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The potential of tilapia cage farming in Semi-Arid Regions: A Case of Dabalo Dam, Dodoma, Tanzania

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Abstract

Aquaculture offers a sustainable solution to meet the global demand for fish and enhance food security. However, in regions where conventional aquaculture faces constraints due to limited water resources and a scarcity of natural water bodies, alternative approaches are needed. This study investigated the feasibility of tilapia cage farming at Dabalo Dam in Dodoma, one of the semi-arid regions in Tanzania. The research examined the growth performance of monosex tilapia (Oreochromis niloticus) over two production cycles, using different stocking densities and seed sources. The fish were reared in a rectangular iron cage for six months, and fed commercial feeds, with feeding ratios adjusted based on body weight and environmental conditions. Monthly weight and daily survival rate measurements monitored the fish growth while water quality parameters were measured intermittently. The results indicated significant growth differences between the production cycles. Cycle 2 demonstrated superior performance, with an average final weight of 395.17 ± 80.50 g, compared to 120.88 ± 0.75 g in cycle 1. Survival rates remained high in both cycles, demonstrating the fish population's resilience to the prevailing environmental conditions within the dam. The study highlights that seasonal fluctuations in water quality parameters and dam depth affect farming operations, posing both challenges and opportunities. This research offers valuable information on the potential of water reservoirs to support aquaculture development and improve livelihoods in semi-arid areas. However, the success of such initiatives depends on factors such as water conditions, seed quality, and stocking density considerations.

Keywords: *Dabalo dam; Growth performance; Livelihood enhancement; Semi-arid regions; Tanzania; Tilapia cage farming*

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Introduction

Aquaculture is considered a sustainable solution to meet the growing global demand for fish and improve food security (Allison, 2011; El-Sayed and Fitzsimmons, 2023; Prabu *et al*., 2019). As the global population increases, the demand for food, including fish, is increasing. However, fish farming in arid and semi-arid regions faces numerous challenges, including limited water supply due to the absence of perennial rivers, low precipitation rates, and high evaporation rates (Mramba and Kahindi, 2023; Msengi *et al*., 2024). The water scarcity in these regions requires the exploration of alternative methods for aquaculture. One of the best alternatives is to use existing water reservoirs, such as dams, constructed for other purposes. These can hold promise for sustainable cage fish farming, intensifying fish production without competing with limited land and freshwater resources (Garcia *et al*., 2013; Tacon *et al*., 2007).

Cage fish farming in semi-arid regions has been conducted globally, providing valuable insights and strategies applicable in various contexts (Henry-Silva *et al*., 2022; Moura *et al*., 2016). For example, in Asian countries such as China, cage fish farming in reservoirs has been successfully implemented, demonstrating significant improvements in fish production and economic returns (Zhang *et al*., 2023). Similarly, in India, cage fish farming in reservoirs has been promoted as a means to improve fish production and provide employment opportunities in rural areas (Debnath *et al*., 2022). In Brazil, studies have shown that cage fish farming in water reservoirs can lead to substantial increases in fish yield while promoting sustainable water use (Garcia *et al*., 2013; Moura *et al*., 2016). Furthermore, in Egypt, another semi-arid country, research has shown that integrating cage fish farming with existing agricultural practices can improve water use efficiency and increase farmers' income (El-Sayed, 2016; Shaalan *et al*., 2018; Soliman and Yacout, 2016).

In most African countries, pond culture is the predominant fish-growing system (Allison, 2011; Berg *et al*., 2021; Mdegela *et al*., 2011; Mulokozi *et al*., 2020) while cage farming is still in the feasibility phase. For instance, in Tanzania, the number of fishponds used for aquaculture had reached 21,300 by 2015 (Rukanda and Sigurgeirsson, 2018), and this number has continued to grow with increasing aquaculture production and awareness of its benefits. However, pond culture is water-intensive, which makes it less suitable for semi-arid regions where water is scarce. As a result, utilizing existing water reservoirs for cage fish farming has been proposed as a viable alternative (Abwao *et al*., 2023; Henry-Silva *et al*., 2019). Despite this potential, research on the feasibility and sustainability of cage farming in Tanzania is still limited. While cage fish farming is established in larger water bodies, specifically Lake Victoria, small water bodies such as dams and ponds have yet to witness significant development of this fish farming system.

This study investigates the potential of water reservoirs, with a specific focus on the Dabalo Dam in Dodoma, Tanzania, to support and sustain cage farming ventures, thereby addressing the challenges of food security and economic sustainability. Dodoma, the capital city of Tanzania, is located in the central part of the country in a semi-arid climate. The region receives an average annual rainfall of 567 mm, with a prolonged dry season lasting 7-8 months (Msengi *et al*., 2024; Rapp *et al*., 1972; URT, 2017). Due to limited access to large natural water bodies suitable for traditional fish farming and the decline of native fish species in local reservoirs (Gayo, 2021; Turner *et al*., 2018), Dodoma relies on external sources for its fresh fish supply. Although fish farming initiatives have been reported in the region (Mramba and Kahindi, 2023; Ngongolo *et al*., 2023), they primarily involve pond culture and are still insufficient to meet local fish demand.

Despite challenges such as water scarcity and fluctuating environmental conditions, Dodoma presents an opportunity for cage fish farming to improve food security and livelihoods. The region is home to several man-made water reservoirs such as Hombolo, Mtera, and Dabalo (Christiansson, 1979; Gayo, 2021; Mgandu *et al*., 2020) which were constructed by the colonial government mainly for flood control purposes. This study focuses on the Dabalo Dam, which was originally constructed in 1957 (Rapp *et al*., 1972) and has been used by local community for various activities including artisanal fishing, domestic use, and crop irrigation. Although the potential for tilapia cage farming in the Dabalo Dam has only recently been realized, crucial information about its production capacity and other relevant aspects remains largely unknown to the community. This lack of awareness hampers the community's ability to fully utilise the potential of the dam for socio-economic development. By analyzing the growth performance of tilapia reared in the cages installed at the Dabalo Dam for two successive production cycles from 2022 to 2024, this study highlights the substantial potential of utilizing available water resources to maximize fish production.

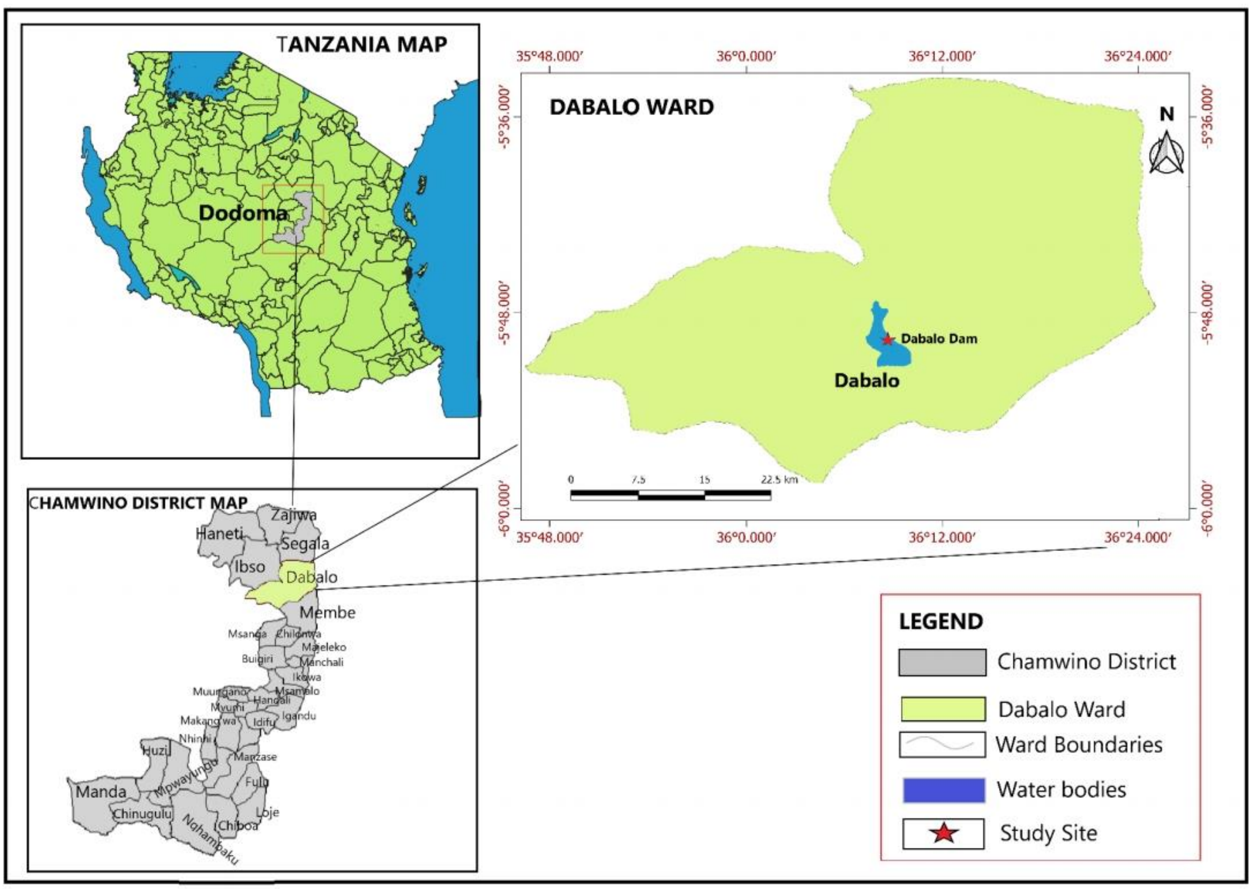
Materials and Methods

Study site

The study was carried out at the Dabalo dam in Chamwino district, Dodoma region, Tanzania (Figure 1), in the tilapia cages installed by a group of fish farmers. The dam covers an area of approximately 3 km² with depths varying seasonally. During the wet season, the depth of the Dabalo dam ranges from 5 to 7 meters, decreasing to 2.5 meters in the dry season, as observed during the study. Dodoma's semi-arid climate receives a rainy season from December to March and a prolonged dry season from April to November (Msengi *et al*., 2024; URT, 2017). The region supports drought-tolerant crops such as sorghum, millet, and paddy for food, while grapes, sunflowers, and groundnuts are grown as cash crops (URT, 2017). The population of Dodoma is rapidly increasing, further accelerated by the relocation of government headquarters from Dar es Salaam to Dodoma and the establishment of the University of Dodoma (Mramba and Kahindi, 2023; Msongaleli *et al*., 2023).

Figure 1

The Tanzanian map showing a study site



Fish seed and stocking

The study was carried out over two consecutive production cycles to evaluate the sustainability of the cage fish farming practice in the dam. Each cycle differed in the seed source and stocking density, allowing for a comparison of growth performance and seed quality conditions. Monosex tilapia fry *(Oreochromis niloticus)* were kept in rectangular iron cages measuring 8 metres in length, 5 meters in width, and 3 meters in depth (120 m^3). In cycle 1, the fry were sourced from the Pwani region in eastern Tanzania, while the seeds for cycle 2 were obtained from the Simiyu region in northern Tanzania. The cycle 1 stocking density was 10,000 fingerlings and the cycle 2 stocking density was 6,700 fingerlings in cages of identical dimensions and at the same location. Stocking in cycle 1 occurred in October 2022, while in cycle 2, it was conducted in August 2023. Initially, the fry were introduced to a *hapa* net within the cage for a two-week acclimatisation period. This allowed them to reach a fingerling size suitable for the grow-out net. Following acclimatisation, the fingerlings were transferred to the grow-out net, where they continued their growth for up to six months (24 weeks), as the normal time to reach table size. During these six months of rearing, data collection was carried out from the time of stocking into the grow-out net until the harvest period. However, in cycle 1, the rearing period extended beyond six months, as most of the fish did not attain table-size within the expected timeframe.

Feeding management and sampling design

The fish in the study were fed commercial feeds, sourced from reputable companies such as Koudgis, Skretting, Aller Aqua, and Aqua Group. The choice of feed company varied depending on availability and market dynamics. The feed was purchased from different regions in Tanzania, including Mwanza, Morogoro, and Dar es Salaam. The feeding protocols were closely followed to meet nutritional requirements, with adjustments based on body weight and environmental conditions. Initially, at the fry level, a feeding ratio of 10% of body weight was used in both cycles to promote growth. In cycle 1, the feeding ratio was reduced to 2% of body weight by week 24, and in cycle 2, it was further reduced to 1% at a similar stage. Weight measurements were taken monthly using a portable weigh balance to monitor fish growth, except during the eight weeks in cycle 2 due to adverse weather conditions. Survival rates were recorded daily by counting fish mortality and comparing it to the stocked density. Growth parameters such as weight gain (WG), daily weight gain (DWG) and specific growth rate (SGR) were analysed in each sampling month to assess feeding regimes and environmental effects on fish growth. After harvest, fish were sold to local communities surrounding the dam, with bulk stock transported to Dodoma town to meet regional demand. The sales operations were carried out on the same day of harvest at a standardised price of TZS 10,000 (≈ $4)/Kg. The growth parameters were calculated as follows;

Survival rate (%) = 100× (Stock density-mortality/Stock density) ……………………… (1)

WG (g) = FW-IW ………………………………………..(2)

DWG (g fish day^{-1}) = (FW-IW)/Time (days)…………………………………(3)

SGR (% day^{-1}) = $100 \times (\ln [FW] - \ln [IW]) / (Time\ (days))$……………...............(4)

Where; FW = Final fish weight, IW= Initial fish weight.

Water quality monitoring

The water quality parameters were sampled intermittently throughout the study period, taking into account both dry and wet seasons being considered. Key parameters such as temperature, pH, dissolved oxygen, and depth of the dam were measured, though with limited frequency. Standard laboratory equipment, including a dissolved oxygen (DO) metre and pH meter, were used for *in situ* measurement of DO and pH and temperature levels. The depth of the water in the dam was measured using a graduated rope attached to a sinker. The total dissolved solids (TDS) in the dam were measured with a conductivity metre. Additionally, visual observations of water clarity and fish behaviour were used as indicators of water quality in the dam.

Data analysis

Data on fish growth performance were analysed using R software (version 4.4.0) and descriptive statistics for water quality parameters. Initially, normality was assessed using the Shapiro-Wilk test. For normally distributed data, homogeneity of variance was checked using Bartlett's test, while for non-normally distributed data, Levene's test was applied. One-way analysis of variance (ANOVA) was used to analyse growth parameters that were normally distributed, while the Kruskal-Wallis test was used for growth parameters that were not normally distributed. The results were presented as mean ± standard error (SE), and statistical significance was determined at a threshold of p <0.05.

Results

Water quality parameters

The water quality values during the study are presented in Table 1. A notable indicator of water quality observed was the fluctuation in water clarity, especially at the beginning of the rainy season. The increased precipitation introduced debris, changing the colour of the water to brown. The depth varied with seasonal changes and farming cycles. In cycle 1, the depth decreased to 2.5 m during the dry season, while in cycle 2, it did not exceed 3.5 m. During the rainy season, the depths increased to 5.5 m in cycle 1 and 6 m in cycle 2. Dissolved oxygen levels ranged from 5.02 mg/l to 8.64 mg/l, peaking in the wet season and increasing from cycle 1 to cycle 2. The temperature was higher in the dry season, with more stable conditions in cycle 2. The pH showed minimal variation, remaining slightly alkaline. Total dissolved solids (TDS) were higher in the dry season and decreased significantly in the wet season, decreasing from cycle 1 to cycle 2.

Table 1

Variation of water quality parameters within Dabalo Dam during the study (mean ± SD)

Parameter	Cycle 1		Cycle 2	
	Dry season	Wet season	Dry	Wet season
DO (mg/l)	4.42±0.44	6.98±0.88	6.46±0.67	8.64±0.53
Temperature (°C)	24.6±1.1	22.7±1.2	24.9±0.9	23.7±1.2
pH	7.64±0.11	7.7±0.09	7.68±0.08	7.69±0.03
TDS (mg/l)	650	460	420	-
Water depth (m)	2.5	5.5	3.5	6

DO = Dissolved oxygen, TDS = Total dissolved solids

- Missing data

Fish growth trend

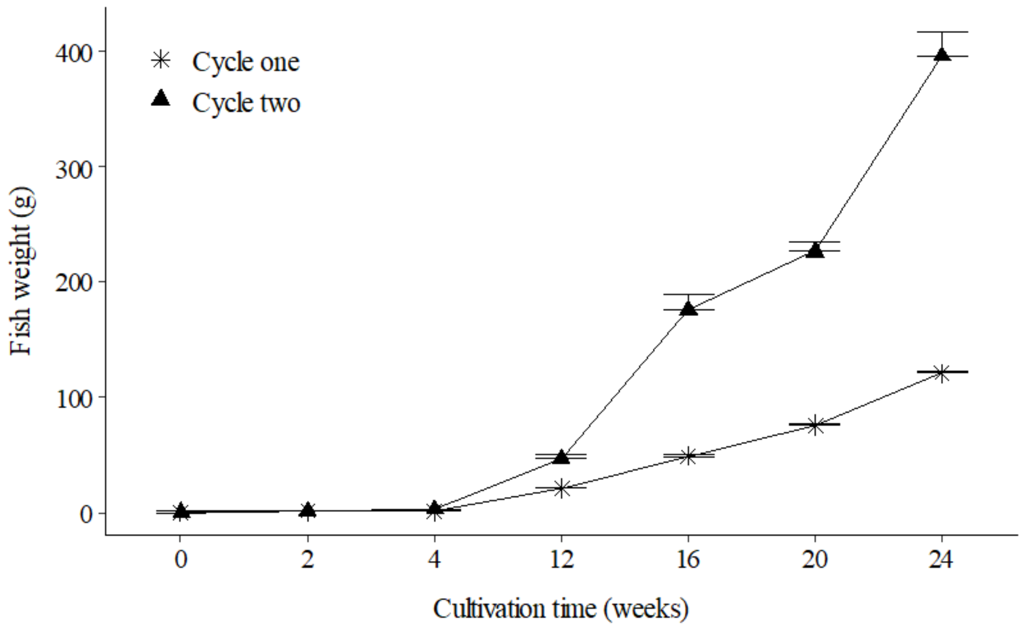
The overall performance of the fish growth, indicated by parameters such as weight gain (WG), daily weight gain (DWG), and specific growth rate (SGR), demonstrated notable differences between cycle 1 and cycle 2 of the cage fish farming at the Dabalo dam (Table 2). In cycle 1, the growth performance showed a pattern of moderate growth that gradually increased over time with the average final weight, but at a slower rate compared to cycle 2 (Figure 2). Cycle 2 showed consistently higher growth performance throughout the duration of the farming cycle. The average weight achieved at the end of six months (week 24) of farming was 120.88 ± 5.752 g and 395.17 ± 80.501 g for cycle 1 and cycle 2, respectively.

Weight gain

The weight gain (WG) values showed a substantial contrast between cycle 1 and cycle 2 (Table 2). Fish in cycle 2 demonstrate a significantly higher weight gain compared to cycle 1 at all-time points. Similarly, the DWG trends revealed distinct patterns between cycle 1 and cycle 2. In cycle 1, the DWG ranged from 0.02 g/day to 0.27 g/day, while in cycle 2, it ranged from 0.03 g/day to 1.17 g/day. The highest DWG values in cycle 1 were recorded in the last weeks, while in cycle 2, the peak was observed at week 16. There were statistically significant differences in DWG between cycle 1 and cycle 2, as well as between various sampling weeks, with cycle 2 indicating enhanced growth. The trend was similar in both cycles, with fish showing a consistent increase in DWG, except at week 4 for cycle 1 and week 20 for both cycles, when a reduction in DWG observed.

Figure 2

Change in tilapia weight during the two farming cycles



Specific growth rates

The trend of specific growth rate (SGR) in the first weeks, mid-weeks, and last weeks of fish farming reveals distinct patterns between cycle 1 and cycle 2 (Table 2). Tilapia SGR varied significantly between cycle 1 and cycle 2, with cycle 1 showing higher growth rates initially and then decreasing over time, while cycle 2 shows a more varied pattern. The SGR in cycle 2 demonstrates consistently high SGR throughout the farming cycle, with little to no decrease in growth rate during the midweeks and increased growth even in the last weeks. Most of the differences between weeks are statistically significant, indicating differences in growth dynamics between the two cycles.

Survival rates

Both cycles exhibited consistently high survival rates (SR) throughout the farming cycle, with negligible variations observed between cycle 1 and cycle 2 (Table 2). SR remained relatively stable and exceeded 98%, indicating the overall health and resilience of the fish population to environmental conditions within the dam. Despite minor differences in SR between the two cycles, the p-values indicated significant variability in survival rates at specific stages of growth (Table 2), with p-values typically below 0.001.

Discussion

The results on fish growth performance demonstrate that tilapia cage farming at Dabalo Dam has significant potential for successful growth and production, as the fish exhibited notable weight gain, daily weight gain, and specific growth rates, with high survival rates. The significantly higher final weight in cycle 2 indicate better growth potential under the prevailing conditions, suggesting that the tilapia seed used can achieve larger sizes, when best management practise is considered. However, the observed variations in growth parameters between the two production cycles are likely to be attributed to fluctuations in environmental conditions, stocking density, and seed quality.

Table 2

Growth parameters of tilapia at Dabalo Dam during the study period (mean ± SE)

Time (Week)	**Growth performance parameters**					
	WG (g)			**DWG (gday^{-1})**		
	Cycle 1	Cycle 2	P-value	Cycle 1	Cycle 2	P-value
IW (g)	0.415±0.07	0.89 ± 0.27				
2	0.33 ± 0.02	0.41 ± 0.08	> 0.05	0.02 ± 0.00	0.03 ± 0.01	> 0.05
4	0.3 ± 0.03	1.91± 0.13	< 0.0001	0.01 ± 0.00	0.07 ± 0.00	<0.001
12	15.39 ± 0.62	30.12 ± 3.71	0.003	0.18 ± 0.01	0.36 ± 0.04	0.004
16	27.79 ± 0.9	31.51 ± 14.51	< 0.0001	0.25 ± 0.01	1.17 ± 0.13	<0.0001
20	26.91 ± 1.11	53.2 ± 7.09	0.017	0.19 ± 0.01	0.39 ± 0.05	0.013
24	44.71 ± 1.52	173.00 ± 21.51	< 0.001	0.27 ± 0.01	1.03 ± 0.13	<0.001
FW(g)	120.88±0.75	395.17±80.50	< 0.001			
	SGR (%day^{-1})			**SR (%)**		
2	10.84 ± 0.38	4.71 ± 0.64	< 0.0001	98.87 ± 0.00	99.88 ± 0.00	< 0.0001
4	1.84 ± 0.19	4.29 ± 0.19	< 0.001	99.67 ± 0.00	99.64 ± 0.00	0.009
12	1.61 ± 0.03	1.23 ± 0.11	0.003	99.50 ± 0.00	99.84 ± 0.00	< 0.0001
16	0.76 ± 0.02	1.19 ± 0.08	0.001	99.78 ± 0.00	99.84 ± 0.00	< 0.0001
20	0.32 ± 0.01	0.18 ± 0.02	< 0.001	99.83 ± 0.00	99.78 ± 0.00	< 0.0001
24	0.28 ± 0.01	0.33 ± 0.03	0.145	99.33 ± 0.00	99.9 ± 0.00	< 0.0001

The variations in weather patterns between the two cycles, including the timing and amount of rainfall could have profound implications for fish acclimation to environmental stressors (Duan, 1998), potentially explaining the observed differences in growth rates between the two cycles. The low amount of rainfall in 2022 (Tanzania Meteorological Authority, 2023) resulted in reduced water levels and poorer water quality in the dam during cycle 1. Studies report that fish exposed to poor water quality conditions often exhibit reduced feed intake and slower growth rates (Ajiboye *et al*., 2015; Schram *et al*., 2010). In cycle 1 of the study, rainfall began when the fish were only two months old (8 weeks), whereas in cycle 2, it started when the fish had already reached three months (12 weeks) of growth. As previously reported by Duan (1998), early exposure to a new environment can hinder feed intake, thus slowing growth.

Throughout the two production cycles, the water quality parameters remained within the optimal range for tilapia, despite slight variations between seasons and cycles. The lower levels of dissolved oxygen in cycle 1 compared to cycle 2 can be attributed to the low or delayed rainfall between late December 2022 and March 2023. On the contrary, elevated levels of DO during the wet season were likely the result of increased aeration from rainfall and runoff (Li *et al*., 2015). Moreover, the observed increase in depth in cycle 2 in both seasons suggests an overall rise in water levels, possibly due to changes in inflow patterns and climatic dynamics. Research has shown that variations in inflow patterns and seasonal rainfall significantly influence water levels in aquatic systems thus affecting aquatic life (Yao *et al*., 2016).

The minimal fluctuations in pH between seasons and production cycles were possibly the result of the dam buffering capacity. The buffering capacity of a water body, which is influenced by the presence of natural buffers such as carbonate minerals, helps to stabilize pH levels despite water pollution (Grochowska, 2020). The observed stability in pH could thus reflect the dam's effective buffering capacity, contributing to a more consistent environment for fish growth. On the other hand, the temperature range of 22.7 °C to 24.9 °C recorded in this study is suitable for tilapia farming as tilapia are hardy and with a wide range of tolerance (Azaza *et al*., 2008; Hamed *et al*., 2021). Despite a wide range of temperatures, sudden change can hinder their overall growth performance (El-Sayed, 2006). Seasonal temperature variation was approximately 1.9 °C for cycle 1 and 1.2 °C for cycle 2, indicating that the temperatures were relatively more stable in cycle 2, giving consistency to the tilapia and a stable environment to grow well.

The higher TDS levels observed during the dry seasons and in cycle 1 could result from evaporation and reduced rainfall, which prevent the dilution of solids within the dam. Increased evaporation rates during the dry season leave dissolved solids in the pond, increasing the concentrations of TDS. Additionally, less rainfall reduces the dilution effect, causing the accumulation of dissolved substances from feeding, metabolic waste, and other sources (Coldebella *et al*., 2017). The use of water by the surrounding community for crop irrigation and other domestic uses during dry periods can also contribute to increased TDS, as the dam water sources are replenished without means to dilute the water.

The quality of fish seeds plays a pivotal role in determining fish growth and performance (Musuka and Nyimbili, 2017). Variability in genetic characteristics and environmental adaptability can influence performance, especially when seeds are sourced from environments similar to their own. (Geletu and Zhao, 2023). In this study, fish seeds were sourced from two different suppliers, which could introduce genetic variations that could impact growth trajectories. According to the weather forecast by the Tanzania Meteorological Agency (TMA, 2024), the weather conditions in the Simiyu region, where the fish seeds for cycle 2 were sourced, are nearly identical to those in Dodoma and differ significantly from those in the Pwani region. Specifically, Pwani experiences higher temperatures compared to both Dodoma and Simiyu (TMA, 2024). As a result, Simiyu tilapia seeds were more likely to survive at a higher rate due to their potential adaptation to the conditions within the dam. The sustained growth and higher weight attained at the end of the production cycle observed in cycle 2 suggest that these seeds may be more suitable for efficient growth in semi-arid regions with similar climatic conditions as Dodoma.

Stocking density significantly influences fish growth performance in a fish farming system (Garcia *et al*., 2013; Ngongolo *et al*., 2023; Oké and Goosen, 2019). In cycle 1, the stocking density was 10,000 fish/120 m^3 (83 fish/m3), while in cycle 2, it was reduced to 6,700 fish/120 m^3 (55 fish/m^3). The lower stock density in cycle 2 likely provided more space and resources, facilitating better growth opportunities compared to cycle 1. Garcia *et al*. (2013) similarly reported improved growth performance, feed conversion rates, shorter harvesting time, reduced production costs, and increased operating profit for tilapia in cages at lower densities (800 fish/6 m^3) in a hydroelectric reservoir in Brazil. Furthermore, Yi *et al*. (1996) found that tilapia stocked at 50 fish/m^3 achieved optimal growth performance, reaching up to 565 ± 13.9 g during the production cycle . Similarly, Gibtan *et al*. (2008) recorded a maximum average final weight of 219.71 ± 1.42 g on Lake Kuriftu, Ethiopia, using a stocking density of 50 fish/m^3.

The dynamics of daily weight gain in cycle 1 were characterized by peaks and troughs in the midweek, followed by stabilization or slight decline towards the end of the production cycles. This trend was associated with the changes in environmental conditions prevailing during that time. Variations in specific growth rates between the two production cycles suggest that the fish in cycle 2 experienced optimized conditions or practices that supported steady growth throughout the farming cycle. However, the higher specific growth rates (SGR) in the early weeks of tilapia farming in both cycles align with the physiological growth rates of young fish, which are higher than those of adults (Hopkins, 1992). Young fish have relatively higher rates of food consumption (Post and Parkinson, 2001), which in turn promotes their higher growth rates compared to adults. The relatively stable and high survival rates (SR) observed in this study indicate the resilience of the fish population to environmental conditions within the Dabalo dam. These findings align closely with those of Huss *et al*. (2008) in their study on Eurasian perch, where they observed improved winter survival associated with effective strategies such as efficient energy reserve storage and optimal growth rates. This suggests that similar mechanisms may contribute to the observed resilience of the fish population in the Dabalo dam environment.

Conclusion

The findings of this research indicate that tilapia cage farming in water reservoirs is a viable strategy to enhance aquaculture productivity in semi-arid regions. The observed robust growth and high survival rates of fish in Dabalo Dam confirm the feasibility of this farming method. However, year-specific weather variations can significantly impact fish performance during production cycles. Therefore, ensuring optimal conditions, such as appropriate stocking densities, selecting seeds adapted to local climates, and implementing effective management practices, is crucial for maintaining fish health and productivity in water reservoirs

Recommendation

To optimize tilapia cage farming in water reservoirs like Dabalo Dam, this study recommends implementing appropriate stocking densities and selecting seeds that are genetically adapted to the local climate to improve survival rates and overall growth performance. Additionally, aligning the stocking schedule with seasonal weather patterns is advised to reduce environmental stressors and support healthier fish growth.

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