

Comparative single- and co-nursing of Nile tilapia, *Oreochromis niloticus* and African catfish, *Clarias gariepinus* fingerlings in hapa-in-pond system

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Abstract

This study was conducted to compare single- and co-nursing of the Nile tilapia, *Oreochromis niloticus* and the African Catfish, *Clarias gariepinus* fingerlings in hapa-in-pond system. Three (3) treatments, *A* (tilapia fingerlings only), *B* (catfish fingerlings only) and *C* (1:1 tilapia and catfish fingerlings) were studied. The fingerlings of both fishes ranged between 1.20 and 1.50 g, at initial mean weights 1.32 ± 0.02 , 1.34 ± 0.08 and 1.32 ± 0.10 g for *A*, *B* and *C*, respectively. Nursing of the fingerlings was carried out in nine (9) fine mesh net hapas, each of dimensions 5.0 x 2.0 x 1.2 m; installed in about 0.2-hectare earthen pond and each hapa stocked with 60 fish. The fish were fed separately with the same brand of commercial tilapia feed, catfish feed and their equal mixture at a declining rate of 10.0 to 4.0% fish biomass hapa⁻¹, 3 times daily for 77 days. Harvested biomass of juvenile fish and returns on investment ranged from 0.65 ± 0.03 to 0.95 ± 0.02 kg m⁻¹ and 161.40 ± 53.94 to 684.80 ± 17.81%, respectively; with those of *C* being significantly higher (Tuker's HSDT, $P < 0.05$). Hence, co-nursing of *O. niloticus* and *C. gariepinus* fingerlings is recommended over nursing them separately.

Keywords: Catfish feed, fish feed, monoculture, polyculture, tilapia feed

Introduction

Globally, the Nile tilapia, *Oreochromis niloticus* is a major aquaculture species due mainly to its fast growth and its ease production of fingerlings under captivity (Gómez-Márquez *et al.*, 2003; FAO, 2024) [1, 2]. Currently, it is the main farmed fish species in Ghana, contributing about 80% of cultured fish production (FC, 2023) [3]. This is followed by the African catfish, *Clarias gariepinus* constituting about 20.0%. The farming of *C. gariepinus* over the years continues to increase due to its ability to survive a wide range of environmental conditions, high stocking densities and relative fast growth under culture conditions (James and Sampath, 2003; Ekanem *et al.*, 2012) [4, 5]. It is usually cultured in diversified culture systems such as earthen ponds, concrete tanks, plastic tanks, tarpaulin tanks and in floating fish cages.

The higher survival and the faster growth of *C. gariepinus* during the grow-out stage compare with those of *O. niloticus*, compels most fish farmers to farm the former. Hence, *O. niloticus* and *C. gariepinus* are important fish species in Ghana aquaculture and both may be cultured efficiently in high density as they have similar feeding requirements. The production of both species is expected to increase in the years ahead.

Even though the technique of composite fish farming (i. e. polyculture) is practised in Ghana, it is to a limited extent and the practice is not purposeful as no fixed ratios of fishes are co-cultured in a system. In some instances, composite farming of tilapia and *C. gariepinus* is aimed at avoiding overcrowding when mixed-sex tilapia is stocked in a culture system; as the fry produced by the tilapia are consumed by the *C. gariepinus*.

The practice of polyculture is eco-friendly as different species with complementary ecological functions are co-cultured for enhanced resource utilization to ensure minimal waste discharge and ecological sustainability (Ahmed *et al.*, 2020; Jha *et al.*, 2021; Thomas *et al.*, 2021; Ghosh *et al.*,

2025) [6, 7, 8, 9]. Polyculture of different fish species is considered a sustainable fish farming practice that enhance efficient utilization of available water resources for improved productivity and profitability; resulting in reduced economic vulnerability (Kumar *et al.*, 2019; Mansour *et al.*, 2021; Amoussou *et al.*, 2022) [10, 11, 12]. Polyculture limits the negative impacts of the environment on intensive farming as diversification and adaptation of different fish species within a culture system are enhanced (Wang and Lu, 2016) [13].

Fish species used in polyculture must be compatible and non-competing (Wang and Lu, 2016; Fitzsimmons and Shahkar, 2017; Chithambaran, 2019) [13, 14, 15]. The practice has socioeconomic importance, since it introduces several produces with different consumer demand, maximizes the efficient use of the culture system, controls fish recruits, and it increases profitability (Husain *et al.*, 2016; Mahmud *et al.*, 2016; Sudirman *et al.*, 2020) [16, 17, 18]. In polyculture, fish species have a potentially higher net return than monoculture due to the expected increase fish yield (Rouse and Stickeny, 1982; Reddy *et al.*, 2002; Lutz, 2003; Mac'Were *et al.*, 2006; Ghosh and Mandal, 2021) [19, 20, 21, 22, 23]. However, an optimal species ratio for efficient use of different ecological strata within a culture system and healthy species interaction (inter- and intra-specific competition) must be ensured (Ali *et al.*, 2017; Sudirman *et al.*, 2020) [24, 18].

Even though composite grow-out production of *O. niloticus* and *C. gariepinus* is not a new thought in Ghana, composite nursing of their fry/fingerlings is uncommon and there is no available information on the practice. Besides, composite nursing of the fingerlings of the two (2) fish species is expected to increase the profit margin of hatchery operators, since weight for weight, the fingerling cost of *C. gariepinus* is about two-fold that of *O. niloticus*. The rapid development of the aquaculture sector in Ghana calls for an improved methods and practices of fingerling nursing alongside their cost-effectiveness.

Although there are numerous tilapia and catfish hatcheries in Ghana, none of these practises co-nursing of the 2 fingerlings concurrently within the same nursing system; and neither has any study been carried out to evaluate the practice. Hence, the objective of the present study was to compare single and co-nursing of *O. niloticus* and *C. gariepinus* fingerlings in hapa-in-pond system, with the aim of establishing the appropriate nursing option for tilapia and catfish hatchery operators. In light of this, the present study evaluated single- and 1:1 co-nursing of *O. niloticus* and *C. gariepinus* fingerlings fed separately with commercial tilapia and catfish feeds; and their equal mixture in hapa-in-pond system for 77 days.

Materials and Methods

Study site

The study was carried out for a period of 77 days at the Aquaculture Research and Development Centre (ARDEC) of Water Research Institute (WRI) of the Council for Scientific and Industrial Research (CSIR), Ghana. The site is located between latitude 6° 13' North and the longitude 0° 4' East, Akosombo, Eastern Region, Ghana.

Experimental set-up

The experiment was conducted in hapa-in-pond system consisted of nine (9) fine mesh netting hapas, each of dimensions 5.0 x 2.0 x 1.2 m (i.e. length, width and height), installed along the lengths of about 0.2-hectare earthen pond and each hapa separated from the other by a distance of about 5 m. The hapas were randomly labelled according to three (3) treatments, viz. *A* (catfish fingerlings only), *B* (tilapia fingerlings only), and *C* (1:1 catfish and tilapia fingerlings) with 3 hapas allocated to each treatment.

Experimental feeds

The experimental feeds were the same brand of commercial formulated fish feeds separately for tilapia and catfish, procured from a commercial fish feed retail outlet close to the study area. The feeds were in extruded pellet forms with the same diameter (2.0 mm) and 40.0% crude protein (CP) contents according to indications on the labels of the feed bags by the manufacturer (Table 1).

Table 1: Information on the labels on the bags of studied tilapia and catfish feeds

Parameter (%)	Tilapia Feed	Catfish Feed
Crude Protein	40.00	40.00
Crude Fat	10.00	6.50
Crude Fibre	5.00	4.00
Moisture	10.00	10.00
Ash	10.00	12.00
Phosphorus	1.00	1.20
Calcium	1.00	1.50

During the initial four (4) weeks of the experiment, about 30.00 kg of each feed was crushed into sizes 0.4 to 0.8 mm for the experimental fingerlings to pick. A third feed was obtained by uniform mixture of equal portions of the 2 feeds. About 50.0 g samples of each feed were obtained in about 300 ml containers for proximate composition analyses. The excess feeds were sealed and kept in a cool, dry and well-ventilated place which was inaccessible to unauthorized personnel. After the fourth week, the nursed fish were fed with the uncrushed pellets until the end of the study.

Proximate composition determination of experimental feeds

Proximate composition analyses of the feeds were carried out in triplicates following standard methods (AOAC, 2019)^[25] at the Department of Nutrition and Food Science, University of Ghana, Legon. Applying the protocol, the percentage (%) dry matter (DM), % crude protein (CP), % ash, % crude lipid (CL) and % crude fibre (CF) were determined. Percentage nitrogen-free extract (carbohydrate), % NFE was computed using the formula: % NFE = % DM - (CP + Ash + CL + CF) %. Gross energy contents of the feeds were computed using average physiological fuel values 23.64, 39.54 and 17.15 MJ kg⁻¹ for protein, fat and carbohydrate, respectively (Anani *et al.*, 2024)^[26].

Stocking and feeding of experimental fingerlings

Each hapa was stocked with 60 fingerlings, with treatment *A* being tilapia only, *B* being catfish only and *C*, both tilapia and catfish in the ratio of 1:1 (i. e. 30 tilapia and 30 catfish). The initial weights of the fingerlings ranged between 1.20 to 1.50 g and the initial mean weights for the various treatments were 1.32 ± 0.02, 1.34 ± 0.08 and 1.32 ± 0.10 g for treatments *A*, *B* and *C*, respectively. The fingerlings were fed manually at a rate of 10.0% of their body weight (biomass) 3 times (between 8:00-8:30 am, 12:00-12:30 pm and 4:00-4:30 pm) daily. Treatments *A*, *B* and *C* were fed with tilapia feed, catfish feed and their equal mixture, respectively. When the fingerlings in each hapa attained a mean weight of ≥ 5.0 g, the feeding rate was reduced to 5.0% and then to 4.0% when the mean weights were 5.0 to 20.0 g. Finally, the fingerlings were fed at 4.0% when their mean weights were above 20.0 g, which continued until the end of the nursing period. However, feeding frequency of 3 was maintained throughout.

Water quality parameters monitoring

Water quality parameters [temperature, pH, dissolved oxygen (DO), total ammonia and total alkalinity] in the experimental hapas, as well as at the inlets and the outlets of the pond were measured weekly. Temperature, pH and DO were measured using pre-calibrated multi-parameter water quality meter, model HI 9828 (Hanna Instruments Ltd., Chicago, II, USA). Total ammonia and total alkalinity were measured using a spectrophotometer (UV mini-1240).

Fish growth monitoring

To monitor the growth of the nursed fingerlings, they were measured weekly between 6:00 and 9:00 am. Each hapa was partially withdrawn from the pond to confine the fish at the bottom of the open end of the cover. The fingerlings were netted and put into a large plastic bowl containing pond water. The fish were weighed in bulk batches of 10 using top loading electronic balance (EMB 500-1 - Kern). For *C*, the *O. niloticus* and *C. gariepinus* fingerlings were separately weighed. The mean weights and the biomass of fish in each hapa under each treatment were computed, based on which the feeding rates were adjusted. At the end of the eleventh week, all the fish from each of the replicates of each treatment were harvested, counted and weighed individually to determine survival and the final weight.

Growth performance indicators computation

Growth performance was determined in terms of survival rate (SR), weight gain (WG), specific growth rate (SGR), feed conversion ratio (FCR) and feed efficiency (FE) as below:

Survival rate (SR)

$$SR = \frac{\text{initial number of fingerlings stocked} - \text{total mortality}}{\text{initial number of fingerlings stocked}} \times 100\%$$

Mean weight gain (MWG)

The MWG was computed as:

$$MWG = \text{fingerling final mean body weight (g)} - \text{fingerling initial mean body weight (g)}$$

Specific growth rate (SGR)

The SGR is the instantaneous change in weight of the fish expressed as the percentage increase in body weight per day over any given time interval. It was calculated by taking natural logarithms of the fish body weight, and expressed as percentage per day.

$$SGR = \frac{\ln(\text{fingerling final mean body weight}) - \ln(\text{fingerling initial mean body weight})}{\text{culture period (77 days)}} \times 100\%$$

Where \ln = natural logarithm

Feed conversion ratio (FCR)

The FCR is defined as the quantity of dry feed fed per unit live weight of fish gain. It often serves as a measure of efficiency of a feed. It was computed as:

$$FCR = \frac{\text{total feed fed (g)}}{\text{live weight gained by fish}}$$

Feed efficiency (FE)

FE is simply the reciprocal of FCR (i.e. $1/FCR$) times 100%. It was computed as:

$$FE = \frac{\text{live mean weight gained by fingerlings (g)}}{\text{total feed fed (g)}} \times 100\% = \frac{1}{FCR} \times 100\%$$

FE greater than 50% is considered 'good' growth (Houlihan *et al.*, 2001) [27].

Protein efficiency ratio (PER)

$$PER = \frac{\text{live mean weight gained by fingerlings (g)}}{\text{mean crude protein fed (g)}}$$

Computation of economic parameters

The total revenue, TR generated from the sales of the juvenile fishes produced was computed by multiplying the weight of each category by the corresponding unit price as:

$$TR = P \cdot Q \text{ (Dilon and Hardaker, 1993; Zannatul et al., 2019) [28, 29].}$$

Where: P and Q denote price (GHS) per unit weight of juvenile fish and the quantity (kg) produced, respectively.

The rate of returns on investment (ROI) which measures the extent to which the juvenile tilapia and catfish produced

generates adequate returns on the capital invested was determined as:

$$ROI = \frac{\text{profit}}{\text{total production cost}} \times 100\%$$

The higher it is, the more profitable is the venture (Wood, 1999) [30].

Data analyses

All data on fish growth performance and feed utilization were statistically analysed using the SPSS (version 24.0) software. The data were tested for normality using the Kolmogorov-Smirnov test, and homogeneity using the Levene's test. All percentages and ratios were arcsine transformed then statistical analyses were carried out using one-way analysis of variance (ANOVA). When differences were observed among treatments, Tukey's honest significant difference test (Tukey's HSDT) was applied to identify differences between specific pairs of treatments. Differences were regarded as significant when $P < 0.05$.

Results**Proximate composition of feeds**

In general, the analysed parameters of both the tilapia and the catfish feeds were similar to those declared by the producer whilst the parameters of the mixed feed were about half the sum of those of the two feed types (Table 2).

Table 2: Proximate composition (% as-fed), gross energy (kJ g⁻¹) and the unit price (GHS kg⁻¹) of the tilapia and catfish feeds and their equal mixture

Parameter	Tilapia Feed	Catfish Feed	Mixed Feeds
Moisture	8.69 ± 0.41	8.45 ± 0.11	8.61 ± 0.33
Crude Protein	42.77 ± 0.13	41.67 ± 0.05	42.56 ± 0.15
Crude Fat	4.43 ± 0.10	8.32 ± 0.04	7.11 ± 0.15
Crude Fibre	5.10 ± 0.14	6.21 ± 0.09	5.43 ± 1.20
Ash	13.78 ± 0.07	11.32 ± 0.14	12.89 ± 0.41
Carbohydrate	25.23 ± 0.21	24.03 ± 0.19	25.18 ± 0.37
Gross Energy	16.19 ± 0.41	17.26 ± 0.39	16.83 ± 0.65
Price	13.45	15.30	14.38

Values are means ± standard deviations of three replicates. The average exchange rate of the Ghana cedi to the USA dollar in 2023 was: GHS11.20 = 1.00 USD

The computed gross energy contents of the feeds were similar and they were 16.19 ± 0.41, 17.26 ± 0.39 and 16.83 ± 0.65 KJ g⁻¹ for tilapia feed, catfish feed and mixed feeds, respectively. The cost of a unit weight of the feeds ranged from 13.45 to 15.30 GHS kg⁻¹ (1.20 to 1.37 USD kg⁻¹) with that of the catfish being the highest and the tilapia, the least.

Growth performance and feed utilization by the nursed fingerlings

The growth performance and feed utilization by the single- and the co-nursed Nile tilapia, *Oreochromis niloticus* and the African catfish, *Clarias gariepinus* fingerlings are shown in Table 3 below:

Table 3: Growth performance and return on investment of single- and co-nursed Nile tilapia, *Oreochromis niloticus* and African catfish, *Clarias gariepinus* fingerlings in hapa-in-pond system for 77 days

Parameter	Nursing Type		
	Tilapia Only (A)	Catfish Only (B) (A)	1:1 Catfish and Tilapia (C)
Initial mean weight (g)	1.32 ± 0.02 ^a	1.34 ± 0.08 ^a	1.32 ± 0.10 ^a
Tilapia			1.31 ± 0.10
Catfish			1.32 ± 0.11
Final mean weight (g)	33.04 ± 8.85 ^b	32.04 ± 7.85 ^b	38.52 ± 6.00 ^a
Tilapia			46.29 ± 0.48
Catfish			33.07 ± 3.84
Mean weight gain	31.72 ± 7.83 ^b	30.70 ± 7.77 ^b	37.20 ± 5.90 ^a
Tilapia			44.98 ± 0.38
Catfish			31.75 ± 3.73
Mean daily weight gain (g daily ⁻¹)	0.45 ± 0.13 ^a	0.44 ± 0.11 ^a	0.48 ± 0.03 ^a
Tilapia			0.60 ± 0.02
Catfish			0.43 ± 0.07
Mean survival rate (%)	67.22 ± 9.18 ^c	78.70 ± 16.31 ^b	88.52 ± 5.01 ^a
Tilapia			79.26 ± 13.39
Catfish			98.89 ± 1.92
Mean specific growth rate (% day ⁻¹)	4.57 ± 0.38 ^b	4.51 ± 0.42 ^b	4.74 ± 0.10 ^a
Tilapia			4.63 ± 0.07
Catfish			4.13 ± 0.09
Mean feed conversion ratio	1.15 ± 0.09 ^a	1.06 ± 0.08 ^a	1.08 ± 0.08 ^a
Mean protein efficiency ratio	1.74 ± 0.92 ^c	1.97 ± 0.78 ^b	2.35 ± 0.62 ^a

Figures are means ± standard deviations of three replicates. Means within the same row with different superscripts are significantly different (Tukey’s HSDT, *P* < .05)

The combined final mean weight, FMW (38.52 ± 6.00 g); mean weight gain, MWG (37.20 ± 5.90 g); mean survival rate, MSR (88.52 ± 5.01%); mean specific growth rate, MSGR (4.74 ± 0.10% day⁻¹) and the mean protein efficiency ratio, MPER (2.35 ± 0.62) of the co-nursed *O. niloticus* and *C. gariepinus* fingerlings were significantly higher (Tukey’s HSDT, *P* < 0.05) than those of either the single-nursed *O. niloticus* or *C. gariepinus* fingerlings. The recorded figures of FMW, MWG, MDWG and MSGR for *O. niloticus* were higher than those of *C. gariepinus* under either single- or co-nursing conditions. The highest mean feed conversion ratio (MFCR) of 1.15 ± 0.09 and the least MSR of 67.22 ± 9.18% were recorded in the single-nursed *O. niloticus*.

Recorded water quality parameters

There were no significant differences (ANOVA, *P* > 0.05) in recorded water quality parameters among treatments. The

recorded range figures for temperature, pH, dissolved oxygen (DO), total ammonia and total alkalinity were 29.6-32.9 °C, 7.0-8.1, 6.8-9.4 mg L⁻¹, 0.268-0.427 mg L⁻¹ and 14.7-44.7 mg L⁻¹, respectively. The corresponding range figures mean were 30.8 ± 0.8-32.9 ± 1.1 °C, 7.4 ± 0.4-7.8 ± 0.4, 6.5 ± 1.1-8.6 ± 0.7 mg L⁻¹, 0.318 ± 0.03-0.363 ± 0.05 mg L⁻¹ and 20.9 ± 8.7-38.13 ± 8.3 mg L⁻¹ for temperature, pH, dissolved oxygen (DO), total ammonia and total alkalinity, respectively.

Profitability of single- and co-nursed *O. niloticus* and *C. gariepinus* fingerlings

The mean production costs, in terms of feed input of single- and co-nursed *O. niloticus* and *C. gariepinus* ranged from 137.10 to 179.00 GHS (12.25 to 16.00 USD), with that of co-nursed being the least (Table 4).

Table 4: Production cost, yield, revenue and return on investment of single- and co-nursing of Nile tilapia and African catfish fingerlings in hapa-in-pond system for 77 days

Parameter	Nursing type		
	Tilapia only (A)	Catfish only (B)	1:1 Tilapia and Catfish (C)
Cost per kg of feed (GHS)	13.45	15.30	14.38
Feed input (kg)	11.80 ± 1.12 ^a	11.70 ± 0.83 ^a	9.55 ± 0.10 ^b
Cost of feed input (GHS)	158.70 ± 14.43 ^b	179.00 ± 12.72 ^{ab}	137.10 ± 1.48 ^{bc}
Fingerling cost	60.00 ± 0.00 ^c	150.00 ± 0.00 ^a	105.00 ± 0.00 ^b
Mean juvenile fish harvested (kg m ⁻²)	0.65 ± 0.03 ^c	0.75 ± 0.02 ^b	0.95 ± 0.02 ^a
Estimated mean value of biomass (GHS)	615.00 ± 5.51 ^c	860.00 ± 9.79 ^b	1,900.00 ± 7.59 ^a
Mean net revenue (GHS)	396.30 ± 3.41 ^c	531.00 ± 6.86 ^b	1,657.90 ± 8.31 ^a
Mean return on investment (%)	181.21 ± 23.63 ^b	161.40 ± 53.94 ^c	684.80 ± 17.81 ^a

Figures are means ± standard deviations of three replicates. Means within the same row with dissimilar superscripts are significantly different (Tukey’s HSDT, *P* < 0.05)

The average exchange rate of the Ghana cedis to the USA dollar in 2023 was: GHS11.20 = 1.00 USD

The mean biomass of juvenile fishes harvested ranged from 0.65 to 0.95 kg m⁻² with that of co-nursed being significantly higher (Tukey’s HSDT, *P* < 0.05). The estimated mean value of juvenile fish produced ranged from

615.00 to GHS1, 900.00 (54.90 to 169.65 USD), with that of co-nursed being significantly higher and the single-nursed *O. niloticus* being lower. The highest mean return on investment (ROI), 684.80% was recorded in co-nursed

fingerlings whilst the least (161.40%) was recorded in single-nursed *C. gariepinus*, despite single-nursed *O. niloticus* recording the least mean net revenue of GHS396.30 (35.40 USD) and that of *C. gariepinus* being GHS531.00 (47.40 USD).

Discussion

The analysed nutritional values of both commercial tilapia and catfish feeds used in the study were similar to those declared by the producer. The crude protein contents in both feeds and their equal mixture were comparable to the recommended range of 30 to 40% for tilapia and catfish fingerlings (Fitzsimmons, 2005; Lim and Webster, 2006; Potongkam and Miller, 2016) [31, 32, 33]. Considering the sufficiency of carbohydrates and fats contents of the feeds, their protein contents might have been used mainly for fish growth (Natacha *et al.*, 2012; Craig, 2017) [34, 35].

Water quality parameters which directly affect fish survival, health, well-being and growth are key factors considered in fish culture systems (Yavuzcan *et al.*, 2017; Xiao *et al.*, 2023) [36, 37]. Unsuitable levels of key water quality parameters such as temperature, dissolved oxygen (DO) and pH often induce physiological stress that may lead to mortality of cultured fish species (Lu *et al.*, 2020; Nguyen *et al.*, 2021) [38, 39]. The recorded water quality parameters in the current study were within the required ranges for optimum performance of Nile tilapia and the African catfish since neither the single- nor the co-nursed fingerlings were impacted negatively. This also suggests that the catfish and tilapia feeds, as well as their equal mixture used in the current study were appropriate for nursing the fingerlings as they did not have adverse effect on water quality.

The results of the present study indicate that the co-nursed fingerlings recorded significantly higher (Tukey's HSDT, $P < 0.05$) total biomass than those of the single-nursed. Besides, the daily weight gain, the combined growth performance indicators were significantly higher in the co-nursed than in either of the single-nursed. These findings are in agreement with those of other studies. For instance, Nabil and Naggat (2010) [40] observed that the growth rates of *C. gariepinus* in monoculture were lower than those of its polyculture with *O. niloticus*. Similarly, were the observations made by Mansour *et al.* (2021) [11] in a study in which striped catfish and Nile tilapia were co-cultured. Further, Kumar *et al.* (2018) [41] also recorded higher growth performance and yield of Indian major carps and pacu (*Piaractus brachyomus*) when the two fishes were co-cultured. Higher growth performance and yield in polyculture have been attributed to absence of feed competition and the maximization of feed utilization by the cultured fish species (Dawood *et al.*, 2025) [42]. In the current study, the co-nursed fingerlings yielded about 26% more than the single-nursed *C. gariepinus* fingerlings and about 46% more than that of *O. niloticus*. These findings are in line with those of Ghosh and Mandal (2021) [23] who observed that polyculture of different species resulted in increased productivity with yields being 20 to 30% more than those of monoculture.

The highest total production cost (Tukey's HSDT, $P < .05$) recorded in the single-nursed *C. gariepinus* was mainly due to the highest prices of both catfish feed (15.30 GHS kg⁻¹) and its fingerlings (GHS150.00) compared to those (15.30 GHS kg⁻¹ and GHS60.00, respectively) of tilapia. Hence, this resulted in reduced return on investment (ROI) for the single-nursed *C. gariepinus* compared with those of the single-nursed *O. niloticus* and its co-nursed with *C.*

gariepinus. The significantly higher (Tukey's HSDT, $P < .05$) ROI recorded in the co-nursing was mainly due to the least production cost which was associated with high yield and hence, high revenue generated from juvenile fish produced. This demonstrates that co-nursing of *O. niloticus* and *C. gariepinus* fingerlings is more economically advantageous, higher resource efficiency and more profitable than the single-nursing of either of them. These observations agreed with those made by other researchers. Kumar *et al.* (2018) [41] recorded that integrated system is more economical, resource efficient and profitable than makhana monoculture. Duarah and Mall (2020) [43] observed that co-culturing of carps such as Indian river shad (*Gudusia chapra*) alongside major carps, significantly increases profitability for fish farmers. Husain *et al.* (2016) [16] and Ali *et al.* (2017) [24] observed that polyculture is more profitable than monoculture since more than one type of fish that attract different prices are obtained at harvest, boosting revenue generated (Moray *et al.*, 2014) [44]. In the current study, the market price of a unit weight of the juvenile *C. gariepinus* produced was about two and half times that of the *O. niloticus*. Finally, the result is also in line with that of Prasetyono and Syaputra (2018) [45], that polyculture produces optimal profits due to the potential of capital, feed and facilities resources being maximized, in addition to higher production capacity.

Conclusion and Recommendation

In conclusion, the co-nursing approach of the Nile tilapia, *Oreochromis niloticus* and the African catfish, *Clarias gariepinus* fingerlings in a hapa-in-pond system is suitable. The strategy enhanced fish survival, fish growth performance and harvested fish biomass resulting in higher profitability than those of single-nursing of either *O. niloticus* or *C. gariepinus*. Hence, co-nursing of Nile tilapia and African catfish fingerlings in hatcheries is recommended for higher yields and profits. However, the practice should be evaluated in other fish culture systems.

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