

Breeding synchronization enhances reproductive efficiency in resource-limited Nile tilapia (*Oreochromis niloticus*) hatcheries

Istiaq A. Chowdhury

Institute of Marine Sciences, University of Chittagong, Chattogram, Bangladesh.
Corresponding author: I. A. Chowdhury, iachowdhury@cu.ac.bd

https://doi.org/10.67784/1019

Abstract. The study evaluated broodfish resting regimes affect reproductive performance and fry production of Nile tilapia (*Oreochromis niloticus*) under controlled hatchery conditions. Four treatments were evaluated: weekly resting of spawning females (T-WR), bi-monthly resting (T-BMR), monthly resting (T-MR) and no rest (T-NR). One-way ANOVA indicated, resting regime significantly affected total egg production ($F_{(3,8)}$ = 42.78, $p < 0.001$), which was the highest in T-WR (38.13±1.12 g female^{-1}), followed by T-BMR (27.47±1.26 g), T-NR (22.40±1.02 g) and T-MR (19.07±0.85) ($p > 0.05$) yet decline was significant in T-NR ($p < 0.001$). Total egg production in T-WR (4,080±115 g hapa^{-1}) was significantly higher than T-BMR (2,912±107), T-NR (2,038±91) and T-MR (1,983±84; $p < 0.001$). Monthly spawning rates differed significantly ($F_{(3,8)}$ = 27.56, $p < 0.001$), with higher synchrony in T-WR (89.2±0.2%) and T-BMR (88.3±0.3%) than in T-MR (86.7±0.7%) and T-NR (75.8±0.8%). T-WR achieved the highest fry output (75,000 fries hapa^{-1}), hatching rate (73.5%), and egg mass (4,080 g hapa^{-1}), whereas T-NR produced fewer fry (34,000) and the lowest hatching rate (66.7%) ($p < 0.05$). Structured short-term resting enhances fecundity, spawning synchrony, and seed yield.
Keywords: breeding synchrony, broodfish, freshwater aquaculture, resource-limited aquaculture, resting regime.

Introduction. Tilapia (*Oreochromis* spp.) is a keystone of freshwater aquaculture, providing protein, supporting rural livelihoods, and enabling small-scale entrepreneurship across tropical and subtropical regions, whose rapid growth, environmental tolerance, and culture adaptability have driven global expansion, enhanced nutritional security, and underscored the need for reliable, predictable seed supply to sustain industry development (Arumugam et al., 2023; Alam et al., 2024; Ali et al., 2025).

In Bangladesh and similar contexts, tilapia hatcheries are constrained by poor broodstock management, irregular spawning, and variable seed quality, driven by technical, environmental, and financial limitations, with insufficient reproductive synchronization, further deflation fry consistency and increasing fingerling costs (Ali et al., 2023; Islam et al., 2023; Chandan & Roy, 2024). In settings with limited resources, these issues appear as irregular spawning, variable fry quality, and asynchronous cohorts, caused by technical restraints, inconsistent availability of broodstock, and variations in the environment (Islam et al., 2023). Synchronizing broodstock maturation and spawning produces unvarying cohorts, dropping labor and resource use, refining survival and batch management, enhancing genetic traceability, and supporting an expectable, cost-effective, and quality-oriented hatchery operation (Engdaw & Geremew, 2024). Beyond competence, synchronization improves sustainability by reducing dependency on wild fry, mitigating ecological and biosecurity risks, enabling precise production planning, stabilizing earnings, and increasing resilience to climatic inconsistency (Pant et al., 2024; Haque & Mahmud, 2025).

Technical advances to attain reproductive synchronization in tilapia incorporate a spectrum of strategies, ranging from cost-effective environmental managements such as modifiable photoperiod, regulatory water temperature, improving stocking density, and

regulating sex ratios to more direct methods involving exogenous hormonal intrusions and assisted reproductive practices (Little et al., 1993; Bhujel, 2000). Recent studies show that controlled hormonal stimulation using gonadotropin releasing hormone (GnRH analogues), human chorionic gonadotropin (hCG), or their combination with dopamine antagonists effectively shortens spawning latency, improves ovulation synchrony, and enhances fertilization and hatchability rates (Pan et al., 2024; Rbbani et al., 2025). Environmental manipulations, such as photoperiod adjustment, offer non-pharmacological avenues for synchronization, improving female reproductive indices in tilapia through extended or continuous light regimes (Khalil et al., 2024). Improved consistency and frequency of spawning can be achieved by implementing specific feeding strategies for broodstock, including balanced protein-energy ratios, essential fatty acids (n-6 linoleic acid), vitamins (A, D, E), and trace minerals, that improve fecundity, egg quality, and larval performance, enhancing returns from hormonal or environmental synchronization (Engdaw & Geremew, 2024). Functional dietary additives, such as nucleotides and biofloc-enhanced feeds, have been shown to elevate gonadosomatic index and digestive enzyme activity, stabilizing reproductive performance under variable pond conditions (Aure et al., 2024; Sallam et al., 2025).

Bangladesh's smallholder-dominated systems, integrating low-cost hormonal protocols with photoperiod manipulation and targeted nutritional packages can improve seed reliability, reduce per-fry costs, and enhance marketing efficiency and farmer income stability (Ali et al., 2025). Building on this framework, this study evaluates low-input environmental and hormonal strategies, their interaction with broodstock nutrition, and associated operational and economic trade-offs, aiming to provide a modular toolkit for sustainable, cohort-based tilapia seed production in resource-limited hatcheries (Engdaw & Geremew, 2024; Rbbani et al., 2025). This study investigates the influence of breeding synchronization strategies through periodic resting of brood on the reproductive responses and fry production performance of Nile tilapia (*Oreochromis niloticus*) in resource-limited hatchery, hypothesized that implementing optimized resting regimes would significantly improve spawning success, cumulative egg production, and hatchery seed yield compared to conventional practices.

Material and Method

Study area. The research work was conducted from March to October 2024 in a private owned tilapia hatchery located in the northern part of Bangladesh. The total area of hatchery is about 3.0 ha, including 2 breeding ponds, 3 sex reversal pond and 1 nursing pond. The eight-month (240-day) trial was conducted in a 1,000 m^2 earthen brood pond of the hatchery, using brood hapas to standardize mating and facilitate egg collection (Basiita, 2020; Bhujel, 2000).

Hapa configuration and stocking. Twelve 30 m^2 rectangular hapas, made of 5-6 mm mesh to enhance water exchange and aeration, were suspended in the pond following standard Nile tilapia conditioning protocols (Bhujel, 2000; Trong, 2013). Each hapa was stocked at 6 fish m^{-2} with 120 females (180±2 g) and 60 males (220±2 g), maintaining a 2F:1M ratio to optimize fry production and minimize male aggression (Akar, 2012; Amaddou et al., 2021). Additional nine 5 m^2 rectangular hapas with the same mesh size were suspended for weekly resting of spawned females for one treatment.

Treatments. Four broodfish conditioning regimes were evaluated in triplicate (n = 12 hapas per treatment across ponds):

1. T-WR (weekly resting of only spawned females): only the females that successfully spawned were provided with a short, scheduled recovery period between consecutive spawning events. Following each three-week interval, the cohort was again permitted to resume breeding;
2. T-MR (monthly resting of all brood): broodfish were rested for one month after every one month of egg collection;

3. T-BMR (bi-monthly resting of all brood): females underwent a programmed recovery phase of one month after every two months of breeding;

4. T-NR (no rest; continuous breeding): females were maintained under uninterrupted spawning for the entire period.

Resting period followed established broodstock management guidelines, providing brief, regular recovery to enhance gamete quality and synchronize spawning (Basiita, 2020; El-Sayed & Kawanna, 2004). Given female tilapia's 3–4-week asynchronous cycles, weekly egg collection was implemented to maximize seed yield and minimize egg/fry loss (Bhujel, 2000; Asase et al., 2021).

Feeding and husbandry. All groups received a nutritionally balanced commercial diet at 1.5-2.0% body mass day^{-1}, a range consistent with broodstock nutrition studies linking moderate rations to sustained reproductive performance (El-Sayed & Kawanna, 2004; Abu-Elala et al., 2021). Feed was offered twice daily (9:00 and 16:00 h). Routine husbandry included hapa inspection, removal of debris/biofouling, and observation of courtship/spawning behaviour.

Water quality monitoring. Key variables, namely temperature checked by Zeal spirit thermometer, England, dissolved oxygen (DO) tested by Hanna dissolved oxygen chemical test kit (HI3830, Romania), and pH tested by pen pH meter (The HI98107 pHep®; manufactured by Hanna Instruments, Romania), were observed at least two times weekly at 08:00-09:00 and 15:00-16:00 h to capture diel variation. Management targeted conditions within recognized reproductive optima for Nile tilapia (approximately 26-30°C, DO > 5 mg L^{-1}, pH ≈ 6.8-8.5), given the strong link between physico-chemical stability and brood performance (Siddique et al., 2022; FAO, 2024a; Hamad et al., 2024). Aeration and water exchange were applied as needed at pond level to maintain these ranges.

Egg collection and response variables. Eggs were collected weekly from each hapa using mouth-brooding checks, then counted and weighed to quantify treatment-wise reproductive output (eggs hapa^{-1} week^{-1}; total egg mass), egg weight was measured by drying the eggs using tissue paper and then counted to calculate the unit weight of each egg. Treatment wise monthly spawning rate was recorded by calculated total number of females spawned from each hapa; hatching percentage of different treatments were calculated to check the performance of assigned treatments by counting the monthly collected number of eggs from each hapa by volumetric measurement and then calculated the hatched fry released from each batch of collection. Frequent collection was employed to (i) minimize egg/fry losses and (ii) encourage rapid re-conditioning, consistent with reports that higher collection frequency shortens inter-spawning interval and elevates cumulative production (Bhujel, 2000; Asase et al., 2021).

Statistical analysis. All experiments were conducted in triplicate, and the data were presented as the mean±standard deviation. Statistical analysis was performed using one-way ANOVA followed by Tukey's HSD test. A significance level of $p < 0.05$ was used to assess differences between groups. All the data analyses were performed using MS Excel Professional Plus 2019, and SPSS trial version 29.

Results. This study assessed the effects of female broodfish resting regimes on Nile tilapia reproduction over a single eight-month cycle (March-October). Four treatments were evaluated: weekly resting of spawned female (T-WR), bi-monthly resting (T-BMR), monthly resting (T-MR), and continuous breeding (T-NR). Mean monthly egg production per spawner (g) was measured across three replicates per treatment to compare intra- and inter-treatment reproductive performance.

Effect of broodfish resting regimes on total egg production. One-way ANOVA analysis revealed broodfish resting regimes has a significant effect on total egg production per female ($F_{(3,8)} = 42.78$, $p < 0.001$) (Table 1). The highest cumulative egg

production was recorded in T-WR (38.13±1.12 g female^{-1}), which was significantly greater ($p < 0.001$) than T-MR (19.07±0.85 g female^{-1}) and T-NR (22.40±1.02 g female^{-1}) (Table 1). These findings confirm that weekly resting (T-WR) maximizes cumulative egg output, while monthly resting (T-MR) severely limits production.

Monthly egg production per female. Analysis of variance showed a significant treatment effect on mean monthly egg production per female ($F_{(3,8)} = 18.64$, $p < 0.01$) (Table 1). While T-WR (4.77±0.18 g) and T-MR (4.77±0.19 g) had similar monthly averages ($p = 0.97$), T-BMR (4.58±0.21 g) was slightly lower but not statistically different ($p = 0.21$). In contrast, T-NR exhibited a significantly reduced monthly production (2.80±0.16 g) compared with all other treatments.

Total harvested eggs per hapa. ANOVA detected a highly significant difference among treatments for total harvested eggs per hapa ($F_{(3,8)} = 51.32$, $p < 0.001$) (Table 1). The T-WR treatment yielded the highest harvest (4,080±115 g hapa^{-1}), which was significantly greater ($p < 0.001$) than T-MR (1,983±84 g hapa^{-1}) and T-NR (2,038±91 g hapa^{-1}). T-BMR produced an intermediate yield (2,912±107 g hapa^{-1}), which was significantly higher than both T-MR ($p < 0.01$) and T-NR ($p < 0.05$) but lower than T-WR ($p = 0.003$).

Monthly spawning rate (%). Monthly spawning rate varied significantly across treatments ($F_{(3,8)} = 27.56$, $p < 0.001$) (Table 1). The T-WR treatment recorded the highest spawning success (89.2±0.2%), which was statistically similar to T-BMR (88.3± 0.3%, $p = 0.62$) but significantly greater than both T-MR (86.70±0.7%, $p = 0.014$) and T-NR (75.8 ± 0.8%, $p < 0.001$) (Figure 1).

Table 1

Effects of broodfish resting regimes on reproductive performance of Nile tilapia (*O. niloticus*) under hatchery conditions (mean±SD)

Treatment	*Total egg production/ female (g)*	*Monthly egg production/ female (g)*	*Total harvested egg/hapa (g)*	*Spawning rate (%)*	*Hatching rate (%)*
T-WR	38.13±1.12^{a}	4.77±0.18^{a}	4,080±115^{a}	89.2±0.2^{a}	73.5±0.4^{a}
T-BMR	27.47±1.26^{b}	4.58±0.21^{a}	2,912±107^{b}	88.3±0.3^{a}	73.2±0.5^{a}
T-MR	19.07±0.85^{c}	4.77±0.19^{a}	1,983±84^{c}	86.7±0.7^{b}	72.6±0.6^{a}
T-NR	22.40±1.02^{bc}	2.80±0.16^{b}	2,038±91^{c}	75.8±0.8^{c}	66.7±0.7^{b}
ANOVA ($F_{(3,8)}$)	42.78	18.64	51.32	27.56	6.84
p value	< 0.001	< 0.01	< 0.001	< 0.001	< 0.05

Note: Values are presented as mean±standard error (SE). Within each column, means sharing at least one common superscript letter are not significantly different, whereas means with different superscript letters differ significantly ($p < 0.05$).

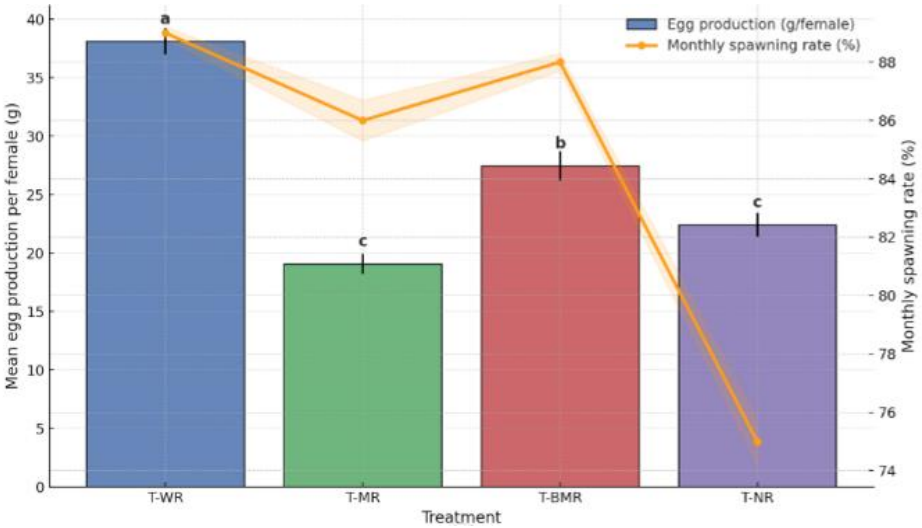


Figure 1. Resting regime effects on egg production and spawning rate.

Hatching rate (%). The hatching rate showed a significant treatment effect ($F_{(3,8)}$ = 6.84, $p < 0.05$), highest in T-WR (73.5±0.4%) and lowest in T-NR (66.7±0.7%) (Table 1). Similarly, the monthly hatched fry number varied significantly across treatments, with T-WR achieving the maximum (75,000 fries/hapa), followed closely by T-MR (72,000) and T-BMR (71,000), while T-NR produced considerably fewer fry (34,000) (Table 2). Overall, the T-WR (weekly resting) strategy optimized cumulative egg production, harvest yield, and spawning synchronization. The T-BMR (bi-monthly resting) regime provided moderate recovery benefits but reduced total fry availability due to fewer collection cycles. In contrast, T-MR (monthly resting) produced the lowest total yield, while T-NR (continuous spawning) severely compromised reproductive performance, likely due to ovarian fatigue and energy depletion in females. These results strongly indicate that structured, short resting intervals enhance reproductive efficiency and should be recommended for commercial tilapia hatchery management.

Table 2

Production data on different resting regimes

Treat-ment	*Monthly average spawning rate (%)*	*Total egg production/ female (g)*	*Monthly average egg/female (g)*	*No. of egg/hapa /month*	*Monthly hatched fry/hapa (nos)*	*Hatching rate (%)*	*Total harvested egg/hapa/ crop (g)*
T-WR	89.2	38.13	4.77	101,998	75,000	73.5	4,080
T-MR	86.7	19.07	4.77	99,164	72,000	72.6	1,983
T-BMR	88.3	27.47	4.58	97,061	71,000	73.2	2,912
T-NR	75.8	22.40	2.80	50,960	34,000	66.7	2,038

Discussion. Tilapia is a key global aquaculture species, especially in tropical and subtropical regions like Bangladesh. The present study investigates the influence of broodstock resting regimes and breeding synchronization strategies on reproductive performance, with an emphasis on elucidating how optimized broodstock management practices can enhance egg production, spawning efficiency, and overall seed output in commercial hatchery systems. The present study evaluated the effects of four brood resting protocols, T-WR (presumably within-optimal-frequency regime), T-MR (low-frequency), T-BMR (moderate-frequency), and T-NR (high-frequency) on breeding responses of Nile tilapia reared in hapas based pond culture systems. All treatments used identical broodstock density. Key findings include: T-WR achieved the highest total egg per female (38.13 g), highest monthly spawning rate (89.2 %), and greatest harvested egg per hapa (4080 g). T-BMR yielded intermediate values (27.47 g, 88.3 %, 2912 g respectively), whereas T-MR and T-NR delivered lower outputs: T-MR (19.07 g per female, 86.7 %, 1983 g respectively), and T-NR (22.40 g per female, 75.8 %, 2038 g respectively).

The current study provides compelling evidence that implementing weekly resting (T-WR) for broodstock tilapia significantly boosts important reproductive indicators: total egg production per female, egg yield harvested per hapa, and monthly spawning frequency, in contrast to bi-monthly (T-BMR), monthly (T-MR), or continuous spawning (T-NR) methods. The overall monthly egg production per female was statistically comparable among T-WR, T-BMR, and T-MR, but considerably lower in T-NR. This suggests that while regimes without rest severely hinder reproductive efficiency, regular resting even at intervals as infrequent as monthly can help maintain baseline productivity, with weekly intervals being the most effective in maximizing both quantity and synchronization. The results are consistent with recent studies conducted in Ghana, which showed that a 7-day resting period for broodstock led to better outcomes than both a 3-day period and continuous spawning, yielding a 103% rise in fry production compared to the treatment with no rest, the study reported mean fry outputs of 1,503± 868 (no rest), 2,030±637 (3-day rest), and 3,051±1,054 (7-day rest), underlining the tangible benefits of frequent rest on reproductive efficiency (Addo et al., 2024). Similarly, nutrition-focused reviews emphasize that diet composition through balanced macro and micronutrients and functional additives such as prebiotics, enzymes, and probiotics

significantly improves broodstock reproductive performance and offspring quality (Engdaw & Geremew, 2024).

***Biological rationale**: **physiological recovery and ovarian resilience**.* Weekly resting likely affords female broodstock the opportunity to rebuild energy reserves, regenerate oocytes, and recover from the metabolic costs of spawning thus preventing ovarian fatigue and prolonging high reproductive output. This recuperative period may support sustained granulosa-cell function and replenish yolk precursor pools, critical for robust oogenesis (Addo et. al., 2024). In contrast, continuous spawning (T-NR) likely causes chronic energy depletion, reducing physiological stability and reproductive output. Although bi-monthly and monthly resting allow partial recovery, cumulative egg production remains highest with weekly resting, which best balances recovery and spawning frequency.

***Operational impact**: **spawning synchrony and hatchery efficacy**.* The elevated spawning rates in T-WR (89.2±0.2%) and T-BMR (88.3±0.3%) highlight the efficacy of short resting intervals in maintaining spawn synchrony. This synchronization is critical for hatchery operations, it facilitates planned egg collection, simplifies labor scheduling, and promotes uniform fry batches. In contrast, T-MR (86.7±0.7%) and especially T-NR (75.8 ±0.8%) reflect asynchronous spawning patterns, complicating management and reducing operational efficiency. Broodstock resting strategies significantly improved fry production and spawning performance in Nile tilapia. Specifically, resting systems resulted in an increase from 20.6 to 31.7% in larvae per female, highlighting the importance of structured rest periods for enhancing reproductive performance (Abou-Zied, 2015). Bhujel (2000) emphasized that low egg output and poor spawning synchrony limit tilapia seed production, but proper broodstock conditioning with adequate resting improves performance. From a hatchery perspective, weekly resting enhances both biological yield and operational efficiency.

***Integrating nutrition**: **synergies with rest regimens**.* While resting intervals facilitate physiological recovery, the significance of nutritional fortification in optimizing reproductive performance cannot be overstated. Well-balanced diets with proteins, fats, carbohydrates, vitamins, minerals, and functional additives enhance vitellogenesis, yolk deposition, egg quality, and reproductive efficiency. Inclusion of specific lipid sources, such as linoleic-acid-rich oils, further boosts gonadal lipid reserves, supporting embryonic development, fry production, and larval survival (Engdaw & Geremew, 2024). Inclusion of 6 g kg^{-1} *Arthrospira platensis* (spirulina) nanoparticles in broodstock diets improved fry production by 32.2%, elevated steroid hormones (FSH, LH, testosterone, progesterone, prolactin), and enhanced feed conversion, indicating that integrating such nutritional strategies with broodstock rest can further boost reproductive efficiency (Mabrouk et al., 2024).

***Strategic recommendations for commercial hatcheries**.* Based on present results and extant literature, the following management recommendations emerge:

1. Implementing weekly spawner rest (T-WR): this schedule maximizes egg production, spawning success, and harvest yield. Abou-Zied (2015) reported a 31.7% increase in fry per female with a 7-day rest versus continuous spawning, highlighting the value of short resting periods for maintaining spawn synchrony;
2. Combine with nutrient-enriched diets: integrating high-protein diets and functional additives (e.g., probiotics, spirulina nanoparticles, specific lipids) during rest and spawning cycles may synergistically improve oocyte quality, fecundity, and fry viability. Supplying broodstock with a high-energy diet led to noticeable improvement in oocytes development, fecundity, fertility and hatching rates (Engdaw & Geremew, 2024);
3. Focus on spawn synchronization: weekly rest contributes to highly synchronized spawning. Hatcheries should align harvesting operations to take advantage of precise spawning windows, improving hatchery throughput. Bhujel (2000) noted that low egg

yield and poor spawning synchrony hinder tilapia seed production, but proper broodstock conditioning with adequate resting can enhance synchrony and seed output;

4. Future experimental designs: research should explore factorial combinations of resting interval and nutritional regimens (e.g., T-WR plus nanoparticle supplementation versus T-BMR plus enriched diet) to identify optimal strategies for maximizing output and cost-efficiency;

5. Economic modelling: cost-benefit analysis should quantify trade-offs between rest-induced downtime and increased per-spawning yields especially when enhanced by nutrition thus guiding resource allocation. A study by Burad-Méndez et al. (2023) assessed tilapia farming's scale effects on production, investment, and profitability using the benefit–cost ratio (B/C), providing insights into the economic aspects of tilapia hatchery management.

Broader perspectives: environmental and genetic context. While this study focused on rest interval effects, it is important to situate broodstock management within broader aquaculture frameworks. Environmental parameters like photoperiod, temperature, water quality coupled with genetic factors such as strain-specific responses, also profoundly influence reproductive outcomes. In many commercial systems, broodstock belong to genetically improved strains (e.g., genetically improved farmed tilapia), which may respond differently to rest regimens than wild or less-selected strains (FAO, 2024b). Understanding genotype-environment-management interactions will be critical for tailoring broodstock protocols to maximize reproductive efficiency under varied production systems. This study demonstrates that structured weekly rest periods markedly enhance Nile tilapia reproductive performance by improving egg and fry yield and synchronizing spawning.

Conclusions. The resting models of broodfish play a crucial role in assessing reproductive effectiveness, coordinating spawning activities, and overall seed production in *Oreochromis niloticus*. Implementing a weekly spawner resting schedule (T-WR) resulted in the highest egg production, better cohort synchrony, and improved fry yields, while continuous spawning (T-NR) led to ovarian fatigue and turn down in fecundity. These findings emphasize that well-planned recovery periods present a practical and cost-effective approach to stabilizing fry availability, improving hatchery efficiency, and promoting sustainable tilapia farming in limited resources. The study's results are consistent with global experiences in tilapia hatcheries, where structured recovery periods and cohort-based management improve reproductive efficacy, enable standardized incubation and larval care, and ensure traceable broodstock lineage. For resource-constrained and smallholder hatcheries, adoption of such practices can maximize fry availability, strengthen smallholder livelihoods, and support sustainable intensification of aquaculture in Bangladesh and similar tropical freshwater environments.

Acknowledgements. I sincerely thank the hatchery owner for his support, motivation, and generous provision of facilities, resources, infrastructure, broodstock, and logistics essential for this research. I also acknowledge the technical staff for their dedication and assistance in experimental setup, hatchery operations, and maintenance of optimal conditions, which were crucial to the successful completion of the study.

Authors Contributions. IAC independently conducted the research and was responsible for the conceptualization, methodology, investigation, data collection, formal analysis, interpretation of results, and writing and revision of the manuscript.

Conflicts of Interest. The author declares that there is no conflict of interest.

Data Availability. The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Funding. This research received no external funding.

References

Abou-Zied, R. M. (2015). Effect of rest systems during spawning season on the spawning efficiency of Nile tilapia in commercial hatcheries. *Egyptian Journal of Animal Production, 52*(3), 173-177. https://doi.org/10.21608/ejap.2015.93622

Abu-Elala, N. M., Ali, T. E. S., Ragaa, N. M., Ali, S. E., Abd-Elsalam, R. M., Younis, N. A., Abdel-Moneam, D. A., Hamdien, A. H., Bonato, M., & Dawood, M. A. O. (2021). Analysis of the productivity, immunity, and health performance of Nile tilapia (*Oreochromis niloticus*) broodstock-fed dietary fermented extracts sourced from *Saccharomyces cerevisiae* (Hilyses): a field trial. *Animals, 11*(3), 815. https://doi.org/10.3390/ani11030815

Addo, S., Oblie, E. N. A., Duodu, C. P., Amponsah, S. K. K., Sowah, W., & Asamoah, E. K. (2024). Effects of broodstock sex pairing ratios and rest periods of the Nile tilapia *Oreochromis niloticus* on fry production. *Ghana Journal of Science, 64*(2), 1-11. https://dx.doi.org/10.4314/gjs.v64i2.11

Akar, A. M. (2012). Effect of sex ratio on reproductive performance of broodstock Nile tilapia (*Oreochromis niloticus*) in suspended earthen pond hapas. *Journal of the Arabian Aquaculture Society, 7*(1), 19-28.

Alam, M. M., Haque, M. M., & Santi, M. (2024). Barriers to the export of farmed *Pangasius* and *Tilapia* from Bangladesh to the international market: evidence from primary and secondary data. *Aquaculture Journal, 4*(4), 293-315. https://doi.org/10.3390/ aquacj4040022

Ali, H., Belton, B., Haque, M. M., Murshed-e-Jahan, K., & Ignowski, L. (2023). The structure, conduct, and performance of the hatchery segment of the aquaculture value chain in Bangladesh. *Frontiers in Aquaculture, 2*, 1219458. https://doi.org/10.3389/faquc.2023.1219458

Ali, H., Haque, M. M., & Murshed-e-Jahan, K. (2025). Transformation of the farm segment of the aquaculture value chain in Southern Bangladesh. *Aquaculture, 596*(1), 741730. https://doi.org/10.1016/j.aquaculture.2024.741730

Amaddou-Ly, M., Ngom, A., Fall, A. B., & Diouf, O. (2021). Broodstock sex ratio improves fry production in Nile tilapia (*Oreochromis niloticus*) in northern Senegal. *International Journal of Advanced Research, 9*(2), 72-76. https://doi.org/10.21474/IJAR01/12419

Arumugam, M., Jayaraman, S., Sridhar, A., Venkatasamy, V., Brown, P. B., Abdul-Kari, Z., Tellez-Isaias, G., & Ramasamy, T. (2023). Recent advances in tilapia production for sustainable developments in Indian aquaculture and its economic benefits. *Fishes, 8*(4), 176. https:// doi.org/10.3390/fishes8040176

Asase, A., Darco, J. E., Temta, W. B., Asare, D., & Henneh, S. (2021). Effects of frequency of eggs and fry harvest on seed production and growth of Nile tilapia. *International Journal of Fisheries and Aquatic Studies, 9*(5), 18-22. https://www.doi.org/10.22271/fish.2021.v9.i5a.2558

Aure, S. E. M., Mamplata, A. P., Ortañez, M. G. (2024). Broodstock fecundity and fry survivability in Nile tilapia (*Oreochromis niloticus*): effects of dietary nucleotide supplementation in an on-farm feeding trial. *Proceedings International Conference on Fisheries and Aquaculture, 11*(1), 1-15. https://doi.org/10.17501/23861282.2024.11101

Basiita, R. K. (2020). Better management practices for tilapia broodstock conditioning and mass spawning in hapas in ponds. Penang, Malaysia: CGIAR Research Program on Fish Agri-Food Systems. Guidelines: FISH-2020-13, 9 pp.

Bhujel, R. C. (2000). A review of strategies for the management of Nile tilapia (*Oreochromis niloticus*) broodfish in seed production systems, especially hapa-based systems. *Aquaculture, 181*, 37-59. https://doi.org/10.1016/S0044-8486(99)00217-3

Burad-Méndez, A., Domínguez-May, R., Olvera-Novoa, M. A., Robledo, D., & Salas, S. (2023). Economic analysis of Nile tilapia (*Oreochromis niloticus*) production based on farm size and number of rearing tanks. *Latin American Journal of Aquatic Research, 51*(5), 747-759. https://doi.org/10.3856/vol51-issue5-fulltext-3071

Chandan, C. S. S., & Roy, P. (2024). Aquaculture practices in Bangladesh: a synopsis on prospects, productivity, and problems. *Journal of the World Aquaculture Society, 55*(1), 4-25. https://doi.org/10.1111/jwas.13045

El-Sayed, A. F. M., & Kawanna, M. (2004). Effects of photoperiod on the performance of farmed Nile tilapia *Oreochromis niloticus*: I. Growth, feed utilization and survival of fry and fingerlings. *Aquaculture, 231*, 393-402. https://doi.org/10.1016/j.aquaculture.2003.11.012

Engdaw, F., & Geremew, A. (2024). Broodstock nutrition in Nile tilapia and its implications on reproductive efficiency. *Frontiers in Aquaculture, 3*, 1281640. https://doi.org/10.3389/faquc.2024.1281640

FAO (2024a). Hatchery rearing of tilapia eggs and fry (Sec. 10.8). Food and Agriculture Organization. Available at: https://www.fao.org/4/t8389e/T8389E11.htm. Accessed: April, 2026.

FAO (2024b). The state of world fisheries and aquaculture 2024. Blue transformation in action. FAO, Rome, 264 pp. https://doi.org/10.4060/cd0683en

Hamad, S., El-Kassas, S., Abo-Al-Ela, H. G., Abdo, S. E., Al Wakeel, R. A., Abou-Ismail, U. A., & Mohamed, R. A. (2024). Interactive effects of water temperature and dietary protein on Nile tilapia: growth, immunity, and physiological health. *BMC Veterinary Research, 20*(1), 349. https://doi.org/10.1186/s12917-024-04198-2

Haque, M. M., & Mahmud, M. N. (2025). Potential role of aquaculture in advancing sustainable development goals (SDGs) in Bangladesh. *Aquaculture Research, 2025*, 6035730. https://doi.org/10.1155/are/6035730

Islam, M. R., Olowe, O. S., Mely, S. S., Hossain, M. A., Das, M., & Zaman, M. F. U. (2023). Review of the current situation, problems, and challenges in fish seed production and supply for Bangladesh's aquaculture development. *Aquatic Living Resources, 36*, 32. https://doi.org/10.1051/alr/2023028

Khalil, D. K., Ali, M. A. M., & Badran, M. F. (2024). The impact of interaction of photoperiods and vitamins supplementation on the hematological parameters, reproductive hormones, liver function, and reproductive performance of the female Nile tilapia (*Oreochromis niloticus*). *Egyptian Journal of Aquatic Biology and Fisheries, 28*(2), 825-842. https://doi.org/10.21608/ejabf.2024.351795

Little, D. C., Macintosh, D. J., & Edwards, P. (1993). Improving spawning synchrony in the Nile tilapia, *Oreochromis niloticus* (L.). *Aquaculture Research, 24*(3), 399-405. https://doi.org/10.1111/j.1365-2109.1993.tb00563.x

Mabrouk, M. M., Ashour, M., Younis, E. M., Abdel-Warith, A. W. A., Bauomi, M. A., Toutou, M. M., Mansour, A. I. A., Abdelaty, B. S., Elokaby, M. A., Devies, S. J., El-Haroun, E., & Gwida, A. G. A. (2024). *Arthrospira platensis* nanoparticles dietary supplementation improves growth performance, steroid hormone balance, and reproductive productivity of Nile tilapia (*Oreochromis niloticus*) broodstock. *PLoS ONE*, *19*(6), e0299480. https://doi.org/10.1371/journal.pone.0299480

Pan, Y., Xu, G., Huang, T., Gu, W., Liu, E., & Wang, G. (2024). Effects of exogenous hormones on spawning performances, serum gonadotropin and sex steroid hormone in Manchurian trout (*Brachymystax lenok*) during sexual maturation. *Fishes, 9*(7), 269. https://doi.org/10.3390/fishes9070269

Pant, J., Bhujel, R. C., du Carmu, A. D. F., de Jesus, L. S., Gomes, S., Pereira, M., Teoh, S. J. (2024). Sustainable production and dissemination of genetically improved farmed tilapia seed in smallholder farming systems: a case study from Timor-Leste. *Agricultural Systems, 219*, 104031. https://doi.org/10.1016/j.agsy.2024.104031

Rbbani, G., Siriyappagouder, P., Murshed, R., Joshi, R., Nedoluzhko, A., Galindo-Villegas, J., & Fernandes, J. M. O. (2025). Optimization of Nile tilapia artificial breeding using human chorionic gonadotropin (hCG) hormone. *Methods and Protocols, 8*(3), 57. https://doi.org/10.3390/mps8030057

Sallam, G. R., El-Basuini, M. F., Alhoshy, M., Al-Absawey, M. A., Habib, Y. J., Elhetawy, A. I. G., Teiba, I. I., Abdel-Rahim, M. M., Abdelaty, B. S., Kashuit, A. A., Fayed, W. M., Mabrouk, H. A. H., & Shehata, A. I. (2025). Strategic application of biofloc technology for optimizing physiological homeostasis and reproductive efficiency in red tilapia (*Oreochromis* spp.) broodstock under long-term rearing conditions. *Aquaculture International, 33*, 464. https://doi.org/10.1007/s10499-025-02141-2

Siddique, M. A. B., Ahammad, A. K. S., Bashar, A., Hasan, N. A., Mahalder, B., Alam, M. M., Biswas, J. C., & Haque, M. M. (2022). Impacts of climate change on fish hatchery productivity in Bangladesh: a critical review. *Heliyon, 8*(12), e11951. https://doi.org/10.1016/j.heliyon.2022.e11951

Trong, T. Q. (2013). Optimization of selective breeding program for Nile tilapia (*Oreochromis niloticus)*. PhD thesis, Wageningen University, the Netherlands, 176 pp.

Received: 15 June 2026. Accepted: 30 August 2026. Published online: 06 November 2026.
Author:
Istiaq Ahmad Chowdhury (IAC), Institute of Marine Sciences, University of Chittagong, Chattogram-4331, Bangladesh, e-mail: iachowdhury@cu.ac.bd https://orcid.org/0000-0003-0135-0005
This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.
How to cite this article:
Chowdhury, I. A. (2026). Breeding synchronization enhances reproductive efficiency in resource-limited Nile tilapia (*Oreochromis niloticus*) hatcheries. *Aquaculture, Aquarium, Conservation & Legislation, 19*(6), 2673-2682. https://doi.org/10.67784/1019