CONTRIBUTION 5.5

Evaluating the outcomes of selective breeding in optimizing the growth performance of tilapia (*Oreochromis spp.*) for commercial production in the Bahamas

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Abstract

Tilapia (*Oreochromis spp.*) is the second most farmed fish globally and is the most introduced aquaculture species. Different strains of tilapia have been developed through selective breeding programs over the years to optimize its three main performance traits: growth rate, hardiness, and marketability. Of all the strains developed, one of the most popular is the red hybrid tilapia (*O. urolepis* female was crossed with a red-gold male *O. mossambicus*), which was developed to improve the aforementioned traits under commercial production conditions. A strain of the *O. aureus* crossed with *O. niloticus* tilapia with a white colour was also developed to optimize both growth and marketability.

This comparative study assessed the growth potential of two tilapia strains (red hybrid, and *O. niloticus* X *O. aureus* White hybrid) in a recirculating aquaponics system in the Bahamas. Tanks were established with fry of each strain, starting off at roughly 5 grams. Fish were fed 5% of their body weight daily using commercial tilapia starter feed (40% protein). The fish weight was monitored, and feed conversion ratios were calculated on a weekly basis for the duration of the study period. The results indicated that for all the parameters measured, the *O. aureus X O. niloticus* strain showed more favourable growth under prevailing Bahamian climate than the red hybrid tilapia. It can therefore be concluded that farmers in the Bahamas and in similar climatic regions should consider the *O. niloticus* as a strain of economic significance for cultivation.

KEYWORDS: tilapia, growth performance, feed conversion rate, aquatic genetics

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1. INTRODUCTION

Aquaculture, which is the cultivation of aquatic organisms, has experienced exponential growth over the last few decades, and has established itself as a fundamental facet of food production globally. It contributes significantly to global nutrition, well-being, and income (Debnath et al., 2023). It is the world's most diverse (Bartley, 2022) and one of the fastest growing food production sectors (Edwards et al., 2019; Anderson et al., 2017), with production increasing from 72.8 to 82.1 million tons in just three years (Bartley, 2022). This growth represents an average annual growth rate of 6.2% (Bartley, 2022). Aquaculture has for almost 10 years supplied upward of 50% of the seafood consumed globally (Miao & Wang, 2020), thus highlighting its importance as a food production sector, particularly in developing countries.

There are several factors such as technological, scientific, and economic advancements driving the growth of aquaculture. Molecular diagnostics and biotechnology have made the detection and treatment of diseases more seamless, while innovations in vaccination strategies, antimicrobial treatments, and biosecurity measures have mitigated disease-related losses (Biggs, 1985). Advanced water treatment systems allow for more precise monitoring and management of water quality parameters crucial for healthy aquatic ecosystems (Brooks et al., 2006), and there has been a growing emphasis on environmental sustainability, resulting in the development of metrics and technologies for minimizing the ecological footprint of aquaculture, including recirculating aquaculture systems (RAS) and integrated multi-trophic aquaculture (IMTA) (Ahmed et al., 2019; Wartenberg et al., 2017). Nutritional science has also supported the growth of the sector through tailored formulations specific to species, life stages and environmental or farming conditions (Saoud et al., 2012). Another significant factor supporting the growth of the aquaculture sector is selective breeding programs, which have been able to optimize aquatic species for various desirable traits including growth and diseases resistance (Symonds et al., 2019; Janssen et al., 2017).

1.1 Freshwater Aquaculture

Freshwater aquaculture not only addresses the rising global demand for seafood but also plays a vital role in rural economies, job creation, and poverty alleviation, particularly in regions with suitable water resources. Freshwater aquaculture has also proven to be more climate resilient than marine aquaculture. Additionally, freshwater aquaculture accounts for most of the reported aquaculture production (Bartley, 2022), and over 75% of all edible aquaculture products globally (Naylor et al., 2021). It encompasses a range of species including finfish (tilapia, carp, catfish), and crustaceans (shrimp, prawns, crayfish).

1.2 Tilapia

Tilapia (*Oreochromis spp.*) is a prominent and extensively cultivated species in the field of aquaculture owing to its adaptability, rapid growth, and versatility. It is native to Africa and the Middle East but has been introduced and successfully farmed in many regions worldwide. Tilapia's popularity in aquaculture is attributed to several key factors. Firstly, it exhibits exceptional growth rates, allowing for efficient production in a relatively short period. Additionally, tilapia can thrive in diverse environmental conditions, including various water quality parameters and temperature ranges, making it well-suited for aquaculture operations in different geographical locations (Syed et al., 2022). Furthermore, tilapia has a herbivorous diet

preference, primarily consuming algae, and aquatic plants, which can be advantageous for sustainable aquaculture practices (Njiru et al., 2004). Its mild-flavored white flesh is preferred by consumers (Lako et al., 2018). Tilapia is currently classified as the second most farmed finfish globally and in 2018 accounted for 5.28% of all aquaculture production. In fact, the annual growth rate of tilapia aquaculture is 10%, which is markedly higher than that of the aquaculture sector overall (Miao & Wang, 2020). Over the years, different strains of tilapia have been identified and targeted for their desirable traits, and selectively bred to create a more climate resilient product (Abisha et al., 2022).

1.3 Selective breeding

Selective breeding has been practiced for years in the food production sector in both livestock and crops. Selective breeding is a controlled process where specific individuals are chosen to become parents, based on their genetic makeup and desirable traits (Simm et al., 1996). Over generations, this process amplifies the prevalence of these desired traits, based on heritability within the population. In the context of tilapia aquaculture, selective breeding focuses on traits such as growth rate, size, fillet yield, disease resistance, and tolerance to environmental conditions (Abwao et al., 2023). Several strains of tilapia have been developed over the years through selective breeding programs, and those of relevance to this study will be highlighted.

1.4 Red hybrid

Red hybrid tilapia is a selectively bred strain of tilapia that is not a naturally occurring species but rather a product of controlled crossbreeding between different tilapia species. The first recorded case was the result of a mutation in the typically black *Oreochromis mosambicus* where a reddish orange individual crossed with a regular *Oreochromis niloticus* (Watanabe et al., 1989). One of the most notable features of red hybrid tilapia is its distinctive red or pinkish coloration, which is a result of selective breeding for pigmentation. This unique characteristic holds significant market appeal, as consumers often prefer the vibrant appearance of red tilapia because of its resemblance to desirable marine species such as the red snapper and sea bream (Watanabe et al., 1989). Research on red hybrid tilapia has primarily focused on improving growth rates, feed efficiency, and disease resistance while maintaining the desired red coloration (Hamzah et al., 2017). Additionally, studies have explored the genetic basis of red coloration in these hybrids, enabling breeders to produce more consistent and visually appealing stocks. Red hybrid tilapia is recognized for its adaptability to various aquaculture systems, making it a valuable choice for both small-scale and commercial tilapia farming operations and it exhibits improved growth rates and feed conversion (Watanabe et al., 1989). It is important to note that the specific genetic lineage of red hybrid tilapia can vary depending on the breeding program and geographic location (Briñez R et al., 2011).

1.5 *Oreochromis niloticus* and *Oreochromis aureus* hybrid

Oreochromis niloticus and *Oreochromis aureus* are two distinct and widely cultured strains of tilapia, each with unique characteristics. *O. niloticus*, commonly known as Nile tilapia originated from the Nile region of Africa and is known for its rapid growth, adaptability to varying environmental conditions, and high fillet yield (Ponzoni et al., 2011). It has become one

of the more important species in global aquaculture owing to its ability to thrive in diverse farming systems, making it a preferred choice for commercial production. The *O. aureus*, or blue tilapia, which originated near Lake Victoria in Kenya is recognized for its tolerance to brackish and slightly saline waters (Popma & Lovshin, 1996). It is often utilized in aquaculture systems located in areas with limited freshwater resources. While both strains offer advantages to aquaculturists, their specific traits and adaptability make them suitable for different farming contexts and environmental conditions, contributing to the versatility of tilapia aquaculture worldwide.

The hybridization of *Oreochromis niloticus* and *Oreochromis aureus* combines the desirable traits of both parent species. This hybrid exhibits a balance between the rapid growth of Nile tilapia and the salinity tolerance of blue tilapia (Yu et al., 2022; Ridha, 2010). It has gained attention in aquaculture for its potential to thrive in brackish water environments while still achieving substantial growth rates. Additionally, this hybrid's genetic diversity contributes to its resilience against certain diseases, further enhancing its appeal in sustainable aquaculture practices (El-Hawarry, 2012). The *O. niloticus* X *O. aureus* hybrid also presents advantages related to fillet quality and fillet yield. It often exhibits a high fillet-to-body weight ratio, making it an efficient choice for processing and maximizing the utilization of fish for human consumption (Thodesen et al., 2011). The capacity of this hybrid to adapt to various farming systems, including pond culture, cage culture, and recirculating aquaculture systems, enhances its versatility in aquaculture operations. As aquaculture continues to face challenges related to environmental sustainability and resource management, the *O. niloticus* X *O. aureus* hybrid outshines other strains, as it combines the strengths of its parent species to meet the growing demand for tilapia production in a wide range of conditions while minimizing environmental impact.

2. METHOD

Selective Breeding of White Hybrid Fish sourced from Aquasafra Inc., a hatchery located in Bradenton, Florida.

In 1993, the parent fish *O. niloticus* and *O. aureus* arrived at Aquasafra's facilities, embarking on a continuous breeding journey while preserving the genetic integrity of each strain. Over the course of 23 generations, a meticulous selection process was employed, with a keen emphasis on preventing inbreeding. Currently, the Aquasafra facility hosts 50 distinct families, each consisting of 60 fish, totaling 3000 individuals per strain and 6000 fish per generation. Typically, three generations coexist on the premises, with the most recent one being specifically cultivated for production and eventual sale.

In every succeeding generation, the breeding endeavors are customized to emphasize specific characteristics within each lineage. For the *O. niloticus* strain, the focus remains on achieving accelerated growth, improved body conformation, reduced striping in coloration, exceptional Feed Conversion Ratio (FCR), bolstered disease resistance, and a recent addition being their ability to thrive on lower protein diets. The hatchery's efforts center around fostering swifter growth, enhancing body structure, maintaining pristine white coloration, optimizing FCR, maximizing egg yield and fecundity, fortifying disease resistance, and, in line with current trends, ensuring adaptability to lower protein diets. The fry shipped are an F1 hybrid, from the cross of a male *O. niloticus* and female *O. aureus*.

The white hybrid tilapia was compared against red hybrid tilapia sourced from a conventional aquaculture supplier in Miami, Florida.

2.1 Experiment Design

Two 150-gallon fiberglass tanks were dedicated in a recirculating system for the purpose of this experiment. The water in the system was maintained at the following water quality parameters for the duration of the study- temperature: 27^{0}C, dissolved oxygen: 88%, pH: 6.8, ammonia: 0.

Each of the tanks was populated with 25 fry from both the red and white hybrid strains, with an average weight of 5 grams per fish. The fish were fed 5% of their body weight daily, distributed across three feeding sessions at 7 am, 12 pm, and 4 pm. The feed used was a commercial juvenile tilapia feed with 40% protein content. Weekly, each fish was weighed, and these data served as the foundation for adjusting their feed portions. The data presented in this paper covers a ten-week period.

2.2 FCR

The Feed Conversion Ratio (FCR) is a critical metric used in aquaculture and animal agriculture to measure the efficiency of an organism to convert feed consumed into body mass gain. It is calculated as follows:

FCR = Total Feed Consumed (in weight) / Body Weight Gain (or Product Weight)

3. RESULTS AND DISCUSSION

Overall, the results suggest that the white hybrid demonstrated a higher growth rate and more efficient feed conversion compared to Red Hybrid during the study period.

Table 1. The average weight and standard deviation of the two tilapia hybrids over the study period.

	White Hybrid		Red Hybrid	
Week	Weight (g)	SD	Weight (g)	SD
0	5.4	1.0	5.0	1.0
1	7.1	1.7	6.9	1.6
2	9.4	2.4	7.7	1.1
3	11.0	3.9	8.5	2.6
4	15.6	12.5	10.9	15.6
5	21.4	7.0	11.1	3.5
6	30.6	8.7	17.8	5.9
7	43.2	13.1	25.6	7.7
8	60.9	19.2	34.0	8.9
9	77.4	20.2	46.7	12.2
10	92.5	27.1	54.4	14.4
ANOVA	p: 0.0021			
T-test	Average weight		p: 0.23	

The data presented in Table 1 represent the weekly average weights of the two groups of fish, along with their corresponding standard deviations. The weight of the two tilapia strains (White Hybrid and Red Hybrid) was measured in grams over a ten-week period. The initial weights of both strains at the beginning of the study period were relatively comparable, with White Hybrid starting at 5.4g and Red Hybrid at 5.0g, however, as the weeks progressed, it became evident that White Hybrid consistently outperformed Red Hybrid with respect to growth. The White Hybrid consistently recorded significantly higher growth rates compared to the Red Hybrid. This was particularly noteworthy when examining week 10, where White Hybrid averaged 92.5g in weight, while the Red Hybrid fish averaged 54.4g. While an apparent disparity was noted, as indicated by the ANOVA test, the subsequent T test results indicated no significant difference in the weights of the two fish sets over the study period. Notably, the standard deviation in the white hybrid group was observed to be higher. This finding suggests that, although the red hybrid appeared to exhibit a slower growth rate, its growth within the group was consistent. Conversely, the white hybrid, despite potentially faster growth on average, displayed greater variability in its individual fish weights. This nuanced observation underscores the complexity of the growth patterns within these fish populations and opens avenues for further exploration.

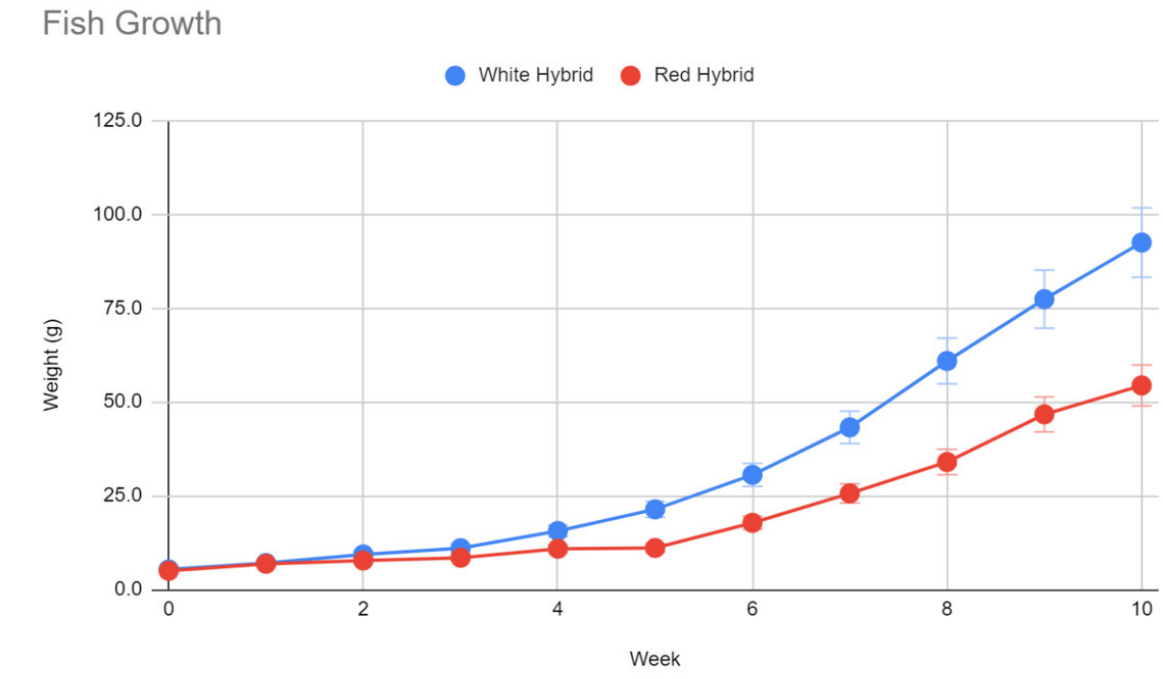

Figure 1. Graph showing growth of fish from both hybrid varieties over the 10-week study period.

The growth trajectory of the White Hybrid exhibits a near-exponential pattern, characterized by a rapid and substantial weight increase throughout the ten-week duration, whereas the Red Hybrid recorded a more linear growth trajectory, representative of a comparatively slower rate of weight gain.

Figure 2. Red hybrid tilapia (5 months old)

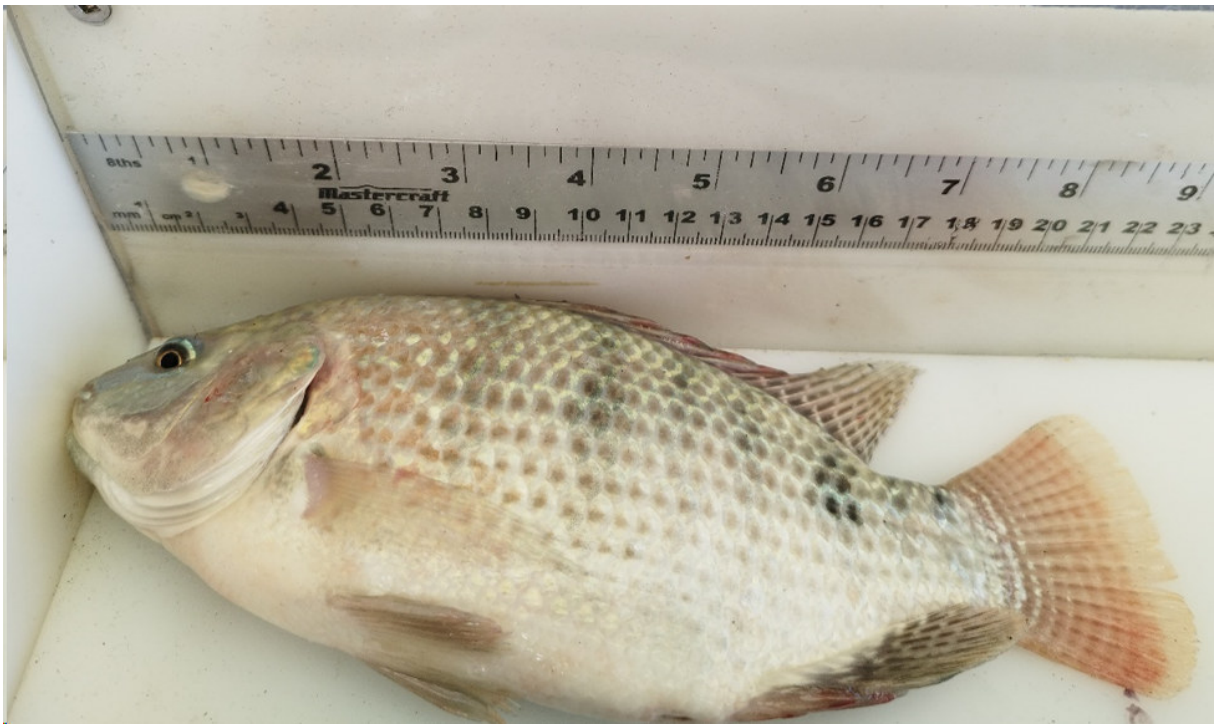

Figure 3. White hybrid tilapia (5 months old)

Table 2. Table showing the daily growth rate and Feed Conversion Ratio (FCR) of the two fish varieties during the study period.

Growth Rate g/day			FCR	
	Observed	Literature	Observed	Literature
Red Hybrid	0.7	0.4-1.37	1.34 (±0.8)	0.9-1.07
White Hybrid	2.2	1.5	0.95 (±0.4)	2.6-3.18 (±0.14)

Growth Rate (g/day) (Table 1):

The observed growth rate for Red Hybrid was 0.7 grams per day. This signifies that, on average, Red Hybrid fish gained 0.7 grams in weight daily over the course of the study. This value falls within the typical range for Red Hybrid tilapia of 0.4 to 1.37 grams per day (Kohinoor et al., 1999).

In contrast, the observed growth rate for White hybrid is 2.2 grams per day. This indicates that this hybrid fish strain exhibited a much more rapid growth rate than Red Hybrid during the study period. The literature value for *O. niloticus* X *O. aureus* hybrid growth rate is 1.5 grams per day (El-Hammady et al., 2008).

Feed Conversion Ratio (FCR) (Table 1):

The recorded FCR for Red Hybrid is 1.34, with a literature range of 0.9 to 1.07. FCR represents the amount of feed required to produce a unit of weight gain. In this case, Red Hybrid required 1.34 units of feed to gain 1 unit of weight. The observed FCR is slightly higher than the upper limit of the literature range (Kohinoor et al., 1999), suggesting that Red Hybrid may have been less efficient in converting feed to body weight in this study.

The observed FCR for white hybrid is 0.95, with a literature range of 2.6 to 3.18 (±0.14) (Essa, 2000). In contrast the white hybrid exhibited a more efficient conversion of feed to body weight, as indicated by the FCR below the literature range. This suggests that *O. niloticus* X *O. aureus* required significantly less feed to achieve the same weight gain as Red Hybrid.

CONCLUSION

The preliminary results suggest that throughout the study the white hybrid tilapia outperformed the red hybrid with respect to both growth rates and feed efficiency. This highlights the importance of selective breeding in improving growth and feed utilization in tilapia aquaculture. These findings also suggest that selective breeding can play a crucial role in enhancing the sustainability and productivity of aquaculture.

The next steps in this experiment would involve a comparison of the respiration rates and stress tolerance levels between the two tilapia strains. Understanding how these strains respond to environmental stressors and their respiratory dynamics can provide valuable insights into their overall adaptability and resilience. The study will also continue monitoring the growth of both tilapia hybrids until harvest. This will involve assessing additional factors such as fillet yield and consumer preference between the red and white hybrid. Fillet yield is important for understanding the economic value of aquaculture production, while consumer preference data will help inform marketing strategies and product positioning in the aquaculture industry.

In summary, this study demonstrates the immediate benefits of selective breeding and hints at its broader potential in aquaculture. It shows that genetics can be harnessed to create more efficient and sustainable aquatic species. As the research progresses, it will provide valuable insights into how to meet the growing global demand for seafood while advancing sustainability goals in aquaculture.

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