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Osmoregulatory cost of Nile tilapia across salinity gradients on growth and oxygen consumption rates

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ABSTRACT

Nile tilapia (Oreochromis niloticus) exhibits remarkable phenotypic plasticity, particularly regarding its adaptability to varying environmental salinities. This study aimed to comprehensively evaluate the bioenergetic costs and rearing performance of Nile tilapia subjected to a micro-salinity gradient. A 30-day in vivo experiment was conducted at the Aquaculture Laboratory and Experimental Ponds of Universitas Sriwijaya. The study used a completely randomized design comprising five salinity treatments: P0 (0 ppt; freshwater control), P1 (1 ppt), P2 (2 ppt), P3 (3 ppt), and P4 (4 ppt). The result showed that an optimal survival rate was recorded at 1 ppt (P1; 85%), contrasting sharply with the lowest survival observed in the freshwater control (P0; 35%). Conversely, somatic growth peaked at 2 ppt (P2), yielding the highest absolute weight gain (13 g), while the maximum length extension (3 cm) was co-dominantly observed in the 2 ppt and 3 ppt treatments. Interestingly, despite recording the lowest survival, the highest feed efficiency was maintained in the control group (P0; 48.43%). Furthermore, the metabolic cost of osmoregulation peaked at 3 ppt (P3), as evidenced by the maximum oxygen consumption rate (0.26 mg O_2 g^{-1} h^{-1}). Overall, the data suggest that low-to-moderate salinity levels (1–2 ppt) provide a substantially more optimal rearing environment compared to strictly freshwater or higher salinity conditions. Operating within this micro-salinity range effectively balances osmoregulatory energy expenditure with maximized growth and survival rates, offering strategic bioenergetic insights for sustainable tilapia aquaculture operations.

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INTRODUCTION

Nile tilapia (*Oreochromis niloticus*) remains a dominant species in the global aquaculture landscape as a highly strategic species, primarily due to its remarkable phenotypic plasticity, rapid somatic growth, and robust tolerance to fluctuating water quality parameters. As a highly euryhaline teleost, this species exhibits an exceptional capacity to survive across a broad salinity spectrum, ranging from strictly freshwater environments (0 ppt) to high-salinity marine conditions exceeding 20 ppt (El-Sayed, 2020; Al Jamali, 2023). In the current era of global climate change, where coastal aquaculture zones and freshwater reservoirs are increasingly subjected to seawater intrusion and unpredictable salinity fluctuations, this physiological adaptability makes Nile tilapia a highly promising candidate for expansion into brackish water and salinized inland aquatic systems.

However, cultivating tilapia outside its native freshwater habitat requires a profound understanding of its physiological limits. Salinity is a critical environmental determinant that directly dictates the energetic costs of osmoregulation, as the fundamental biological mechanism by which fish maintain hydromineral homeostasis and internal osmotic balance. Exposure to suboptimal or inappropriate salinity gradients inevitably triggers osmotic stress. Under such conditions, bioenergetics dictates that metabolic energy originally allocated to somatic growth, immune defense, and reproduction is diverted to fuel the energetically demanding ion pumps required to maintain internal equilibrium (Esbaugh, 2025). Consequently, this energy reallocation often manifests as a significant reduction in feed intake, compromised feed conversion efficiency, and stunted growth.

Furthermore, as Sampaio and Freire (2016) elucidated, the basal metabolic rate and oxygen consumption of fish escalate sharply in response to suboptimal salinity levels, reflecting the heavy energetic tax imposed by active osmoregulation. Two significant hormones involved in osmoregulation are prolactin and cortisol. Prolactin is secreted by P cells in freshwater fish pituitary glands and prevents Na^{+} influx through the permeable membrane. The steroid hormone cortisol is secreted by the interrenal cells in the kidney heads and plays an essential role in the euryhaline organism adaptation to different salinities (Trisyani *et al.*, 2025).

While previous literature has documented that certain strains of Nile tilapia can achieve optimal growth trajectories at low to moderate salinities, typically around 5–10 ppt (Syahrizal *et al.*, 2021), the physiological responses are highly variable and strictly dependent on fish size, genetic strain, and concurrent environmental stressors. Moreover, there remains a notable scarcity of comprehensive data addressing the specific bioenergetic responses of red Nile tilapia to micro-salinity gradients (e.g., 0–4 ppt), which are highly characteristic of early-stage seawater intrusion or slightly brackish estuarine systems. Few studies have simultaneously evaluated growth, feed efficiency, survival, and oxygen consumption across a micro-salinity gradient below 5 ppt. Therefore, rigorous empirical studies are urgently needed to pinpoint the precise optimal salinity threshold that minimizes osmoregulatory costs while maximizing production performance. Addressing this critical knowledge gap, the primary objective of this study is to systematically evaluate the effects of varying micro-salinity levels on the survival, absolute growth, feed efficiency, metabolic oxygen consumption rates, and overall rearing water quality of red Nile tilapia. The findings are anticipated to provide actionable, science-based bioenergetic guidelines for optimizing tilapia aquaculture operations in systems susceptible to salinity shifts.

METHODS

This study employed a comparative study design, comparing five different salinity concentrations in tilapia culture: 0 ppt (P0), 1 ppt (P1), 2 ppt (P2), 3 ppt (P3), and 4 ppt (P4). Each aquarium was filled with 20 L^{-1} and 20 fish (stocking density of 1 fish L^{-1}). The equipment used included a 40×40×40 cm^3 aquarium, an aerator, a filter, a dissolved oxygen (DO) meter, a pH meter, a salinometer, a digital scale, and a ruler. The materials included red tilapia measuring approximately

10 cm, commercial feed, salt for adjusting salinity, and water. The tanks used for tilapia rearing were seven 40×40×40 cm^3 aquariums. Before use, the aquariums were filled with water and treated with 0.3 g of potassium permanganate, then left to stand for 24 hours. After 24 hours, the rearing tanks were rinsed with clean water and refilled with 20 L of water. Subsequently, the water was allowed to settle, and salt was dissolved in the rearing medium.

Before stocking, fish length and weight were measured using a ruler and scale as an initial sampling. Subsequently, the fish were acclimated and then stocked at a density of 1 fish per liter, or 20 fish per aquarium. Following this, the pH and water temperature in the grow-out tanks were measured again. Fish were grown out for 30 days, with routine feeding three times a day: morning (08:00), noon (12:00), and afternoon (16:00), with a feed rate (FR) of 5%. Subsequently, fish behavior and grow-out tanks were monitored, along with measurements of water quality parameters such as temperature and pH in the morning and afternoon. During the grow-out period, the body weight of dead fish was recorded. The parameters observed in this activity include: absolute weight growth, absolute length growth, feed efficiency, survival rate, specific growth rate, oxygen consumption rate, and water quality as follows:

Calculation of absolute weight growth according to Effendi (2002), using the following formula:

$$\mathrm{W} = Wt - W0 \qquad (1)$$

Where W is absolute weight gain, Wt is the weight of the fish at the end of the rearing period, and W0 is the weight of the fish at the beginning of the rearing period.

Calculation of absolute length growth according to Effendi (2002), using the following formula:

$$\mathrm{L} = Lt - L0 \qquad (2)$$

Where L is absolute length gain, Lt is the length of the fish at the end of the rearing period, and L0 is the length of the fish at the beginning of the rearing period.

The feed efficiency calculation formula according to NRC (1977) is as follows:

$$\mathrm{FE} = \frac{(Wt - W0)}{F} \text{ x } 100 \qquad (3)$$

Where FE is feed efficiency, Wt is the weight of fish at the end of the rearing period, and W0 is the weight of fish at the beginning of the rearing period.

Calculation of fish survival rates according to Effendi (2002), using the following formula:

$$\mathrm{SR} = \frac{Nt}{N0} \text{ x } 100 \qquad (4)$$

Where SR is the survival rate, Nt is the number of individuals at the end of rearing, and N0 is the number of individuals at the beginning of rearing.

The formula for calculating the specific growth rate, according to Tacon (1993), is as follows:

$$\mathrm{SGR\ (\%\ per\ day)} = \frac{\mathrm{LnWt - LnW0}}{\mathrm{t}}\ x\ 100 \qquad (5)$$

Where SGR is the specific growth rate, Wt is the fish weight at the end of the rearing period, W0 is the fish weight at the beginning of the rearing period, and t is the cultivation period.

The Oxygen Consumption Rate (OCR) is calculated according to NRC (1977) using the formula:

$$OCR = \frac{v \times (DO_{to} - DO_{tt})}{w \times t} \quad (6)$$

Where v is the volume of water in the tank, DO_{to} is the dissolved oxygen concentration at the start of the observation, DO_{tt} is the dissolved oxygen concentration at the end of the observation, w is fish weight, and t is the duration of observation. All data computations were performed using IBM SPSS Statistics and Microsoft Excel 2019.

RESULTS AND DISCUSSION

The results of absolute weight gain are shown in Figure 1, and the absolute length measurements are shown in Figure 2.

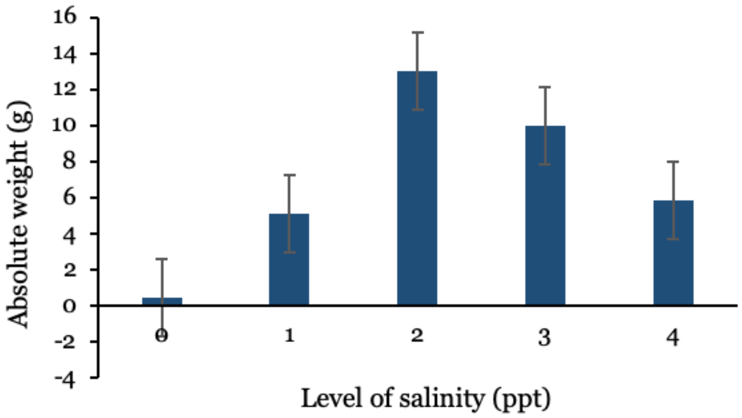

Figure 1. Absolute weight growth of nile tilapia at different salinities

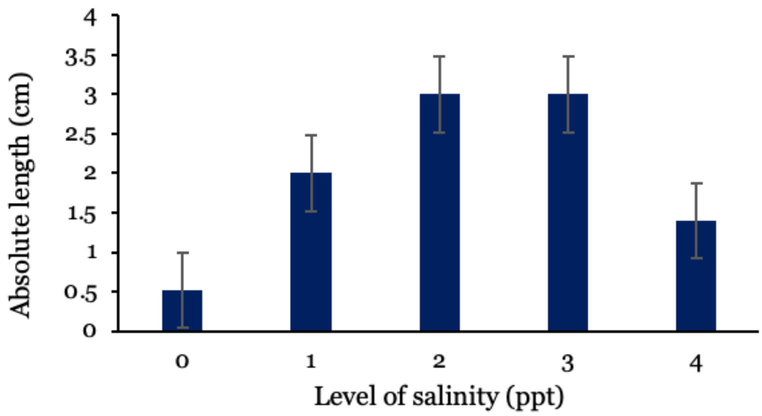

Figure 2. Absolute length growth of nile tilapia at different salinities

The somatic growth trajectories of Nile tilapia exhibited highly variable, salinity-dependent responses across the experimental treatments. The highest absolute length extension was achieved under severe osmotic stress in P2 and P3 (3 cm), while the most substantial absolute weight gain was recorded in P2 (13 g). The pronounced growth spike at a higher salinity may indicate a stress-induced compensatory physiological response or acute fluid retention prior to systemic failure. In contrast, the growth at P2 (13 g) reflects true somatic accretion under manageable environmental conditions.

The growth observed in P2 was due to osmoregulatory energy activity correlated with growth, whereby the energy required during the osmoregulation process was lower because the environmental salinity was at isoosmotic levels, allowing the fish to utilize that energy for growth (Laudin et al., 2023). Fundamentally, increased salinity dictates tilapia growth by altering energy allocation; a significant proportion of dietary energy is inevitably diverted from somatic growth to fuel the energetically demanding Na^+/K^+-ATPase pumps required to stabilize internal osmotic balance. Salinity levels that align closely with tilapia's natural physiological and osmoregulatory capacity can enhance growth by minimizing this energetic tax (Yu *et al.*, 2024). Conversely, excessively high salinity drastically alters growth dynamics, often decelerating it due to metabolic overload (Fransisca and Muhsoni, 2021). Biologically, fish growth is driven by the efficient conversion of ingested nutrients into metabolic energy for cellular synthesis and physical activity (Mulqan *et al.*, 2017). With strategic feeding management, nutrients can be effectively assimilated, yielding optimal biomass expansion provided the environmental stress remains within tolerable limits (Ulum *et al.*, 2020).

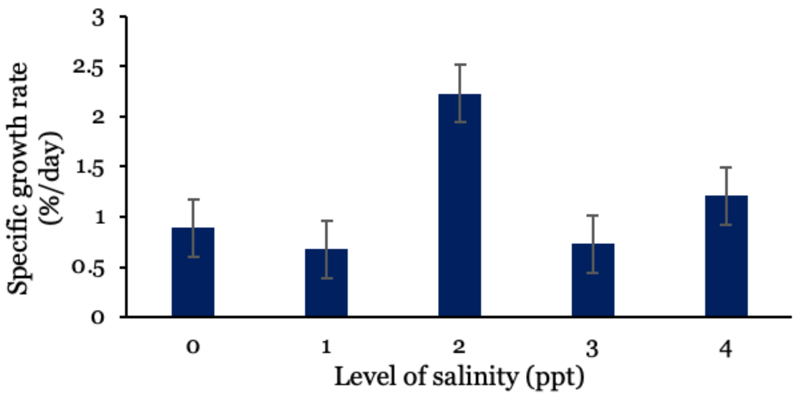

Figure 3. Specific growth rate of tilapia at different salinities

An analysis of the specific growth rates (SGR) further elucidated the physiological impact of the salinity gradient shows in Figure 3. The documented SGR values were 0.089%/day (P0), 0.68%/day (P1), 2.23%/day (P2), 0.73%/day (P3), and 1.21%/day (P4). The most sustainable and functionally optimal SGR was found in P2 (2 g L^{-1}) at 2.23%. This robust growth rate indicates that the fish maintained normal physiological functions and effectively managed the mild environmental stress imposed during the 30-day rearing period. Typically, the standard SGR for cultivated tilapia ranges from 1–5%/day. The observed variance in growth rates across treatments is a multifactorial phenomenon heavily driven by ambient salinity. Beyond simple osmotic pressure, salinity directly influences basal metabolic energy demands, voluntary feed intake, protein digestibility, and the secretion of growth-stimulating hormones (e.g., Growth Hormone/IGF-1 axis) (Bhatt *et al.*, 2026). As Royan *et al.*, (2014) noted, elevated salinity environments prolong the adaptation phase and ultimately inhibit the long-term growth rate of tilapia due to chronic physiological exhaustion.

Figure 4 shows feed efficiency (FE) metrics demonstrated a pronounced inverse relationship with increasing salinity beyond the control group. As depicted in Figure 4, the FE values were highest in the freshwater control at 48.43% (P0), sharply declining to 6% (P1), 32% (P2), 5% (P3), and culminating at a minimum of 3.11% in P4. Feed intake in treatment P2 was higher, presumably because salinity affects the fish's metabolic rate; fish require more energy to survive in a high-salinity environment, causing them to consume more feed (Nassar et al., 2021). The stark reduction in feed efficiency under high-salinity treatments provides clear evidence that escalating osmotic stress critically impairs nutrient utilization. Elevated salinity induces a state of chronic stress that can downregulate the activity of key intestinal digestive enzymes, such as proteases and lipases, thereby diminishing overall feed assimilation (Zamani *et al.*, 2020). High FE values, such as those in P0 and P2, underscore the fish's biological capacity to efficiently partition dietary energy into muscle biomass under supportive, low-stress conditions. Conversely, diminished FE indicates a severe metabolic penalty; most metabolizable energy derived from the feed is exhausted on osmoregulatory survival mechanisms rather than somatic tissue synthesis (Boyd, 2015; Fu *et al.*, 2007).

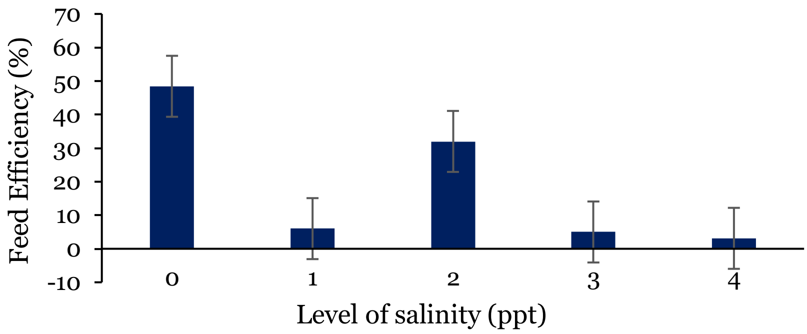

Figure 4. Feed efficiency of nile tilapia at different salinities

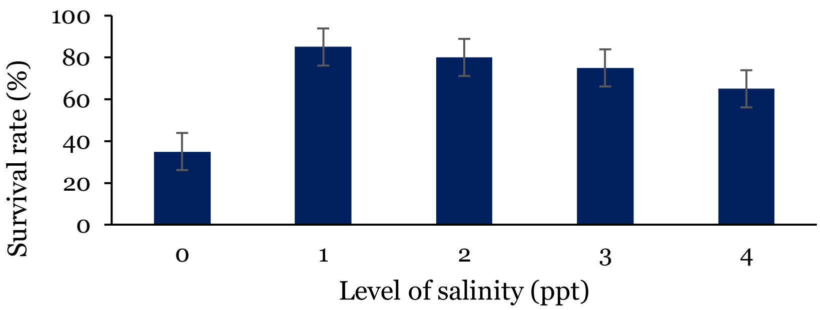

Figure 5. Survival of nile tilapia at different salinities

The survival rates of Nile tilapia under different salinity conditions are shown in Figure 5. The survival trajectories provided critical insights into the environmental tolerance thresholds of red Nile tilapia. Survival rates were 35% for P0, 85% for P1, 80% for P2, 75% for P3, and 65% for P4. Strikingly, the highest survival rate (85%) was achieved in the mildly saline environment of P1 (1 g L^{-1}), rather than the absolute freshwater control (P0). This suggests that a micro-saline environment provides an "iso-osmotic relief" that minimizes physiological stress and reduces rearing mortality. While Andriyan (2018) established that typical freshwater fish survival ranges from 73.5% to 86.0%, survival is not solely a function of feed intake; it is heavily dictated by holistic aquaculture management, including stocking density, water quality stability, and pathogen control (Zaenuddin *et al.*, 2015). Importantly, as highlighted by Fransisca and Muhsoni (2021), tilapia survival progressively declines as salinity approaches critical upper limits. Elevated salinity decreases the solubility of dissolved oxygen in the water column, creating a hypoxic challenge that can trigger mass mortality. Furthermore, escalating salinity widens the osmotic gradient between the aquatic medium and the fish's internal plasma, forcing the tilapia to expend unsustainable levels of metabolic energy on active ion transport to prevent cellular dehydration (Chakraborty *et al.*, 2021).

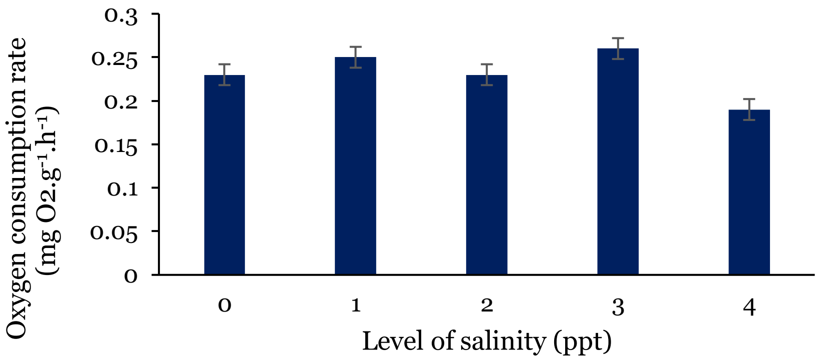

Figure 6. Oxygen consumption rates of nile tilapia at different salinities

Figure 6 shows the oxygen consumption rates of Nile tilapia under different salinity conditions. Metabolic oxygen consumption rates (OCR) served as a direct proxy for quantifying the bioenergetic costs of osmoregulation. The recorded OCR values were: 0.23 mg O_2 g^{-1} h^{-1} (P0); 0.25 mg O_2 g^{-1} h^{-1} (P1); 0.23 mg O_2 g^{-1} h^{-1} (P2); a peak of 0.26 mg O_2 g^{-1} h^{-1} (P3); and a sudden drop to 0.19 mg O_2 g^{-1} h^{-1} in P4. These values indicate that baseline oxygen requirements remained adequate to support vital functions across most treatments. Physiologically, oxygen demand fluctuates based on blood cell morphology, hemoglobin-oxygen affinity, and ambient physicochemical factors. Higher ambient salinity generally reduces oxygen solubility while simultaneously increasing the fish's respiratory demand to fuel ion-exchange pumps (Malini & Muliani, 2016). The peak OCR at P3 represents the maximum metabolic effort exerted by the fish to maintain homeostasis. Interestingly, the noticeable decline in oxygen consumption at P4 (0.19 mg O_2 g^{-1} h^{-1}) suggests the onset of metabolic depression as a known physiological coping mechanism where severely stressed aquatic organisms suppress their overall metabolic rate to survive extreme, energy-draining environmental conditions, as also supported by Barany *et al.* (2021).

Water quality during fish cultivation is presented in Table 1. Maintaining optimal physicochemical parameters is a fundamental prerequisite for physiological stability.

Table 1. Water quality during cultivation

Treatments	Temperature (℃)	pH	Salinity (ppt)
P0	28.5 – 33.4	5.05 – 7.61	0
P1	27.6 – 34.1	5.83 – 7.70	1
P2	26.1 – 30.8	6.50 – 8.20	2
P3	28.7 – 31.3	6.48 – 9.05	3
P4	27.5 – 32.7	6.34 – 8.70	4

According to Table 1, the pH ranges were broadly viable (5.05–7.61 for P0; up to 6.48–9.05 for P3), while temperatures fluctuated between 26.1°C and 34.1°C across all experimental units. According to the National Standardization Agency (BSN, 2009), the idealized parameters for tilapia aquaculture dictate temperatures of 25–32°C, dissolved oxygen >3 mg/L, and a pH between 6.5 and 8.5. The success of any aquaculture intervention relies heavily on mitigating environmental extremes. Poor water quality, particularly extreme pH or temperature fluctuations, acts as a primary stressor that compromises the neuroendocrine system, leading to immunosuppression and elevated mortality risk (McCabe, 2023). Suboptimal conditions also induce anorexia in fish, directly halting growth by drastically reducing feed intake (Farabi and Latuconsina, 2023). Therefore, rigorous water quality control remains non-negotiable for commercial Nile tilapia operations (Lamangkaraka *et al.*, 2024). Environmental pH actively regulates the toxicity of metabolic wastes like ammonia, while thermal profiles govern the basal metabolic rate. An increase in ambient temperature, within the optimal thermal tolerance window, directly accelerates kinetic cellular processes, thereby amplifying both oxygen consumption and potential growth rates (Ririhena and Palinussa, 2021).

CONCLUSION

This study demonstrates that the optimal rearing environment for red Nile tilapia (*Oreochromis niloticus*) lies strictly within a micro-salinity gradient of 1–2 ppt. Specifically, 1 ppt maximizes survivability (85%) by providing critical iso-osmotic relief, while 2 ppt optimizes sustainable somatic growth. Salinities exceeding 2 ppt impose a severe energetic tax, diverting metabolic energy from growth to osmoregulation and leading to metabolic depression and reduced feed efficiency. Furthermore, extreme osmotic stress (≥ 4 ppt) ultimately breaches the species' physiological tolerance, resulting in total mortality. Therefore, maintaining a 1–3 ppt salinity range is strongly recommended to balance bioenergetic costs and maximize production yields, serving as a viable aquaculture strategy in coastal areas prone to seawater intrusion.

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REFERENCES

Al Jamali, A. H. (2023). Re-evaluating eurahaline nature of Nile tilapia, Oreochromisniloticus: a hatchery perspective. *Int J Fish Aquat Stud*, *11*, 223-231. https://doi.org/10.22271/fish.2023.v11.i5c.2869

Andriyan, M. F. (2018). *Pengaruh salinitas terhadap tingkat kelangsungan hidup dan profil darah ikan nila (Oreochromis niloticus) yang diberi kombinasi pakan dan buah mengkudu (Morinda citriffolia L.)* (Doctoral dissertation, Universitas Muhammadiyah Gresik). http://eprints.umg.ac.id/id/eprint/4304

Barany, A., Gilannejad, N., Alameda-López, M., Rodríguez-Velásquez, L., Astola, A., Martínez-Rodríguez, G., Roo, J., Muñoz, J. L., & Mancera, J. M. (2021). Osmoregulatory plasticity of juvenile greater amberjack (*Seriola dumerili*) to environmental salinity. *Animals*, *11*(9), 2607. https://doi.org/10.3390/ani11092607

Bhatt, S., Sahu, N. P., Gupta, S., Krishnan, S., Nathaniel, T. P., Vasanthakumaran, K., Nirala, S. K., & Varghese, T. (2026). Dietary potassium supplementation improves the growth and physio-biochemical responses of genetically improved farmed tilapia (Oreochromis niloticus) reared in medium-saline Inland waters. *Fishery Technology*, *63*(1), 113-124. https://doi.org/10.56093/ft.v63i1.166718

Boyd, C. E. (2015). Overview of aquaculture feeds: Global impacts of ingredient use. In *Feed and feeding practices in aquaculture* (pp. 3-25). Woodhead Publishing.

BSN, (2009). Produsi benih ikan nila hitam (Oreochromis niloticus Bleeker) kelas pembesaran di kolam air tenang. SNI 7550:2009. *Badan Standarisasi, Jakarta*.

Chakraborty, S., Rahman, A. F. M. A., Sarker, B. S., Minar, M. H., & Hossain, M. B. (2021). Effects of salinity on the feeding efficiencies, growth performances and survival rate of 11th strain of tilapia (GIFU) in laboratory condition. *Current Journal of Applied Science and Technology*, *40*(13), 38–51. https://doi.org/10.9734/cjast/2021/v40i1331391

Effendi, M. I. (2002). *Biologi perikanan*. Yayasan Pustaka Nusatama.

El-Sayed, A.F.M. (2020). *Tilapia Culture, 3rd Edition*. Academic Press, London.

Esbaugh, A. J. (2025). Physiological responses of euryhaline marine fish to naturally-occurring hypersalinity. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, *299*, 111768. https://doi.org/10.1016/j.cbpa.2024.111768

Farabi, A. I. ., & Latuconsina, H. . (2023). Manajemen kualitas air pada pembesaran udang Vaname (Litopenaeus vannamei) di UPT. BAPL (Budidaya Air Payau dan Laut) Bangil Pasuruan Jawa Timur. *Jurnal Riset Perikanan Dan Kelautan*, *5*(1), 1–13. https://doi.org/10.33506/jrpk.v5i1.2097

Fransisca, N.E. & Muhsoni, F.F., (2021). Laju pertumbuhan dan kelangsungan hidup ikan nila (*Oreochromis niloticus*) pada salinitas yang berbeda. *Juvenil: Jurnal Ilmiah Kelautan dan Perikanan,* 2(3), 166-175. https://doi.org/10.21107/juvenil.v2i3.11271

Fu, C.-N., Li, D.-P., Hu, W., Wang, Y.-S., & Zhu, Z. (2007). Growth and energy budget of F2‘all-fish’ growth hormone gene transgenic common carp. *Journal of Fish Biology*, *70*(2), 347–361. https://doi.org/10.1111/J.1095-8649.2007.01301.X

Lamangkaraka, R. R., Mulis, M., Koniyo, Y., & Alvionita, M. (2024). Analisis kualitas air pada sistem budidaya ikan nila (Oreocromis nilotius) di Balai Benih Ikan Andalas, Kota Gorontalo. *The NIKe Journal*, *12*(2), 61-66. https://doi.org/10.37905/nj.v12i2.26546

Laudin, B., Indrawati, E., & Ratnawati, R. (2023). Dinamika pertumbuhan juvenil ikan nila salin pada tingkatan salinitas yang berbeda. *Journal of Aquaculture and Environment*, *5*(2), 45-53. https://doi.org/10.35965/jae.v5i2.2642

Malini, D. M., & Muliani, R. (2019). Konsumsi oksigen ikan pelagis di Muara Segara Anak, Taman Nasional Alas Purwo. *Bioeksperimen: Jurnal Penelitian Biologi*, *2*(2), 111-118. https://doi.org/10.23917/bioeksperimen.v2i2.2489

Marzuqi, M., Astuti, N. W. W., & Suwirya, K. (2012). Pengaruh kadar protein dan rasio pemberian pakan terhadap pertumbuhan ikan kerapu macan (Epinephelus fuscoguttatus). *Jurnal Ilmu dan Teknologi Kelautan Tropis*, *4*(1), 55-65. Jurnal.pdf

McCabe, M. M. (2023). *Aquaculture Fish Responses Towards Temperature Stress: A Critical Review* (pp. 83–132). https://doi.org/10.1007/978-981-99-2193-5_5

Mulqan, M., Rahimi, E., Afdhal, S., & Dewiyanti, I. (2017). *Pertumbuhan dan kelangsungan hidup benih ikan nila gesit (Oreochromis niloticus) pada sistem akuaponik dengan jenis tanaman yang berbeda* (Doctoral dissertation, Syiah Kuala University). Jurnal.pdf

Nassar, S., G. A. Hassan, A., F. Badran, M., & M. Abdel-Rahim, M. (2021). Effects of salinity level on growth performance, feed utilization, and chromatic deformity of the hybrid Red tilapia, Oreochromis niloticus x O. mossambicus. *Egyptian Journal of Aquatic Biology and Fisheries*, *25*(2), 49-61. https://doi.org/10.21608/ejabf.2021.158248

NRC [National Research Council]. (1977). Nutrient requirement of warmwater fishes and shelfishes revised edition. *Washinton D.C (US): National Academy Press*. 102 p

Nurliah, N., & Lestari, D. P. (2018). Penambahan getah pepaya (Carica papaya) pada pakan pelet dengan dosis yang berbeda untuk pertumbuhan dan kelangsungan hidup ikan mas (Cyprinus carpio). *Jurnal Perikanan Unram*, *8*(2), 30-37. https://doi.org/10.29303/jp.v8i2.99

Oktari, L. D. (2022). *Pengaruh pemberian probiotik yang berbeda terhadap sintasan dan laju pertumbuhan benih ikan Nila (Oreochromis niloticus)* (Doctoral dissertation, Universitas Pendidikan Ganesha). http://repo.undiksha.ac.id/id/eprint/12619

Ririhena, J. E., & Palinussa, E. M. (2021). Pertumbuhan dan kelangsungan hidup ikan nila (Oreochromis niloticus) di UPTD budidaya air tawar. *Jurnal Ilmiah agribisnis dan Perikanan (agrikan UMMU-Ternate) Vol, 14*(2). https://doi.org/10.35800/bdp.10.2.2022.37624

Royan, F., Rejeki, S., & Haditomo, A. H. C. (2014). Pengaruh salinitas yang berbeda terhadap profil darah ikan nila (Oreochromis niloticus). *Journal of aquaculture management and technology*, *3*(2), 109-117. https://ejournal3.undip.ac.id/index.php/jamt/article/view/5239

Sampaio, L.A. & Freire, C.A. (2016). An overview of the effects of salinity on nitrogenous excretion and osmoregulation in fish. *Fish Physiology and Biochemistry*, 42(3), 559-573. https://doi.org/10.1016/j.jembe.2015.07.014

Siltri, D.M., Yohandri, Y. and Kamus, Z.K.Z., (2016). Pembuatan alat ukur salinitas dan kekeruhan air menggunakan sensor elektroda dan LDR. *Sainstek: Jurnal Sains dan Teknologi*, 7(2), 126-139. https://doi.org/10.31958/js.v7i2.133

Syahrizal, M., Rahman, A. & Simanjuntak, C.H. (2021). Pengaruh salinitas terhadap pertumbuhan dan kelangsungan hidup ikan nila (Oreochromis niloticus). *Jurnal Akuakultur Tropis*, 6(1), 44-52. https://repositori.unibos.ac.id/handle/123456789/5599

Tacon A. E. J., (1993) Feed ingredient for warmwater fish, fish meal and other processed feedstuffs. *FAO Fisheries Circular* 856, 64 p. https://www.cabidigitallibrary.org/doi/full/10.5555/19941401324

Trewavas, E. (2011). *Tilapiine fishes of the genera sarotherodon, oreochromis and danakilia*. British Museum (Natural History), London. https://doi.org/10.5962/bhl.title.123198

Trisyani, N., Nuhman., Setiawati, M. dan Susila, C. (2025). Salinity adaptation on the growth and survival of saline tilapia (Oreochromis niloticus) for environmental sustainability. *IOP Conf. Series: Earth and Environmental Science*, 1473, 012035. https://doi.org/10.1088/1755-1315/1473/1/012035

Ulum, B., Junaidi, M. dan Rahman, I., (2020). Pengaruh frekuensi pemberian pakan terhadap pertumbuhan dan kelangsungan hidup banggai cardinal fish (BCF). *Jurnal Kelautan:* Indonesian *Journal of Marine Science and Technology*, 13(1), 15-23. https://doi.org/10.21107/jk.v13i1.5938

Yu, J., Li, D., Zhu, J., Zou, Z., Xiao, W., Chen, B., & Yang, H. (2024). Salt tolerance performance and associated gene analysis of three tilapia species (strains). *Journal Fish Physiology and Biochemistry*, 26(1), https://doi.org/10.1007/s10695-025-01489-9

Zaenuddin, M., Sutresna, I. W., & Setyono, B. D. (2015). Pertumbuhan dan kelangsungan hidup benih ikan nila Oreocromis niloticus dalam sistem resirkulasi dengan bahan penyaring yang berbeda. *Jurnal Perikanan UNRAM*, *6*(1), 49-56. https://doi.org/10.29303/jp.v6i1.50

Zamani, N.P., Putra, A. & Fadli, N. (2020). Pengaruh pakan dan kondisi lingkungan terhadap efisiensi pemanfaatan nutrisi pada ikan budidaya. *Jurnal Ilmu Perikanan dan Kelautan*, 12(2), 101-110. https://doi.org/10.14710/sat.v1i1.2459