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Performance of *Oreochromis niloticus* and *Oreochromis andersonii* in controlled laboratory conditions in Zambia

Rose K. Basiita[a,*], Trong Q. Trinh[b], Masautso E. Sakala[c], Patience Chungu[a], Tom Malambo[a], Buumba Hampuwo[a], Catherine Mwema[a], John A.H. Benzie[b]

[a] WorldFish, P.O. Box 51289, Lusaka, Zambia
[b] WorldFish, Jalan Batu Maung, 11960 Batu Maung, Penang, Malaysia
[c] National Research and Development College, Lusaka, Zambia

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ABSTRACT

In the present study, two hatchery strains of *Oreochromis niloticus* and two of *O. andersonii* sourced from different hatcheries in Zambia were subjected to the same feeding and management regimes in a controlled indoor tank environment. All strains were stocked at a mean weight of 2.1 ± 0.01 g and harvested after 175 days. Mean final body weight at harvest for the two *O. andersonii* groups was 65.2 ± 31.5 g and 73.8 ± 38.5 g, which was significantly ($P < 0.05$) lower than those for the two *O. niloticus* groups at 178.5 ± 74.7 g and 187.8 ± 73.6 g. There was no significant difference in body weight at harvest between hatchery strains within either species. The mean specific growth rate (SGR) and the daily growth coefficients (DGC) had similar patterns with the *O. niloticus* strains DGC values more than one and half times those of *O. andersonii*. The high survival values within all groups (range 86–96 %), their good condition factor index values (range 3.2–3.5) and lack of significant differences between species indicated the experimental conditions were suitable for both species and provided a valid test of their relative growth. Food conversion ratios (FCRs) for *O. niloticus* of 1.22 ± 0.11 and 1.07 ± 0.05 were significantly ($P < 0.05$) better than for *O. andersonii* of 1.81 ± 0.10 and 1.84 ± 0.18. The experiment provided rare well-controlled data comparing the growth performance of these species and different hatchery strains in Zambia, as a contribution to better informing investment decisions for the aquaculture industry there and in Southern Africa.

1. Introduction

Tilapia species, originating from Africa, are the second most farmed fish group in the world after carps, providing a sustainable source of food to millions (Conte et al., 2017). Global tilapia production exceeded over 4 million metric tonnes in 2018 (FAO, 2020). The Nile tilapia (*Oreochromis niloticus*) is the dominant species produced worldwide and in most African countries, although several other species are cultured in smaller amounts e.g. the Kafue Bream, *O. andersonii* and *O. macrochir* in Zambia, *O. shiranus* in Malawi and *O. mossambicus* in Mozambique and South Africa.

The success of *O. niloticus* has led to an interest in whether other species could be the basis of new aquaculture industries of significant scale (Kefi and Mwango, 2018). However, published reliable data on the performance of these species, particularly their performance relative to *O. niloticus*, is limited. Such information is key to guiding successful investments in developing the aquaculture sector in sub-Saharan Africa, in particular, to assist assessing the extent to which candidate species have the potential to be competitive in local and international export markets.

One promising candidate for development in southern Africa is *O. andersonii* on which a local aquaculture industry has been developed in Zambia. Although there is a thriving *O. niloticus* industry that provides the majority of production in the country, *O. andersonii* has been considered the most suitable farmed tilapia species in Zambia (Gopalakrishnan, 1988; Cayron-Thomas, 2010; Musuka and Musonda, 2012; Kefi and Mwango, 2018). The species is indigenous and popular among some smallholder farmers and commercial ventures especially where *O. niloticus* is restricted for culture. However, the results available from a single on-farm experiment showed that *O. niloticus* yield (5322 kg/ha/year) was higher than that of *O. andersonii* (4920 kg/ha/year) (Kefi and Mwango, 2018). In another study, it was reported that

* Corresponding author.
E-mail addresses: basiitarose@gmail.com, b.komugisha@cgiar.org (R.K. Basiita).

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O. niloticus was more efficient in utilizing plankton and other natural food in ponds and grew faster than *O. andersonii* (Simataa and Musuka, 2013). These limited data suggest a relatively poor performance by *O. andersonii* relative to *O. niloticus* on two critical issues pertinent to aquaculture production and profitability– growth rate and feed efficiency – and indicate the need for well-controlled experiments to establish the relative performance of the two most farmed species by production volume in Zambia.

The objective of this study was to compare the relative growth performance and feed efficiency of *O. andersonii* and *O. niloticus* under well-defined and controlled conditions. The study used fish obtained from commercial hatcheries in Zambia and hence providing rare benchmarking data on the performance of farmed types in the country. These results are pertinent to industry and government decision makers in Zambia and more broadly in sub–Saharan Africa.

2. Materials and methods

2.1. Fish

The study was carried out at the Natural Resources Development College (NRDC) in Zambia. Six to eight weeks old fingerlings of *O. andersonii* and *O. niloticus* (eight fish groups of 500 fish each) were obtained from six commercial hatcheries in Lusaka, Copperbelt and Southern provinces. The fish were acclimatized in the experimental unit for two weeks prior to the start of the experiment. All male stock had been requested as the use of sex reversed fingerlings is a recommended practice among farms in Zambia given the production advantages of growing all male tilapia compared to mixed sex regardless of the species (Kefi and Mwango, 2018). Because of the small size of fingerlings at the start of the experiment, fish were not sexed at stocking but all were assumed to be sex reversed as requested at purchase. Four groups from three commercial hatcheries (abbreviated as PL, ML and CL throughout this manuscript) in Lusaka province were chosen for the experiment because they were of comparable size (initial weight for all groups was 2.1 ± 0.3 g) and not significantly different. Two strains of *O. andersonii* (*O. andersonii*–PL and *O. andersonii*–ML) and two of *O. niloticus* (*O. niloticus*–PL and *O. niloticus*–CL) were tested. Each group was placed in four replicate 75 litre–aquaria (length 62 cm × wide 32 cm × height 38 cm), giving a total of 16 tanks. Each tank was stocked with 20 randomly assigned fish from the relevant strain on 15 December 2020, resulting in a total of 320 fish, 80 fish per strain. The fish were reared for 175 days and growth monitored through regular sampling every 3 weeks.

2.2. Feeding

Fish were hand fed on a commercial diet four times daily (7:00–08:00 h, 10:00–11:00 h, 13:00–14:00 h and 16:00–17:00 h) except on the days of sampling. Fifty grams of feed was weighed each morning and placed in a well labeled container corresponding to each experimental aquarium. Fish were fed ad libitum and the amount of eaten feed per aquarium was determined at the end of the day by subtracting the remaining feed from the initial 50 g. Using the commercial feed chart provided for tilapia species at different sizes by the manufacturer, the starter feed (type GR2 0.3–0.6 mm crumble, 44 % crude protein and 9 % crude fat) was used for the first six weeks followed by the GR3 (0.5–1 mm crumble, 44 % crude protein and 9 % crude fat) for the next three weeks based on the fish size. From week 10 onwards, the grower feed (2 mm pellet, 40.0 % crude protein and 7.0 % crude fat) was used. The daily initial feed amounts were also adjusted to start at 100 g per container per aquarium, and the amount of eaten feed was determined as described earlier. Analysis of the feed compositions closely matched that provided by the manufacturer except for lower crude protein contents for all the feeds, but more so that of the 2 mm grower feed (Table 1). The current cost of the feed used is 19.84 Kwacha per kg (1 USD = 16.5 Kwacha).

2.3. Management

All experimental aquaria were well aerated with two air–stones per aquarium. Sludge was siphoned out and 60 % of the aquarium volume of water was changed twice a week. During the experiment; pH, water temperature and dissolved oxygen were measured daily using the pH/ ORP & Dissolved Oxygen kit HI 98196 of Hanna Instruments, USA. Mortality was checked and recorded daily, and dead fish were removed immediately from the aquaria.

2.4. Data collection and calculations

Fish were measured at the start (stocking) and end (harvest) of the study. It became apparent at harvest that the fish were not all male, so fish were then sexed by observation of external genitalia. Stocking weight and final weight were measured individually using an electronic scale (KERRO P3B, model BL P3B/6002, D = 0.01 g and max weight 600 g) to the nearest hundredth of a gram. Standard and total length were measured individually by a ruler to the nearest 1 mm. Condition factor (CF) was calculated for each surviving fish as $CF = \frac{final \quad weight}{final \quad length^3} \times 100$.

The daily growth coefficient (DGC) and specific growth rate (SGR) were calculated based on mean values for stocking and final weights per aquarium, as $DGC = \frac{\sqrt[3]{final \quad weight} - \sqrt[3]{stocking \quad weight}}{number \quad of \quad days}$ and $SGR = \frac{\ln(final \quad weight) - \ln(stocking \quad weight)}{number \quad of \quad days}$. Feed conversion ratio (FCR) was calculated per aquarium as $FCR = \frac{feed \quad intake}{\frac{final \quad weight}{number \quad of \quad final \quad fish} - \frac{stockign \quad weight}{number \quad of \quad stocked \quad fish}}$. Final survival rate (%) of fish per aquarium was calculated as; $Survival \quad rate \quad (\%) = \frac{Number \quad of \quad surviving \quad fish \ at \ harvest}{Number \quad of \quad fish \ at \ stocking} \times 100$.

2.5. Statistical analysis

Descriptive statistics were based on the 294 observations of the final measurement of each group made at harvest. The data collected during the experiment are presented as mean ± standard deviation. Statistical analysis was performed using R version 3.6.3 (R Core Team, 2020), with significance set at $P < 0.05$.

Data for final body weight (FBW) did not conform to the normal distribution and was therefore square root transformed to account for the non-normal distribution of the trait and to fulfill the assumptions of the residuals for a linear model analysis. Interaction between

Table 1
Results on ingredient content analysis for sampled fish feeds.

Feed sample	Dry matter		Crude fat		Calcium		Phosphorous		Crude protein		Ash	
	L	M	L	M	L	M	L	M	L	M	L	M
GR2	91	94.9	9	9.6	N/A	3.2	1.1	1.3	44	40.2	8.2	8.5
GR3	91	95.2	9	9.1	N/A	2.2	1.1	1.2	44	39.9	8.2	9.3
Pellet	91	94.4	7	5.9	N/A	3.3	1.4	1.6	40	32.7	N/A	11

Notes: Values are expressed as % kg^{-1} feed; L = as on label and M = measured in laboratory.
GR2 feed: size 0.3–0.6 mm, GR3 feed: size 0.5–1.0 mm, Pellet: size 2 mm.

species–hatchery population and sex was not significant for models for harvest weight and growth rates.

Therefore the model for final $\sqrt{bodyweight}$, DCG and SGR was $y_{ijk} = \mu + combination_i + sex_j + e_{ijk}$ (Model 1) where y_{ijk} is $\sqrt{bodyweight}$ or DCG or SGR of the k fish, μ is the population mean, $combination_i$ is the fixed effect of the species–hatchery combination i (*O. andersonii*–ML, *O. andersonii*–PL, *O. niloticus*–CL and *O. niloticus*–PL), sex_j is the fixed effect of sex j (female and male) and e_{ijk} is the random residual term. For condition factor, the same model was used except the fixed effect of sex (sex_j) was removed (Model 2). For the analysis of survival, a logistic regression model was used with the same fixed effect as in Model 2 but without the residual term (Model 3).

3. Results

3.1. Water quality parameters

Water quality parameters were stable over time and were not significantly different between treatments. Values for pH ranged from 7.9 to 8.0, water temperature from 22.4 to 24.5 °C and dissolved oxygen (mg/l) from 3.3 to 4.2.

3.2. Fish growth parameters: mean final body weight (FBW), the daily growth coefficient (DGC), and mean specific growth rate (SGR)

There were significant differences in all growth parameters between species but none among the hatchery populations within species. Mean final body weight (FBW) for *O. andersonii* was significantly ($P < 0.05$) lower than that of *O. niloticus*, while there were no significant differences in body weight between hatchery strains within either species (Table 2). Similarly, the daily growth coefficients (DGC) and the mean specific growth rate (SGR) were significantly higher for the *O. niloticus* strains than the *O. andersonii* ones, with the *O. niloticus* growing more than 1.3 times (SGR) to 1.5 times (DGC) the rate of *O. andersonii*.

Disaggregated data on final body weight by sex confirmed that males were larger at harvest than females in both *O. niloticus* and *O. andersonii* in the present study (Table 3). *O. niloticus* strains had relatively more males (5.4 males to one female) than the *O. andersonii* ones (3.0 males to one female). The mean difference in size between *O. niloticus* and *O. andersonii* was 111.7 g for males and 98.8 g for females. These numbers indicate a 100 % greater growth of male *O. niloticus* compared to male *O. andersonii* and a 50 % greater growth of female *O. niloticus* compared to female *O. andersonii*. There was no significant interaction between species-hatchery combination and sex in Model 1 tested.

3.3. Condition factor and survival

All groups had similar condition factors ranging from 3.2 to 3.5, with no significant difference among the *O.niloticus*-CL, *O.niloticus*-PL and *O. andersonii*-PL groups. The only exception was the condition factor for *O. andersonii*-ML strain which was statistically significantly lower than the rest of the groups (Table 4). There were high survival values within all groups (range 86–96 %) and no significant difference in survival was detected among the four groups.

Table 3
Mean ± standard deviation final body weight of the different species–hatchery combinations by sex of fish at the final measurement.

Species–Hatchery	Sex	N	Final body weight
O. andersonii–ML	Female	19	47.9 ± 23.2
	Male	53	83.0 ± 38.8
O. andersonii–PL	Female	22	50.8 ± 20.3
	Male	54	71.0 ± 33.5
O. niloticus–CL	Female	1	166.7 ± − 0.0
	Male	68	178.7 ± 75.2
O. niloticus–PL	Female	12	129.7 ± 45.5
	Male	65	198.6 ± 73.0

3.4. Feed intake and FCR

There was no significant difference in feed intake among the four groups (Table 4). There were significant differences in FCR between the species, but no significant differences between groups within species ($P > 0.05$) with FCR with mean values ranging from 1.07 to 1.22 in *O. niloticus* and 1.81 to 1.84 in *O. andersonii*.

4. Discussion

Evidence that the differences in performance observed in the present experiment reflected the abilities of both species tested rather than one of the species being in an environment to which it was not suited is given by the data on condition factor and survival. Condition factor is an indicator of the well-being of the fish and the higher the condition factor, the heavier a fish is for a given length. Although the condition factor among the *O. andersonii* groups was lower than that of the *O. niloticus*, all hatchery strains for both species tested had good condition factor values (3.2–3.5) which fell within healthy tilapia isometric ranges for adult fish (Ighwela et al., 2011). The high condition factor for both species of tilapia in the present study implied that all fish were in a good healthy condition desirable for fish in farms (Ighwela et al., 2011; Ayode, 2011). Therefore observed differences in growth and FCR between the species reflected their true abilities in the environment tested rather than any differences in health status or condition. This inference was also supported by the high survival in all groups and the lack of significant differences in survival between groups (Table 4).

In the current study, the males grew larger than the females in both species, this was consistent with available data from several other tilapia species (Bhatta et al., 2013; Fuentes-Silva et al., 2013; Kefi and Mwango, 2018). Although *O. niloticus* strains had relatively more males than the *O. andersonii* ones, the difference in growth observed in the current study between species could not be attributed to the higher number of males in *O.niloticus* groups but rather their specific species' growth abilities, since there were size differences between species for each sex separately.

This is further confirmed by the lack of detection of significant interactions between species-hatchery combination and sex, in the analysis.

Table 2
Mean ± standard deviation of initial body weight (IBW) and final body weight (FBW) at harvest (g), daily growth coefficient (DGC) (g/day), specific growth rate (SGR) (g/day) for the four species–hatchery group combinations.

Species-	IBW		FBW		DGC		SGR	
Hatchery strain	N	Mean ± SD	N	Mean ± SD	N	Mean ± SD	N	Mean ± SD
O. andersonii–ML	80	2.07 ± 0.27^a	72	73.8 ± 38.5^b	4	0.017 ± 0.010^b	4	0.021 ± 0.002^b
O. andersonii–PL	80	2.07 ± 0.34^a	76	$65. \pm 31.5^b$	4	0.016 ± 0.010^b	4	0.020 ± 0.001^b
O. niloticus–CL	80	2.06 ± 0.27^a	68	178.7 ± 75.2^a	4	0.025 ± 0.020^a	4	0.026 ± 0.001^a
O. niloticus–PL	80	2.06 ± 0.26^a	77	187.8 ± 73.6^a	4	0.026 ± 0.010^a	4	0.026 ± 0.000^a

Notes: Data in the same column with different superscript are significantly different ($P < 0.05$).
N is sample size with body weight (both IBW and FBW) assessed for individual fish while DGC and SGR were assessed by tank.

Table 4
Mean ± standard deviation condition factor (CF) assessed by individual fish while feed intake (FI) and feed conversion ratio (FCR) for the four species–hatchery combinations ('strains'). N is sample size with condition factor assessed by individual fish while feed intake (g) and FCR assessed by tank.

Species–	CF		Survival (%)		FI (g)		FCR	
Hatchery strain	N	Mean ± SD	N	Mean ± SD	N	Mean ± SD	N	Mean ± SD
O. andersonii–ML	72	3.2 ± 0.3^{b}	4	90.0 ± 4.1^{a}	4	2315.0 ± 152.0^{b}	4	1.84 ± 0.18^{a}
O. andersonii–PL	76	3.4 ± 0.3^{a}	4	95.0 ± 4.1^{a}	4	2174.8 ± 103.2^{b}	4	1.81 ± 0.10^{a}
O. niloticus–CL	68	3.5 ± 0.4^{a}	4	86.3 ± 14.4^{a}	4	3669.8 ± 312.7^{a}	4	1.22 ± 0.11^{b}
O. niloticus–PL	77	3.4 ± 0.4^{a}	4	96.3 ± 4.8^{a}	4	3788.0 ± 260.4^{a}	4	1.07 ± 0.05^{b}

The relatively faster growth performance of *O. niloticus* over *O. andersonii* in the present study was consistent with reports from previous studies elsewhere (Day et al., 2016; Wegener, 2016;) and a single study carried out on farm more than a decade ago in Zambia (Cayron-Thomas, 2010). Furthermore, the *O. niloticus* FCR values in the current experiment were comparable to other reports for the species (Goda et al., 2007; Mustapha et al., 2012; Bamba et al., 2014; Day et al., 2016) while the FCR values for *O. andersonii* in the current study (FCR = 1.8) was better than that observed by Day et al. (2018) in the same species (FCR = 2.53 ± 0.28).

While still limited, these data have clear implications for the relative cost effectiveness of farming with these two species. A faster growth means fish of the desired market size can be achieved in a shorter period of time and hence a faster return on investment. Additionally, by completing the production cycle earlier, the farmer could be assured of a reduction in risk of loss resulting from various factors that may arise such as disease outbreaks, theft, climatic and weather changes affecting temperature, dissolved oxygen, and flooding among other risks (FAO, 2018). Fast growth also provides the farmer with increased flexibility by providing the option to produce a given size of fish earlier or by growing larger fish in the same time period. Larger-sized fish often gain better market prices (Tsikliras and Polymeros, 2014) and thus, increased growth can lead to greater return on investment, or better liquidity for a farmer, all else held constant.

In this regard, given that feed is the major cost for a farm, lower FCRs would translate into significant economic benefits for the farmer in addition to having an earlier harvest resulting from a faster growth rate (Besson et al., 2020). Lower FCR is also known to decrease environmental impacts due to reduced quantities of inputs in the aquatic environment (de Verdal et al., 2018). Although FCR values for both species were good (< 2.0) relative to those achieved on-farm, the current study indicated a 56 %, greater feed cost to producing a kilo of *O. andersonii* compared to *O. niloticus* over the same time period. This could make all the difference between a farm making a loss or profit, or the difference between bare returns on investment or sufficient returns to support sustainable livelihoods.

Genetic selection for faster growth could improve performance of *O. andersonii*. A selective breeding program for the indigenous *O. andersonii* has been embarked on by the Zambian government and partners to try and address the constraint of slow growth (African Development Bank, 2016; Genschick et al., 2017). In the present study *O. niloticus* grew 166 % faster than *O. andersonii*. Given this difference, several generations of selection for improved growth in *O. andersonii* would be required to achieve similar levels of growth and thus highlights the need for a long-term breeding program as opposed to short-term projects which may not realize significant improvements useful to the industry. Lessons can be drawn from other fish genetic improvement programs that have had significant impacts on the aquaculture industry such as *O. niloticus* improvement implemented initially in the Philippines from 1989 by the International Center for Living Aquatic Resources Management (ICLARM) with partners (Ponzoni et al., 2011) and *Oncorhynchus kisutch* (Coho salmon) that started in 1992 in Chile by the Institute for Fisheries Development (IFOP) and the Universidad de Chile (Neira et al., 2004).

A careful economic evaluation will be required to assess the competitiveness of farms using *O. andersonii* and which species to use for general industry development plans. The present differentials with *O. niloticus* suggest competitiveness in international export markets would be challenging on current performance, and plans to counter that would be needed for longer term developments. However, these issues are also critical for developments focused on smallholder farmers given the small profit margins experienced by many smallholder farmers currently in Zambia (Kaminski et al., 2019). It is clear that the majority of farmers including smallholders engage in fish farming primarily for income generation as evidenced by Kaminski et al. (2019), where over two-thirds of farmers indicated the main reason for their engagement in fish farming activities is income generation. The farmers' success will depend on the costs of inputs including quality feed and seed, the effectiveness of individual business plans, the nature of the markets (even local ones) being accessed and the competitors supplying that market. Farming at a profitable and yet affordable price is important but often underappreciated in terms of its contribution to global food security and socio-economic development (Tsikliras and Polymeros, 2014; Belton et al., 2018; Kaminski et al., 2020).

5. Conclusion

The controlled experimental comparison of growth between *O. niloticus* and *O. andersonii* in Zambia demonstrated faster growth and more efficient feed utilization of *O. niloticus* under the same management regime. Both species showed good FCR rates in the experiment but that of *O. niloticus* exceeded that of *O. andersonii*, meaning it is more cost effective to rear in culture, an important factor to take into account for aquaculture industry planning given the current small profit margins experienced by many farmers with the prevailing costs of production.

The growth trait and economic factor are very critical and hence further controlled research studies in ponds and cage environment are recommended as this was out of our current scope of work given the limited resources available to the study. Therefore, more up to-date assessments on these key species in the same environment to depict their current performance in the culture units including ponds and cages used by most farmers and well-designed market preference studies for the studied species will be vital in assessing the industry position henceforth.

The results benchmarking the current performance of the native *O. andersonii* relative to *O. niloticus* in a controlled environment in the present study will benefit and directly feed into the current genetic improvement program the Zambian government has recently embarked on for native *O. andersonii*, using the available local populations.

CRediT authorship contribution statement

Rose K. Basiita: Conceptualization, Methodology, Validation, Data curation, Investigation, Project administration, Writing - original draft, Writing - review & editing. **Trong Q. Trinh:** Conceptualization, Methodology, Validation, Data curation, Formal analysis, Writing - review & editing. **Masautso E. Sakala:** Data curation, Investigation, Writing - review & editing. **Patience Chungu:** Conceptualization, Methodology, Writing – review & editing. **Tom Malambo:** Data curation, Investigation, Writing - review & editing. **Buumba Hampuwo:** Writing – review

& editing. **Catherine Mwema:** Validation, Writing – review & editing. **John A.H. Benzie:** Conceptualization, Methodology, Resources, Supervision, Writing - review & editing.

Ethics statement

This research was undertaken under the broader project for the Zambia Aquaculture enterprise Development project research approval for the Genetic improvement program of the Kafue bream under Zambia Research Body ECRES CONVERGE IRB no. 00005948 with study reference 2020-Aug-011. Additionally, the WorldFish guiding principles of Animal Care, Welfare and Ethics Policy were adhered to particularly while handling fish (WorldFish, 2004).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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Conflict of interest

The authors of this manuscript declare there are no conflicts of interest associated with it.

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