A Review on Zebrafish (*Danio Rerio*) as an Ideal Model Organism

A.M. Rana
Associate Professor
Rizvi College of Arts, Science and Commerce

Abstract

Zebrafish (*Danio rerio*) have gained significant popularity as an ideal model organism in the fields of genetics, developmental biology, neuroscience, and disease research. Their small size, transparent embryos, rapid development, and genetic similarity to humans make them an invaluable tool for scientific research. This paper provides an overview of the unique biological characteristics of zebrafish, their advantages as a model organism, their application in various research fields, and their contributions to our understanding of human health and disease.

Key Words: Zebra fish, Model organism

Introduction

Zebrafish (*Danio rerio*), a member of the Cyprinidae family, are small freshwater fish commonly found in streams, ponds, rice fields, and other slow-moving or stagnant water bodies (Parichy, 2006; Spence et al., 2008). Their adaptability and unique characteristics have made them an invaluable model for research across various fields, including biomedicine, toxicology, and aquaculture (Ribas & Piferrer, 2014; Ulloa et al., 2013)

Researchers have utilized zebrafish to study improvements in aquaculture, focusing on areas such as husbandry, survival, immune response, nutrition, and growth (Hedrera et al., 2013; Oyarbide et al., 2012; Ulloa et al., 2013). Their short life cycle (~3 months), high reproductive output (100–200 eggs per clutch), and ease of care make them ideal for large-scale studies (Kimmel et al., 1995). Zebrafish embryos develop rapidly, hatching within two days, and their larvae can sustain themselves for up to five days by consuming their yolk (Lawrence, 2007). During this stage, their organs and systems function similarly to adults, allowing researchers to explore physiological processes at various life stages. Both larvae and adults thrive on diverse diets, including live feeds and plant-based experimental diets(Hedrera et al., 2013; Ulloa et al., 2013).

The zebrafish genome has been fully sequenced (assembly ZV9), providing researchers with advanced tools like RNA sequencing (RNA-seq) to investigate dietary effects at the molecular level (Cui et al., 2014; Li et al., 2013; Liu et al., 2014; Long et al., 2013; Xu et al., 2013) These insights have been applied not only to zebrafish but also to other aquaculture species.

In genetics, zebrafish offer a rich platform for innovation. Numerous transgenic lines, such as those expressing green fluorescent protein (GFP), allow for real-time observation of cellular processes (Renshaw et al., 2006). For example, GFPlabeled lines enable the tracking of immune cells like neutrophils during inflammation, providing a live, dynamic view of immune responses. It has also been shown that neutrophil migration from hematopoietic tissue to inflamed areas is correlated with pro-inflammatory cytokine production, making these transgenic models valuable for studying inflammatory processes (Barros-Becker et al., 2012).

In addition to their contributions to aquaculture and genetics, zebrafish are widely used in microplate assays, which allow researchers to conduct experiments efficiently with small sample volumes and replicate conditions. Their applications extend into fields like nutritional genomics and immunity, where zebrafish continue to illuminate the complex interplay between diet and health.

Overall, zebrafish stand out as a remarkable model organism due to their genetic accessibility, physiological parallels to humans, and utility in diverse research areas. Their role in developmental biology, disease modeling, and drug discovery underscores their importance in advancing both basic and applied science.

Biological Features of Zebrafish

Zebrafish possess several biological characteristics that make them excellent for scientific research. Their small size, about 2–4 cm in adulthood, makes them easy to maintain in laboratory settings, reducing costs and facilitating large-scale experiments (Kimmel et al., 1995). Transparent embryos allow researchers to observe developmental processes in real-time without invasive techniques, thanks to the lack of pigmentation in early stages (Spence et al., 2007).

Zebrafish embryos develop rapidly, with key milestones occurring within hours of fertilization, making them ideal for studying genetic mutations and environmental influences (Kimmel et al., 1995). They also share significant genetic similarity with humans, with about 70% of human genes and roughly 80% of human disease-related genes conserved in zebrafish (Spence et al., 2008) Additionally, their high reproductive capacity, with females laying up to 300 eggs per week, supports large-scale genetic and drug screening experiments (Parichy, 2006) .

Advantages of Zebrafish as a Model Organism

Zebrafish can be easily genetically modified, allowing researchers to study gene function, cellular dynamics, and organ development through technologies like CRISPR/Cas9 (Hwang et al., 2013; Renshaw et al., 2006). Their suitability for high-throughput screening is enhanced by their small size and rapid development, enabling large-scale assessments of drug efficacy and toxicity(Li et al., 2013).

Furthermore, zebrafish research is considered ethically less contentious, especially in early developmental stages when they cannot experience pain, offering an alternative to mammalian models (Lawrence, 2007).

Applications of Zebrafish in Research

Developmental Biology

Zebrafish have been vital in studying vertebrate development, with their transparent embryos and external fertilization providing insights into gastrulation, organogenesis, and neural development (Kimmel et al., 1995).

Genetics and Genomics

The fully sequenced zebrafish genome and mutant strains have advanced understanding of the genetic basis of development and disease(Westerfield, 2007). Genetic screens using zebrafish have identified genes related to pigmentation, heart development, and neurogenesis (Li et al., 2013).

Disease Modeling

Zebrafish models have been applied to human diseases, including cardiovascular disorders, cancer, and neurodegenerative diseases like Alzheimer's and Parkinson's (Li et al., 2013; Liu et al., 2014) their transparency allows real-time tracking of disease progression and treatment effects.

Drug Screening and Toxicology

Zebrafish's small size and transparent embryos enable large-scale drug screening and toxicity assessments, aiding pharmaceutical research (Li et al., 2013).

Challenges and Limitations

Despite their advantages, zebrafish have limitations. While they share significant genetic similarities with humans, they are not perfect analogs for all physiological processes (Ribas & Piferrer, 2014). Environmental factors like water temperature and pH can affect experimental outcomes, necessitating strict controls (Lawrence, 2007; Spence et al., 2008).

These features, advantages, and applications make zebrafish an indispensable model organism in modern scientific research.

Conclusion

Zebrafish (Danio rerio) are an invaluable model organism, offering a unique combination of genetic tractability, developmental transparency, and physiological relevance to human biology. Their contributions to our understanding of development, disease mechanisms, and drug discovery have been profound. While challenges remain, the advantages of using zebrafish in scientific research are undeniable, making them an essential tool for advancing knowledge in genetics, medicine, and biotechnology.

References

Barros-Becker, F., Romero, J., Pulgar, A., & Feijóo, C. G. (2012). Persistent oxytetracycline exposure induces an inflammatory process that improves regenerative capacity in zebrafish larvae. *PLoS ONE*, *7*(5), 1–9. https://doi.org/10.1371/journal.pone.0036827

Cui, J., Liu, S., Zhang, B., Wang, H., Sun, H., Song, S., Qiu, X., Liu, Y., Wang, X., Jiang, Z., & Liu, Z. (2014). Transciptome analysis of the gill and swimbladder of Takifugu rubripes by RNA-Seq. *PLoS ONE*, *9*(1). https://doi.org/10.1371/journal.pone.0085505

Hedrera, M. I., Galdames, J. A., Jimenez-Reyes, M. F., Reyes, A. E., Avendaño-Herrera, R., Romero, J., & Feijóo, C. G (2013). Soybean Meal Induces Intestinal Inflammation in Zebrafish Larvae. *PLoS ONE*, *8*(7), 1–10. https://doi.org/10.1371/journal.pone.0069983

Hwang, W. Y., Fu, Y., Reyon, D., Maeder, M. L., Shengdar, Q., Sander, J. D., Peterson, R. T., Yeh, J. J., & Keith, J. (2013). Efficient In Vivo Genome Editing Using RNA-Guided Nucleases Woong. *Nature Biotechnology*, *31*(3), 227–229. https://doi.org/10.1038/nbt.2501.Efficient

Kimmel, C. B., Ballard, W. W., Kimmel, S. R., Ullmann, B., & Schilling, T. F. (1995). Stages of embryonic development of the zebrafish. *Developmental Dynamics*, *203*(3), 253–310. https://doi.org/10.1002/aja.1002030302

Lawrence, C. (2007). The husbandry of zebrafish (Danio rerio): A review. *Aquaculture*, *269*(1–4), 1–20. https://doi.org/10.1016/j.aquaculture.2007.04.077

Li, Z. H., Xu, H., Zheng, W., Lam, S. H., & Gong, Z. (2013). RNA-sequencing analysis of TCDD-induced responses in zebrafish liver reveals high relatedness to in vivo mammalian models and conserved biological pathways. *PloS One*, *8*(10). https://doi.org/10.1371/journal.pone.0077292

Liu, S., Gao, G., Palti, Y., Cleveland, B. M., Weber, G. M., & Rexroad, C. E. (2014). RNA-seq analysis of early hepatic response to handling and confinement stress in rainbow trout. *PLoS ONE*, *9*(2), 1–8. https://doi.org/10.1371/journal.pone.0088492

Long, Y., Song, G., Yan, J., He, X., Li, Q., & Cui, Z. (2013). Transcriptomic characterization of cold acclimation in larval zebrafish. *BMC Genomics*, *14*(1). https://doi.org/10.1186/1471-2164-14-612

Oyarbide, U., Rainieri, S., & Pardo, M. A. (2012). Zebrafish (Danio rerio) larvae as a system to test the efficacy of polysaccharides as immunostimulants. *Zebrafish*, *9*(2), 74–84. https://doi.org/10.1089/zeb.2011.0724

Parichy, D. M. (2006). Evolution of danio pigment pattern development. *Heredity*, *97*(3), 200–210. https://doi.org/10.1038/sj.hdy.6800867

Renshaw, S. A., Loynes, C. A., Trushell, D. M. I., Elworthy, S., Ingham, P. W., & Whyte, M. K. B. (2006). A transgenic zebrafish model of neutrophilic inflammation. *Blood*, *108*(13), 3976–3978.

https://doi.org/https://doi.org/10.1182/blood-2006-05-024075

Ribas, L., & Piferrer, F. (2014). The zebrafish (Danio rerio) as a model organism, with emphasis on applications for finfish aquaculture research. *Reviews in Aquaculture*, *6*(4), 209–240. https://doi.org/10.1111/raq.12041

Spence, R., Gerlach, G., Lawrence, C., & Smith, C. (2008). The behaviour and ecology of the zebrafish, Danio rerio. *Biological Reviews*, *83*(1), 13–34. https://doi.org/10.1111/j.1469-185X.2007.00030.x

Ulloa, P. E., Peña, A. A., Lizama, C. D., Araneda, C., Iturra, P., Neira, R., & Medrano, J. F. (2013). Growth response and expression of muscle growth-related candidate genes in adult zebrafish fed plant and fishmeal protein-based diets. *Zebrafish*, *10*(1), 99–109. https://doi.org/10.1089/zeb.2012.0823

Westerfield, M. (2007). The Zebrafish Book; A guide for the laboratory use of zebrafish (Danio rerio). *(No Title)*.

Xu, H., Lam, S. H., Shen, Y., & Gong, Z. (2013). Genome-Wide Identification of Molecular Pathways and Biomarkers in Response to Arsenic Exposure in Zebrafish Liver. *PLoS ONE*, *8*(7). https://doi.org/10.1371/journal.pone.0068737