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Effect of hybridization on reproductive performance of *Oreochromis karongae*, *Oreochromis shiranus* and *Oreochromis mossambicus*

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Abstract

The study assessed the effect of hybridization on reproductive performance of *Oreochromis karongae*, *Oreochromis shiranus* and *Oreochromis mossambicus* for a period of 120 days. Number of eggs per batch, number of females spawned, relative fecundity, egg size, hatching period, hatchability and hatchling survival were assessed. The results revealed higher number of eggs per batch and relative fecundity in the crosses where *O. shiranus* and *O. mossambicus* were females than female *O. karongae*. The results also revealed that egg size, hatching period, hatchability and hatchling survival were species specific. Significant differences were noted for number of eggs and larvae produced by the three species ($p < .05$). Interspecific and pure crosses for the same female species did not differ significantly for the number of eggs per batch, relative fecundity, egg size, hatching period, hatchability and hatchling survival. However, number of female spawned was found to be higher in the interspecific crosses of female *O. karongae* than in pure cross of *O. karongae*. Findings from this study suggest that hybridization can be used to improve reproductive performance of *O. karongae* as the females spawned increased, and it is a value addition in aquaculture management of indigenous species.

KEYWORDS

egg size, fecundity, hatchability, hatching period, hatchling survival

1 | INTRODUCTION

Aquaculture is a viable alternative for increasing fish production worldwide, either directly or indirectly. It plays a significant role in the livelihoods of people as a source of income, food and high-quality protein nutrition. Furthermore, aquaculture is expected to play an important role to meet the protein demand for the increasing world human population which is estimated to reach 9.7 billion by 2050 (United Nations, 2015). Finding means to feed these people has become an issue of global concern since capture fisheries has reached its maximum potential (FAO, 2010). Culturing species with high growth and reproductive performances may be one of the solutions to high demand for fish.

Tilapia are the most prominent aquaculture species worldwide because they are easily cultured, reproduce without difficulty under captivity and reach marketable size at 6–7 months. *Oreochromis* species are the major tilapia species dominating aquaculture industry with the most leading species being *O. niloticus* and *O. mossambicus* (Boyd, 2004; Gupta & Acosta, 2004).

In Malawi, the most popular *Oreochromis* species cultured are *O. shiranus* and *O. karongae*. *Oreochromis shiranus* has high reproductive capability but slow growth while *O. karongae* has low fecundity and hatchability (Msiska & Costa-Pierce, 1997) but grows faster as compared to *O. shiranus* (Maluwa & Dickson, 1996). The other species cultured is *O. mossambicus* which has high fecundity and is mostly cultured in the southern part of Malawi. Strengthening locally available species by exploiting their growth and reproductive performances through hybridization and nutrition may improve fish production of indigenous species with little genetic modification.

Hybridization as a genetic improvement in fish has been used to increase growth performance due to production of hybrid vigour (Basavaraju et al., 1995; Owodeinde et al., 2012). It has also been used as a tool for combining traits such as good flesh quality, disease resistance and increased environmental tolerances like salinity (Lahav & Lahav, 1990), better food conversion, transfer desirable traits and reduce unwanted reproduction through production of sterile fish (Bartley et al., 2001; Rahman et al., 2013). However, hybridization has some side-effect on gene pollution of native species. It can either dilute or genetically assimilate the native genotype leaving no 'pure' natives (Huxel, 1999). Hybrids can also escape to the natural environment and undergo backcrosses with the parental species (Rahman et al., 2013).

Production of monosex populations especially all-males through hybridization has been shown to prevent uncontrolled reproduction. Males are often preferred as they grow faster than the females (El-Zaeem & Salam, 2013). Hybridization of species with different sex determination system like *O. mossambicus* (XX-female/XY-male) and *O. homorum* (WZ-female/ZZ-male) produced all-male offspring (Wohlfarth, 1994).

In Malaŵi, research on hybridization of *O. karongae* and *O. shiranus* has been conducted and results showed that hybridization improved fecundity of *O. karongae* (Nzohabonayo, Kang'ombe et al., 2017) and growth performance of hybrids from crosses of *O. karongae* and *O. shiranus* (Kassam & Sangazi, 2016). However, there has not been much research on the hybridization of *O. mossambicus* with *O. karongae* and *O. shiranus*.

Results emanating from this research may have significant effect on the improvement of reproductive performance of the three *Oreochromis* species in general and particularly *O. karongae* which has been reported to have low fecundity and hatchability (Msiska & Costa-Pierce, 1997). Therefore, this study was undertaken to evaluate the effect of hybridization of three species of the family Cichildae (Genus *Oreochromis*) *O. karongae*, *O. shiranus* and *O. mossambicus* on reproductive performance.

2 | MATERIALS AND METHODS

The experiments were conducted at Bunda Fish Farm located at Lilongwe University of Agriculture and Natural Resources (LUANAR) in Lilongwe (Latitude 14°35′S and longitude 33°50′E), Malaŵi, from October 2018 to February 2019 for 120 days. *Oreochromis karongae* and *O. shiranus* were obtained from Lake Malaŵi, whereas *O. mossambicus* was obtained from the Shire River (Chikwawa). Male and female brooders were transferred to Bunda Fish Farm and acclimatized separately for 1 month in hapas. Diet containing 30% crude protein and 10% crude lipid (Table 1) as recommended by Nzohabonayo, Kassam, et al. (2017) was used to feed brooders during and after acclimatization. A complete 3 × 3 diallel crossing was made to obtain nine combinations as shown in Table 2.

After acclimatization, broodstock of *O. karongae*, *O. shiranus* and *O. mossambicus* were selected and randomly allocated to 18 experimental hapas (3 × 2 × 1.2 m each) installed in a 700 m^2 pond. Broodstock of the three *Oreochromis* species were reciprocally crossed at a ratio of 1:1 (male:female), at a stocking density of 2 fish/m^2. A total of nine treatments were replicated twice.

TABLE 1 Formulation and proximate composition of dietary lipid fed to broodstock

	Diet 30% CP, 10% CL
Ingredients	
Soybean meal (%)	24.5
Fish meal (%)	24.5
Maize bran (%)	46
Premix (%)	1.5
Salt (%)	0.5
Cassava (%)	1
Proximate analysis	
Moisture (%)	14.87 ± 0.50
Protein (%)	29.8 ± 0.30
Lipid (%)	10.17 ± 0.09
Fibre (%)	6.7 ± 0.09
Ash	8.44 ± 0.07

Abbreviations: CL, crude lipid; CP, crude protein.

Source: Nzohabonayo, Kassam, et al. (2017).

Chicken manure was applied to boost primary productivity in the pond at the percentage of 500 kg ha^{-1} $week^{-1}$ (Kang'ombe & Brown, 2008). The fish were hand fed twice a day (9:00 and 14:00 hr) at 5% body weight. Water quality parameters including temperature, pH and dissolved oxygen were monitored using the water quality checker Model U-5000 G twice a day during morning and afternoon hours. Titration method was used to determine ammonia concentration (Ogbonna & Chinomso, 2010) every 2 weeks.

2.1 | Data collection

2.1.1 | Batch and relative fecundity

A month after conditioning, female broodstock were checked bi-weekly for spawning activity. Spawned eggs were removed from the buccal cavities of females, using the clutch method (Ahmed et al., 2006) and counted using hand tally counter to obtain batch fecundity (total number of eggs per spawn). The number of females which spawned was recorded in each treatment. Eggs were cleaned and transferred into 5 L McDonald incubation jars to complete incubation process. An electronic analytical balance HF-300 calibrated to the nearest 0.0001 g was used to weigh individual eggs. Relative fecundity was calculated as number of eggs per gram of female weight.

2.1.2 | Diameter of individual egg

Tilapia eggs are ovoid shape; therefore, to evaluate their diameter, two parameters (long and short axes of the egg) were measured.

Sample of eggs was measured to the nearest 0.05 mm using ruler (KANON, Hardened stainless). Egg long axis refers to the length of the longest axis and short axis refers to the width, perpendicular to the longest axis of the egg. The following equation was used to determine the egg diameter (Coward & Bromage, 1999):

$$\text{Mean egg diameter (mm)} = \frac{\text{long axis length} + \text{short axis length}}{2}$$

2.1.3 | Hatchability and survival percentage

Eggs were cleaned and incubated in 5 L McDonald incubation jars in a recirculating system. Fertilized eggs were classified according to the criteria for age staging used by Ahmed et al. (2006) and Geffen et al. (2006). Water temperature was maintained at 25 ± 1°C using water heater. The embryonic development of the fertilized eggs up to the post-yolk sac fry stage was followed. Hatching period, number of eggs hatched and number of live fry were recorded. Hatching percentage and larvae survival percentage were calculated as follows (Pandit et al., 2017):

$$\text{Hatching percentage} = \frac{\text{Number of eggs hatched}}{\text{Total number of eggs incubated}} \times 100$$

$$\text{Fry survival (\%)} = \frac{\text{Number of fry alive (after yolk absorption)}}{\text{Total number of eggs hatched (before yolk absorption)}} \times 100$$

2.2 | Statistical analysis

Data on reproductive parameters such as batch and relative fecundity, egg weight and diameter between species combinations were analysed for significance difference ($p < .05$) using analysis of covariance (ANCOVA), where the effect of body female weight was controlled as covariate. Significant differences in means were separated with Sidak-adjusted post hoc multiple comparisons test. Incubation data were analysed using one-way ANOVA, and data failing to meet the assumptions for parametric tests were analysed using a nonparametric statistical method, Kruskal–Wallis test. Where data differed significantly ($p < .05$), Mann–Whitney *U* test was applied. Log10-transformed regression analyses were used to test for linear relationship between the batch fecundity and weight of female. Statistical analysis was performed using IBM Statistical Package for the Social Sciences Statistics 20, and MS Excel was used to plot graph.

3 | RESULTS

3.1 | Reproductive parameters of different crosses of *O. karongae, O. shiranus and O. mossambicus*

Table 3 shows the number of females which spawned, adjusted of number of eggs per batch, relative fecundity, egg weight and diameter. Weight of female which was fixed as covariate significantly ($p < .05$) affected number of eggs per batch and relative fecundity. The adjusted mean number of eggs per batch was higher for pure *O. mossambicus* cross (377.94 ± 12.32 eggs), while the lowest was registered for the pure cross *O. karongae* (180.00 ± 31.17 eggs). Combinations of crosses where *O. karongae* were females and were significantly different ($p < .05$) from combinations of crosses where *O. shiranus* and *O. mossambicus* were females for batch fecundity.

A pure cross of *O. mossambicus* (♀ O. M X ♂ O. M) registered higher relative fecundity (4.88 ± 0.15 eggs g of female^{-1}), while a pure cross of *O. karongae* (♀ O. K X ♂ O. K) had the lowest relative fecundity (3.11 ± 0.37 eggs g of female^{-1}). Significantly lower ($p < .05$) relative fecundity was found in crosses where *O. karongae* were females than crosses where *O. shiranus* and *O. mossambicus* were females.

The relationship between batch fecundity and standardized total weight of the three species is presented in Figure 1 and Table 4. Batch fecundity was positively correlated with weight of female for all the three species. *Oreochromis mossambicus* registered a strong positive correlation (92%), while *O. shiranus* showed the lowest positive correlation (52%).

The observation made on the females spawned in each cross during experimental period showed that combination of crosses where *O. shiranus* and *O. mossambicus* were females and had a higher number of females spawned. In addition, small number of females spawned in the crosses where *O. karongae* acted as males were recorded when compared with the same female species combinations (6, 4 and 2 females, respectively, for cross of ♀ O. M x ♂ O. K; ♀ O. S X ♂ O. K and ♀ O. K X ♂ O. K). The total number

TABLE 2 Diallel crossing design of three *Oreochromis* species

	Females (♀)		
Sex of parent stock	***O. karongae***	***O. shiranus***	***O. mossambicus***
Males (♂)			
O. karongae (O.K)	(♂) O. K X (♀) O. K	(♂) O. K X (♀) O. S	(♂) O. K X (♀) O. M
O. shiranus (O.S)	(♂) O. S X (♀) O. K	(♂) O. S X (♀) O. S	(♂) O. S X (♀) O. M
O. mossambicus (O.M)	(♂) O. M X (♀) O. K	(♂) O. M X (♀) O. S	(♂) O. M X (♀) O. M

Note: The underlined combinations were pure crosses.

Abbreviations: O.K, *Oreochromis karongae*; O.M, *Oreochromis mossambicus*; O.S, *Oreochromis shiranus*; ♂, Male; ♀, Female.

TABLE 3 Adjusted reproductive parameters of different crosses of *O. karongae*, *O. shiranus and O. mossambicus* for 120 days (mean ± *SE*)

Crosses	*N*	BF	RF	EW (mg)	ED (mm)
♀ O. M x ♂ O. K	6	372.60 ± 16.26^a	4.72 ± 0.19^a	6.19 ± 0.25^b	2.37 ± 0.06^b
♀ O. M X ♂ O. S	10	373.51 ± 13.48^a	4.83 ± 0.16^a	5.84 ± 0.21^b	2.32 ± 0.05^b
♀O. M X ♂ O. M	11	377.94 ± 12.32^a	4.88 ± 0.15^a	6.30 ± 0.19^b	2.28 ± 0.05^b
♀ O. S X ♂ O. K	4	371.05 ± 20.77^a	4.79 ± 0.25^a	6.00 ± 0.32^b	2.31 ± 0.08^b
♀ O. S X ♂ O. S	9	347.54 ± 13.42^a	4.62 ± 0.16^a	6.41 ± 0.21^b	2.36 ± 0.05^b
♀ O. S X ♂ O. M	8	369.24 ± 14.09^a	4.72 ± 0.17^a	6.11 ± 0.22^b	2.40 ± 0.05^b
♀ O. K X ♂ O. K	2	180.00 ± 31.17^b	3.11 ± 0.37^b	26.29 ± 0.48^a	4.11 ± 0.12^a
♀ O. K X ♂ O. S	5	227.26 ± 21.21^b	3.46 ± 0.25^b	25.81 ± 0.32^a	3.94 ± 0.08^a
♀ O. K X ♂ O. M	6	215.12 ± 18.11^b	3.18 ± 0.21^b	25.67 ± 0.28^a	4.04 ± 0.07^a

Note: Covariate (body length) evaluated at 78.27 g.

Abbreviations: BF, batch fecundity; ED, egg diameter; EW, egg weight; *N*, number of female which spawned; O.K, *Oreochromis karongae*; O.M, *Oreochromis mossambicus*; O.S, *Oreochromis shiranus*; RF, relative fecundity; ♂, Male; ♀, Female.

*Significant differences ($p < .05$) between the Sidak-adjusted estimated marginal mean from the ANCOVA post hoc analysis are indicated by different superscript letters.

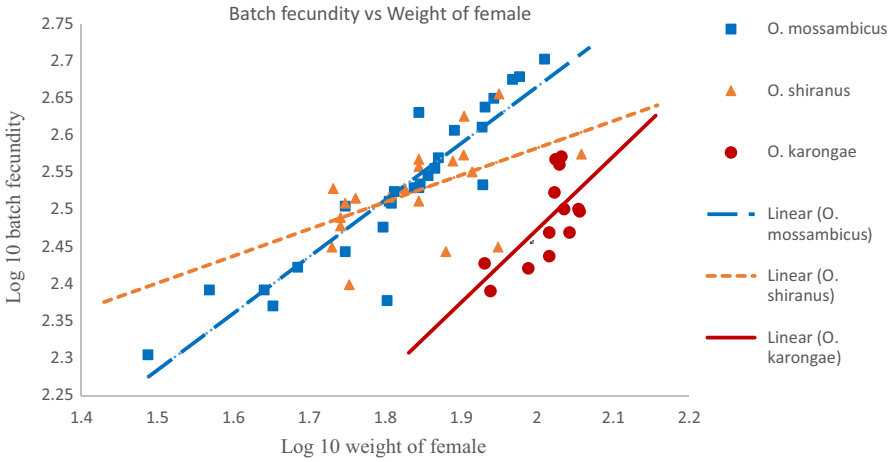

FIGURE 1 Relationship between batch fecundity and weight of female of *O. mossambicus*, *O. shiranus* and *O. karongae* [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 4 Log10 regression equations between body weight and batch fecundity of *O. mossambicus*, *O. shiranus and O. karongae*

Female species	Log10 regression equations of batch fecundity (*Y*) and body weight (*X*)	Correlation coefficients	*N*	*p*-Value
O. mossambicus	$Y = 0.7629\ X + 1.1395$	$r = .92$	27	<.001
O. shiranus	$Y = 0.3635\ X + 1.856$	$r = .52$	21	<.05
O. karongae	$Y = 0.9818\ X + 0.5092$	$r = .66$	13	<.05

Note: Y: batch fecundity; *X*: body weight; *r*: correlation coefficients; *N*: sample size.

Abbreviations: O.K, *Oreochromis karongae*; O.M, *Oreochromis mossambicus*; O.S, *Oreochromis shiranus*.

of females which spawned during the experimental period was more than double (five females) for cross of female *O. karongae* and male *O. shiranus* and triple (six females) for the cross of female *O. karongae* and male *O. mossambicus* when compared with pure cross of *O. karongae* (two females). This implies that there is an improvement of total number of eggs produced in hybridization of female *O. karongae* with *O. shiranus* and *O. mossambicus* during the experimental period.

Weight of female which was fixed as covariate did not significantly ($p > .05$) affect egg weight and diameter. Pure cross of *O. karongae* (♀ O. K X ♂ O. K) registered higher egg weight and diameter (26.29 ± 0.48 mg and 4.11 ± 0.12 mm respectively), while a cross of *O. mossambicus* and *O. shiranus* (♀ O. M X ♂ O. S) had the lowest egg weight (5.84 ± 0.21 mg) and pure cross of *O. mossambicus* (♀O. M X ♂ O. M) had the lowest egg diameter (2.28 ± 0.05 mm). Significant differences ($p < .05$) were found in egg weight and diameter between combinations of crosses. Egg weight and diameter from female *O. shiranus* and *O. mossambicus* were significantly lower than those from female *O. karongae*.

Water quality parameters were in the acceptable range for breeding of tilapia. Mean dissolved oxygen were as follows: 5.45 ± 0.95 mg/L in the morning and 8.26 ± 1.63 mg/L in the afternoon, mean temperature were: 24.2 ± 2.51°C in the morning and

TABLE 5 Hatchability of hybrids eggs incubated in a recirculating system (mean ± *SE*)

Crosses	Hatching period (days)	Hatchability percentage (%)	Hatchling survival percentage (%)
♀ O. M x ♂ O. K	4.00 ± 0.00[b]	94.31 ± 1.61[a]	99.26 ± 0.13[a]
♀ O. M X ♂ O. S	4.00 ± 0.00[b]	95.56 ± 1.41[a]	99.37 ± 0.31[a]
♀O. M X ♂ O. M	4.00 ± 0.00[b]	96.21 ± 1.73[a]	98.97 ± 0.43[a]
♀ O. S X ♂ O. K	5.00 ± 0.00[b]	96.86 ± 0.25[a]	98.86 ± 0.03[a]
♀ O. S X ♂ O. S	5.00 ± 0.00[b]	96.98 ± 2.06[a]	98.89 ± 0.15[a]
♀ O. S X ♂ O. M	5.00 ± 0.22[b]	96.11 ± 0.43[a]	99.28 ± 0.13[a]
♀ O. K X ♂ O. K	7.00 ± 0.00[a]	78.78 ± 0.54[b]	97.31 ± 0.13[b]
♀ O. K X ♂ O. S	7.50 ± 0.50[a]	79.49 ± 0.84[b]	96.61 ± 0.54[b]
♀ O. K X ♂ O. M	6.50 ± 0.50[a]	83.65 ± 0.70[b]	97.26 ± 0.00[b]

Note: Different superscripts in the same column imply that such treatments were significantly different at 5% level.

Abbreviations: O.K: *Oreochromis karongae*; O.M: *Oreochromis mossambicus*; O.S: *Oreochromis shiranus*; ♂, Male; ♀, Female.

27.3 ± 2.11°C in the afternoon, pH ranged between 7.58 and 8.72, while mean total ammonia nitrogen was registering 0.25 ± 0.02 mg/L.

3.2 | Incubation parameters of *O. karongae*, *O. shiranus and O. mossambicus* eggs in a diallel crossing

Table 5 shows that the longer hatching period was observed for the eggs from a cross of female *O. karongae* and male *O. mossambicus* (7.50 ± 0.50 days), while the shortest hatching period was found in crosses where *O. mossambicus* were females (4.00 ± 0.00 days). The highest percentage hatchability was observed for the eggs from pure cross of *O. shiranus* (96.98 ± 2.06%), while the lowest percentage hatchability was observed for eggs from pure cross of *O. karongae* (78.78 ± 0.54%).

Hatchling survival percentage was higher for larvae from a cross of female *O. mossambicus* and male *O. shiranus* (99.37 ± 0.31%), while the lowest was observed for larvae from a cross of female *O. karongae* and male *O. shiranus* (96.61 ± 0.54%). Mean hatching period, hatchability and hatchling survival for crosses where *O. mossambicus* and *O. shiranus* were females were statistically higher ($p < .05$) than those of *O. karongae*.

Water quality parameters during the incubation period were in the acceptable range. Mean dissolved oxygen was as follows: 6.45 ± 1.36 mg/L, temperature was 25 ± 1°C, pH range was 7.3–8.58, while ammonia was very low registering < 0.05 mg/L.

4 | DISCUSSION

The results of this study revealed that *O. mossambicus* can hybridize with both *O. karongae* and *O. shiranus* and give viable offspring. There was significant difference ($p < .05$) in number of eggs per batch for the nine crosses. Combinations of crosses where *O. karongae* were females were significantly lower ($p < .05$) in number of eggs per batch than combinations of crosses where *O. shiranus* and *O. mossambicus* were females. Accordingly, the highest number females spawned were observed for *O. mossambicus* and *O. shiranus* females crosses (Table 3). Female *O. shiranus* and *O. mossambicus* had significantly higher relative fecundity than female *O. karongae*. This shows that the two species have higher reproductive potential than *O. karongae*. However, a strong positive correlation was found in *O. mossambicus* and *O. karongae* female crosses for batch fecundity.

The study also found an improvement in total number of eggs produced during experimental period for interspecific crosses of female *O. karongae* as the number of females which spawned was higher in the interspecific crosses (♀ O. K X ♂ O. S and ♀ O. K X ♂ O. M) than in pure cross of *O. karongae*. According to Trewavas (1983), *O. karongae* displays less stunting and low reproductive capacity as compared to other tilapiine species. *Oreochromis mossambicus* and *O. shiranus* allocate more of their resources to the production of smaller eggs in large number and are prolific spawners with early maturity (Kapute et al., 2016; Webb & Maughan, 2007).

The general pattern of lower number of females which spawned in pure cross of *O. karongae* may be due to less aggressiveness of males for *O. karongae* brooders since the number of females which spawned increased in the hybridization. Furthermore, *O. karongae* lays bigger eggs which could imply that fish allocate more resources to produce eggs, then spend time to make a second spawn unlike the other *Oreochromis* species used in this study. In addition, the significant difference found in batch fecundity may have been due to the difference in female weight as *O. karongae* attain maturity when it is larger size and older age (Maluwa et al., 1995) than the other *Oreochromis* species (Froese & Pauly, 2019) used in this study.

The study found significant differences ($p < .05$) in egg weight and diameter (Table 3). The combination of crosses where *O. karongae* were females had significantly higher egg weight and diameter than the combination of crosses where *O. shiranus* and *O. mossambicus* were females. *Oreochromis karongae* produce bigger egg size

compared to the egg sizes reported for *O. shiranus* (Nzohabonayo, Kang'ombe, et al., 2017) and *O. mossambicus* (De Silva, 1986).

This egg size difference of the three *Oreochromis* species could have influenced hatching period and hatchability as well as survival of larvae since large eggs are more yolk laden for provision of nutrition to the larval stages. The bigger egg sizes were associated with lower relative fecundity. This result is in agreement with Lobon-Cervia et al. (1997) who reported that when the egg size increases, the relative fecundity decreases and vice versa.

Fecundity and egg size results have further shown that energy allocated to egg production in *O. shiranus* and *O. mossambicus* was not geared towards the production of larger eggs as *O. karongae* does but towards the production of small-sized eggs in the same breeding season. Comparisons of tilapia reproductive performance could be a complicated issue because it is affected by brood size, previous spawning history, the production setting and the limitation of broodstock selection (Faizzi, 2008).

Hatching period, hatchability and hatchling survival were found to be significantly different ($p < .05$) among eggs and larvae of different combinations (Table 5). The maximum hatching period found in this study was lower compared to the higher hatching period (14.7 days at the lowest temperature 25°C) reported by Valeta et al. (2013) for *O. karongae*. The differences in hatching period for the present study may be attributed to the size of the eggs and species performance.

The present study found that there was no significant difference ($p > .05$) between hybrid eggs and pure eggs of the same female species. Hybridization did not have significant effect ($p > .05$) on hatching period of eggs from the same female species. The difference in hatching period, hatchability and hatchling survival was attributed to the difference in egg weight and diameter of those species.

A review on research done on *Salmonids* reported that larger eggs take more advanced morphological process to complete embryos epiboly stage, hatching and yolk absorption (Kamler, 2002). Earlier research found that increasing egg diameter led to longer development times (Pepin et al., 1997). However, Beacham et al., (1985) did not find significant difference between small and bigger eggs in regard to hatching period of chum salmon (*Oncorhynchus keta*) and coho salmon (*Oncorhynchus kisutch*).

The study found out that when hatching period is shorter, hatchability and larvae survival percentage are higher and vice versa. This may be attributed to the fact that, when eggs stay longer in the incubation jars in the recirculation system setup, development of infections due to dead eggs such as fungal, parasites and bacteria increases water pollution thereafter affects embryonic stage development of the eggs. This reduces the hatchability percentage and increases larvae mortality. Egg size especially egg diameter is also a major intrinsic factor affecting ontogenetic percentage of development in fish larvae (Kamler, 2002).

Eggs for *O. karongae* were bigger than the ones of *O. mossambicus* and *O. shiranus*. This egg size difference may be an important explanation for the difference in incubation parameters found in this study. Valeta et al. (2013) found out that the difference in hatchability and larvae survival of *O. karongae* were associated with temperature where higher hatchability and larvae survival were registered at higher temperatures (29°C). However, the results from this study on hatchability and larvae survival of *O. karongae* were higher than the results reported by Valeta et al. (2013). This may have due to the combination of factors like egg mortalities experienced by the authors at the beginning of the experiment which was as a result of temperature shock that was not adequately managed when introducing eggs in the jars as well as the design of the recirculating system, water exchange and shape of the incubator used.

Water quality parameters such as dissolved oxygen, temperature, pH and ammonia were uniform. The system used was closed and the same for all treatments. Water parameters were within tolerable limits for good performance of the tilapia eggs (Beveridge & McAndrew, 2000). Therefore, dissolved oxygen, pH and ammonia may not have significantly influenced different variables tested.

In conclusion, this study revealed high batch and relative fecundity in *O. shiranus* and *O. mossambicus*. The study also found higher number females which spawned in interspecific crosses of *O. karongae*. In addition, egg size, hatching period, hatchability and hatchling survival were species specific. Hybridization has influenced reproductive performance *O. karongae* as the number of females which spawned increased, and it is a value addition in aquaculture management of indigenous species.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests in this manuscript.

AUTHOR CONTRIBUTION

E. N contributed for conception and design, data collection, analysis, interpretation, wrote the manuscript, revised it critically for important intellectual content and submitted the manuscript. D. K, J. K and J. M supervised and contributed for conception and design, revised it critically for important intellectual content, made comments and corrections. They also gave the final approval of the version to be published and agreed to be accountable for all aspects of the work.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

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