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ORIGINAL RESEARCH ARTICLE

Reproductive and Phenotypic Performance of Hybrid Crosses Between GIFT and Red Tilapia Strains

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ABSTRACT

The reproductive and hybrid potentials of hybrids derived from a partial diallel cross between GIFT (Genetically Improved Farmed Tilapia) and Red Tilapia strains were evaluated. A partial diallel cross was initiated to produce a strain of tilapia with commercial appeal because of its inherited reddish coloration and superior growth rate with efficient feed conversion of GIFT tilapia. Broodstock of GIFT and Red tilapia were selected by size, maturity, and colour traits Four mating combinations of R × G (Red ♂ × GIFT ♀), G × R, R × R, G × G were paired in triplicate and placed in the hapas (1 × 1.5 × 1 m) that was placed in 10 m² earthen ponds at a 1:3 (male x female) ratio. Four mating cycles were carried out at the time when swim-up fry were recorded. Total fry counts were analysed by one-way ANOVA (Duncan's test, $p \leq 0.05$). The expressed phenotype of: Red, Spotted Red, Wild, and Mixed colouration was recorded and descriptively compared. The highest number of fry was recorded in the pure strain (G × G and R × R: 161.5 ± 0.06–1.71 fry), followed by R × G (156.75 ± 0.13–0.30) and G × R (153.25 ± 0.28–0.43) ($p < 0.05$). The purebred bred true while the hybrids produced phenotypes: R × G (63 Red, 26.3 Spotted, 45.5 Wild, 22.8 Mixed) and G × R (36.5 Red, 25.3 Spotted, 72 Wild and 19 Mixed colouration), this infers additive gene action with sex-linked effect G × R hybrids exhibited hybrid vigor for early fry growth but reduced reproductive output, making them suitable for grow-out systems, whereas pure lines are vital for consistent seed supply and uniform colour.

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Hybridisation, Reproductive performance, Phenotypic traits, Colour expression, Genetic improvement, Crossbreeding.

INTRODUCTION

Although the ability of fish to reach market size in record time remains a trait that affects decision, in the case of preference between the hybrids of *Oreochromis mossambicus*, *Oreochromis niloticus*, and *Oreochromis aureus* that are reddish, the markets favoured the reddish colouration (Arumugam et al., 2023). Nwachi *et al.* (2020) reported a better growth rate and ability to adapt to varying environmental conditions in the culture of UPM red tilapia and Gift tilapia. Hence, pairing Gift with red tilapia seeks to combine the strengths of each strain for a better outcome (performance and market appeal). Research has shown that inheritance of colours at hybridization remains complex because of sex-linked interactions (Nwachi and Dasuki 2025).

Nwachi and Irabor (2022) opined that the disparity in the growth rate between male and female tilapia (sexual dimorphism) is an important factor in the overall production of tilapia. At culture stocking of mixed population could lead to uncontrolled breeding and population explosion. Hence, most tilapia producers followed specific principles with the main goal of producing and raising only the preferred sex and even colour for good size and uniformity (Nwachi *et al.*, 2020).

Pairing of Gift to red tilapia will not only produce hybrids with their accompanied heterosis but also a fish with a preferred colouration. Nevertheless, achieving these goals brings into realisation the need to maintain consistency for colour and sex across generations.

It is of note that during the breeding season, colour serves as a signal for sexual selection. The intensity of colour reflects the health status and quality of the individual. This influences sexual selectivity and the choice of a female to select a mate (Pinzoni 2023; Nwachi *et al.,* 2020). During the breeding season, the display of colour increases the chances of getting a mate and the time it will take for the actual release of eggs and final fertilization to produce swim-up fry. In general, males of some species display visual cues in species recognition and mate selection.

Genetic and environmental factors influence the expression of phenotypic traits, although diet can modulate colour intensity and behavioural expression (Postema *et al.,* 2023). Researchers like Nwachi *et al.* (2023) and Cuthil *et al.* (2023) infer that strains of tilapia originally produced from selection and hybridization (Gift and red tilapia) may reflect intricate inheritance patterns

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that trade one trait for another. Hence, the crossing of Gift to red tilapia is with the expectation that a strain of tilapia that inherits the reddish colouration from the reddish parent (satisfying commercial appeal) and the ability to efficiently convert feed to flesh is produced.

MATERIALS AND METHODS

Site Selection

The study was carried out at the teaching and research farm of Delta State University, Abraka. Nigeria. (5.77915° N, 6.09780° E)

Selection of Experimental Fish

A total of 100 broodstock of the test fish for both male and female were obtained from a private farm in Lagos (Fig. 1(a & b). Selection was based on the modified method of Nwachi and Irabor (2022). Selected broodstock: weight 46 to 157g of length 12.35 to 19.80 cm for Gift tilapia and Red tilapia. Similarly, the test fish that had a protruding stomach and a reddish vulva with matured eggs coming out, on gentle massage for the female and male with prominent papilla with reddish/pinkish tips that release milt on gentle stroking, was chosen.

Figure 1a: Gift tilapia broodstock

Figure 1b: Red tilapia broodstock

Experimental setup

The experimental unit was a hapa of (1 x 1.5 x 1) m, the brood stock was paired in ratio of one male to 3 females (1:3). The hapa was placed in an earthen pond of 10 m^2, the experimental units (Hapa) were in triplicate and the placing of the hapa and the pairing of the test fish was in a random manner. The crossing sequences include Gift tilapia male to Red tilapia female, the reciprocal crossing, and the crossing of the base stock to each other (Gift tilapia to Gift tilapia and Red tilapia to Red tilapia).

Tilapia Breeding

The mouth of the male brood stock was clipped to prevent injury to the female fish during courtship or an outright fight. Male exchanged was initiated using the modified Nwachi *et al* (2025) methods. Hatching was acknowledged at the sighting of swim-up fry in the hapa, at which the swim was removed, likewise the male fish. A period of 20 days was observed after each hatching before returning another male to the hapa. This breeding procedure was carried out four times to increase accuracy in summation. A total of 100 swim-up fry were collected, placed in a rearing receptacle of (36 x 15 x 36) cm, in triplicate, fed with artemia, and reared for 56 days, while maintaining basic water quality index as recommended by Boyd and Lichtk. The pairing involved a red tilapia male to a Gift female (R♂ x G ♀) to produce H_1, a Gift tilapia male to red tilapia female (G♂ x R♀) to produce H_2, and crossing of both Gift tilapia and Red tilapia to itself to produce a pure strain as G_1 and R_1.

Statistical Analysis

The data obtained were subjected to analysis of variance (ANOVA) using the Sigma plot statistical package (version 12.0) to evaluate the number of days it takes the pairing to produce fry and the total number of fry produced at each production cycle. The means of both the number of days for production and the total number of fries produced were separated using the Duncan test at $p \leq 0.05$ at 95% confidence.

RESULTS

The study assessed five key water quality parameters: temperature, pH, dissolved Oxygen, total dissolved solids, and ammonia in Table 1 under four different treatment conditions labelled H1, H2, P1, and P2. The results show high consistency across all treatments, with minimal variation and low standard errors. The Temperature (°C) ranged from 25.21°C (P1) to 25.32°C (H2), with values of 25.25°C (H1) and 25.22°C (P2). The standard error was 0.023. The pH levels were slightly acidic to near-neutral, with values of 6.55 (H1), 6.64 (H2), 6.52 (P1), and 6.63 (P2). The standard error was only 0.006.

Dissolved Oxygen (DO) concentrations were consistently high, ranging from 8.23 mg/L (H1) to 8.32 mg/L (P1). Other values included 8.31 mg/L (H2) and 8.24 mg/L (P2), with a standard error of 0.013. Total Dissolved Solids (TDS) showed very low concentrations: 0.221 mg/L (H1), 0.220 mg/L (H2), 0.223 mg/L (P1), and 0.221 mg/L (P2), with a standard error of 0.054. Ammonia (mg/L) levels were nearly identical across treatments: 0.2987 (H1), 0.2982 (H2), 0.2985 (P1), and 0.3001 (P2). The standard error was 0.021.

Table 1: Summary of Water Quality Parameters Across Treatments (H1, H2, P1, P2)

S/N	Parameters	H_1	H_2	P_1	P_2	Standard Error
1	Temperature (^{0}C)	25.25	25.32	25.21	25.22	0.023
2	pH	6.55	6.64	6.52	6.63	0.006
3	Dissolve Oxygen (mgL^{1-})	8.23	8.31	8.32	8.24	0.013
4	Total dissolve solids (mgL^{1-})	0.221	0.220	0.223	0.221	0.054
5	Ammonia (mgL^{1-})	0.2987	0.2982	0.2985	0.3001	0.021

Table 2: Number of days it takes before production of swim-up fry

S/N	Genotype	R x G (days)	G x G (days)	R x R (days)	G x R (days)
1	nT1	28 ± 0.56^a	28 ± 0.06^a	28 ± 0.61^a	33 ± 0.07^b
2	nT2	20 ± 0.43^a	20 ± 0.22^a	20 ± 0.34^a	25 ± 0.43^b
3	nT3	16 ± 0.06^a	15 ± 0.41^a	16 ± 0.65^a	22 ± 0.76^b
4	nT4	14 ± 0.52^a	13 ± 0.02^a	12 ± 0.28^a	15 ± 0.43^a
	Mean total	19.5	19	19	23.75

Table 3: Fry number and associated performance trait of partial diallel cross of Red tilapia to Gift tilapia

S/N	Genotype	R x G	G x G	R x R	G x R
1	nT1	142 ± 0.30^{ab}	155 ± 0.69^b	155 ± 1.71^b	135 ± 1.27^a
2	nT2	159 ± 0.13^a	163 ± 0.06^b	164 ± 0.04^b	153 ± 0.43^a
3	nT3	161 ± 0.21^a	165 ± 0.91^b	164 ± 0.61^b	160 ± 0.02^a
4	nT4	165 ± 0.28^a	163 ± 0.32^a	165 ± 0.28^a	165 ± 0.33^a
	Mean total	156.75	161.5	161.5	153.25

Table 4: Colour variation at diallel crossing of Red tilapia to Gift tilapia

Genotype		Rep	Red	Spotted Red	Wild	Mixed Red
Red ♂	Gift ♀	1	57	25	43	17
		2	63	29	45	25
		3	65	27	48	21
		4	67	24	46	28
		Mean	67	26.25	45.5	22.75
Red ♂	Red ♀	1	155			
		2	164			
		3	164			
		4	165			
		Mean	162			
Gift ♂	Red ♀	1	31	21	64	19
		2	38	25	70	20
		3	36	28	75	19
		4	41	27	79	18
		Mean	36.5	25.25	72	19
		1				
		2				
		3				
		4				
		Mean				
Gift ♂	Gift ♀	1			155	
		2			163	
		3			165	
		4			163	
		Mean			161.5	

The number of time (days) that it takes to produce swim-up fry varied across genotypes as shown in Table 2. It takes a longer time for the G x R combination to produce swim-up compared to the other mating combinations of (R × G, G × G, R × R). At 28 days, nT1 consisting of R × G, G × G, and R × R produced swim-up fry with no significant difference. The G x R pair takes a total of 33 days with statistically significant ($p < 0.05$). The R × G, G × G, and R × R in genotype nT2 produced swim-up fry after 20 days, with a mean value of 20±0.22 to 20±0.43 days, although the G × R takes a total of 25 days.

In the Genotype nT3 combination, it takes 15 to 16 days for the R × G, G × G, and R × R combinations to produce swim-up fry. However, the shortest time of production of swim-up was by R × G, G × G, R × R, and G × R combination produced swim-up at 14±0.52, 13±0.02, 12±0.28, and 15±0.43 days, respectively, for the nT4 genotype

The reproductive performance of four genotypes (nT1–nT4) was evaluated under four mating combinations: Red × Gift (R × G), Gift × Gift (G × G), Red × Red (R × R) and Gift × Red (G × R). at mean ± standard error, and statistical significance of $p < 0.05$. Across all genotypes, the G × G and R × R crosses produced the highest average number of fry (161.5 each), followed by R × G (156.75), while the G × R cross yielded the lowest average fry number (153.25). In nT1, G × G and R × R yielded significantly higher fry counts (155 ± 0.69 and 155 ± 1.71, respectively), while G × R recorded the lowest value (135 ± 1.27), at ($p < 0.05$).

The fry production at nT2 and nT3 crossing followed a similar trend, with significantly lower fry production in the G × R cross compared to the same-strain crosses. While nT4 displayed uniform fry production across all crosses, with no significant differences. In general, the overall mean for this trait was highest in the G × R cross (23.75), while R × G, G × G, and R × R showed similar and lower values (19–19.5).

In Table 4, the offspring colour phenotype distribution resulting from various genotype crosses of male and female tilapia. Four distinct breeding combinations were evaluated across four replicates each, with offspring categorized into four colour types: Red, Spotted Red, Wild, and Mixed Red (Fig. 2). The Red male crossed with a Red female to give Red offspring across all replicates (mean = 162), indicating that both parents are likely homozygous for the Red coloration characteristics.

Similarly, the Gift male crossed with a Gift female produced only Wild-type offspring (mean = 161.5), with no expression of Red, Spotted Red, or Mixed Red phenotypes. The Red male crossed with a Gift female yielded a varied collection of offspring, with a predominance of Red (mean = 63), but also notable proportions of Spotted Red (26.25), Wild (45.5), and Mixed Red (22.75) phenotypes. In a likewise manner, the Gift male crossed with a Red female produced a high number of Wild-type offspring (72), followed by Red (36.5), Spotted Red (25.25), and Mixed Red (19).

Figure 2a: Red

Figure 2b: Spotted

Figure 2c: Wild.

Figure 2d: Mixed Red

DISCUSSION

Environmental Stability and Controlled Conditions

The uniformity of key water quality parameters across all treatments (Table 1) could be used to infer that all the other variations are due to genetic rather than environmental factors. Parameters such as temperature (25.21–25.32°C), pH (6.52–6.64), dissolved Oxygen (8.23–8.32 mg/L), total dissolved solids (0.220–0.223 mg/L), and ammonia (0.2982–0.3001 mg/L) all remained at the basic recommended optimal ranges for tilapia culture (Khaliq *et al.,* 2024; Siddique *et al.*, 2025). In general, the level of the physico-chemical parameter is a factor because this is required for the metabolic process that can impair the reproductive efficiency of fish. (Xu and Boyd 2016). The low standard errors indicated that the same condition was observed throughout the culture environment, reducing errors from the experimental setup, making it possible to observe the phenotypic differences to evaluate the link to genetic variation.

Genetic Basis of Growth *Performance*

Table 2 revealed that the product from the cross between Gift × Red (G × R) exhibited greater performance in genotypes nT1, nT2, and nT3 compared to the other pairings. These frameworks give the basic principle of hybrid vigor/heterosis, which indicates better performance as a result of gene action (Hu *et al.*, 2024; Nwachi *et al.*, 2023). The G × R pairing products might benefit from combining the fast growth and environmental resilience of Gift tilapia with the morphological and pigmentation traits of Red tilapia, as suggested by Nwachi et al. (2020) in their study of UPM red tilapia and Gift tilapia. It is of note that this type of genetic complementation was opined by Gomes *et al.* (2024) but has been previously documented in other aquaculture species, where hybrid crosses give output with improved feed conversion, faster growth, and greater adaptability.

Interestingly, genotype nT4 did not follow this trend and showed no significant variation across cross types. A situation that could arise when a genotype maintains stable phenotypes despite genetic or environmental variability (genetic canalization), this view was expressed by Flatt, (2005). It could also imply a threshold effect, where nT4 possesses alleles that buffer against heterotic expression or exhibits low genetic responsiveness to hybridization due to possible fixed loci.

Reproductive Trade-offs in Hybrid Crosses

A different trend was observed in the total fry output (Table 3), where purebred crosses (Gift × Gift and Red × Red) exhibited higher reproductive performance than hybrid combinations (G × R and R × G). This inverse relationship between growth and reproduction indicates a common trade-off in aquaculture genetics, as reported by Roff (2000) in the model that predicts life history traits. It is of note that boosted somatic growth is often accompanied by reduced investment in reproductive tissues and gamete viability (Powell *et al.*, 2010). In the study, the Gift × Red cross was dominant in growth parameters, but underperformed in fry number across genotypes nT1 to nT3, with substantial reductions in reproductive output (135 ± 1.27 fry for nT1).

The result of this study suggests a design for a breeding program for either a particular trait or growth rate. This implies that hybrid crosses may be ideal for grow-out systems due to their superior body performance. However, they are less suitable for hatchery propagation, where high fry production and reproductive consistency are vital. It also underlines the necessity of maintaining purebred lines for broodstock management to ensure optimal reproductive yields.

Colour Inheritance and Genetic Segregation

In the study, as shown in Table 4, the genetic architecture of pigmentation in tilapia reveals that the Red × Red cross consistently produced red fry, suggesting both parents are homozygous for the red allele, likely a dominant trait. Similarly, the Gift × Gift crosses that resulted in the production of entirely wild-coloured fry signified a lack of red alleles in the Gift genetic background.

However, both Red × Gift and Gift × Red crosses produced offspring with varying colouration of; red, spotted red, wild, and mixed red phenotypes, indicating an additive gene action. The variation in colour expression between reciprocal crosses (red in Red ♂ × Gift ♀ than in Gift ♂ × Red ♀) suggests the potential influence of maternal effects, sex-linked inheritance, or cytoplasmic inheritance in pigment determination (Fang *et al.*, 2022). These studies recommend directional crossing whenever breeding programs are aimed at producing specific colour phenotypes for market preference.

In general, the segregation observed in hybrid crosses in the study infers Mendelian inheritance involving multiple alleles and modifier genes. Spotted and mixed phenotypes likely arise from addictive gene action or incomplete dominance. These results align with earlier work on red tilapia genetics, which suggested that colour expression is polygenic and influenced by a combination of autosomal and sex-linked genes (Kocher *et al.*, 2024; Nwachi *et al.*, 2023; Paris *et al.*, 2022).

Implications for Tilapia Breeding Programs

The combination of growth indices, reproductive output, and phenotypic data that infer a complex trade-off that must be managed in tilapia breeding:

- G × R hybrids give a result that favours a design seeking to improve growth traits but may require backcrossing or use of pure lines for broodstock to mitigate reproductive limitations.
- Purebred lines (G × G and R × R) serve as essential reservoirs for reproductive capacity and phenotypic consistency, particularly in colour-focused markets or seed production systems.
- Directional mating strategies should be adopted when targeting specific offspring colour types, accounting for potential maternal inheritance patterns and cross-specific outcomes.
- The use of diallel crossing designs, as applied in this study, proves effective in disentangling additive, non-additive, and maternal genetic effects (Gomes et al., 2024).

CONCLUSION

In conclusion, this study supports a dual-track breeding strategy: Combining hybrid vigour for commercial grow-out performance while preserving genetic integrity and reproductive efficiency through well-maintained pure lines. This balanced approach is essential for sustainable tilapia aquaculture development in regions like Nigeria, where both productivity and seed supply remain critical constraints (Nwachi and Dasuki, 2025).

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DISCLOSURE OF CONFLICT OF INTEREST

No conflict of interest to be disclosed

STATEMENT OF CONSENT

Informed consent was obtained from participants.

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