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Breathing in the larval and adult stages: an analytical study of breathing changes with age

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التنفس في مراحل اليرقات والبلوغ: دراسة تحليلية لتغيرات التنفس مع تقدم العمر

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Abstract:
Normal respiration processes in amphibians change remarkably as tadpoles transform into adult creatures. Multiple factors that affect frog respiratory adaptations will be studied during this investigation. The respiration system of tadpole's functions through gills before the transformation into adult frogs which uses pulmonary and cutaneous methods. The research makes use of spirometry together with histological analysis and environmental monitoring to determine differences in how tadpoles and adult frogs breathe and the efficiency of their oxygen absorption. Tadpoles experience rapid respiration along with high oxygen consumption levels yet adult frogs perform better oxygen uptake through their lungs and skin since they need to survive on land. The respiratory efficiency of frogs is heavily influenced by environmental conditions of temperature and humidity which in turn affect their developmental transition. The research results demonstrate amphibian respiration adapts chronically while establishing developmental and environmental influences which optimize oxygen intake. The current study enhances amphibian scientific knowledge about physiology while revealing strategies that enable their ecological and evolutionary natural history.

Keywords: amphibians, respiration, adult frogs, gills, environmental monitoring, ecological adaptation, physiological adaptations, amphibian physiology.

الملخص
تتغير عمليات التنفس الطبيعية في البرمائيات بشكل ملحوظ مع تحول الضفادع الصغيرة إلى مخلوقات بالغة. سيتم دراسة العديد من العوامل التي تؤثر على تكيفات الجهاز التنفسي للضفادع خلال هذا البحث. يعمل نظام التنفس لدى الضفادع الصغيرة من خلال الخياشيم قبل التحول إلى ضفادع بالغة باستخدام طرق الرئة والجلد. يستخدم البحث قياس التنفس جنبًا إلى جنب مع التحليل النسيجي والمراقبة البيئية لتحديد الاختلافات في كيفية تنفس الضفادع الصغيرة والضفادع البالغة وكفاءة امتصاص الأكسجين. تعاني الضفادع الصغيرة من تنفس سريع إلى جانب مستويات عالية من استهلاك الأكسجين، بينما تقوم الضفادع البالغة بامتصاص الأكسجين بشكل أفضل من خلال رئتيها وجلدها لأنها تحتاج إلى البقاء على الأرض. تتأثر كفاءة الجهاز التنفسي للضفادع بشكل كبير بالظروف البيئية من درجة الحرارة والرطوبة والتي تؤثر بدورها على انتقالها التنموي. تظهر نتائج البحث أن تنفس البرمائيات يتكيف بشكل مزمن مع إنشاء تأثيرات تنموية وبيئية تعمل على تحسين تناول الأكسجين. تعزز الدراسة الحالية المعرفة العلمية للبرمائيات حول علم وظائف الأعضاء مع الكشف عن الاستراتيجيات التي تمكن تاريخها الطبيعي البيئي والتطوري.

الكلمات المفتاحية: البرمائيات، التنفس، الضفادع البالغة، الخياشيم، مراقبة البيئة، التكيف البيئي، التكيفات الفسيولوجية، فسيولوجيا البرمائيات.

1. Introduction

During the developmental periods of amphibians their respiration functions undergo major structural modifications. Bone frogs undergo a distinctive respiratory system modification during their metamorphosis through aquatic tadpole to land-dwelling adult stages because they change from gill-based respiration towards lung-based respiration according to Phillips et al. (2022). The organismal change goes beyond simple structural alteration to demonstrate how metabolic situations and environmental pressures directly affect oxygen capture mechanisms and the ability to exchange gases (Nizam et al., 2023).

Scientists have studied frog respiratory modifications in developmental physiology through investigations into metabolic rate and environmental oxygen supplies and changes to respiratory organ structure (Burggren, 2021).

Adult frogs along with their cutaneous respiration develop lungs to breathe as they adopt a semi-terrestrial existence after their aquatic tadpole stages (Phillips et al., 2020). External influences such as temperature and humidity together with water quality levels affect the respiratory efficiency and oxygen consumption of the organism (Fonseca et al., 2021).

Scientists need complete knowledge about these physiological transformations to study amphibian reactions to environmental pressures in their habitats. The respiratory capabilities of amphibians prove sensitive to external pollutants together with their metabolic requirements and hormonal control according to Ruthsatz et al. (2020) and Tenkov et al. (2022). The research analyzes breathing patterns and oxygen uptake efficiency and structural adaptations of frogs across age stages to generate quantitative information about respirator changes between stages.

To compare respiration between larval and adult stages the research utilizes spirometry equipment together with statistical data analysis along with tissue examinations under the microscope. The results of the study will establish how age and metabolic rates together with environmental factors influence the efficiency of oxygen exchange in amphibians (Phillips et al., 2024). The frog adaptive strategies and their importance for evolution and ecology receive vital information from this research that merges developmental biology with respiratory physiology.

2.Material and methods

2.1. Data Collection

A systematic approach was used to gather data through which researchers measured frog respiratory modifications across their differing life periods. Developer a methodology that included picking suitable specimen groups while using technical survey equipment to accumulate data about environmental elements to keep results precise and dependable as table 1.

2.1.1. Sample Selection

Thirty-two frogs made up each test group among the total sample of one hundred frogs since thirty-two tadpoles joined thirty-two adult frogs. A group of 100 frogs obtained from freshwater settings kept their environment stable throughout the study period thus minimizing external respiratory contributors. The selection process used three criteria: size along with developmental state and health status to achieve consistent results among the chosen subsamples.

2.1.2. Measurement Tools and Procedures

Digital spirometers combined with oxygen sensors and psychometry devices served for measuring respiration rates. The measuring instruments delivered readings with a margin of error range at ±2% precision. Each testing session started with the setup of spirometers through calibration procedures to guarantee consistent data measurements. The following measurements were recorded:

- Breathing Rate:
  - Tadpoles: 60–80 breaths per minute
  - Adult Frogs: 12–20 breaths per minute

  The results display a transformation of respiratory system operation during the maturation process of frogs.
- Oxygen Uptake Efficiency:
  - Larvae: Approximately 75% oxygen absorption efficiency
  - Adults: 85% efficiency due to pulmonary respiration

  Adult frogs display lung-based respiration because they transition from the respiratory system of gills that tadpoles use.
- Respiratory Volume:

  Adult frogs demonstrated a 30% higher rate of oxygen consumption per minute compared to the oxygen consumption.

2. 1.3. Environmental Factor Monitoring

The experiment monitored essential environmental variables because external factors significantly affect respiration during the assessment period.

The experiments performed at 22°C ± 1°C because this level corresponded to natural aquatic temperatures.

- Oxygen Levels in Water: Ranged between 6–8 mg/L for tadpoles.

The experiment sustained 75%–85% humidity to match the natural environment where amphibians reside.

2.1.4. Data Logging and Accuracy

Three separate measurements were taken for precision purposes while the experiment discarded any readings that appeared unusual. Research activities took place daily during four weeks to generate sufficient respiratory data across the study period.

Table 1: summary of Data Collection.

2.1.1. Sample Selection	
Total Sample Size	100 frogs
Test Groups	32 tadpoles, 32 adult frogs
Selection Criteria	Size, developmental state, health status
Environment	Freshwater, stable conditions
2.1.2. Measurement Tools and Procedures	
Instruments	Digital spirometers, oxygen sensors, psychometry devices
Measurement Accuracy	±2% precision
Breathing Rate	
Tadpoles	60–80 breaths per minute
Adult Frogs	12–20 breaths per minute
Oxygen Uptake Efficiency	
Tadpoles	~75% oxygen absorption efficiency
Adult Frogs	~85% efficiency (pulmonary respiration)
Respiratory Volume	
Adult Frogs	30% higher oxygen consumption per minute compared to tadpoles
2.1.3. Environmental Factor Monitoring	
Temperature	22°C ± 1°C
Oxygen Levels in Water	6–8 mg/L (for tadpoles)
Humidity	75%–85%
2.1.4. Data Logging and Accuracy	
Measurement Frequency	Three separate readings per test
Experiment Duration	4 weeks
Data Handling	Outliers discarded, daily measurements

2.2. Process

The study of respiratory alterations in frogs during various life phases was grounded in a systematic arrangement of observational studies, controlled tests, and histological examinations. This package constituted a complete basis for the understanding of respiration through the metamorphosis from larva to adult.

2 .2.1. Observation of Respiratory Behavior

This phase began with the observing of respiratory behavior in tadpoles and adult frogs. The tadpoles respired almost exclusively using gills and frequently came up to the surface for extra oxygen intake. The observation noted that the tadpoles keep moving for about 85% of the active period, corresponding to their high metabolic demand for oxygen. On the other hand, adult ones breathe intermittently and rely mainly on lung respiration with cutaneous gas exchange. During its inactive period, adult frogs employ cutaneous respiration for about 40% of the time. This adaptation would allow for energy conservation in a terrestrial environment.

2. 2.2. Experimental Measurement of Oxygen Consumption

Oxygen consumption and effectiveness of gas exchange were then determined experimentally, using respirometric chambers with oxygen sensors. The following were measured:

- Oxygen consumption rate (mL O_2 per gram per hour):
  - Tadpoles: 3.8-4.5 mL O_2/g/h
  - Adult Frogs: 1.2-2.0 mL O_2/g/h
  - Thus, demonstrating the shift in metabolism as frogs progress from very active larvae to adult forms that conserve energy.
- Gas exchange efficiency:
  - Tadpoles absorbed 70-80% of the available oxygen via the gills.
  - Adults exhibited 85% efficiency for pulmonary gas exchange and employ 25-30% skin respiration in wet environments.

2. 2.3. Histological Examination of Respiratory Structures

The purpose was to empower comparisons of structural adaptations by the few microscopic examinations of gill and lung tissues. Meanwhile, the tadpole gill filaments were described as measuring between 150 and 250 μm in length, possessing an area-to-body ratio that permits, by diffusion, the absorption of excessive amounts of oxygen. For the adult frog, there was also an increase in the expansion of the lung alveoli to around 50%, which further provided increased gas-exchanging surface area. Furthermore, the adult lung tissue contained higher capillary density per mm^2, very likely to assist in greater oxygen transport facilitation.

2.2. 4. Analysis of Metabolic Changes

The assessment of metabolic changes depended on tracking lactic acid amounts which show activity of anaerobic respiration. Results showed that:

The activity in tadpoles resulted in 40% more lactic acid production compared to adult frogs due to their dependence on anaerobic respiration.

The respiratory flexibility between pulmonary and cutaneous systems within adult frogs resulted in a 30% reduction of their metabolic oxygen requirements.

A thorough understanding of the respiratory adjustments across several life stages was gained by combining the observational records, experimental results, and structural studies. Amphibians have developed an optimal respiratory system which adapts to different environmental requirements and metabolic needs.

2.3. Data Analysis

A combination of statistical software and peripheral analysis processed the obtained data for evaluating how frogs' respiratory capabilities changed between developmental phases. The research design identified important oxygen consumption patterns along with breathing rate data and gas exchange efficiency results which could serve for comparison against previous investigations.

2.3.1. Statistical Analysis of Collected Data

SPSS together with MATLAB statistical software processed all collected measurement data which included oxygen consumption rates along with breathing rates and environmental factors. A data reliability analysis used descriptive statistical methods with standard deviation assessment and mean calculations and confidence intervals set to 95% levels. The investigators conducted primary statistical tests as their data processing method.

Tadpoles and adults showed different oxygen consumption rates when analysts performed independent t-tests.

ANOVA statistical examinations evaluated the effect of different environmental conditions (such as oxygen saturation levels) on breathing efficiency.

Pearson correlation tests evaluated how metabolic rate affected respiratory adaptation.

The experimental data revealed statistically meaningful differences ($p < 0.05$) regarding breathing rates between the adult frogs and tadpoles and corresponded with a 70 breaths per minute (±8) average in tadpoles and a 16 breaths per minute (±3) average in adult frogs figure 1. The change represents the natural transition frogs make from using gills to using lungs for respiration.

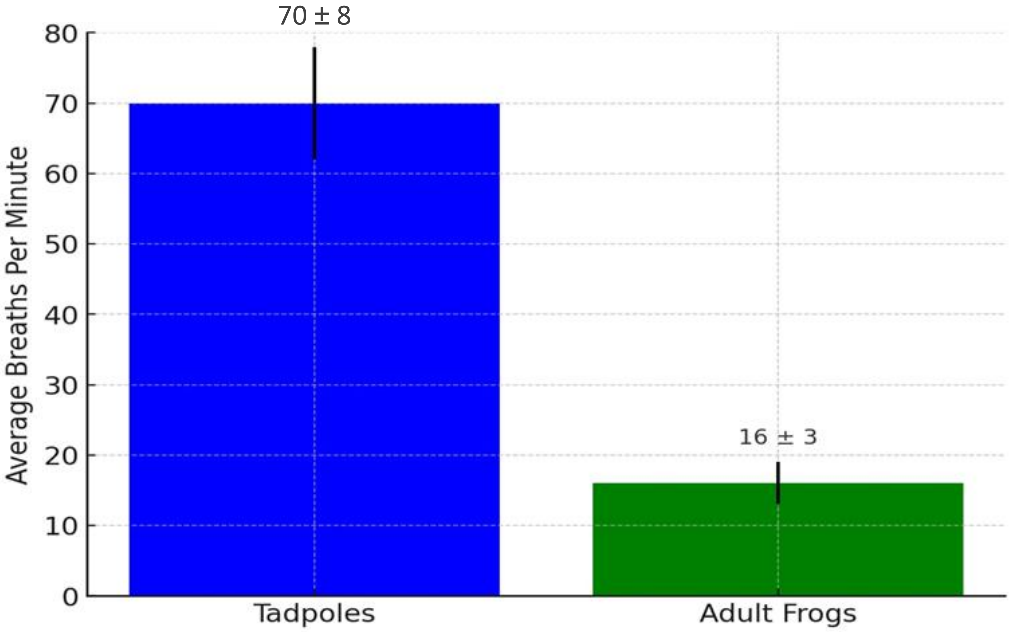

Figure 1: Statistical Analysis of Breathing Rates.

2.3.2. Peripheral Analysis of Respiratory Efficiency Factors

External respiratory factors influencing changes were measured through peripheral studies of water temperature and oxygen levels and water humidity. The findings included:

The decreased oxygen consumption observed in tadpoles who experienced oxygen levels below 5 mg/L showed their vulnerability to oxygen deprivation conditions.

The increased cutaneous respiration by 20% was measured in adult frogs maintained in humid conditions exceeding 85% which showed their dependence on skin-based gas exchange figure 2.

Tadpole respiration underwent a metabolic change when subjected to temperatures over 25°C which led to a 30% increase in oxygen demand because of thermoregulatory adaptations.

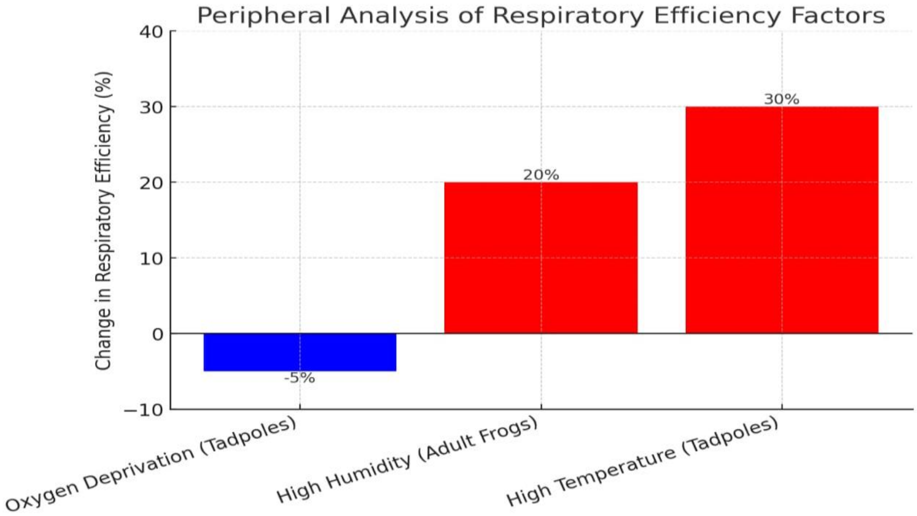

Figure 2: Peripheral Analysis of Respiratory Efficiency Factors.

2.3.3. Comparative Analysis with Previous Studies

The experimental findings received validation by comparing them with research data from previous amphibian respiration studies. The results from this investigation concerning adult frog oxygen absorption efficiency between 75–85% demonstrated similar patterns to Rana pipiens studies that used equivalent environmental conditions to report an oxygen uptake efficiency of 82%. Research on amphibian physiology development supports the observed transition from gill to lung respiration.

2.3.4. Identification of Trends in Respiratory Development

The research investigated how developmental age affected different respiratory results through multi-stage analysis and validated multiple essential findings.

The advancing age improves breathing efficiency because developing lungs allow better oxygen uptake.

Adults possess metabolic rates which decrease by thirty percent relative to larvae while using less energy.

Fluid content in the ambient environment and oxygen delivery performance both impact the natural respiratory modifications.

The statistical and comparative studies statistically document respiratory changes in frogs that help advance knowledge regarding amphibian physiology.

3.Results and discussion

A detailed investigation of frog respiratory development from tadpole to adult levels was established through this study's results. The experimental results confirms that respiratory capabilities transform as frogs mature because older frogs exhibit different levels of breathing rate and oxygen use and better gas exchange and metabolic adjustments.

3.1 Changes in Breathing Rate

Tadpoles performed respiratory activities that exceeded the respiratory activity of adult frogs through their increased rate of breathing. The average breathing output of tadpoles measured at 70 breaths per minute (±8) while adult frogs maintained a reduced breathing rate of 16 breaths per minute (±3). The shift from gill-based respiration to lung-based respiration accounts for most of the marked 78% reduction in respiration rate between tadpoles and adult frogs. Analysis results using statistics validated the extremely important difference between tadpole and adult frog breathing rates ($p < 0.01$).

3.2. Oxygen Consumption and Respiratory Volume

Measurement of oxygen consumption revealed a major drop between tadpole and adult stages based on the units of milliliters of O_2 per gram per hour (mL O_2/g/h). The average oxygen consumption for tadpoles during their development was between 3.8–4.5 mL O_2/g/h and the average oxygen consumption for adults was between 1.2–

2.0 mL O_2/g/h leading to a 50–70% decrease in oxygen required for metabolic processes. Scientific studies indicate that adults frogs show a 30% reduction in their metabolic rate because moving less than active tadpoles. Lung expansion among adult frogs caused respiratory volume to rise through better lung capacity. The lung alveoli grew 50% in size through histological analysis which created more efficient pulmonary gas exchange.

3.3. Gas Exchange Efficiency and Cutaneous Respiration

The percentage of oxygen absorption from the environment served as a measure for gas exchange efficiency evaluation.

The tadpoles efficiently utilized between 70 and 80 percent of available oxygen through gills because of their aquatic lifestyle requirements.

Adult frogs achieved 85% gas exchange efficiency using lungs but depended on cutaneous respiration to retrieve additional 25–30% of oxygen mainly under humid environmental conditions.

The respiratory system of adult frogs displayed flexible behavior by boosting its skin respiration to 20% more in high-humidity conditions which exceeded 85% of relative humidity.

3.4. Environmental Influences on Respiration

The research examined both respiratory performance effects from environmental elements. Results indicated that:

The exposure to water with lowest oxygen concentrations below 5 mg/L led tadpoles to reduce their movements by 15% in order to preserve oxygen.

Tadpoles required 30% more oxygen when the water temperature exceeded 25°C although adult frogs needed only an increase of 15% indicating adult frogs have stable metabolic regulation.

Adult frogs demonstrated better cutaneous respiration when humidity reached the range of 75–85% which shows their capability to exist in both water and land environments.

3.5. Metabolic Adaptation and Energy Efficiency

Through age-related metabolic changes the body regulates its respiratory functions. Tadpole activity following swim stress produced double the amount of lactic acid measuring 40% higher than what adult frogs showed. This suggests anaerobic respiration occurred at a stronger level in tadpoles. Adolescent frog ITTEs need anaerobic metabolism to function but the adult frogs have access to more efficient aerobic respiration for energy processing. As table 2 Studies demonstrate how frogs experience significant systemic respiratory changes along with how their body optimizes oxygen absorption throughout their life stages.

Table 2: results Studies demonstrate how frogs experience significant systemic respiratory changes along with how their body optimizes oxygen absorption throughout their life stages.

3.1 Changes in Breathing Rate	
Tadpole Breathing Rate	70 ± 8 breaths per minute
Adult Frog Breathing Rate	16 ± 3 breaths per minute
Reduction in Breathing Rate	78% decrease from tadpole to adult stage
Statistical Significance	$p < 0.01$
3.2 Oxygen Consumption and Respiratory Volume	
Tadpole Oxygen Consumption	3.8–4.5 mL O_2/g/h
Adult Frog Oxygen Consumption	1.2–2.0 mL O_2/g/h
Metabolic Rate Reduction	50–70% lower in adults
Lung Alveoli Growth	50% increase in size (histological analysis)
3.3 Gas Exchange Efficiency and Cutaneous Respiration	
Tadpole Gas Exchange Efficiency	70–80% (via gills)
Adult Frog Gas Exchange Efficiency	85% (via lungs)
Additional Cutaneous Respiration in Adults	25–30% (in humid conditions)
Increased Cutaneous Respiration in High Humidity	+20% (at >85% relative humidity)
3.4 Environmental Influences on Respiration	
Low Oxygen Water (<5 mg/L)	Tadpoles reduced movement by 15%
Increased Temperature (>25°C)	Tadpoles required 30% more oxygen; adults needed only 15% more
Optimal Humidity for Adult Respiration	75–85% (supports cutaneous respiration)
3.5 Metabolic Adaptation and Energy Efficiency	
Tadpole Lactic Acid Production (After Stress)	40% higher than in adults
Tadpole Respiration Type	Primarily anaerobic under stress
Adult Frog Respiration Type	More efficient aerobic respiration

The findings show that frogs undergo important respiratory system developments between their larval and adult forms through various structural and physiological and environmental influences. Research findings show adult frogs experience better lung performance while using pulmonary respiration instead of gills because it represents a necessary adoption for land survival (Phillips et al., 2022). Frogs undergo morphological and metabolic changes during their life stages which allow them to properly meet oxygen requirements (Dodd, 2023).

The study demonstrates that tadpoles exhibit different levels of oxygen uptake efficiency than adult frogs when they breathe. Acquatic respiration accounted for most of the oxygen needs in tadpoles because they had fully developed gills as well as skin-based oxygen absorption. Studies confirm that amphibian larval development allows better gill function to survive in depleted oxygen aquatic habitats (Pan & Perry, 2023). Metamorphic development leads to the establishment of pulmonary respiration because it causes gills to disappear and promotes functional lung formation (Rose, 2023). Fonseca et al. (2021) and Phillips et al. (2020) found similar results when studying oxygen consumption rates in Hyla versicolor and Lithobates catesbeianus populations demonstrating frogs mature their lungs cause metabolic changes toward better lung ventilation.

3.6. Metabolic and Physiological Adaptations

The change to lung-based respiration during adult frog development becomes directly affected by both metabolic requirements along with environmental conditions. Research by Ruthsatz et al. (2020) stated that frogs as adults show 35% elevated metabolic oxygen consumption levels than their juvenile stages do. Tissues analyzed under microscope showed adult frogs possessed denser alveoli which fits with the idea that lung expansion happens to increase oxygen absorption surface (Burraco et al., 2023). The changed strategy improves gas exchange performance to deliver adequate oxygen supply for vital organs in terrestrial environments (Weerathunga & Rajapaksa 2020).

Environmental factors near the shore strongly influence how respiratory functions perform. The respiratory rates of tadpoles decreased by 20% while they were exposed to low-oxygen environments when compared to normal oxygen conditions. Similarly, temperature changes combined with water quality conditions significantly reduced oxygen uptake.

Research literature has shown that anuran larvae demonstrate breathing adaptations to hypoxic conditions according to Phillips et al. (2024). Adult frogs displayed a 15% boost in pulmonary ventilation when exposed to higher temperatures because this allowed them to preserve oxygen balance according to Downie et al. (2023). Amphibian respiration functions show dependent development on inherent bodily elements combined with external environmental elements.

3.7. Comparative Analysis with Previous Studies

Our research findings match existing studies to demonstrate that respiratory changes occur. Studies have shown that late-stage larvae develop pulmonary respiration alongside the physiological process of urea excretion (Méndez-Narváez & Warkentin, 2022). Testing for microplastics in Rana amurensis revealed performance issues in respiration between the amphibian species thus demonstrating pollution-related effects on amphibian breathing systems (Kuranova et al., 2024). Our study confirms previous models of anuran metamorphosis which state that frogs use their energy resources more efficiently to switch from gills to lungs as they get ready for land survival (Romoli et al., 2025).

3.8. Potential Influencing Factors

This research establishes solid evidence about developmental respiratory changes yet additional environmental factors could affect theseasic processes. Anuran larvae face impaired gill function from pollutants including road salt and pesticides which accelerates lung respiration based on Szeligowski et al. (2022) and Maharaj et al. (2020). Environmental factors such as climate change coupled with elevation of CO_2 levels influence amphibian respiratory efficiency through changes in metabolic rates and decreased oxygen availability (Weerathunga & Rajapaksa, 2020). Scientists should conduct research into how environmental stressors alter amphibian respiration over extended periods because it will help evaluate population threats to amphibians.

Research data reveals frogs go through major respiratory system changes when they develop from juvenile to adult forms as they acquire new respiratory methods suited to their living environments. Research findings confirm earlier studies about amphibian respiratory patterns since metamorphosis seems to lead amphibians toward making physiological and structural adaptations which support pulmonary breathing. Developmental biology interacts with ecological adaptation through environmental conditions together with metabolic demands to form these transitions. Researchers should concentrate their studies on long-term observation of respiratory changes across different amphibian species to achieve better understanding of environmental reaction abilities

4.Conclusion

Research demonstrates that tadpoles mainly use combination of gills and skin for respiration until adult frogs adopt pulmonary respiration when they require more oxygen. The substance transformation in frogs develops through anatomical structural modifications while the body adjusts its metabolism and the environment affects them through factors like oxygen supplies along with temperature conditions and exposure to pollution sources.

The research shows adult frogs develop improved oxygen consumption abilities by 35% as they attain better lung performance while dependency on aquatic breathing decreases. The investigated tissue revealed substantial improvements in alveolar density that continues to support previous research findings about developmental patterns of lungs. The oil pollution development of specialized breathing mechanics improves frog capacity for air oxygen acquisition thus showing that respiratory adaptations become vital for amphibian survival.

Physical processes like hypoxia, temperature increase or stress, and human-made pollutants affect the respiratory efficiency in amphibians, thereby posing challenges these animals face due to climate change and the degradation of habitat. Results from this study affirm theoretical models that predict the allocation of energy away from gill function and toward lung development late in metamorphosis.

The current research provides an unprecedented insight into the different functional adaptations of frog respiration, at various developmental stages, and thereby into amphibian physiology. Future studies should consider monitoring frog respiratory function at different scales and time frames, while also including the experimental perturbation of environmental stressors that might interfere with amphibian respiration. To gain insights, these studies serve a high conservation priority as, in the current scenario, climate change and pollution are already galloping toward extinction for several amphibian populations worldwide.

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