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Is There An Optimal Stocking Density When Raising Tilapia In Intensive Systems?

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Abstract:
Background: There is a wide variation in the implementation of tilapia housing densities in intensive systems, resulting in important differences in productive growth rates, feed efficiency, mortality and, consequently, in the profit of production systems. Therefore, this study aims to evaluate, through a literature review, the main effects of using different stocking densities when raising tilapia in intensive production systems. Defining stocking density requires a complex analysis of different parameters that should involve not only total biomass production. Based on the studies evaluated in this review, the stocking densities tested varied greatly (40 to 500 juveniles/m3) across studies, indicating a lack of standard in production systems, thus influencing growth performance, fish welfare and the net income of the systems. However, regardless of the differences in stocking densities used, there was a tendency for fish rearing at lower densities to exhibit higher growth performance as well as survival rates. But, they were not always accompanied by better results in biomass production and net income, which tend to be greater the greater the population density.
Conclusion*:* Therefore, studies are needed to develop models that integrate different aspects involving animal welfare, growth performance, sustainability and profit, indicating to producers the best housing densities to be used.
Key Word*:aquaculture; growth performance; Oreochromis niloticus; welfare.*

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I. Introduction

Aquaculture development

Aquaculture, known as the raising of aquatic animals and plants in controlled or semi-controlled environments[1], plays a fundamental role as a source of food, nutrition, and livelihoods for millions of people around the world.

Although the first civilizations, such as the Egyptians and Romans, already practiced some form of fish farming, it was in the Middle Ages that this practice became widespread. European monks built fish ponds to ensure a source of protein during periods of fasting, while many noble families owned their own private fish ponds as a symbol of status and wealth[2].

After the Industrial Revolution, fish farming experienced significant technological improvements, including the development of artificial ponds and the implementation of pumps and filters for water circulation. In the 19th century, aquaculture became a commercial activity, with fish farms producing large amounts of fish for sale[3]. Furthermore, in the 20th century, there was a growing concern about overfishing in the world's oceans. According to FAO around 1/3 of natural stocks are already considered under threat from overfishing. Thus, domestic breeding systems are an important solution to meet global demands, preserving natural fauna[4].

In 2020, the fishing-aquaculture sector reached significant production in the world, with 214 million tons, and aquaculture is responsible for approximately 50% of the total. Additionally, fish consumption reached 20.2 kg per capita/year, representing around 17 % of the world's animal protein. There is also an expectation that, by 2030, the increase in consumption will be 18% higher than that observed in 2018[4].

II. Development

Tilapia production

In this context, Nile Tilapia (*Oreochromiusniloticus*), originally from Africa, has emerged as a prominent choice in global fish farming. Originally from the Nile River basin, tilapia was widely disseminated in global aquaculture, being today the second most cultivated species in the world, behind carp[5].

Brazil occupies the 13th position in the world aquaculture market, and today tilapiculture represents 63.93% of the country's national production of farmed fish. Currently, Brazil is the fourth largest tilapia producer in the world, reaching the mark of 550,060 tons in 2022. In terms of exportation, tilapia represents 98% of fish sold internationally, especially to the United States and Taiwan[5].

From the producers' point of view, tilapia has advantages due to its good adaptability to different cultivation environments, resistance to diseases, early slaughter (6 months), high fillet yield, dietary diversity, good reproductive rate throughout the year and has also high acceptability by the end consumer[6].

The*Oreochromiusniloticus* production systems has undergone numerous zootechnical improvement processes, such as fry quality and masculinization, adoption of improved strains, the development of specific high-quality feeds and the implementation of breeding in network tanks, thus contributing to better productive results and profits for producers[7].

In production systems, storage densities directly influence the cost of production, and when high rates are used, there is an increase of the total volume produced/area, reducing the unit cost of production[8]. However, increasing storage density, individual weight tends to decrease, negatively impacting its commercial value[9].

In this sense, great variation in the implementation of tilapia housing densities in production systems is observed, resulting in important differences in productive growth rates, feed efficiency, mortality and, consequently, in the profit obtained.

Therefore, this study aims to evaluate, through a literature review, the main effects of using different stocking densities when raising tilapia in intensive production systems.

Effects of stocking density

Stocking density is determined by the concentration of fish kept in a farming system[10]. High density brings increases in production/area, however it can have a negative impact on growth rate and mortality, when the animals' physiological and space needs are not met[11]. On the other hand, when in densities too low, fish may not form shoals, increasing stress on the flock and the total gain per tank may be compromised[12].

Tilapia are polygynous animals whose males define the social hierarchy and territory through agonistic confrontations. Tilapiculture production systems use monosexual male breeding, thus avoiding reproduction in tanks, which contributes to a more competitive environment with more frequent confrontations. In addition, the classification and standardization by fish sizes, a practice commonly used by tilapia producers, increases and prolongs fights over social hierarchy, since the animals have similar size/abilities in confrontations[13,14]. Vijayan et al. and Ellis et al. observe that at high stocking densities, erosion of dorsal fins can occur in fish[15,16].

In this sense, the effect of housing density can significantly impact social stress in production systems, influencing competition for food, growth, stress and fish mortality[16].

Tilapia farming can involve three general phases: breeding (larvaes to juveniles), rearing and fattening. Thus, resulting in slaughters between 700g and 1.2kg, with approximately 6 to 12 months[17], with a wide variety between production systems. A compilation of the studies analyzed here are shown at table 1.

Luz et al. evaluated the survival rate, length and weight of tilapia larvae, six days after hatching (average initial weight: 0.009 +/- 0.002g), as well as the temperature, salinity and conductivity of the water in which they were kept, at different stocking densities (1, 10, 20 and 30 larvae/L) up to 28 days of age, and found that dissolved oxygen and pH decreased as density increased, whereas total ammonia concentration, turbidity and biomass showed a direct relationship with the increase of stocking density[18].

However, El-Sayed testing densities between 3 and 20 larvae/L, for 40 days, found a negative correlation between increase in density and average weight and survival rate, recommending values of up to 5 larvae/L at this stage[19]. Sanchez and Hayashi, studying different densities (2, 4, 6, 8 and 10 larvae/L), also identified a reduction in growth with increasing housing density, recommending the implementation of 2 larvae/L, to obtain greater weight per animal at the end of this phase[20].

Lima and Barbosa studying densities of 2,4 and 6 larvae/L found that an increase in stocking density negatively influenced larvae weights throughout the experiment, but had a positive effect on survival and resistance of larvae, may be related to reduction of agonistic confrontations in territorial species when increasing densities[21].

El Nouman et al. evaluating Tilapia fingerlings (mean weight 8.5 ± 0.36 g) stocked at densities of 120, 180 and 360 fish/m^3 found that the increase in fish density reduced the final weight of the fish. The percentage of the fish weight increased and reached 111% ± 1.45% in the lowest fish density (120 fish/m^3), 79% ± 1.87% in the medium density (240 fish/m^3), and 63% ± 2.03% of high fish density (360 fish/m^3), therefore the daily growth rate was better in the lowest density. However, the total production in the cage increased with increasing fish density, and the return to the cost of food was better with higher fish density. The authors suggested that 240 fish/m^3 was the best stocking density for growing Nile tilapia fingerlings in floating cages[22].

Garcia et al. working with juveniles with an initial weight of 78g and densities of 800, 2000, 2500 or 3000 of fish/6m^3 cage, that is, approximately 130, 330, 415 or 500 fish/m^3, concluded that the use of lower densities housing for juveniles resulted in more uniform flocks, with better performance and feed conversion, greater precocity of slaughter and lower rates of mortality, disease and deformities[23].

Gibtan et al. studying juvenile tilapia (76 +/- 0.25g) in housing densities of 50, 100, 150 and 200 fish/m^3, concluded that higher final weight/fish are obtained at the lowest density (50 fish/m^3) and it should be the most appropriate strategy. However no difference was found in terms of mortality rate. For the gross production parameter, the highest density (200 fish/m^3) presented higher values[24].

Moniruzzaman et al. raised juvenile tilapia (average weight: 15.20+/-0.15g) for 120 days in net tanks at densities of 50, 75, 100 and 125 fish/m^3, and concluded that fish at the lowest density (50 fish/m^3) showed greater body length, final weight, weight gain, daily weight gain and daily gain rate as well as lower feed conversion, compared to those of other densities. Only the 125 fish/m^3 treatment showing lower survival rate. However, although total gross and net production was higher in the treatment with 100 fish/m^3, the authors concluded that tanks with lower density (50 fish/m^3) presented better cost:benefit and economic viability among the treatments studied[25].

Osofero et al. evaluated juvenile tilapia (initial weights: 29±4.81g), housed in 50, 100, 150 and 200 fish/cages (1 m^3), for 90 days, and found that with increasing density, there was a drop in total crude protein produced in the carcasses, but there were no differences in daily gain, final weight, growth rate, feed conversion and survival rate. Thus recommending that the ideal density, under working conditions, was 150 fish/cage[26].

Kunda et al. in a study with juvenile tilapia in net tanks in Bangladesh, comparing stocking densities of 40, 60 and 80 fish/m^3, (initial weight: 39 g), found lower growth rates with increasing stocking density, and concluded that the intermediate density (60 fish/m^3) would present greater net profit to the producer[27].

Khairnar and Holeyappa studying juvenile GIFT tilapia (initial weight: 37.11±1.48 g) housed at 100, 150 and 200 fish/m^3 in net tanks, evaluating not only zootechnical performance, but also hematological parameters, body composition and cortisol levels, concluded that fish raised at lower density had better physiological and growth parameters[28].

Klanian and Adame evaluated the performance of tilapia fingerlings raised in super-intensive recirculation systems, kept at 400, 500 and 600 fish m^{-1}, finding lower growth rates for animals kept at the highest stocking rate (600 m^{-1}), but did not find differences in the survival rate between treatments[29].

Datta and Kumar using GIFT tilapia fingerlings (0.6 ± 0.02g) at densities of 40, 50, 60, 70 and 80 animals/m^3, in net tanks, for 180 days, found lower survival and specific growth rates with increasing density, with the maximum survival rate (96.25%) and the highest average growth rate being observed in animals with the lowest density (40 animals/m^3; 112.20g). The worst results were found in animals handled at higher density (80 animals/m^3; 61.80g). However, the highest biomass was produced in the treatment with 70 animals/m^3, as well as the best feed conversion (1.32), the latter being considered by the authors to be the best cost:benefit among the treatments[30].

Total biomass production is a value used to justify high stock densities. However, Ayroza et al. showed that despite the highest biomasses being achieved at the highest densities, the highest net profit was obtained at densities of 100 and 200 juveniles/m^3, concluding that the highest operational costs (effective and total) are not covered by the sales price in densities of 300 to 400 juveniles/m^3, thus recommending the rearing of juvenile tilapia with densities of up to 200 fish/m^3 [31].

According to Costa et al. evaluating juvenil at 250, 350 and 450 fishes/m^3 concluded that increasing stocking density caused a decrease in the final weight of fish, weight and daily weight ;gain, standard length and survival rate. However there was no influence of stocking density on final biomass, blood glucose and serum cortisol concentrations. The authors indicated that 250 fish/m³ density stock was shown to be the most suitable for fish performance[32].

Ellis et al. reported that high stocking densities cause physiological reactions in fish as a result of stress and the animals' welfare conditions [16].

Costa reported superior performance in apparent feed conversion rates in treatments with lower fish densities, with 250 fish/m³ presenting a conversion of 1.17, higher (56%) than the higher density treatment of 450 fish. /m³. The same author observes that the difference observed between treatments is possibly due to greater competition for food caused by excess population at higher densities [33].

Marengoni in small volume net tanks (4 m³) obtained indexes with superior feeding conversion performance (FC) for treatments with lower densities as follows: 250, 300, 350 and 400 tilapia/m³ with indexes of 1.54; 1.55; 1.65 and 1.75, respectively, representing an increase of 14% in relation to treatments with lower and higher densities[34].

For Ono and Kubitza, the FC index for raising fish such as tilapia in net tanks should vary between 1.4 and 1.8 [35]. According to Kubitza the closer to consumption capacity a fish is fed, the greater the growth will be, however, the worse the feed conversion will be. The author recommends that tilapia reach a weight range of 150 to 200g, given that feed consumption increases significantly, feed conversion should be prioritized over growth[36].

III. Conclusion

Based on the studies reviewed, stocking density affects tilapia welfare and performance. It was identified that stocking densities varied enormously (40 to 500 fish/m3) in the studies, indicating a lack of standard in the production systems, as well as in the growth performance found. However, regardless of the differences in stocking densities tested, there was a tendency for fish raised at lower densities to present higher performance and survival rates, but those were not always accompanied by the results of biomass production and net income, which tend to be greater the greater the stock density. Therefore, studies are needed to develop models that integrate factors involving both welfare, growth performance, sustainability and profit, indicating to producers the best housing densities to be used.

Table 1: Stocking density (SD), Initial weight (g), Survival rate(SR), Physiological data, Biomass and gross prodution, SD recomendation in the study (fish/m^3), Housing system, and reference.

STOCKING DENSITY (SD)	INITIAL WEIGHT (g)	GROWTH PERFORMANCE (GP)	SURVIVAL RATE (SR)	PHYSIOLOGICAL DATA	BIOMASS/GROSS PRODUCTION	RECOMENDATION (FISH/M^3)	HOUSING SYSTEM	REFERENCE
1, 10, 20 and 30 l/L	0.009± 0.002	ND	ND	-	Higher Biomass at Higher SD	-	Tanks	18
2,4,6,8 and 10 l/L	12.41	Lowergrowth at higher SD	ND	-	Higher Biomass at Higher SD	2 larvae/L	Net cages	20
2,4 and 6 l/L	0.06±0.01	Lower weights at higher SD	Higher SR in higherSD	Higher resistance in higher SD	-	-	Tanks	21
40,50,60, 70 and 80 fish/m^3	0.6±0.02	Lower specific growth rate at higher SD. Best FC at SD=70	Lower SR in higher SD (80)	-	Higher BM at SD=70	70	Pond cage	30
130, 330, 415 and 500 fish/m^3	78 g	Higher GP, uniform flocks and better FC and precocity to slaughter at lower SD	Higher SR in lower SD	Lower diseases and deformities in lower SD	Higher profit at lower SD	130	Net cages	23
50,100,150 and 200 fish/m^3	76g±0.25	Higher final weight and weihgt gain at lower SD	ND	-	Higher gross production=200 SD	50	Net cage	24
50,75,100 and 125 fish/m^3	15.20±0.15	Higher body lenght, final weight, weight gain and lower FC at lower SD	Lower SR only in 125 fishes/m^3	-	Higher total gross at SD= 100 fishes/m^3	50	Net cages	25
50,100,150 and 200 fish/m^3	29±4.81	Lower crude protein in the carcasses at higher SD. SD had no effect on GP parameters.	ND	-	Higher profit index at SD=150	150	Net cages	26
40,60 and 80 fish/m^3	39	Lower growth rate at higher SD	ND	-	-	60	Net cages	27
100, 150 and 200 fish/m^3	37.11±1.48	Higher growth performance at lower SD		Highest Hematological parameters at higher SD Cortisol was high for all	-	100	Net cages	28

				treatmens				
100,200,300 and 400 fish/m^3	43.08±2.98	Lower weight gain and aparente FC at Higher SD	ND	-	Higher BM at 400 SD. Higher net profit at SD= 100 and 200	200	Net cages	31
250,300,350 and 400 fish/m^3	76.74-80.45	Superior FC at lower SD	ND	-	Higher BM at 400 SD	400	Net cages	34
250, 350 and 450 fish/m^3	30±2.70	Lower final weight, weight gain, daily weight gain and standarlenght at higher SD	Lower SR at higher SD	ND for blood glucose and cortisol	ND	250	Net cages	32
120, 180 and 360 fish/m^3	8.5±0.36	Lower weight at higher SD. Higher daily growth at lower SD	-	-	Higher BM at Higher SD	240	Net cages	22

+ND= no differences between treatments; SD= Stocking density; FC = feed conversion

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