Cost-benefit analysis of the production of juvenile tropical Gar "pejelagarto" (*Atractosteus tropicus* Gill): comparing four feeding schemes

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ABSTRACT

Objective: To determine the production cost and profitability of different feeding strategies during tropical gar larviculture.

Design/methodology/approach: Growth and survival obtained from the evaluation of an experimental diet with cornstarch, compared to a conventional strategy (commercial diet for rainbow trout co-feed with *Artemia nauplii*). The experimental diet was evaluated with co-feeding with *Artemia*, and with no *Artemia*. The production cost was estimated for each strategy and the unit cost per juvenile was calculated, as well as their sale cost. For economic analysis, their cost-benefit ratio and the breakeven point were also determined.

Results: Direct feeding with no *Artemia* strategy during larviculture is not profitable. According to the cost-benefit ratio, comparing the strategy with the experimental diet in co-feeding with the conventional strategy, the profitability of the first was greater. The breakeven point between the profitable strategies was similar, but the greater survival with the experimental diet suggests a higher impact on the optimization of the production system.

Limitations on study/implications: The lack of economic analysis on the tropical gar larviculture affect indirectly the tropical gar production system as there is no accurate information on its production costs.

Findings/conclusions: From a financial point of view, the feeding strategy using an experimental diet with co-feeding is the most profitable process in larviculture.

Keywords: native fish, financial feasibility, co-feeding, breakeven point, system optimization.

INTRODUCTION

Aquaculture production is dominated by high commercial value fish, generally exotic, although there is a demand for native species, based on the need not to lose the natural wealth and aquatic biodiversity in different regions of the world (Torres-Orozco & Pérez Hernández, 2011). Aquaculture of native fish represents an improvement to the quality of production of these resources, particularly in tropical areas (Márquez-Couturier & Vázquez-Navarrete, 2015).

At the state of Tabasco, Mexico, one of the most exploited native species is the tropical gar *Atractosteus tropicus* (Márquez *et al.*, 2013). In recent years, fishing pressure and environmental factors have decreased their catches over time (Márquez-Couturier & Vázquez-Navarrete, 2015; Palma-Cancino *et al.*, 2019a). Aquaculture of this species has had important advances since the beginning of this century as a fishing alternative (Márquez *et al.*, 2006). Its reproduction in captivity is known (Márquez *et al.*, 2013), as well as its enzymatic activity during development (Guerrero-Zárate *et al.*, 2014; Frías-

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Quintana *et al.*, 2015), it's fattening and production costs during this stage (Palma-Cancino *et al.*, 2019b), and the design of diets and feeding strategies during their larval development and pre-juvenile production (Frías-Quintana *et al.*, 2010, 2016, 2017; Nieves-Rodríguez *et al.*, 2018; Palma-Cancino *et al.*, 2019a).

Yet, there is a notable lack of research on their production costs due to their feeding strategies during the larval stage (Palma-Cancino *et al.*, 2019a). Another gap in scientific studies on the economics of the pejelagarto is the lack of an adequate analysis of the operational costs of production, as well as a unit cost of the pre-juvenile fish. This makes it difficult to estimate the real value of the product and generates uncertainty for potential tropical gar producers in relation to the adequate selling price of the hatchlings. The purpose of this research is to estimate the real cost of production of *A. tropicus* larviculture, to compare the unit costs per pre-juvenile, the cost-benefit ratio when using different feeding schemes to a conventional one, and to estimate the break-even point for each production scheme.

MATERIALS AND METHODS

Biological data and feeding schemes. To assess the production costs and their corresponding cost-benefit analysis, biological data generated by Palma-Cancino *et al.* (2019a) in the Tropical Aquaculture Laboratory of the Universidad Juárez Autónoma de Tabasco were used; where the response in growth, survival and cannibalism of *A. tropicus* to different feeding schemes (two of them including an experimental diet proposed by Frías-Quintana *et al.*, 2016) were evaluated. The feeding scheme for each treatment was initiated from larval seeding (five days after hatching). The feeding treatments were defined as follows: control treatment (C): conventional diet, consisting of floating extruded trout feed with 45% protein and 16% lipids, Silver Cup® brand (Alimentos de Alta Calidad El Pedregal S. A. de C. V.) with 10 initial days of co-feeding with *Artemia salina* nauplii (Biogrow ®); treatment 1 (T1) consisted on Silver Cup® diet without co-feeding; treatment 2 (T2) an experimental cornstarch diet (Frías-Quintana *et al.*, 2016) with co-feeding the first 10 days with *A. salina*; and treatment 3 (T3) consisted only of the experimental cornstarch diet. The averages weight and length, as well as the survival percentage for each treatment (feeding scheme), are presented in Table 1.

Table 1. Growth parameters (mean±SD) and survival (percentage) obtained at the end of *Atractosteus tropicus* larviculture (45 days after hatching), under four different feeding schemes. Biological data obtained from Palma-Cancino *et al.* (2019a).

Treatment	Weight (g±SD)		Length (mm±SD)		Survival (%)
	Initial	Final	Initial	Final	
C	0.029±0.002	2.16±0.73	17.40±0.60	87.50±9.35	15.56
T1	0.029±0.002	1.78±0.45	17.40±0.60	80.44±7.38	5.56
T2	0.029±0.002	3.37±1.46	17.40±0.60	97.74±13.07	32.33
T3	0.029±0.002	2.18±0.83	17.40±0.60	84.51±12.82	1.00

C (Control): Conventional diet consisting of floating extruded trout feed with Silver Cup®, 45% protein and 16% lipids and 10 initial days of co-feeding with *Artemia salina* naupliius (Biogrow®); T1: Silver Cup® diet without co-feeding; T2: experimental cornstarch diet with co-feeding the first 10 days with *A. salina*; T3: experimental cornstarch diet.

Production costs and unit costs per organism. An individual cost per juvenile was estimated for each diet, based on the operational and feeding costs. Operational costs consisted of energy, labor and broodstock maintenance costs. The energy costs (C_E) were calculated by estimating the total Kwh expenditure of the pump and thermostat and multiplying them by the current rate established by the Comisión Federal de Electricidad (Federal Electricity Commission, CFE) for 2021; the labor costs C_L, consisting of a wage for a worker, using the daily minimum wage as a reference, according to that established by the Diario Oficial de la Federación (Official Journal of the Federation, DOF, 2020), which currently consists of 5.37 USD daily for 50 days (duration of the culture from spawning). The broodstock maintenance cost (C_{BM}) is a fixed cost, equivalent to 18.91 USD, estimated for the maintenance of five males and one female for the duration of larviculture, from Palma-Cancino *et al*. (2019b).

The feeding costs were calculated using the inert diet commercial price as reference (F_D) and the price of live feed (F_L), in the Silver cup® treatments; while in the experimental diet treatments, the feeding cost was estimated by adding individually the unit costs of ingredients (for T2 and T3) and live feed (only for T2). For both cases, a cost per kilogram was determined and multiplied by the total feed expense used in Palma-Cancino *et al*. (2019a). As the costs would represent only the expense generated for a culture of 3,600 organisms, it was extrapolated to an estimate for 16,000 organisms, 80% of the minimum 20,000 viable eggs per spawn of a 3-4 kg female estimated by Márquez *et al*. (2013).

The equation to calculate each treatment total costs (TC) was as follows:

$$TC = C_E + C_L + C_{BM} + \left(\left(F_L + F_D\right) * 16000\right)$$

Finally, the unit costs (*CpU*) arose from a ratio between the *TC* of each treatment, and a 16,000 individuals batch of multiplied by the survival (S_T) in each treatment, following Palma-Cancino *et al*. (2019a). The equation used was as follows:

$$CpU = \frac{TC}{S_T * 16000}$$

Cost-benefit ratio and breakeven point. To calculate the cost-benefit ratio (*BCR*) for each of the treatments, we used the total cost of larviculture and the generated income (*TS*) for the total viable organisms for sale (same as that used to calculate the *VCpU*) multiplied by the unit price per pre-juvenile (*SpU*) of 0.38 USD wholesale, according to personal observations made by the authors on-farm in the state of Tabasco. Both values were adjusted using a minimum acceptable rate of return (MARR) of 10% (*r*) at a five-year (*t*) prospection. The equation was adjusted from Kay *et al*. (2012), and Palma-Cancino *et al*. (2019b) as follows:

$$BCR = \sum TS\left(1-r\right)^{-t} / \sum TC\left(1-r\right)^{-t}$$

To estimate the breakeven point for the number of pre-juveniles (*BQ*), the previously mentioned selling price per unit of SpU=0.38 USD was used. The fixed costs ($F \times C$) were calculated with the proportion of the annual depreciation of the 50-day cropping system, estimated at 61.69 USD, based on the system described by Palma-Cancino *et al*. (2019b); and the sum of the C_E, C_L, and C_{BM} for 50 days, equivalent to 297.14 USD, so $F \times C$=358.83 USD. The equation used was the following modified from Sathiadhas *et al*. (2009):

$$Breakeven\ Quantity\left(BQ\right)=\frac{F \times C}{\left(SpU-CpU\right)}$$

All calculations were performed in the Microsoft Office 365 Excel software (Microsoft Corp., USA).

RESULTS AND DISCUSSION

Production costs and unit costs per pre-juvenile. The total costs (*TC*) of production of each treatment are presented in Table 2. A considerable cost in live feed is observed for treatments C and T2. The improved survivals when using *Artemia* sp. as live feed reported by Escalera-Vázquez *et al*. (2018), Sáenz de Rodrígañez *et al*. (2018) and Palma-Cancino *et al*. (2019a), suggest this is a necessary expense to control mortality to some extent during this larviculture process.

Table 2. Total operational costs (TC) breakdown for a 16,000 batch of *Atractosteus tropicus* larvae, estimated for each treatment. All values are in USD. [1]Mexico prices of electricity by the Comisión Federal de Electricidad (CFE). [2]Minimum daily wage in Mexico according to DOF (2020).

Treatment	Energetic cost[1]	Labor cost[2]	Breeder mantainance cost	Live feed cost	Inert feed cost	TC
	USD					
C	9.79	268.44	18.91	41.36	17.08	355.59
*T*1	9.79	268.44	18.91	0	6.39	303.53
*T*2	9.79	268.44	18.91	41.36	16.68	354.78
*T*3	9.79	268.44	18.91	0	16.68	313.42

C (Control): Conventional diet consisting of Silver Cup® floating extruded trout feed with 45% protein and 16% lipids, with 10 initial days of co-feeding with Artemia salina nauplius (Biogrow®); T1: Silver Cup® diet without co-feeding; T2: Experimental corn starch diet with co-feeding with *A. salina* the first 10 days; T3: Experimental corn starch diet.

The unit costs (Table 3) revealed the high cost of producing without using initial co-feeding, given that T1 and T3 were the highest obtained per pre-juvenile. These results differ from those reported by Frías-Quintana *et al*. (2016), who recommend eliminating the use of *Artemia nauplii,* since using only the experimental corn starch-based diet would increase survival and reduce costs. In contrast, the lower T2 unit cost suggests optimization of the production cycle when using the experimental diet compared to Silver Cup®, which concurs with the same author. Specifically, the high unit cost in T1 is due to the low organism survival obtained by Palma-Cancino *et al*. (2019a), which also concurs with Frías-Quintana *et al.* (2017) who obtained low survival when using Silver Cup® feed without co-feeding, during the larviculture of *A. tropicus*.

Table 3. Cost production per juvenile of tropical gar from an egg-spawning of approximate 16,000 larvae. Viable juveniles were estimated using the survival rate observed during larviculture in Palma-Cancino *et al.* (2019a).

Treatment	Viable juveniles	Unitary cost (USD)
C	2,490	0.14
T1	160	1.96
T2	5,173	0.07
T3	890	0.35

C (Control): Conventional diet consisting of Silver Cup® floating extruded trout feed with 45% protein and 16% lipids, with 10 initial days of co-feeding with *Artemia salina* nauplius (Biogrow®); T1: Silver Cup® diet without co-feeding; T2: Experimental corn starch diet with co-feeding with *A. salina* the first 10 days; T3: Experimental corn starch diet.

The obtained results indicate that the designed T2 corn starch diet (Frías *et al.*, 2016; Palma-Cancino *et al.*, 2019a) has a lower production cost when compared to the commercial Silver Cup® diet, used during the larviculture of pejelagarto. This coincides with the results by Barragán *et al.* (2017), who elaborated balanced diets for tilapia (*Oreochromis* sp.), reporting lower production costs compared to commercial balanced feeds. Similarly, Miranda-Gelvez & Guerrero-Alvarado (2015) managed to substitute fishmeal with 10% Sacha Inchi (*Plukenetia volubilis*) meal in the feed of juvenile tilapia vermelha (*Oreochromis* sp.), obtaining good growth without affecting product performance, reducing feeding and production costs. However, since the analyzed experimental diet here is not yet large-scale manufactured, the estimated price used of its cost is susceptible to the agricultural input market volatility.

The usage of live feed for some larviculture systems continues to be indispensable because these feeds provide most of the nutritional elements that guarantee the survival and optimal development of the larvae (Abdó-De La Parra *et al.*, 2010). In our research, a higher survival percentage, greater weight and length were observed in the feeding strategies containing *Artemia*. This coincides with Luna-Figueroa *et al.* (2010), in a study evaluating the effectiveness of three live feeds (*Moina wierzejski*, *Artemia franciscana* and *Panagrellus redivivus*) in co-feeding with Aquarian Tropical Flakes® diet, in *Pterophyllum* scalare larvae; obtaining higher larval survival supplying *A. franciscana* nauplii. Specifically, in pejelagarto, Saenz de Rodrigáñez *et al.* (2018), obtained higher survival and growth in co-feeding using *Artemia* nauplii during the first days after hatching, when compared to other types of live feed and micro-encapsulated food, justifying that the use of *Artemia* nauplii to acclimate pejelagarto larvae to inert diets is a suitable practice for *A. tropicus* the larviculture.

Exogenous feeding, or first feeding of organisms completing larval development, is the critical period in the production of seed for aquaculture. Three strategies have been developed to use artificial diets in fish, direct use, late weaning and progressive weaning (Lazo, 2000). In the present study we used progressive weaning at C and T2, supplying artificial feed progressively with a live feed from the start of exogenous feeding; and direct use at T1 and T3. Over time, the proportion of artificial diet is increased, and live feed is reduced, a critical process in carnivorous fish rearing (Márquez *et al*. 2013); this process success depends on both supplied live and inert feed and is reflected in the survival of larvae and their growth, ultimately impacting on the reduction of production costs (Paz *et al*., 2020).

It is to be noted that using experimental diets in *A. tropicus* larviculture is usually feasible (Huerta-Ortiz *et al*., 2009; Frías-Quintana *et al*., 2010; 2016; 2017; Nieves-Rodríguez *et al*., 2018), and can significantly reduce production costs by increasing biomass availability when compared to commercial diets. Similarly, it is important to highlight that using co-feeding and adequate live feed during the first days of culture is necessary to succeed in obtaining the best growth and survival results (Saenz de Rodrigáñez *et al*., 2018; Escalera-Vázquez *et al*., 2018).

Cost-benefit ratio and break-even point. The results of the cost-benefit analysis determined better financial performance for T2 with respect to the others (Table 4). According to the cost-benefit ratio results (*BCR*), only T2 and the conventional strategy (C) are financially profitable (T2=3.45 and C=1.66), since it is necessary that the to be financially profitable (Tran *et al*., 2020).

Table 4. Results of cost-benefit ratio (BCR) and break-even quantity (BQ) analysis for a tropical gar juvenile production under four different feeding schemes. * Financially profitable; ** Not financially profitable.

Treatment	BCR	BQ (quantity)
C	1.66*	1,496
*T*1	0.12**	−236
*T*2	3.45*	1,158
*T*3	0.65**	11,961

C (Control): Conventional diet consisting of Silver Cup® floating extruded trout feed with 45% protein and 16% lipids, with 10 initial days of co-feeding with *Artemia salina* nauplius (Biogrow®); T1: Silver Cup® diet without co-feeding; T2: Experimental corn starch diet with co-feeding with *A. salina* the first 10 days; T3: Experimental corn starch diet.

The lack of profitability in treatments without co-feeding is not surprising. Ajiboye *et al*. (2010), Saenz de Rodrigáñez *et al*. (2018), and Escalera-Vázquez *et al*. (2018) establish how vital the use of live feed is during the beginning of exogenous feeding in larvae of carnivorous tropical fish species.

The use of an experimental diet with corn starch in co-feeding (T2), presents a better financial performance overall, generating arguments from a bioeconomic point of view to sustain the hypothesis that this feeding strategy would optimize the production system of *A. tropicus* pre-juveniles. The latter differs from Márquez *et al*. (2013) who affirms that conventional treatment with commercial rainbow trout diets and weaning at 12 days with *Artemia* nauplii is the most efficient way to carry out the larviculture of the species. The economic results here also partially differ from

Frías-Quintana *et al.* (2016) who propose that direct feeding with an experimental corn starch diet optimizes the larviculture of rainbow trout but agrees that using such an experimental diet increases the production of viable pre-juveniles for sale.

The estimated breakeven quantity for the feeding strategies was relatively similar for C and T2, due to the similar margin in unit production costs and the fact that fixed costs are the same in all treatments. This similarity in sales units (pre-juveniles for this study) is more important for T2 since expecting a relatively low survival of animals during larviculture (30-40%), the investment is recovered with the sale of approximately 25% of the total pre-juveniles produced. This suggests that the rest of the pre-juveniles would be directly profitable and reducing their selling price would optimize the larviculture product system for pejelagarto larviculture. The above agrees with Janssen *et al.* (2018) who comment that an adequate diet in broodstock maintenance and during the early life of larvae or fry is indispensable to generate bioeconomically profitable larviculture programs.

Overall, the financial results obtained here indicate an increase in the economic benefit using the experimental diet designed according to the specific nutrient requirements of *A. tropicus* by Frías-Quintana *et al.* (2016), in co-feeding with *Artemia* nauplii. The latter applies to controlled laboratory conditions, as further trials are required to optimize the production system when using such a diet and feeding strategy. This work presents a first approach to the bioeconomic analysis of *A. tropicus* larviculture on a pilot-commercial scale. However, it is recommended to continue researching production with experimental diets to obtain better yields from each spawning of the reproductive females. It is considered that the cost-benefit ratio of pre-juvenile production will improve, making this system-product more profitable, not only through the correct diet selection but also through the "gene pool" improvement of the species in captivity, as suggested by Vázquez-Navarrete & Márquez-Couturier (2015) and Janssen *et al.* (2018), long-term captive breeding programs by themselves optimize the production costs of aquaculture systems.

Finally, this research provides evidence to suggest a lower selling price of *A. tropicus* pre-juveniles, especially at wholesale, as this could increase farming efforts for the species, incentivize its consumption, help to combat the displacement of this native species by invasive species such as *Oreochromis niloticus* or *Hypostomus plecostomus,* and combat overfishing by offering high nutritional quality farm-produced meat. All the above would significantly increase the sustainability of the cultivation of pejelagarto in Mexico.

CONCLUSIONS

Under controlled conditions, the feeding strategy for *A. tropicus* larvae using an experimental diet of corn starch and progressive weaning with *Artemia* sp. nauplii is more financially profitable for the larviculture of the species. It is recommended to continue research with experimental diets to optimize the production system and scale it up to the pilot-commercial level.

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