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RESEARCH ARTICLE

REPRODUCTIVE PERFORMANCE OF TILAPIA *OREOCHROMIS NILOTICUS* (LINNAEUS, 1758) IN HAPAS INSTALLED IN PONDS AT THE LAYO EXPERIMENTAL STATION (CÔTE D'IVOIRE)

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Abstract

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The limited availability of high-quality fry is a major obstacle to the development of fish farming in Côte d'Ivoire. This study aimed to assess the reproductive performance of *Oreochromis niloticus* reared in hapas installed in earthen ponds. Two hapas, each measuring 7,5 m² and stocked with 42 broodstock (sex ratio of one male to two females), were monitored for six weeks. The broodstock were fed the commercial floating feedcontaining 32 per cent crude protein. The physico-chemical parameters of the water, the zootechnical performance of the broodstock and their reproductive performance were assessed. Environmental conditions remained favourable and stable throughout the trial (temperature: 29,61 ± 0.94 °C; pH: 6,18 ± 0,47; dissolved oxygen: 4,63 ± 0,44 mg/L; conductivity: 0,21 ± 0,02 mS/cm), with neither the pH nor the dissolved oxygen deviating significantly from their reference thresholds (p = 0,156 and p = 0,063).The survival rate exceeded 96 per cent and showed no difference between the two tanks (Fisher's exact test, p = 1.000). The two enclosures proved to be statistically indistinguishable for all biometric variables (p ≥ 0,182; d ≤ 0,22), which allowed the broodstock to be grouped together: the males were then significantly heavier and longer than the females (179,51 versus 138,84 g; 21,91 versus 20,03 cm; p ≤ 0,002 after Holm's correction; Cohen's d = 1,0). Reproductive performance reached an average apparent production of 97 larvae per female and an average production of 362 larvae/m². These results show that the hapa system is a suitable technique for the reproduction of *O. niloticus* and that it can help to improve the availability of fry in Côte d'Ivoire.

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Introduction:-

Aquaculture is now emerging as a key sector of global food production. According to FAO (2024), world production of aquatic products reached 223,2 million tonnes in 2022, of which 130,9 million tonnes came from aquaculture, representing more than 51% of aquatic products intended for human consumption. This trend reflects the strategic importance of aquaculture in the face of stagnating capture fisheries and growing demand for animal protein (FAO, 2022). Among aquaculture species, tilapia *Oreochromis niloticus* occupies a prominent place, with world production estimated at over 7,5 million tonnes in 2023 (El Sayed and Fitzsimmons, 2023). In sub-Saharan Africa, it represents the main freshwater farmed species and constitutes an affordable source of protein for low-income populations (Adeleke *et al*., 2021).In Côte d'Ivoire, fishdemandexceeds 700,000 tonnes for an averageconsumption of about 25 kg/inhabitant/year, while local production, estimated at between 90,000 and 100,000 tonnes, remainsinsufficient (FAO,2024). One of the main constraints to the development of fishfarmingremains the limitedavailability of qualityfingerlings. Control over reproduction thusappears as a determining factor for improvingfarmproductivity (Mugwanya*et al*., 2022). Reproductive performance of broodstockisindeed a central factor in seed production in Nile tilapia:poorgenetic, nutritional, or physiologicalquality of broodstock can significantlyreducelarval production and affect the survival and growth of fingerlings. Similarly, unsuitable practices such as unbalancedfeeding, high stockingdensities, or unfavorablephysicochemical conditions limithatcheryproductivity (Asase*et al*, 2021 ; Engdaw and Geremew, 2021 ; Akian*et al*, 2022).

Among controlled reproduction systems, the hapa (fine-mesh net cage installed in a pond) offers the advantage of better broodstock control, easier larvae collection, and reduced cannibalism, at a moderate installation cost suited to small-scale producers (Bhujel, 2013; El Sayed, 2020). However, quantitative data on its performance under Ivorian conditions remain limited. The present study, conducted at the Layo Experimental Aquaculture Station (Dabou), had the general objective of evaluating the reproductive performance of *O. niloticus* reared in hapas installed in ponds. Specifically, it aimed to analyze the rearing environment conditions, determine the zootechnical performance of broodstock, and characterize their reproductive performance.

Materials and Methods:-

Study site and period:-

The study was carried out at the Layo Experimental Aquaculture Station in southern Côte d'Ivoire (West Africa). The geographical coordinates of the site are: 5°19'35'' North and 4° 18'59'' West. It is a branch of the Oceanographic Research Center. The site is situated approximately 40 km from Abidjan and 6 km from Dabou on the shores of the Ébrié Lagoon (Figure 1). The six-week experiment was conducted in earthen pond No. 17 (16.5 m × 13 m; average depth 0.80 m; surface area 214.5 m²). The pond is supplied with water via a borehole through a 32 mm diameter PVC pipe.

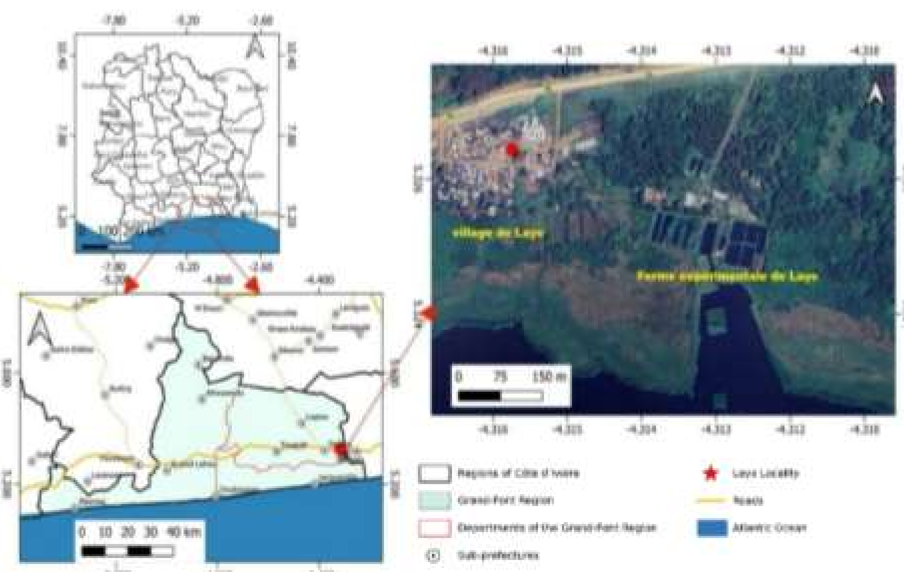

Figure 1: Geographic location of the Layo experimental farm

Biological material and experimental design:-
The broodstock of *O. niloticus*were caught using a seine net (12 mm mesh size) in the station's ponds. They wereselected on the basis of the absence of injuries, deformities and any apparent signs of disease. Sexdeterminationwascarried out by visualexamination of the genitalpapilla. Tworectangular net pens (mesh size 1 mm; 3 m × 2.5 m × 1 m; surface area 7.5 m²) wereinstalled in earthen pond No. 17 usingbamboo supports. Eachhapawasstockedwith 42 broodstock (14 males and 28 females);this corresponds to a sex ratio of 1 male to 2 females and a density of 5.6 broodstock/m². Initial biometricmeasurements of eachindividual (weightrounded to the nearest 0.01 g using a Fisher Scientific balance; total lengthmeasuredusing an ichthyometergraduated in millimetres) weretakenprior to stocking (Table 1).

Table I. Initial biometric characteristics of broodstock (mean ± standard deviation)

Hapa	Sex	Mean weight(g)	Total length (cm)
Hapa 1	Males	150,48 ± 31,58	21,09 ± 2,09
Hapa 1	Females	112,93 ± 30,77	18,54 ± 1,65
Hapa 2	Males	154,44 ± 32,82	20,70 ± 2,38
Hapa 2	Females	120,47 ± 31,04	18,84 ± 1,54

Experimental diet:-
Broodstockwerefed the commercial floatingfeedKoudijs Tilapia Finisher 4 mm, containing 32% crudeprotein. Itsbiochemical composition ispresented in Table II.

Table II: Biochemical composition of commercial feed

Composant	Value
Crudeprotein	32,0% (min)
Crude fat	6,0% (min)
Crudefiber	10,0% (max)
Moisture	10,0% (max)
Ash	1,0% (max)
Phosphorus	1,0% (min)
Calcium	1,0% (min)

Rearing management:-
Broodstock were fed three times a day (8 a.m., 12 p.m., and 4 p.m.) with a commercial floating feed (Koudijs Tilapia 4 mm; 32% crude protein), at a feeding rate of 3% of total biomass per day.

The dailyfeed ration (RA) wascalculatedusingequation (1):-
RA (g) = total biomass (g) × feeding rate (1)
With total biomassobtained as the sum of the products of meanweight by the number of individuals of eachsex. Daily rationswerethus 165,99 g (hapa 1) and 168,78 g (hapa 2). At eachharvest, the hapas in service werereplaced; the removedhapaswerecleaned by brushing, inspected for possible perforations, mended, and then put back into service.

Measurement of physico-chemicalparameters:-
Temperature (°C), pH, dissolvedoxygen (mg/L), and electricalconductivity (mS/cm) weremeasured once a week, between 7 a.m. and 9 a.m., using a LovibondSensoDirect 150 portable multi-parametermeter.

Larvae collection and evaluatedparameters:-
Larvaewerecollectedeverytwoweeks. A bamboo pole slidunder the net made it possible to isolatebroodstock and larvae on one side of the hapa;larvaewerethencollectedusing a fine-meshsieve and transferredintobuckets. The total mass of collectedlarvaewasmeasured, then a representativesamplewasweighed to estimate the meanweight.

The total number of larvae (N) wasestimatedgravimetricallyusingequation (2):-
N = total weight of larvae / mean unit weight of larvae (2)

Collectedindividualsweretransferredinto nursery hapas (1 mm mesh) and feddailywith a powderedfeedcontaining 45% crudeprotein. Performance wasevaluatedusing the followingindicators:
Survival rate (SR, %) = (final number / initial number) × 100;
Weight gain (WG, g) = final meanweight − initial meanweight;
Apparent production per female (APF, larvae/female) = total number of larvae / number of females;
Production per unit area (PUA, larvae/m²) = total number of larvae / hapa surface area.

Statisticalanalysis:-
The tests were selected on the basis of three constraints: small sample sizes, the absence of individual marking of broodstock, and a system limited to two happas. The monitoring of the rearing environment was analysed using Friedman's test (1937). The homogeneity of variances was checked using Levene's test (1960). Comparisons between the sexes were based on Welch's t-test (Student, 1908; Welch, 1947), confirmed by the Mann-Whitney U-test (Mann & Whitney, 1947) and incorporated into a two-factor ANOVA (Zar, 2010). The condition factor was calculated according to Fulton (1904), and survival was analysed using Fisher's exact test (1935). The results were corrected using the Holm procedure (1979) and accompanied by Cohen's d (1988). The data were analysed at a 5% significance level and the results are expressed as mean ± standard deviation.

Results:-

Water physico-chemical parameters:-
Over the six-week monitoring period, pH, dissolved oxygen and temperature remained stable (p = 0,065 to 0,293) (Table III). Only conductivity showed a significant variation (p = 0,009). Comparison with the compliance threshold shows that pH and dissolved oxygen comply with their respective thresholds (6.5 and 5.0 mg/L). However, the temperaturedeviatessignificantlyfrom the threshold of 28.0 °C (p= 0,031).

Table III :Physico-chemical parameters

Parameters	**Mean ± Standard deviation**	***p*-value (Friedman's test)**	**Threshold value for the parameter/ (*p*-value)**
pH	6,18 ± 0,47	0,135	6,5 / (0,156)
Dissolved O_2 (mg/L)	4,63 ± 0,44	0,065	5,0 / (0,063)
Temperature (°C)	29,61 ± 0,94	0,293	28,0 /(0,031**)
Conductivity (mS/cm)	0,21 ± 0,02	0,009 **	-

** : Significancelevel at 0,05

Survival, growth and conditionbroodstock:-
None of the eightcomparisons came close to the significancethreshold (Table IV). The lowest$p$-value is 0,182 for the final weight of the females. The largestdifference (7,73 g) between the two groups of femalesrepresents 5.6 per cent of the meanweight. This corresponds to a Cohen'seffect size of 0,22, wellbelow the threshold for a moderateeffect. The two enclosures are thereforestatisticallyindistinguishable. In Table V, the males are significantlyheavier and longer than the females. The condition factor, however, shows the opposite trend:higher in females at the start of the trial (1,75 versus 1,64;p = 0,002), itbecomesidentical in both sexes by the end of the trial (p= 0,416). Survival rate was 100% in hapa 1 (males and females) and 96,43% in hapa 2, with the onlymortality (one male) occurring at the end of the experiment. In bothhapas, males recordedhigherweight gain thanfemales (Figure 2) : 27,07 g versus 17,72 g in hapa 1 (a difference of 9,35 g) and 27,02 g versus 16,34 g in hapa 2 (a difference of 10,68 g).

Table IV. Comparison of biometric variables betweenhapas at the end of the trial

Sex	**Variable**	**Hapa 1**	**Hapa 2**	***p* (Welch)**	***p*(M-W)**	**d**
Males	Final weight (g)	177,56	181,46	0,844	0,836	-0,08
Males	Final lenght (cm)	21,96	21,87	0,918	0,747	0,04
Females	Final weight (g)	134,97	142,70	0,415	0,182	-0,22
Females	Final lenght (cm)	19,95	20,11	0,718	0,577	-0,10

p(Welch): probability associated with Welch's t-test; p (M-W): probability associated with the Mann-Whitney U test; d: Cohen's effect size (0,2: small; 0,5: medium; 0,8: large); **: significant at the 0,05 level.

Table V. Comparison of biometric variables and condition factor between sexes (hapaspooled).

Variable	Males (n = 28)	Females (n = 56)	t de Welch	*p* (Holm)	*p* (M-W)	d
Initial weight (g)	152,46	123,03	2,991	0,009 **	0,002 **	0,76
Final weight (g)	179,51	138,84	3,788	0,002 **	< 0,001 **	0,99
Initial lenght (cm)	20,90	18,99	4,084	0,001 **	< 0,001 **	1,05
Final lenght (cm)	21,91	20,03	4,057	0,001 **	< 0,001 **	1,02
K initial	1,64	1,75	-3,620	0,002 **	< 0,001 **	-0,88
K final	1,67	1,70	-0,820	0,416	0,277	-0,20

K:Fulton's condition factor ($K = 100 \times P / T^3$, where P is the weight in g and T is the total length in cm); a value greaterthan 1 indicates good physiological condition. Welch'st:Welch's t-test statistic.*p* (Holm):*p*-value of the t-test followingHolm's correction for multiple comparisons. **: significant at the 0,05 level.

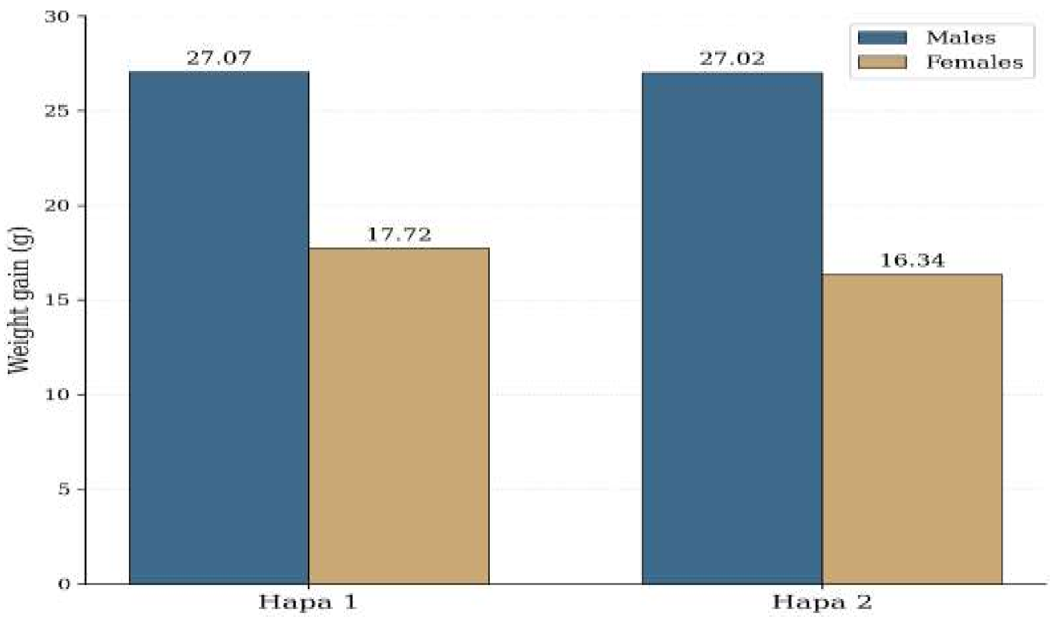

Figure 2: Weight gain of broodstock by sex and hapa

Reproductive performance:-

Total larval production was higher in hapa 1 (2,903 larvae) than in hapa 2 (2,518 larvae). However, the average weight per larva was slightly higher in hapa 2 (0,07 g compared with 0,05 g) (Table VI). Apparent production per female (APF) reached 104 larvae/female in hapa 1 and 90 larvae/female in hapa 2 (average: 97 larvae/female). Production per unit area (PUA) in hapas 1 and 2 was 387 and 336 larvae/m² respectively (average: 362 larvae/m²).

Table VI. Total larval production, averagelarvalweight, and reproductive indices by hapa.

Parameter	Hapa 1	Hapa 2
Total larval production	2 903	2 518
Average larval weight (g)	0,05	0,07
APF (larvae/female)	104	90
PUA (larvae/m²)	387	336

Discussion:-

The physico-chemical parameters recorded remained generally favourable for the reproduction of *O. niloticus*. The average temperature (29,61 °C) falls within the range of 25 to 32 °C recommended for the species (Mélard, 1986; Emam *et al*., 2025). Although the average pH (6,18) was nominally below the optimal range of 7 to 8 indicated for good welfare (Emam *et al*., 2025), it did not differ significantly from the threshold of 6.5 (*p* = 0,156). It cannot therefore be considered a limiting factor in this case, particularly as the species tolerates a wide range of pH values (da Lemos *et al*., 2018). The same applies to dissolved oxygen (4,63 mg/L; p = 0,063 compared with the threshold of 5 mg/L). A level consistent with the requirements for individuals of reproductive size was reported by Abdel-Tawwab *et al.* (2015). The homogeneity of the three sampling points ($p \geq 0{,}065$ for pH, dissolved oxygen and temperature) indicates adequate mixing of the pond. Only conductivity showed differences between the sampling points ($p = 0{,}009$), and the mean value (0,21 mS/cm) reflects satisfactory mineralisation.

The high survival rates (100 per cent and 96,43 per cent) demonstrate that the broodstock are well adapted to the 'hapa' system. The difference between the hapas was not statistically significant (Fisher's exact test, $p = 1{,}000$). The stocking density used (5,6 broodstock/m²) falls within the recommended range of 4 to 8 fish/m² for semi-intensive pond systems (Pedrazzani*et al.,* 2020). This stocking density likely contributed to these results. Indeed, according to Mengistu *et al*. (2020), stocking density is one of the main factors determining survival in this species. The isolated death of a male at the end of the experiment is therefore attributable to individual stress rather than a general deterioration in rearing conditions. Comparable survival rates were reported by Akian*et al*. (2022) for *O. niloticus* reared in hapas in Côte d'Ivoire.

The males were significantly heavier and longer than the females (152,46 versus 123,03 g and 20,90 versus 18,99 cm at the start of the experiment; 179,51 versus 138,84 g and 21,91 versus 20,03 cm at the end). Cohen's effects ranged from 0,76 to 1,05 and were significant after Holm's correction ($p \leq 0{,}009$). This difference is largely explained by the maternal behaviour of oral brood care: when carrying eggs and larvae, females considerably reduce their food intake, which limits their growth (Kuwaye *et al.,* 1993). The condition factor supports this interpretation, as the females entered the trial in better physical condition than the males (1,75 versus 1,64; $p = 0{,}002$), whilst no difference remained at the end of the experiment (1,70 versus 1,67; $p = 0{,}416$). This situation reflects the mobilisation of their reserves during successive spawning cycles. Fulton's condition factors ranged from 1,64 to 1,75 in both sexes. These values are well above the value of 1, which is generally considered indicative of good physiological condition. These results show that the diet helped to maintain the breeding stock despite the reproductive effort.

The reproductive performance obtained confirms the suitability of the 'hapa' system for ensuring efficient larval production. The average APF (97 larvae per female) is very close to the productivity of 93,1 larvae per female reported by Akian*et al*. (2022) for the same species in Côte d'Ivoire. With only two happas, the observed difference between the enclosures cannot be statistically tested and is reported here as inter-unit variability. This may be due to individual differences in fertility, size or physiological condition of the females, as well as to the asynchrony of reproductive cycles characteristic of the species (Coward and Bromage, 2000). The PUA values (336–387 larvae/m²) indicate good productive efficiency of the system in relation to the area utilised. This efficiency is of practical importance, as the availability of fingerlings remains one of the main constraints to the expansion of tilapia fish farming in West Africa (El-Sayed and Fitzsimmons, 2023).

Conclusion:-

This study shows that the reproduction of *Oreochromis niloticus* in hapas installed in ponds at the Layo Station took place under favorable physico-chemical conditions, with high survival rates and satisfactory reproductive performance (mean APF of 97 larvae/female; mean PUA of 362 larvae/m²), consistent with regional references. The hapa system thusappears to be a simple and low-cost controlled reproduction technique, capable of contributing to improvedfingerlingavailability and to the sustainabledevelopment of Ivorianfishfarming.

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Conflicts of Interest:-

The authorsdeclare no conflicts of interestregarding the publication of thispaper.

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