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Feed Adaptation as a Domestication Strategy for the Endemic Celebes Rainbowfish *(Marosatherina ladigesi)* under Controlled Rearing Conditions

Andi Muhammad Fahmi Attariq[1], Nursyahran[1]*
[1] Institut Teknologi dan Bisnis Maritim Balik Diwa, Makassar City, Indonesia
*Correspondent Author**: nursyahran00@gmail.com*
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Abstract

The Celebes rainbowfish *(Marosatherina ladigesi)* is an ornamental fish endemic to South Sulawesi, Indonesia, whose wild populations are declining because of habitat degradation and anthropogenic pressure. Domestication through feed adaptation is a key step towards supporting both conservation and aquaculture of this species. This study evaluated the effects of a commercial diet and three live feeds on the growth and survival of M. ladigesi reared under controlled conditions. We conducted a 42-day feeding trial using a completely randomised design with four treatments and three replicates: commercial feed, *Tubifex sp.,* earthworms, and Daphnia sp. Absolute weight gain and survival rate were measured and analysed using one-way analysis of variance (ANOVA) followed by Tukey's honestly significant difference (HSD) test at a 95% confidence level. Feed type significantly affected both growth and survival ($p < 0.05$). Tubifex sp. showed the highest absolute weight gain (2.58 g), followed by Daphnia sp. (2.00 g) and earthworms (1.70 g), whereas the commercial diet produced the lowest gain (1.25 g). Survival was highest in the Tubifex sp. and earthworm treatments (93.33% each), intermediate with *Daphnia sp.* (76.67%), and lowest with the commercial diet (66.67%). These findings indicate that live feeds, particularly *Tubifex sp.,* support better feed acceptance, growth, and survival during the early domestication of M. ladigesi, and that live-feed adaptation is a promising initial strategy for the domestication and ex situ conservation of this endemic species.

Keywords: fortification domestication; live feed; Marosatherina ladigesi; ornamental fish; survival; Tubifex

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INTRODUCTION

Indonesia is one of the world's megadiverse countries and harbours an exceptionally rich freshwater ichthyofauna, including many species that are restricted to single islands, lake systems, or river basins. This endemism makes Indonesian freshwater fishes highly valuable from both biological and economic perspectives, but it also makes them vulnerable, because small and isolated populations have little capacity to recover from habitat loss, overexploitation, and the introduction of non-native species. In remote regions of eastern Indonesia, non-native fishes have already become dominant components of riverine communities, illustrating how quickly native assemblages can be displaced when management is weak (Wibowo et al., 2020). Sulawesi, located in the biogeographic region of Wallacea, is particularly notable for its endemic freshwater fishes, many of which have attracted interest in the international ornamental fish trade.

The Celebes rainbowfish, Marosatherina ladigesi (Ahl, 1936), locally known as beseng-beseng, is a small, colourful atheriniform fish endemic to the karst streams and rivers of South Sulawesi, particularly in the Maros region from which its generic name is

derived. The species is traded as an ornamental fish, but its exploitation relies largely on wild catches, and destructive fishing and habitat degradation caused by activities such as sand dredging have led to its listing as Vulnerable on the IUCN Red List (Nasyrah et al., 2024). Field studies have shown that wild M. ladigesi are micropredators that feed mainly on small insect larvae and zooplankton, information that can guide the formulation of captive diets resembling their natural food (Nasyrah et al., 2024). Reducing pressure on wild stocks therefore requires the development of reliable captive production, which in turn depends on the ability of wild-caught fish to adapt to artificial environments and feeds.

The global ornamental fish trade is dominated by freshwater species, most of which are now sourced from breeding facilities, although a proportion is still collected from the wild and the exact share of wild-caught fish remains difficult to quantify (Evers et al., 2019). Wild collection can support rural livelihoods, but its sustainability depends on careful management and on the progressive replacement of wild-caught animals with captive-bred stock (King, 2019). Moreover, the handling, transport, and holding of ornamental fishes impose multiple stressors that can result in high and variable mortality, and lessons from food-fish aquaculture regarding stress physiology, feeding, and husbandry can be used to improve welfare and survival in ornamental species (Stevens et al., 2017). For endemic and threatened species such as M. ladigesi, the transition from wild capture to captive production is thus both a conservation priority and a technical challenge.

Domestication can be defined as a dynamic and continuous process that begins as soon as individuals are transferred from wild to captive conditions and proceeds as fish become progressively adapted to human-controlled environments (Teletchea, 2021). In the earliest stages of this process, one of the most critical bottlenecks is feed adaptation, that is, the acceptance by wild fish of the type of food that can be supplied reliably in captivity. Wild fish are adapted to detect and capture moving prey, and many species initially reject inert formulated diets. Studies on pikeperch (Sander lucioperca) have shown that individuals accepting pelleted feed early grew larger than those habituating later, and that live feed was preferred to artificial pellets during the transition, suggesting that weaning success is linked to individual behaviour and to the attractiveness of the offered food (Molnár et al., 2018). Similarly, in the conservation-oriented culture of the longfin smelt (Spirinchus thaleichthys), weaning juveniles from live Artemia to dry commercial pellets required a mixed-diet approach and careful monitoring of growth, survival, and body condition (Mulvaney et al., 2022). These examples show that the type of food offered during early captivity can determine whether domestication succeeds or fails.

Live feeds such as oligochaete worms and cladocerans are widely used in ornamental fish culture because they are readily recognised, stimulate feeding behaviour through movement, and provide high-quality protein and other nutrients. Annelids of the subclass Oligochaeta, including Tubifex sp. and the earthworm Eisenia fetida, are among the most cost-effective live feeds owing to their balanced nutrient profile and ease of culture, and their dietary use has been associated with improved growth, non-specific immunity, and flesh quality in a range of aquaculture species (Mugwanya et al., 2025). In aquarium species, natural foods have been reported to perform differently from commercial flakes, and the effects of a given feeding strategy can diverge markedly between co-housed species with different digestive anatomy, highlighting the need for species-specific feeding studies (Kasprzak et al., 2021). For M. ladigesi, live Tubifex worms produced better

absolute and specific growth, survival, feed conversion, haematological status, and disease resistance than dry Tubifex, Spirulina, and other diets, indicating that live feeds may be particularly suitable for this species (Amrullah et al., 2023).

Beyond nutrition, the success of early domestication depends on the physiological stress experienced by fish and on the quality of the rearing environment. Stocking density affects welfare through complex interactions with water quality, social behaviour, and feeding, and no single optimal density can be defined for all species or life stages (Saraiva et al., 2022). In recirculating and other intensive systems, inappropriate densities can impair behaviour, growth performance, feed utilisation, and immunity (Mugwanya et al., 2022). Water quality is equally important, because the accumulation of ammonia from fish excretion and uneaten feed can disrupt gill function and oxygen transport, cause oxidative stress, and suppress immune responses (Xu et al., 2021). The toxicity of ammonia is influenced by pH, temperature, dissolved oxygen, species, life stage, feeding, and stress, so appropriate water management is a prerequisite for successful culture (Parvathy et al., 2023). In feed adaptation trials, these environmental factors interact with diet: uneaten inert feed can deteriorate water quality, whereas well-accepted live feeds are consumed rapidly and leave fewer residues, potentially reducing stress and mortality.

Despite the conservation and economic importance of M. ladigesi, information on its feed adaptation under controlled conditions remains limited. Most available studies have focused on its ecology, reproduction, and size structure in the wild, while experimental work on captive feeding has been scarce and has rarely compared several locally available live feeds with a commercial diet under the same rearing conditions. In particular, the relative suitability of Tubifex sp., earthworms, and Daphnia sp., three live feeds that are inexpensive and easily cultured by small-scale farmers in South Sulawesi, has not been evaluated simultaneously for this species during the early stages of domestication. Such information is essential for designing practical feeding protocols that can be adopted by local hatcheries and conservation programmes, and for planning subsequent weaning strategies towards formulated diets.

The present study was therefore designed to evaluate feed adaptation as a domestication strategy for M. ladigesi under controlled rearing conditions. Specifically, it aimed to (1) compare the absolute weight gain of M. ladigesi fed a commercial diet, Tubifex sp., earthworms, or Daphnia sp. over a 42-day rearing period, and (2) compare the survival of fish among these feeding treatments. It was hypothesised that live feeds would be accepted more readily than the commercial diet and would therefore result in higher growth and survival. The results are expected to provide baseline information for the development of domestication technology, captive breeding, and ex situ conservation of this endemic Sulawesi species.

METHOD

The experiment was conducted from December 2025 to January 2026 at Padang Alla, Mandai District, Maros Regency, South Sulawesi, Indonesia, using a completely randomised design with four feeding treatments and three replicates: (A) commercial feed as the control, (B) live Tubifex sp., (C) earthworms, and (D) Daphnia sp. Twelve 40-L plastic containers were each filled with 30 L of freshwater and equipped with continuous aeration. A total of 120 M. ladigesi with a mean total length of 8 cm and a mean initial body weight of 2.7 g fish^{-1} were acclimatised to the rearing water, weighed individually with a digital balance (0.01 g precision), and stocked randomly at 10 fish per container, a density chosen to limit competition and social stress during early captivity (Saraiva et al., 2022;

Mugwanya et al., 2022). Fish were fed three times daily at 06:00, 15:00, and 19:00 Central Indonesian Time at a ratio of 3% of biomass, following feeding approaches previously applied to M. ladigesi and other small ornamental fishes (Amrullah et al., 2023; Kasprzak et al., 2021). Faeces and uneaten feed were siphoned every two days, followed by a 50% water exchange; dissolved oxygen, temperature, and pH were measured every morning and afternoon, and ammonia was measured weekly, because ammonia accumulation can impair growth and survival (Xu et al., 2021; Parvathy et al., 2023).

Absolute weight gain (AWG) was calculated as $AWG = W_t - W_0$, where W_t and W_0 are the mean final and initial body weights (g), respectively, and survival rate (SR) was calculated as $SR (\%) = (N_t / N_0) \times 100$, where N_t and N_0 are the final and initial numbers of fish in each container. These indicators are commonly used to evaluate feed acceptance and the performance of fish during the transition from wild to captive conditions (Mulvaney et al., 2022; Amrullah et al., 2023). Data on AWG and SR were tested by one-way analysis of variance (ANOVA), and when significant differences were detected ($p < 0.05$), means were compared using Tukey's honestly significant difference (HSD) test at a 95% confidence level. Water quality data were analysed descriptively by comparing measured values with the ranges considered suitable for freshwater fish culture.

RESULT AND DISCUSSION

All feeding treatments supported positive growth of *M. ladigesi* over the 42-day rearing period, as indicated by higher final body weights than initial weights in every treatment. However, the magnitude of weight gain and the proportion of surviving fish differed markedly among feeds (Table 1). ANOVA showed that feed type had a significant effect on absolute weight gain ($p < 0.05$), and Tukey's HSD test indicated that all four treatments differed significantly from one another ($p < 0.05$). Feed type also significantly affected survival ($p < 0.05$).

Table 1. Absolute weight gain and survival rate of *M. ladigesi* fed different feeds for 42 days (mean of three replicates).

Treatment	Feed	Absolute weight gain (g)	Survival rate (%)
A	Commercial feed	1.25^{a}	66.67
B	*Tubifex* sp.	2.58^{d}	93.33
C	Earthworm	1.70^{b}	93.33
D	*Daphnia* sp.	2.00^{c}	76.67

Different superscript letters in the same column indicate significant differences among treatments (Tukey's HSD, $p < 0.05$)

The highest absolute weight gain was obtained in fish fed *Tubifex* sp. (2.58 g), followed by *Daphnia* sp. (2.00 g) and earthworms (1.70 g), while the commercial diet produced the lowest gain (1.25 g). Absolute weight gain integrates feed intake, digestion, and the conversion of assimilated nutrients into body tissue, and it is therefore sensitive to both diet quality and feed acceptance. The superior performance of *Tubifex* sp. agrees with a previous study on *M. ladigesi*, in which live *Tubifex* worms produced better absolute and specific growth, feed conversion, and feed efficiency than dried *Tubifex*, *Spirulina*, and other diets (Amrullah et al., 2023). Oligochaete worms provide a balanced nutrient profile, and their dietary use has been associated with improved growth and non-specific immunity in a variety of cultured fishes (Mugwanya et al., 2025). Their soft bodies and continuous movement also make them highly attractive to micropredatory fishes, which in the wild feed mainly on small insect larvae and zooplankton (Nasyrah et al., 2024).

These characteristics probably explain why *Tubifex* sp. was consumed readily and converted efficiently into body mass.

Fish fed *Daphnia* sp. showed the second-highest growth, which is consistent with the presence of zooplankton in the natural diet of *M. ladigesi* (Nasyrah et al., 2024). Earthworms produced lower growth than *Tubifex* sp. and *Daphnia* sp., although they still outperformed the commercial diet. Earthworms used as live feed are generally larger and must be chopped before feeding small fish, which may reduce their attractiveness or lead to leaching of nutrients into the water, and their nutrient profile varies with the culture substrate (Mugwanya et al., 2025). The commercial diet, although nutritionally formulated, produced the lowest growth. In wild-caught fish at the beginning of domestication, inert pellets are often ignored or only partly consumed, because individuals must learn to recognise motionless food; studies on pikeperch have shown that live feed is preferred to pellets and that fish accepting artificial feed later grow more slowly (Molnár et al., 2018). The lower growth with the commercial diet in the present study therefore most likely reflects incomplete feed acceptance rather than an intrinsic nutritional deficiency of the diet.

Survival followed a similar pattern. The highest survival was recorded in the *Tubifex* sp. and earthworm treatments (93.33% each), followed by *Daphnia* sp. (76.67%), whereas the commercial diet resulted in the lowest survival (66.67%). Tukey's test showed that survival in the commercial-feed treatment (A) differed significantly from that in the *Tubifex* treatment (B), whereas the earthworm (C) and *Daphnia* (D) treatments were not significantly different from each other. Survival is a central indicator of success during the early stages of domestication because it reflects the combined effects of feed acceptance, physiological stress, and environmental conditions. The transfer of ornamental fishes from the wild into captivity involves multiple stressors, and mortality associated with handling and holding can be high and variable (Stevens et al., 2017). Fish that do not accept the offered food during this period experience prolonged energy deficits, which can weaken immunity and increase susceptibility to disease. In *M. ladigesi*, live *Tubifex* has been shown to improve haematological status and resistance to bacterial infection compared with other diets (Amrullah et al., 2023), which is consistent with the higher survival observed here.

The lower survival in the commercial-feed treatment may also be linked to water quality. Uneaten pellets decompose in the rearing water and release ammonia, which at elevated concentrations disrupts gill function, reduces the oxygen-carrying capacity of the blood, induces oxidative stress, and suppresses immune responses (Xu et al., 2021). The toxicity of ammonia increases with pH, temperature, and stress, and its management through feeding control and water exchange is therefore essential in intensive systems (Parvathy et al., 2023). Although faeces and residual feed were siphoned every two days in this study, small containers with limited water volume are sensitive to short-term fluctuations in water quality, and poorly accepted feeds are more likely to remain uneaten between cleaning events. In contrast, live feeds that are consumed rapidly leave fewer residues and probably contributed to a more stable rearing environment.

Stocking density and social interactions are further factors that influence survival during domestication. The welfare effects of density depend on species, life stage, water quality, and feeding, and inappropriate densities can increase competition, aggression, and stress (Saraiva et al., 2022). In intensive culture, high densities can impair behaviour, growth, feed utilisation, and immunity (Mugwanya et al., 2022). In the present study, all treatments were stocked at the same density, so differences in survival can be attributed

mainly to feed type. However, when food is not readily accepted, competition for the few consumed items may intensify, which could have amplified mortality in the commercial-feed treatment. The relatively high survival in the *Tubifex* and earthworm treatments suggests that the stocking density used was tolerable for *M. ladigesi* when feed was well accepted.

The close correspondence between growth and survival indicates that feed acceptance is the key factor determining performance in the early domestication of *M. ladigesi*. Domestication begins as soon as fish are transferred from the wild into captivity, and progress depends on the ability of individuals to adapt to human-controlled environments and resources (Teletchea, 2021). Live feeds thus offer a practical bridge between wild feeding habits and captive husbandry. Nevertheless, complete dependence on live feeds is costly and may introduce pathogens or contaminants, and long-term domestication will require gradual weaning to formulated diets. Experience with other species shows that mixed feeding regimes, in which live feed is progressively reduced while dry feed is introduced, can facilitate this transition while maintaining growth and survival (Mulvaney et al., 2022). Species-specific nutritional strategies are also needed, because ornamental fishes differ widely in digestive anatomy and may respond differently to the same diet (Kasprzak et al., 2021).

The findings have practical implications for the conservation and sustainable use of *M. ladigesi*. Freshwater ornamental fishes are increasingly sourced from breeding facilities, and replacing wild collection with captive production can reduce pressure on natural populations while supporting livelihoods (Evers et al., 2019; King, 2019). Establishing reliable captive stocks of endemic species is especially important where native assemblages face additional threats from habitat degradation and non-native fishes (Wibowo et al., 2020). The use of locally available live feeds, particularly *Tubifex* sp., represents a low-cost strategy that small-scale farmers and conservation hatcheries in South Sulawesi can adopt during the initial phase of domestication. Future studies should evaluate weaning protocols from live to formulated feeds, report variability among replicates and water quality data in full, assess feed intake and feed conversion, and extend observations to reproduction and the performance of subsequent captive-bred generations.

CONCLUSION

This study demonstrated that feed type significantly affected the growth and survival of the endemic Celebes rainbowfish, Marosatherina ladigesi, during the early stage of domestication under controlled rearing conditions. Fish fed live Tubifex sp. achieved the highest absolute weight gain (2.58 g), which was significantly greater than that of fish fed Daphnia sp. (2.00 g), earthworms (1.70 g), and the commercial diet (1.25 g). Survival was highest in the Tubifex sp. and earthworm treatments (93.33%), intermediate in the Daphnia sp. treatment (76.67%), and lowest with the commercial diet (66.67%). The consistently superior performance of live feeds, particularly Tubifex sp., indicates that feed acceptance is the main factor determining the success of early domestication in this species, and that inert formulated diets are poorly accepted by newly captive fish. Live-feed adaptation using locally available organisms therefore represents a practical and low-cost initial strategy for establishing captive stocks of M. ladigesi for ornamental production and ex situ conservation. Future research should develop gradual weaning protocols from live to formulated feeds, quantify feed intake and conversion efficiency, report water quality and replicate variability in full, and evaluate the reproductive

performance of fish reared under these feeding regimes to support the full domestication of this endemic species.

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