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Research Article

Effect of size heterogeneity of Nile tilapia (*Oreochromis niloticus*) on the optimal harvest time: a bioeconomics approach

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ABSTRACT. A critical problem in the production of Nile tilapia *Oreochromis niloticus* in intensive and hyper-intensive systems is the heterogeneity of body sizes as it influences the final production and economic yield. The objective of this study was to calculate the bioeconomic effect of size heterogeneity on the production of Nile tilapia at a commercial level and to determine the optimum harvest time (OHT) considering four minimum marketable sizes target (*Mms* = 350, 400, 450, 500 g). Two seeding strategies were evaluated: homogeneous seeding (HM) with a 96.55 ± 24.51 g initial body weight and heterogeneous seeding (HT) with a 100.17 ± 5.91 g initial weight. Fish from both treatments were stocked at 40 fish m^{-3} in triplicate using a randomized design. The calculated quasi-profits of variable costs showed an inversely proportional relationship with the minimum market size in both groups. The smaller size dispersion in HM generated higher profits than HT. The OHT for *Mms* [350, 500 g] of HM population was 180 days, with a mode of 641 g. The OHT was also 180 days for the HT population but only for the *Mms* [350, 400 g] and a mode of 578 g. In terms of quasi-profits, the HM produced 19.93% more quasi-profit than the HT in the market size of 350 g at 180 days (HM = 0.50 USD kg^{-1}; HT = 0.44 USD kg^{-1}). The simple bioeconomic model presented here can help producers manage a series of economic decisions associated with OHT, when targeting different market segments requiring different *Mms*.

Keywords: *Oreochromis niloticus*; Nile tilapia; seeding; strategies; bioeconomic; harvesting; minimum marketable size

INTRODUCTION

A critical problem in the production of Nile tilapia *Oreochromis niloticus* in intensive and hyper-intensive systems (30-400 fish m^{-3}) is the heterogeneity of body size. The organisms in the same cohort show different growth rates in response to biotic and abiotic factors (Barbosa *et al*., 2006; Azaza *et al*., 2013).

In the commercial production of tilapia, profitability often depends on the degree of heterogeneity of the population; the best commercial strategy is to produce a uniform size of the animals, though the heterogeneity is a normal condition of the species (Dos Santos *et al.*, 2008). In fact, in recent decades, reducing the variability of trait levels between individuals has become a highly desirable objective of the genetic improvement programs (Bentsen *et al*., 2012; Marjanovic *et al*., 2016).

In fish culture, differences in size between individuals are generally associated with competition for food within a group and the resulting feeding hierarchy (Cutts *et al*., 1998; Hart & Salvanes, 2000). It is known that population density affects the size heterogeneity but not on the size-weight relationship, indicating that the health and well-being of fish are not affected by the size differences (Dos Santos *et al.*, 2008; Gullian *et al*., 2012; Gullian & Arámburu, 2013). Since any significant deviation from the optimal commercial size has a negative impact on the production yield, reducing the variability in size and increasing the uniformity of body weight are important objectives in the culture of tilapia. The fish production of uniform size is desirable in terms of management, since homogeneity facilitates feeding, harvesting and marketing, among other aspects. Uniformity is also important for production planning, and achieving a higher percentage of fish with minimum market size (*Mms*) at an optimum time of harvest is a determining factor for profit. However, optimal harvesting time (OHT) is overestimated when homogeneity of size is

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assumed during the different stages of growth (Araneda *et al*., 2011).

From the consumers' point of view, not only weight but also body size and appearance, play an important role in purchasing decisions. One strategy to decrease the phenotypic variation in the body size and weight is to segregate the fish into groups according to size during the growth stage. The partial harvest of the standing stock is used as a strategy to reduce competition and, therefore, increase the individual growth rate and total yield (Brummett, 2002). However, from a bioeconomic point of view, one of the main drawbacks of this strategy is the increase in production costs, in addition to longer harvest time, compared to a simple harvest of the entire stock. The economically optimal harvesting time is the moment when the market value of fish is maximum (Bjørndal, 1988), which occurs when the marginal revenue of cultured biomass is equal to the marginal cost of cultivating the species an additional unit of time (Martinez & Seijo, 2001; Seijo, 2004). The bioeconomic OHT is more useful in determining the optimum harvest time than the purely biological harvest time and can be calculated when species price and production cost data are available.

Although the size heterogeneity is a critical problem in the bioeconomic of aquaculture production, the dispersion of growth on the OHT in tilapia farming systems has rarely been studied (Llorente & Luna, 2016). Springborn *et al*. (1992) studied the effect of fertilization on the OHT for Nile tilapia on an experimental pond in Thailand by applying a fish production method derived from simple equations for growth and mortality and considering the cost and price data. Gasca-Leyva *et al*. (2008) analyzed the optimal harvesting time for organisms of different sizes, assuming that the heterogeneity is caused by differences in the initial sizes of the planted crop. The model was validated in commercial tilapia culture, concluding that if the heterogeneity of size is considered, the resource should be maintained for a longer time compared to homogeneous models. The objective of the present study was to analyze the effect of the initial dispersion of size on the OHT in a culture of Nile tilapia *Oreochromis niloticus*. An experimental design was developed to compare the performance indicators for two different initial size-populations: heterogeneous size (HT) and homogeneous size (HM). The OHT was estimated for both populations, maximizing the quasi profits of the variable costs of the production under the seeding strategies (HT, HM) for alternative market segments.

MATERIALS AND METHODS

Experimental fish

The trials were carried out on a commercial tilapia farm (Yaxchilam Farm, about 30 km from Merida, Yucatan, Mexico) from February 2015 to January 2016. The organisms were obtained from a batch of 100,000 sex-reversed Nile tilapia fingerlings (Spring Genetics) and handled following the Best Management Practices (BMP) protocol established by SENASICA-COPEFRIS, México (García-Ortega *et al*., 2008).

Experimental design and facilities

The trial was performed in six open circular tanks (1.7 m^3 each; 0.75 m depth). A 1.3 m diameter diffusion hose (Clorilite 1/2" ID 1" OD; OD2FA) was placed at the center of each tank and fixed to the bottom. The dissolved oxygen concentration was increased using a 5-HP blower with air diffusers. The entire experimental area was covered with white plastic sheeting and 70% shade mesh.

Nile tilapia fingerlings were reared at the same stocking density (40 ind m^{-3}) but with different fish sizes: homogeneous size (HM) and heterogeneous size (HT). The initial mean weight ± standard deviation (SD) of the organisms was HM = 100.17 ± 5.91g and HT = 96.55 ± 24.58 g, with three replicates for treatment. The initial variance of HM and HT was σ^2 34.91 and σ^2 604.19, respectively.

Fish were fed three times a day for 330 days with a commercial floating pellet containing 35% crude protein and 3,152 kcal kg^{-1} as metabolizable energy. During the first 26 weeks, the fish were fed at the rate of 3% of initial biomass; after this time, the feeding rate was adjusted to 2% until the end of the experiment. The water temperature and dissolved oxygen were monitored daily at 08:00 and 17:00 h with an oximeter (YSI 550A-12, OH, USA).

Every 15 days, all fish from each tank were individually weighed, and their total length was measured. The fish were removed from the tank using a 1.0” mesh knotless aquarium-type net and returned to the tank after the measurement. A digital scale (Ohaus 0.01g, NJ, USA) was used to record fish weight (g). At 330 days of the experiment, all the fish were harvested, weighed and counted. The absolute growth rate (AGR, g d^{-1}) for each treatment was estimated as a function of Wf - Wi over time (t), where Wf and Wi are the final and initial weights, respectively, while t represents the number of days in the experimental period. Biomass was calculated multiplying the weight of the organisms and the number of fish from each biometry. The mortality was recorded every day, and survival was calculated based on the difference between the number of fish that were stocked and harvested. The ratio of feed provided (kg) to wet fish weight gain during the feeding period was expressed as the feed conversion ratio (FCR).

Heterogeneity indicators and statistical analysis

Size heterogeneity was evaluated through two typical statistical indicators: the coefficient of variation (*CV*) and Fulton condition factor (*K*), which were calculated as:

$CV = \frac{SD_x}{\overline{x}}$, where $\overline{x}$ and SD_x are the weight mean and standard deviation, respectively.

$K = \frac{W}{L^3}$, where W and L are the fish weight and length, respectively.

The Bowley skewness coefficient (S_{kB}) was used to determine the variability of fish size in population with extreme data values (outliers) or a platykurtic distribution. S_{kB} was used to determine if the population has a positive or negatively-skewed distribution.

$S_{kB} = \frac{Q_1+Q_3-2Q_2}{Q_3+Q_1}$, where Q_1, Q_2, Q_3, represent the first, second and third quartiles, respectively.

Data normality was determined by the Kolmogorov-Smirnov test, and the homoscedasticity was analyzed with the Levene test. One-way analysis of variance (ANOVA) at a 5% probability level was used to test the effect of different treatments on growth performance. The data were analyzed in XLSTAT-R function version 5.1 (StatSoft, Tulsa, OK, USA) in Microsoft Excel®.

Bioeconomic indicators

The biometric data of discrete 15-day periods, for the 330-day study period were used for the bioeconomic analysis. During the growth period, the temperature ranged from 26.6 to 29.9°C. Variable costs for the HM and HT treatments included feed, labor and electricity costs (Table 1). The optimal harvest time (OHT) corresponds to the time at which the quasi-profit of the variable costs (understood as the profits obtained after paying for the variable costs of production) is maximized. Identifying the OHT involves considering the heterogeneous weight of individuals over time, the size-specific price and the production costs accumulated over time. The size selection criterion was established considering the market demands, *i.e.*, *Mms* in a range of 350 to 500 g. Using this criterion, the model quantified the specific number of organisms and their biomass in each period. These data were then applied to calculate the OHT.

Table 1. Variable costs of production in an experimental Nile tilapia system considering homogenous (HM) and heterogeneous (HT) seeding strategies.

Parameters	Symbol	Value
Tilapia price (USD kg^{-1})	p	2.00
Laboratory/day (USD d^{-1})	c_l	0.40
Electricity cost/day (USD d^{-1})	c_e	0.01
Cost of feed (USD kg^{-1})	c_f	0.64
Minimum marketable size (g)	*Mms*	350

The quasi profits of the variable costs of production ($quasi\pi_{s,t}$) under the HT and HM seeding strategies (s = {HT, HM} of juveniles) was calculated by equation (1) as follows:

$$quasi\pi_{s,t} = Bv_{s,t} - C_{s,t} \quad (1)$$

where the biomass value *per* seeding method over time ($Bv_{s,t}$) is calculated by:

$$Bv_{s,t} = \sum_i (B_{s,i,t} \times p_i) \quad (2)$$

where $p_i \in W \geq 350\ g$, and $B_{s,i,t}$ is the size-specific biomass distribution i per seeding method s over time t.

The cumulative production costs from seeding time (t = 0) to harvesting time (T) for each seeding method over time ($C_{s,t}$) were calculated *as*:

$$\text{O o } C_{s,t} = \sum_{t=0}^{T} (CF_t + L_t + ce_t) \quad (3)$$

where L_t is the labor production cost over time, calculated by:

$$L_t = c_l \times l_t \quad (4)$$

where l_t: number of farmworkers in the production process over time, and c_l: cost per worker per day, ce_t: overtime electricity cost.

The amount of feed used over time for each s treatment ($A_{s,t}$) is calculated by:

$$A_{s,t} = FCR(B_{s,t+1} - B_{s,t}) \quad (5)$$

$$\text{and } B_{s,t} = \sum_i B_{s,i,t} \quad (6)$$

Food overtime cost is calculated as follows:

$$CF_t = c_f \times A_{s,t} \quad (7)$$

where c_f is the cost of feed per kg.

The size-specific biomass distribution i according to the seeding method overtime was given by:

$$B_{s,i,t} = N_{s,i,t} \times W_{s,i,t} \quad (8)$$

where the number of size-specific individuals surviving overtime ($N_{s,i,t+1}$) in each culture system s is calculated by:

$$N_{s,i,t+1} = N_{s,i,t} \times (1 - \mu_t) \quad (9)$$

where $\mu_{s,t}$ is the dynamic mortality of tilapia culture in seeding method s in time t (Table 2). $W_{s,i,t} \in [350,1500]$,

Table 2. Mortality values over time in Nile tilapia for the heterogeneous and homogeneous seeding methods.

Time (days)	HT		HM	
	Mortality	n	Mortality	n
1		180		180
15	0.00000	180	0.00000	180
30	0.00000	180	0.00000	180
45	0.00000	180	0.00000	180
60	0.00556	179	0.00556	179
75	0.00559	178	0.01117	177
90	0.00562	177	0.00000	177
105	0.00000	177	0.00000	177
120	0.01130	175	0.00000	177
135	0.00571	174	0.02260	173
150	0.00575	173	0.00000	173
165	0.00000	173	0.00000	173
180	0.00000	173	0.00000	173
195	0.00000	173	0.00000	173
210	0.00000	173	0.00000	173
225	0.00000	173	0.00000	173
240	0.00000	173	0.00000	173
255	0.00000	173	0.00000	173
270	0.00000	173	0.00000	173
285	0.00000	173	0.00000	173
300	0.00000	173	0.00000	173
315	0.00000	173	0.00000	173
330	0.00000	173	0.00000	173

and is the experimentally observed size *i* (weight) distribution of organisms in time *t* for each seeding method *s*.

RESULTS

The results of the performance of the tilapia production and the indicators of the heterogeneity of sizes, in the two seeding scenarios HM and HT, are shown in Table 3. As expected, CV_0 and S_{kB0} in both treatments differed significantly, confirming the homogeneity and heterogeneity of the treatments at the initial stocking time ($P < 0.05$). In contrast, the performance parameters, based on feed intake (*FCR*, *K* and final weight), and survival rate were similar even for final biomass ($P > 0.05$) in both conditions. The CV_f of the final weight was not significantly different between the treatments, but S_{kBf} varied significantly (Fig. 1).

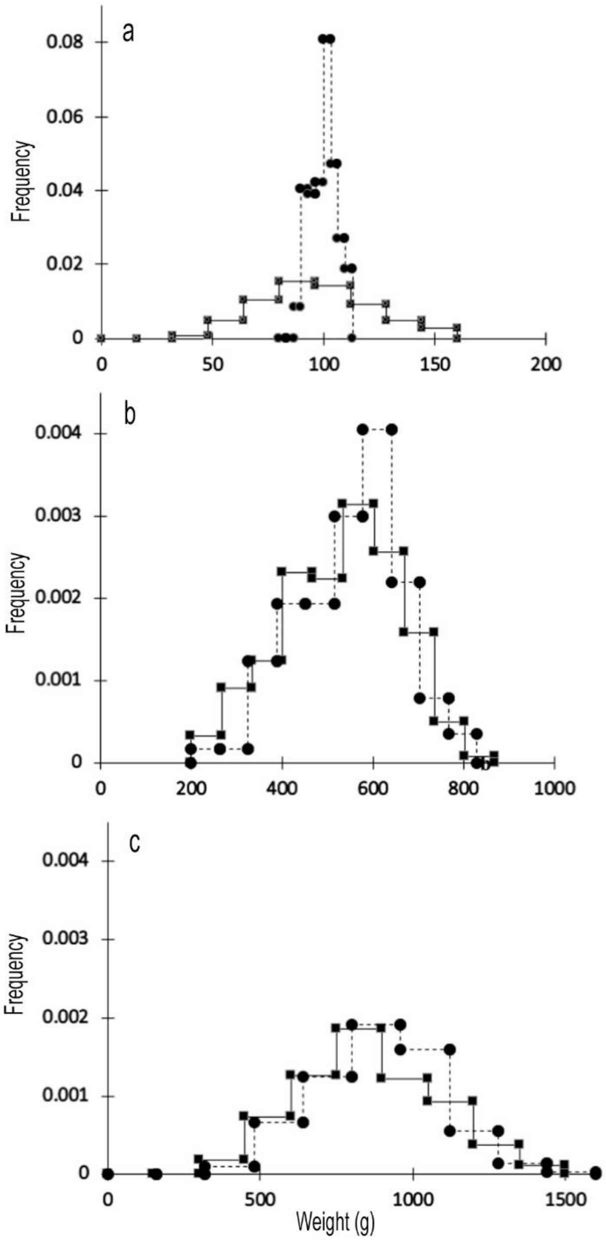

Figure 1. Size distribution in the homogenous (•HM) and heterogeneous (▪HT) groups of Nile tilapia during the growth stage. a) Rearing time = 0, b) Rearing time =180 days, and c) Rearing time =330 days.

Fish size distribution

The K-S test showed that the weight of fish in both treatment groups followed a normal distribution throughout the study period. The negative skewness values were observed, indicating that the data were slightly skewed to the left, especially at the stocking and harvest times. At the stocking time, the skewness was $s\text{HT}_1 = -0.185$ and $s\text{HM}_1 = -0.119$ for HT and HM, respectively. At the end of the experiment (330 days), the skewness of HT was close to zero ($s\text{HT}_{330} = 0.07$), indicating symmetry; however, fish from HM accentuated their left asymmetry ($s\text{HM}_{330} = -0.300$). Kurtosis was initially leptokurtic in HM_1 ($k = 0.776$) and platykurtic in HT_1 ($k = -0.484$; Fig. 1a), but became mesokurtic for both treatments after 180 days of growth and ended with a platykurtic shape ($k\text{HM}_{330} = -0.022$; $k\text{HH}_{330} = -0.465$), which was independent of the initial seeding strategy (Fig. 1b-c).

As expected, weight dispersion differed significantly (*CV*, $P < 0.05$) between the treatments according

Table 3. Performance of Nile tilapia rearing at homogenous (HM) and heterogeneous (HT) seeding strategies. Different letter superscripts in the same row indicate a significant difference ($P < 0.05$). AGR: absolute growth rate; FCR: feed consumed (g); SkB: Bowley coefficient of skewness; CV0 and CV330 correspondent a coefficient of variation at initial and final culture days.

Parameter	HM	HT
Initial number	180	180
Initial weight (g)	100.17 ± 5.91^{a}	96.55 ± 24.58^{b}
Final weight (g)	894.35 ± 198.03^{a}	860.74 ± 230.95^{a}
Initial biomass (g)	18,030.00^{a}	17,379.00^{a}
Final biomass (g)	160,983.23^{a}	154,932.52^{a}
AGR (g d^{-1})	1.78^{a}	1.77^{a}
Survival (%)	96.11^{a}	97.22^{a}
CV_0 (%)	5.90^{a}	25.50^{b}
CV_{330} (%)	22.10^{a}	26.80^{a}
S_{kB0}	-0.13^{a}	-0.01^{b}
S_{kB180}	-0.11^{a}	-0.38^{b}
S_{kB330}	-0.23^{a}	-0.12^{b}
K	0.02068^{a}	0.02065^{a}
Total food (kg)	365.46^{a}	345.89^{a}
FCR	2.35^{a}	2.33^{a}

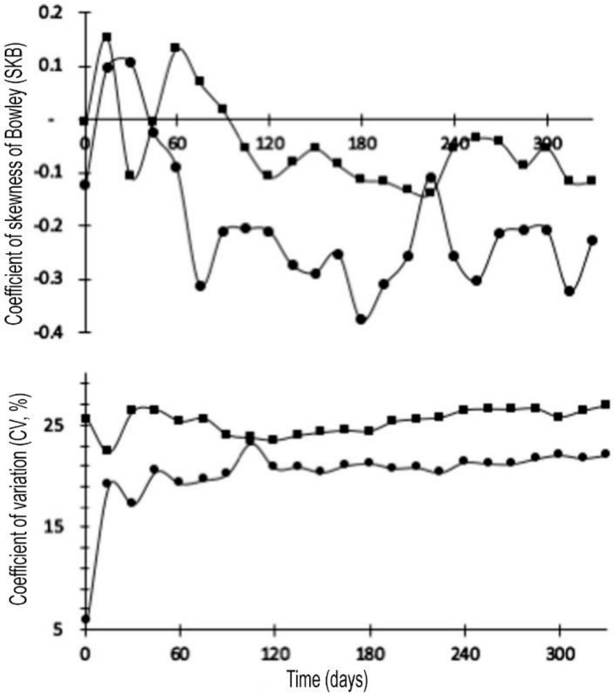

Figure 2. Dynamics of the dispersion of sizes of Nile tilapia rearing at homogenous (•HT) and heterogeneous (▪HM) seeding strategies.

to stocking density; however, no significant differences were found at harvest time (Table 2). In Figure 2, we can see that the HM population became heterogeneous after 15 stocking days. Thus, the *CV* increased from 5 to 19%. After 120 days, the dispersion of the HM stabilized at 20.1%; and in the case of HT increased from 25 to 27% at 330 days.

Bioeconomic analysis

The quasi-profit of variable costs varied inversely with the *Mms* in both groups (Table 4). The OHT for the *Mms* of 350 g and 500 g of the HM population was 180 days, with a mode of 641 g. The OHT was also 180 days for the HT population but only for the *Mms* of 350 and 400g and a mode of 578 g. For *Mms* of 450 and 500 g, the OHT was 195 days to reach the maximum quasi-profit of the variable costs.

In terms of quasi-profits, the HM treatment produced 19.9% more quasi-profits than the HT in the market size of 350 g at 180 days (HM, 180 = USD 53.32; HT, 180 = USD 44.46). The smaller size dispersion in HM generated greater quasi-profits than HT.

The trajectories of the quasi-profits of variable costs for each *Mms* are presented in Figure 3. The maximum quasi-profits of the variable costs occurred at the *Mms* of 350 g with an OHT of 180 days. Although the HM population produced a greater quasi-profit than HT, the quasi-profits decreased as the *Mms* increased.

DISCUSSION

The large variation in the size observed in the tilapia of the same cohort illustrates a high propensity of the organisms to develop and grow at different rates. The results showed that even with a homogeneous seeding strategy, the *CV* of the HM population increased consi-

Table 4. Bioeconomic analysis of optimal harvesting time (OHT) for Nile tilapia at different minimum marketable sizes (*Mms*), rearing at homogenous (HM) and heterogeneous (HT) seeding strategies.

Parameter	HT with alternative *Mms*				HM with alternative *Mms*			
	350 g	400 g	450 g	500 g	350 g	400 g	450 g	500 g
OHT (day)	180	180	195	195	180	180	180	225
Biomass (Kg)	100.267	95.425	88.570	80.989	106.388	103.747	97.335	87.254
Biomass value (USD)	200.535	190.851	177.141	161.979	212.777	207.495	194.671	174.509
Feed cost (USD)	82.851	82.851	97.364	97.364	86.232	86.232	86.232	128.334
Energy cost (USD)	1.627	1.627	1.763	1.763	1.627	1.627	1.627	2.036
Labor cost (USD)	71.600	71.600	77.600	77.6	71.600	71.600	71.600	89.600
Total costs (USD)	156.077	156.077	202.032	176.728	159.459	159.459	159.459	219.970
Quasi profits (USD)	44.457	34.773	25.305	8.257	53.318	48.036	35.212	18.023
Quasi profits (USD kg^{-1})	0.44	0.36	0.29	0.10	0.50	0.46	0.36	0.21

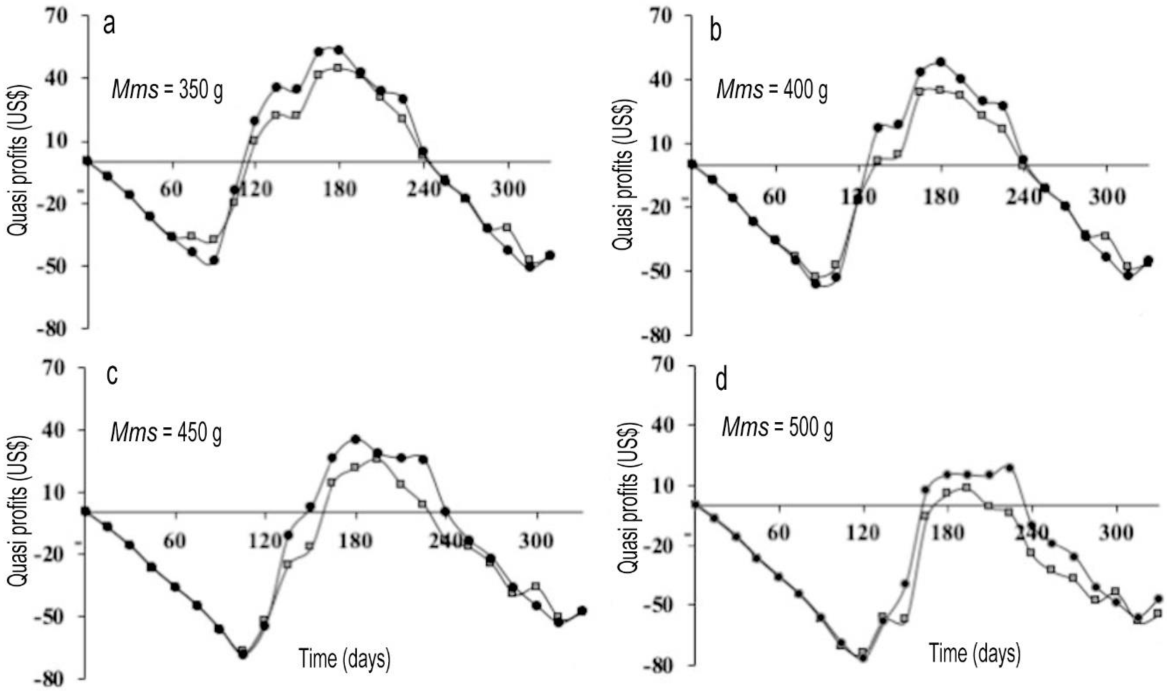

Figure 3. Quasi-profits of variable costs from homogenous (HM = •) and heterogeneous (HT = ▪) conditions as a function of tilapia population heterogeneity when profit is based on minimum marketable sizes (*Mms*): a) *Mms* = 350 g; b) *Mms* = 400 g; c) *Mms* = 450 g; d) *Mms* = 500 g.

derably after 15 days of growth. The difference between the *CV* of both seeding strategies was reduced after 180 days of growth; however, the *CV* of HM was stabilized to 22%, while that for HT, increased from 25 to 27%. However, these values are still low compared to the *CV* of 40-60% reported by some authors for Nile tilapia of the genetically improved farmed tilapia (GIFT) (Ponzoni *et al*., 2005; Khaw *et al*., 2016). In our previous work (Gullian & Arámburu, 2013), the *CV* of the Nile tilapia raised in a hyper-intensive system was 31.6, 34.6 and 33.6% for a stocking density of 400, 500 and 600 ind m^{-3}, which was considerably higher than the present one due to the pressure of intensification. The increase in *CV* indicates intraspecific competition and the influence of social hierarchy, as observed by Jobling (1995) and further exacerbated by a high rearing density. Khaw *et al.* (2016) mentioned that the hereditary competitive interactions also affect the harvest weight in Nile tilapia as the individuals with better genes for survival suppress the growth rate of their social partners. In the present experiment, performance indicators and final survival were not significantly affected by seeding strategies. Still, we can say that the growth rate (1.8 g d^{-1}) is within the expected values for intensive culture systems for tilapia (400 ind m^{-3}), especially if we consider the fact that, in an earlier report, a growth rates of 0.96 g d^{-1} was observed in such cases (Gullian & Arámburu, 2013). Even though there are no statistically significant differences in the biological indicators, it is important to note that the harvested biomass in HM was 3.74% higher than HT; on the contrary, feed intake was 5.66% lower in HM than in HT. These two factors indicate the advantage of the HM over the HT strategy as, on the one hand, the value of production increases and, on the other hand, the cost of feeding decreases.

Our data indicate that even if the fish with minimal size dispersion is sown, the population will become indisputably heterogeneous in a few days. Although this strategy does not seem to offer a benefit, the bioeconomic analysis showed that the quasi-profits of the variable costs of HM-strategy are higher than the HT-strategy. After 180 days of growth, the HM yield generated quasi-gains of 0.06, 0.10, 0.07, 0.11 USD kg^{-1} higher than the HT for the minimum marketable sizes of 350, 400, 450 and 500 g, respectively. Some investigations have analyzed the dispersion of the sizes in the optimum management of the harvest, from an economic point of view (Domínguez-May *et al*., 2011). However, these works have considered the total harvest of all the organisms of the cohort, without considering the sizes that are smaller than the minimum market sizes, which does not contribute economically to the farm.

In other words, such total biomass represents a loss to the producer. Here the proportion that presents greater advantages of production is 350 g, while the lowest is 500 g. However, in this case, marketing costs have not been taken in to account, which depends on farm size, location and the specific market targeted.

It is important to mention that after 15 days of growth, the *CV* of the HM treatment increased by 74% (from *CV* = 5 to 19%). This observation questions the efficiency of grading fish into groups, according to size, as a strategy to decrease phenotypic variation in body weight. The paradigm of partial harvesting has been previously documented in the literature (Brummett, 2002; Yu & Leung, 2006), but we found that the existing harvest management models are still somewhat restrictive and, in general, they are not practical for on-farm applications, mainly due to the increased production costs. Previous authors have shown that for the partial harvest to exceed the harvest of a single batch, it is necessary to carry out rigorous management of several discrete points of partial harvest until obtaining the final harvest (Yu & Leung, 2006). Our data clearly show that competition does not decrease in HM population, but rather it acquires a heterogeneous natural structure in 15 days. In accordance with previous studies, the variations in size over time are not only caused by the initial distribution but also attributable to the effects of size, which influences both the growth and evolution of heterogeneity (Peacor *et al.*, 2007). The organisms that achieve higher growth initially will subsequently also experience a higher increase in body size compared to the smaller individuals (Pfister & Stevens, 2002). This difference, called growth dispensation, is used to define the increase in size variability over time (Gurney &Veitch, 2007).

Finally, one aspect that we would like to highlight is that the biologically optimal harvesting time should be based on the economic aspects of fish production, based on the mode of the population instead of the mean weight of the population. Our data showed that the maximum quasi-profit of the variable costs in the HM strategy for *Mms* of 350 g and 450 g were obtained at 180 days of growing (OHT), when the mode of the population was 641 g. In the HT strategy, the maximum quasi-profit of the variable costs was also obtained at 180 days of growing, when a population reached a mode of 578 g, but only for the target marketable sizes *Mms* = 350 g and 400 g.

When the market target is the *Mms* of 450 and 500 g, the worst strategy would be to carry out an HT strategy since profits would be minimal (0.29 and 0.10 USD kg^{-1}, respectively), and the harvest time would even be longer (195 days). For the target *Mms* of 450 g, the HM strategy would be appropriate, since gains of 0.36 USD kg^{-1} would still be obtained at harvest after 180 days.

In summary, some studies assume that fish heterogeneity is caused by differences in initial sizes, but the present results suggest that dominance is a difficult factor to control in tilapia populations. Thus, heterogeneity in size or variation in fish of the same age appears to be a natural phenomenon in cultivated tilapia populations. The application of the present bioeconomic model, based on the differences in size dispersion at seeding, confirmed the behavior of heterogeneity conclusively over time and allowed quantification of its bioeconomic effect. The seeding of homogenous organisms is highly recommended to the farmers, because the heterogeneity at seeding affects the system performance negatively by lowering biomass, in addition to reducing the quasi-profits of the variable costs.

At present, market competitiveness in aquaculture is growing steadily, and the amount of data that producers have to manage is increasing for wise decision-making. The simple bioeconomic model presented here can help producers in managing a range of economic decisions associated to OHT when targeting different market segments requiring different *Mms*, considering at all times, the natural heterogeneity of the population.

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