	4.50	4.60
10.	10th/ Saturday, 13, April 2024	81	a.m.	Temperature (oC)	27.90	28.00	28.10	28.00
				Ammonia (ppm)	0.50	0.50	0.50	0.50
				pH	9.00	8.90	8.80	8.90
				DO (mg/L)	3.10	3.00	3.20	3.10
			p.m.	Temperature (oC)	29.50	29.60	29.60	29.57
				Ammonia (ppm)	0.25	0.25	0.25	0.25
				pH	8.00	8.00	8.00	8.00
				DO (mg/L)	4.30	4.50	4.50	4.43
11.	11st/ Monday, April 22, 2024	90	a.m.	Temperature (oC)	27.70	27.80	28.00	28.07
				Ammonia (ppm)	0.50	0.50	0.50	0.50
				pH	8.90	9.00	9.00	9.00
				DO (mg/L)	3.00	3.00	3.10	3.10
			p.m.	Temperature (oC)	29.50	29.60	29.60	29.57
				Ammonia (ppm)	0.25	0.25	0.25	0.25
				pH	8.00	8.00	8.00	8.00
				DO (mg/L)	4.90	5.00	5.00	4.97

Note:
Standard reference for measuring water quality parameters for catfish maintenance (Indonesian National Standardization Agency, 2015; Gunawan, 2016):

Water temperature = 25 – 30oC
pH = 6.5 – 8.5
DO = minimum 3 mg/L
Ammonia = maximum 0.01 ppm

Table 3. COD and BOD parameter measurement for Mutiara catfish water quality

No	Sampling to-/time	Parameters	Result (mg/L)	Conformity with eqs*
1	1st/January 5, 2024	COD	33.924	+
		BOD	28.28	-
2	2nd/February 15, 2024	COD	87.86	-
		BOD	7.49	+
3	3rd/Februari 27, 2024	COD	32.125	+
		BOD	6.03	+
4	4th/March 7, 2024	COD	4.691	+
		BOD	2.33	+
5	5th/March 27, 2024	COD	20.806	+
		BOD	3.76	+
6	6th/April 16, 2024	COD	84.15	-
		BOD	21.42	+
7	7th/April 22, 2024	COD	123.90	-
		BOD	29.08	-

Note:

*Environmental quality standards are the acceptable limits or levels of living organisms, substances, energy, components, or pollutants in specific resources that constitute the living environment. The reference standards for measuring the Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) parameters are outlined by the Indonesian National Standardization Agency (2015), with the following limits: COD < 40 mg/L and BOD < 25 mg/L.

+ = compliant

- = non-compliant

95% confidence ($p < 0.05$). Statistical analysis was performed using SPSS 22 software (Ernita et al., 2013; Abumandour & El-Bakary, 2017).

RESULTS AND DISCUSSION

RESULTS

Mutiara catfish have been successfully cultured for 90 days, from the larval stage to the pre-adult stage. A sample at the pre-adult stage (90 days) is shown in Figure 1. Additionally, species identification was conducted based on the determination letter for the Mutiara catfish (number: 019/BI/SH/III/01840), issued by the Animal Systematics Laboratory, Faculty of Biology, Universitas Gadjah Mada. The classification of Mutiara catfish is as follows:

During the rearing of Mutiara catfish, feeding, monitoring of water quality parameters, temperature control, and disease management efforts were carried out. Morphometric aspects assessed included relative gill weight (%) for both the right and left sides, relative arborescent weight (%) for both the right and left sides, the ratio of branchial arch length to total length (%), the ratio of branchial filament length to branchial arch length (%), the average number of branchial filaments per branchial arch, the average density of branchial filaments (filaments/cm), the average number of branchiospinalis per branchial arch, the average density of branchiospinalis (rakers/cm), the ratio of relative arborescent weight (%) for both the right and left sides to total fish weight, and the ratio of the number of arborescent branches to total arborescent weight.

Calculation results of gill morphometry and arborescent of Mutiara catfish (*Clarias gariepinus* (Burchell, 1822))

Morphometry and the ratio of gill and arborescent structures in *Clarias gariepinus* were analyzed at each developmental stage. Samples were taken at the beginning, middle, and end of each developmental stage, specifically during the larval stage were sampled on the 1st, 7th, and 14th days, the juvenile stage was sampled on the 15th, 18th, and 21st days, and post-juvenile to pre-adult stage were sampled on the 22nd, 56th, and 90th. The results of the study

Regnum	: Animalia
Phylum	: Chordata
Subphylum	: Vertebrata
Superclassis	: Gnathostomata
Classis	: Teleostei
Ordo	: Siluriformes
Familia	: Clariidae
Genus	: *Clarias*
Species	: *Clarias gariepinus*

Figure 1. Sample of Mutiara catfish at the pre-adult stage (90 days)

indicate that statistical analysis revealed significant differences in the relative gill weight between the larval, juvenile, and post-juvenile to pre-adult stages. Complete data are presented in Table. 1.

Gill and arborescent of Mutiara catfish (*Clarias gariepinus* (Burchell, 1822))

Mutiara catfish have gills located in the head cavity, which are covered by the operculum. The gills are divided into two symmetrical sides: the right side (dexter) and the left side (sinister). In the larval stage, the gills appear blackish-gray, while in the pre-adult stage, they are pink. Mutiara catfish possess four pairs of branchial arches and eight pairs of branchial filaments. At the larval, juvenile, and post-juvenile to pre-adult stages, the relative gill weight values of Mutiara catfish are 0.01 ± 0.01%, 0.04 ± 0.00%, and 0.50 ± 0.46%, respectively (Table 1.). Statistical analysis revealed significant differences in the relative gill weight between the larval, juvenile, and post-juvenile to pre-adult stages ($p < 0.05$).

Branchial arch

The *branchial arch* of the Mutiara catfish gill is located within the gill chamber. Each arcus consists of two arches that point in the ventral and dorsal directions. The ratio of *branchial arch* length at each developmental stage (larvae, juveniles, and post-juveniles to pre-adults) was 2.10 ± 2.32%, 5.90 ± 1.69%, and 18.85 ± 8.61%, respectively (Table 1.). Statistical analysis revealed a significant difference in the ratio of branchial arch length between the larval, juvenile, and post-juvenile to adult stages ($p > 0.05$).

Filamen branchialis

The *branchial filaments* are perpendicularly attached to the posterior part of the *branchial arch*. In Mutiara catfish, the *branchial filaments* are densely and tightly arranged, with the median part of the filament generally being longer than the lateral part. Statistical analysis showed a significant difference in the ratio of *branchial filament* length to *branchial arch* length between the larval, juvenile, and post-juvenile to pre-adult stages ($p > 0.05$). The average *branchial filament* length per *branchial arch* was highest in the post-juvenile to pre-adult stage, followed by the juvenile stage, and was smallest in the larval stage. The mean values for these stages were 17.84 ± 2.03, 1.18 ± 0.30, and 0.47 ± 0.45, respectively (Table 1.). The mean number of *branchial filaments* per *branchial arch* was 20.11 ± 19.43, 39.44 ± 11.64, and 53.83 ± 17.84 for the larval, juvenile, and post-juvenile to pre-adult stages, respectively (Table 1.). Additionally, the average *branchial filament* density for Mutiara catfish at the larval, juvenile, and post-juvenile to pre-adult stages was 0.18 ± 0.21, 0.10 ± 0.00, and 0.10 ± 0.00, respectively (Table 1).

Branchiospinalis

The *branchiospinalis* (*gill rakers*) of Mutiara catfish is located anterior to the *branchial arch*. The *gill rakers* are densely arranged and relatively small in size. They are unevenly distributed with short and tapered ends. Statistical analysis revealed that the average number of *branchiospinalis* per *branchial arch* in the post-juvenile to pre-adult stages was significantly higher than in the larval and juvenile stages ($p < 0.05$). The mean values for these stages were 7.58 ± 6.34, 16.91 ± 2.71, and 28.80 ± 8.77, respectively (Table 1.). The mean density of branchiospinalis at the larval, juvenile, and post-juvenile to pre-adult stages was 0.13 ± 0.00, 0.23 ± 5.79, and 0.24 ± 0.04, respectively (Table 1.).

Arborescent

Arborescent structures in Mutiara catfish appear during the post-juvenile stage, specifically in the age range of 22 to 56 days. These *arborescents* are formed from the extension of the second and fourth gills on both the right and left sides. The *arborescent* on the second-gill arch is smaller, while the one on the fourth-*gill arch* is larger. The *arborescent* of the pink Mutiara catfish is dendritic in shape. The mean values for the ratio of the right and left relative *arborescent* weights (%) to total fish weight and the ratio of the number of *arborescent* branches to total *arborescent* weight were 0.11 ± 0.08 and 171.11 ± 34.40, respectively (Table 1.).

Measurement of parameters of water quality for Mutiara catfish maintenance

Environmental water parameters during the catfish rearing process were measured every 10 days for general parameters, and every 12 days for BOD and COD indicators, over a 90-day rearing period. The general parameters measured included water temperature, ammonia, pH, and dissolved oxygen (DO).

The results indicated that the water temperature ranged from an average of 27.10 to 29.57°C, DO levels ranged from 3.03 to 7.53 mg/L, ammonia concentrations ranged from an average of 0.25 to 0.67 ppm, and pH values ranged from an average of 7.57 to 9.17. The lowest BOD concentration was recorded at 2.33 mg/L, while the highest was 29.08 mg/L. The lowest COD concentration was 4.691 mg/L, and the highest was 123.90 mg/L. Complete data results are presented in Table. 2.

DISCUSSION

The morphology of the Mutiara catfish is characterized by a laterally compressed body that tapers towards the caudal region, with a color gradient ranging from black to light brown. Occasionally, spots of gray or olive-green are present. The ventral surface is white. The head is flattened and protected by robust bony structures. The dorsal fin extends from near the head to the posterior end of the caudal fin, while the anal fin spans from the anal opening to the base of the tail. The tail fin is rounded and lacks an adipose fin. The pectoral fins bear barbs, and the anal fin contains 61-75 rays. The different strains or variants of this species cannot be distinguished based on morphology alone and must be identified through microsatellite DNA analysis (Skeleton, 1993; FAO, 2025; Iswanto et al., 2015).

The gills of Mutiara catfish are located within the head cavity and are covered by the bones of the gill cover, known as the operculum. The operculum is composed of the bones that protect the gills (Karlina & Luthfi, 2018; Hady et al., 2019; Nwachi et al., 2023). The gills play a crucial role in several metabolic processes in the fish's body during growth and development. These processes include the exchange of oxygen and carbon dioxide, osmoregulation, ion balance, and nitrogen excretion (Hady et al., 2013; Cruz & Fernandes, 2016). A smooth metabolic process is indicative of the fish's overall health. One of the key indicators of successful aquaculture and fish health is their morphology (Ernita et al., 2013; Maina, 2018; Islam et al., 2022). The results showed that the weight of the gills increased proportionally as the fish developed from the larval to the post-juvenile and pre-adult stages.

The increase in the relative weight of the gills from the larval to the preadult stage is believed to influence the fish’s ability to adapt to fluctuations in dissolved oxygen levels. The relative weight of the gills serves as an early indicator of the respiratory system's adaptability to environmental conditions (Ernita et al., 2013; Keyombe et al., 2015; Hady et al., 2019). Mutiara catfish gills exhibit relatively short gill filament sizes, which aligns with findings by Elsheikh (2013) and Fu et al. (2014). They noted that fast-swimming fish, such as skipjack tuna (*Katsuwonus pelamis*) and mackerel (*Scomber japonicus*), have larger gill sizes with shorter diffusion distances. Conversely, species like *Clarias gariepinus*, which inhabit slow-flowing waters, have smaller gill sizes with shorter filaments.

Catfish gills feature a thin membrane located parallel to the operculum bone. This membrane serves as both a water vent and a valve that controls the outflow of water during the gill opening (Ernita et al., 2013). Mutiara catfish have a relatively sparse structure and a certain number of branchial arch. According to Maina (2018), the branchial arch is a respiratory and arteriovenous pathway derived from filamentous blood vessels, directly linked to respiration and circulation. As the ratio of branchial arch increases, it affects the length of the afferent arterial blood vessels, thereby optimizing the gill circulation system. Additionally, the branchial arch plays a crucial role in supporting the fish's digestive system.

According to Mistri et al. (2016), the branchial arch has a wavy structure that contains mucus, which helps facilitate the passage of food to the pharynx. Additionally, the branchial arch is equipped with taste epithelium that aids in discerning the types of food the fish prefer (Ernita et al., 2013). This finding aligns with the study by Kumari et al. (2005), which noted that omnivorous fish typically have a shorter branchial arch compared to herbivorous fish. A shorter branchial arch increases the curvature angle of the pharyngeal cavity, allowing larger food particles to pass more easily. Another important structure in the gills is the gill rakers or serrations. The ceratobranchial rakers are a collection of pharyngeal teeth located at the posterior part of the gills, directly connected to the stomach (Akmal et al., 2020).

Branchial filaments are the primary functional units of gill tissue and are directly linked to the efficiency of gas exchange (Evans et al., 2005). Furthermore, the movement of branchial filaments is crucial in minimizing sediment deposition in the gills, which helps prevent the blockage of blood capillaries (Mistri et al., 2016). In Mutiara catfish, the arrangement of branchial filaments is generally more tenuous and irregular. The results of the study revealed significant differences in the ratio of branchial filament length to branchial arch length across the three developmental stages of the Mutiara catfish gill. Additionally, Mutiara catfish exhibit a high average branchial filament density, which may contribute to their enhanced adaptability to environments with fluctuating dissolved oxygen levels.

Wilson & Laurent (2002) explain that the number and density of filaments influence the quantity of primary and secondary lamellae, thus increasing the surface area available for gas exchange and ion regulation. Branchiospinalis, a small structure formed from cartilage, consists of two pairs (lateral and medial) and is located at the anterior part of the branchial arch. According to Burleson (2009), studies on the role of branchiospinalis in the respiratory system of fish are still limited. Nevertheless, branchiospinalis plays a crucial role in regulating the size of feed particles entering the pharyngeal cavity. Kumari et al. (2005) found that the more pointed shape of branchiospinalis in carnivorous and omnivorous fish serves to prevent feed from escaping and stops large, unwanted food from entering the pharynx.

Mutiara catfish has a low average number of branchiospinalis per branchial arch. This is thought to be influenced by the carnivorous feeding behavior of Mutiara catfish, as they do not rely on complex filtering processes. Kumari et al. (2009) stated that the density of branchiospinalis can be influenced by the volume of water entering through the gills. Given that Mutiara catfish typically inhabit slower-flowing waters, the volume of water passing through their gills is relatively low and slow. As a result, the branchiospinalis in Mutiara catfish is less dense, enabling it to filter the incoming feed more effectively.

Based on the previously described morphometric characteristics, environmental parameters play a crucial role in maintaining the survival of Mutiara catfish. These parameters are essential for the existence, production, and metabolic activities of the fish. The water temperature during the study ranged from 27.10 to 29.57°C (Table 2.), which falls within the normal temperature range for tropical regions, typically between 22 to 35°C, supporting the adaptation process of the fish (Howerton, 2001; Adeyomo et al., 2003; Ogunji & Awoke, 2017). Cnaani (2006) and Ogunji & Awoke (2017) further explained that extreme temperatures can hinder the fish's ability to adapt, affecting their physiological response and potentially leading to death due to disruptions in metabolic pathways and osmoregulatory functions. Additionally, Ogunji & Awoke (2017) noted that water temperature can influence fluctuations in dissolved oxygen (DO) levels. Higher or more extreme temperatures tend to reduce DO levels in water. According to Dianye & Olumuji (2014), DO levels supporting fish maintenance are typically between 3-5 mg/L or higher. The study results showed DO levels ranging from 3.03 to 7.53 mg/L, indicating that the temperature during the maintenance period did not experience extreme fluctuations.

Other environmental parameters, such as pH and COD, are also crucial in maintaining optimal conditions for mutiara catfish rearing. The results showed that the pH value ranged from 7.57 to 9.17 (Table 2.). This pH range slightly exceeds the limit set by the Indonesian National Standardization Agency for catfish rearing, which is between 6.5 and 8.5. The increase in pH above the acceptable limit is likely influenced by elevated COD levels. This is often related to sun exposure and weather fluctuations, such as rain, which can increase the concentration of carbon dioxide, thereby raising acidity (Ani-Sabwa et al., 2014; Dianye & Olumuji, 2014; Ogunji & Awoke, 2017). This is supported by the COD measurement data, which showed that three out of seven samples exceeded the environmental quality standard (Table 3.). While weather fluctuations are unavoidable during catfish rearing, they can be managed by replacing a portion of the rearing water or adding salt to the pond. These actions help maintain the stability of the pH and carbon dioxide concentrations (Gunawan, 2016). Given that the pH increase was relatively small (0.67), it remains within tolerable limits.

The final environmental parameters considered were ammonia and BOD levels. The results showed that ammonia levels ranged from 0.25 to 0.67 ppm (Table 2.). According to the Indonesian National Standardization Agency (2015) and Gunawan (2016), ammonia levels that can be tolerated in catfish rearing should not exceed 0.01 ppm. The observed increase in ammonia levels is likely linked to the rise in BOD levels. The results indicated that two out of the seven samples exceeded the environmental quality standards (Table 3.). This increase is probably due to the accumulation of uneaten feed and fecal matter, which contribute to higher ammonia and bacterial levels in the rearing water. The data also showed that as the rearing period progressed and the fish aged, ammonia and BOD levels increased. This suggests a higher feed consumption activity by the catfish as they grow. This is consistent with the growing endurance of the catfish, supported by the development of additional structures in the gills, such as arborescent organs. Gills and arborescent are the two main organs involved in respiration. The arborescent organ helps the catfish by directly absorbing air, which aids in respiration, especially in environments with insufficient oxygen. This finding aligns with research by Maina and Mbanga (2018), which suggests that arborescent organs help catfish survive in extreme environmental conditions.

CONCLUSION

The morphological characteristics of Mutiara catfish (*Clarias gariepinus* (Burchell, 1822)) are similar to those of other catfish species, as it is the result of crossing four previous strains. Significant differences were observed in the gill morphometry and arborescent features of Mutiara catfish across various developmental stages. The post-juvenile to pre-adult stages exhibited higher values, followed by the juvenile stage, with the lowest values observed at the larval stage. This trend suggests that, over time, the development of the gills and arborescent organs in Mutiara catfish progresses effectively, supporting the fish's survival. Environmental parameters such as temperature, ammonia, pH, dissolved oxygen (DO), chemical oxygen demand (COD), and biochemical oxygen demand (BOD) play a crucial role in the rearing process of Mutiara catfish by maintaining the stability of physiological and osmoregulatory functions.

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