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Economic evaluation of *Arapaima gigas* production in earth ponds: Case study of a small fish farm at San Martin-Peru

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ABSTRACT

Arapaima gigas is an Amazon specie with great commercial demand and high production performance, but its feasibility is variable. The current study aimed to perform an economic evaluation of the production of *A. gigas* on earth ponds in San Martin, Peru. Three hundred young fish (19 ± 0.01 cm and 68.32 ± 0.01 g) were stocked (ten fish·m^{-2} in three ponds of 1000 m^2 for 390 days). Growth performance was evaluated based on the survival, feed conversion rate (FCR), final mean weight, final average length, weight gain, specific growth rate, and productivity. Investment, costs, indicators, and feasibility were determined. *Arapaima gigas* has a profitable production performance in earth ponds in Peru, fish presented a weight gain (kg) of 11 kg in 390 days and productivity of 3,265.70 kg·ha^{-1}. Food and fingerlings were the most important items in the production cost. This production is a low-investment and high-profitable business, with an incremental investment of US$3,287.15, profit of US$ 3,977.38·cycle^{-1}, Net Present Value of US$ 22,149.37, and an Intern Rate Return of 32.28%. This could be a way of increasing the income of small producers through the diversification of their production.

Keywords: Amazon fish; Aquaculture; Profit; Feasibility.

Avaliação econômica da produção de *Arapaima gigas* em tanques de terra: Estudo do caso de uma pequena piscicultura em San Martin-Peru

RESUMO

Arapaima gigas é uma espécie amazônica com grande demanda comercial e bom desempenho produtivo, mas sua viabilidade econômica é variável. O presente trabalho teve como objetivo realizar uma avaliação econômica da produção de *A. gigas* em viveiros em San Martin, Peru. Trezentos juvenis (19 ± 0,01 cm e 68,32 ± 0,01g) foram estocados em uma densidade de dez peixes·m^{-2} em três tanques de 1000 m^2 por 390 dias. O desempenho produtivo foi avaliado com base na sobrevivência, taxa de conversão alimentar, peso médio final, comprimento médio final, taxa de crescimento específico, ganho em peso e produtividade. Foram determinados o investimento incremental (0.3 ha), custos, indicadores e a viabilidade da produção. O *A. gigas* teve um bom desempenho produtivo em viveiros de terra no Peru, com ganho de peso (kg) de 11kg em 390 dias e produtividade de 3.265,70 kg·ha^{-1}. O alimento e os alevinos foram os itens mais importantes no custo de produção. Essa produção é um negócio de baixo investimento e alta lucratividade, com investimento incremental de US$ 3.287,15, lucro de US$ 3.977,38·ciclo^{-1}, Valor Presente Líquido de US$ 22.149,37 e Taxa Interna de Retorno de 32,28%. Esse modelo produtivo pode ser uma forma de aumentar a renda dos pequenos produtores por meio da diversificação de sua produção.

Palavras-chave: Peixes da Amazônia; Aquicultura; Lucro; Viabilidade.

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INTRODUCTION

A large number of fish species are protagonists in tropical aquaculture, which makes it difficult to study them all (Costa, L. et al., 2020; Cueva et al., 2020; Shimada et al., 2014). In this group, the paiche or pirarucú, *Arapaima gigas* (Cuvier, 1829), is an Amazon species that presents great commercial demand due to its characteristics: fast growth (10 kg per year), rusticity, tolerance to low concentrations of oxygen, fillet with optimum quality, color, mild flavor, no intramuscular spines (Brandão et al., 2006; Imbiriba, 2001), and around 50% of fillet yield (Fogaça et al., 2011). These characteristics and the high market prices make this species profitable for fish farmers and have aroused interest worldwide (Valladão et al., 2018). Despite the great potential of *A. gigas* and several studies showing its growth and productive performance, few works show the economic aspects of production, especially considering the entire production cycle.

The production of *A. gigas* is carried out mainly in earth ponds and small farms (Chu-Koo et al., 2017; Valladão et al., 2018), and its production is concentrated in South America (FAO, 2022). Peru produced around one hundred tons in 2020; however, there was a 76% reduction in the production between 2011 and 2020, mainly due to the lack of incentives and the feasibility of the system (Chu-Koo et al., 2017; Murrieta Morey et al., 2020; PRODUCE, 2021). This drop in production leaves a gap in the international market, as the production of *A. gigas* inPeru is mainly destined for export, with the USA and Germany as the main international markets (PRODUCE, 2021). In this way, there is a demand for *A. gigas* meat, which makes studies showing its feasibility even more important.

The feasibility of the production of *A. gigas* is quite variable, with situations of losses and others with an internal rate of return (IRR) above 30%, depending on the stocking density, place of production, average initial weight, and size of cycle production (Chu-Koo et al., 2017; Munoz et al., 2016; Murrieta Morey et al., 2020; Oliveira et al., 2012; Santana et al., 2020). In a systematic review, Ferreira et al. (2020) found only two manuscripts that included economic aspects of *A. gigas* production, showing a large gap in feasibility data for this species. The economic results can subsidize public policies that encourage production, leading to significant local development based on native species such as *A. gigas*. The lack of research with accurate data on economic aspects and the lack of incentives can lead producers to choose exotic species that will entail a risk of environmental impact, as observed in Peru. (Chu-Koo et al., 2017). Therefore, the current study aimed to perform an economic evaluation of the production of *A. gigas* on earth ponds at a farm in San Martin Region, Peru.

MATERIAL AND METHODS

Production System

The data used in the current work were obtained from an earth pond fish farm located in the San Martin region, Peru (6°02’52”S, 77°03’39”W). The farm has 2.5 ha of earth ponds, with 0.3 ha for the production of pirarucú (*A. gigas*) and 2.2 ha for the production of tilapia (*Oreochromis niloticus*) and gamitama (*Colossoma macropomum*) in a polyculture system. This farm was chosen because it represents a typical fish farm in this region and because it has a license for its operation granted by the health authority of the country. In this study, only the production of *A. gigas* was evaluated.

Production Performance

Three hundred young fish (19 ± 0.01 cm and 68.323 ± 0.01 g) were stocked at 0.1 fish·m^{-2} in three equal ponds of 1000 m². Fish were fed twice a day to apparent satiation with a commercial feed for the species. For the first 180 days, 45% of the crude protein in the feed was used, and for the next 210 days, 40% of the crude protein was used. The feeding was supplemented with young live fishes (*O. niloticus* and *Cichlasoma amazonarum*) from nearby farms throughout the entire production cycle. Monthly, biometrics on 10 fish were performed to measure the standard length and weight values. Growth performance was evaluated based on survival, feed conversion rate (FCR = feed given / fish weight gain), final mean weight (FMW = sum of fish weights / number of fish), final average length (FAL = sum of fish lengths / number of fish), weight gain (WG = (final body weight − initial body weight) × 100 / initial body weight), specific growth rate (SGR = (ln final weight - ln initial weight) x 100/ number of days), and final biomass (FB = final number of fish x (final weight of fish – initial weight of fish) / 1000).

The productivity of the farm was 326.57 g·m², the weight gain was 11,557.68 ± 1,010.36, and the FCR was 2.090.19 considering a productive cycle of 390 days. All survival fish did not present any lesions or clinical signs at the production cycle’s end. The performance and survival rate of *A. gigas* during an entire production cycle are presented in Table 1.

Investment

The initial investment considered the construction of a 3000 m² area, with three ponds of 1000 m² (direct investment), and a support building with an office, accommodation, feed storage, and warehouse used for the entire fish farming activity (2.5 ha of ponds). Thus, the proportion of each support item was determined considering the ratio of *A. gigas* production area to the fish farm area (12%) to determine the relative initial investment.

Table 1. *Arapaima gigas* performance parameters during 390 days of production in earth ponds with 0.1 ha each, average of ten *A. gigas*.

Description	Values (average±standard deviation)
Survival (%)	85.00
Initial average length (cm)	19.00 ± 0,82
Final average length (cm)	101.80 ± 12.46
Initial mean weight (g)	68.32 ± 2.03
Final average weight (g)	11,626.00 ± 1,011.48
Average weight gain (g)	11,557.68 ± 1,010.36
Specific growth rate (%)	1.32 ± 0.02
Feed conversion ratio	2.07±0,19
Final Biomass (g m²)	979.71

The investment did not take into account the spending on land acquisition. The values of investments have been corrected to July 2022 using the Peruvian monetary correction index.

Production Cost and Indicators

The costs were estimated for a production cycle of 390 days, considering nursery (90 days), rearing (90 days), and harvesting (210 days). The costs were determined based on the structure of the Total Operational Cost - TOC (Matsunaga et al., 1976) and Total Production Cost - TPC (Martin et al., 1995). The Total Operating Cost is the sum of Effective Operating Cost (EOC) and Depreciation. The EOC was the sum of the spending on fingerlings, feed, fertilizers, lime, use of vehicle and equipment, office supplies, commonly used materials, and labor. Depreciation of infrastructure, equipment, and tools were calculated using the linear method.

The total production cost is the sum of fixed costs (FC) and variable costs (VC). The fixed cost was obtained from the sum of: compensation of land per year (US$ 755.67), considered as leasehold value of the land; remuneration of the entrepreneur (value U$ 1,574.31 monthly for the entrepreneur for all farmed); remuneration of fixed capital (return rate of 10% per annum on the average value of fixed capital, RFC = average value of fixed capital x return rate); and depreciation [D= (*Value*/*useful life*)x*Value*]. The variable cost was obtained by adding the EOC and the interest on working capital (at an interest rate of 10% per year related to interest rate funding).

The following economic indicators were used (Costa et al., 2018; Martin et al., 1995): Production, Initial Investment, Total Operating Cost (TOC), Total Production Cost (TPC), Unitary or Average Costs, Gross Revenue (GR), Operation Profit (OP) = GR – TOC, profit (P) = GR – TPC, Profitability Index (%) = OP/GRx100, Profit Margin (%) = P/GRx100, Revenue Index (%) = GR/Ix100.

Economic feasibility and sensitivity analysis

A cash flow analysis with a horizon of 10 years was performed with the data on investment in fixed capital and EOC. The outputs were an investment in initial fixed capital, the reinvestments in fixed capital over the horizon, the working capital necessary to carry out a productive cycle, and the EOC. The inputs were gross revenue obtained from the sale of production, working capital that should return on the horizon, scrap value, and the residual value of fixed capital goods. The moment zero was considered the moment of the project's implantation. The Economic feasibility Indicators (Martins et al., 2016) used were:

Net Present Value, $NPV=\sum_{t=0}^{n} NCFt/(1+i)^t$;

Benefit/Cost Ratio, $B/C=\sum_{t=0}^{n} [Income/(1+i)^t] / [Expenses/(1+i)^t]$;

Where: NCF = Net cash flow; Income = Cash inflows; Expenses = Cash outflows; i = Discount rate; n = Number of years in operation (0, 1, 2,….10) and t= Year.

The discount rate, at which the NPV is zero, is known as the internal rate of return (IRR). The time needed for the amount invested in an asset to be reimbursed by the discounted net cash outflow produced by the asset is known as the economic payback period. 10% was the discount rate applied. The sensitivity analysis took two possibilities into account: 1-An actual scenario where *A. gigas* was produced on just 0.3 hectares of the farm, as it actually did; 2-A hypothetical situation in which the farm only produces *A. gigas* on all of the 2.5 ha of water surfaces.

RESULTS

The investment for a farm of 2.5 ha of earth ponds was US$ 33,553.63, with the largest part being support infrastructure (70.11%), mainly because of the house (36.78%). The building of the earth ponds represented 29.89% of the investment. The area destined for *A. gigas* (0.3 ha) represented only 3.59% of the total investment in the farm. The low value associated with the acquisition of the vehicle is due to it being a used quadricycle with a small wagon. The determination of relative investment is applied in cases where the farm has more than one productive activity or produces species that share the same infrastructure. This allows the determination of the contribution of each activity or species to the feasibility of the farm, where each is responsible for paying a part of the investment. However, it must be considered that, for new enterprises, the entire farm investment is necessary. The investment required for 2.5 ha and the value of 0.3 ha for *A. gigas* production are presented in Table 2.

The total production cost (TPC) for a 390-day cycle for producing 2,964.63 kg of *A. gigas* was US$ 14,691.57. The variable costs represented 94.81% of the TPC, showing that this farm uses the infrastructure efficiently. As the producer uses capital efficiently, variable costs tend to increase participation. Feed and fingerlings are the most representative costs in *A. gigas* production. The feed plus live food represented 74.66% of TPC. The production cost is detailed in Table 3.

All fish produced was sold at the farm gate at a price of US$ 6.30. The profitability of the production of *A. gigas* was above 25%, internal rates of return above 32%, and Net Present Value of US$ 22,149.37 (0.3 ha) and US$ 189,720.96 (2.5 ha). The economic indicators of the commercial production of *A. gigas* during a productive cycle is presented in Table 4.

Table 2. Investment for a 2.5 ha fish farm and proportional value for the *Arapaima gigas* production in 0.3 ha. Values were adjusted to US$ of November 2022.

Description	Value Total (US$) – 2.5 ha	Value for *A. gigas* (US$) - 0.3 ha	%
Supporting structure	19,206.55	2,304.79	70.11
House (office, accommodation, toilets)	10,075.57	1,209.07	36.78
Feed deposit	2,518.89	302.27	9.20
Fingerlings cleaning and distribution shed	3,148.61	377.83	11.49
Equipment, tools and appliances	1,889.17	226.70	6.90
Vehicle	1,574.31	188.92	5.75
Ponds	8,186.40	982.37	29.89
Total	27,392.95	3,287.15	100.00

Table 3. Production cost for an *Arapaima gigas* farm during 390 days in three earth ponds with 0.1 ha each. Values to November 2022. (US$ 1 = SOL$3.97).

Production Cost	Unit	Quantity	Unit Cost	Total Cost (US$/Cycle)
A- Effective Operating Cost (US$)				13,265.59
Fingerlings	Unit.cycle	300.00	5.04	1,511.34
Live Food	Thousand.cycle	54.00	11.34	612.09
Feed 1 (45% Crude protein)	kg.cycle	276.00	1.81	500.55
Feed 2 (45% Crude protein)	kg.cycle	1,101.00	1.81	1,996.78
Feed 3 (40% Crude protein)	kg.cycle	4,875.00	1.61	7,858.94
Vehicles and equipment expenditures	Month	13.00	15.11	196.47
Lime	kg.cycle	15.00	0.50	7.56
Urea	kg.cycle	5.00	1.21	6.05
Office materials	Month	13.00	6.05	78.59
Consumables	Month	13.00	6.05	78.59
Labor	Month	13.00	28.72	373.30
Transport of fingerlings	Cycle	1	45.34	45.34
B-Depreciation				459.80
C=A+B-Operating Cost (US$)				13,725.39
D=A+D1 Variable Cost				13,928.87
D1-Interest in working capital				663.28
E=B+E1 Fixed Cost				762.70
E1=Opportunity Costs				302.90
F=D+E-Total Production Cost (US$)				14,691.57

Table 4. Economic indicators for an *Arapaima gigas* farm during 390 days in two scenarios. 1-A real scenario with the production of *A. gigas* in just 0.3 ha of the farm. 2-A virtual scenario where the farm produces just *A. gigas* in the 2.5 ha water surface. Values to November 2022. (US$ 1 = SOL$3.97).

Indicators	Real scenario 0.3 ha *A. gigas*	Scenario 2.5 ha *A. gigas*
Investment (US$)	3,287.15	27,392.95
Production (kg.cycle)	2,964.63	24,705.25
Average TOC (US$/kg)	4.63	4.63
Average TPC (US$/kg)	4.96	4.95
Price (US$/kg)	6.30	6.30
Revenue (US$.cycle)	18,668.95	155,574.62
Operating Profit (US$.cycle)	4,943.56	41,302.13
Profit (US$.cycle)	3,977.38	33,255.95
Profitability Index (%)	26.48	26.55
Profit Margin (%)	21.30	21.38
Discount Rate (%)	10.00	10.00
Economic payback (years)	3.84	3.83
Net Present Value (US$)	22,149.37	189,720.96
Internal Rate of Return (%)	32.28	32.62
Benefits /Costs	1.23	1.23

DISCUSSION

The production performance of *A. gigas* in ponds in this farm is better than those found by Scorvo-Filho et al. (2004) in tank systems for 16 months that obtained an FCR of 2.64 and a final weight of 7,917.20±963.55 g; Cavero et al. (2003) found an FCR greater than 3 in 200 days of the crop in net cages. However, the authors recommend that for this system, the sustainable biomass was 22 kg·m^{-3} when the animals had 1.12 of FCR and 1.06 kg of average weight.; and in Lima (2020), the production in earth ponds after 287 days had a survival between 72 and 78%, FCR from 2.75 to 2.85, and the final weight from 8.01 to 9.49 kg. Pereira-Filho et al. (2003) reported in earth ponds a survival of 100%, a FCR of 1.5, and a productivity of 2.5 kg m^2 for a crop of 360 days; however, the animals at the end of the cycle had a final average weight of 7± 1.1kg. Besides, in the current study, the internal rate of return was better than those reported for *A. gigas* in Loreto farms (Gómez et al., 2009), which could be related to the absence of sanitary problems in the cycle studied.

The higher weight gain and final weight compared to the literature data may be due to the lower density employed on the farm, which, despite low productivity (979.71g·m^{-2}), compensates with larger animals and can result in better profitability. This was also observed by Oliveira et al. (2012), evaluating two stocking densities for young fish of *A. gigas* and obtained better performance (survival, final weight, weight gain, and production) and financial return at the lowest density, showing that in the final stages, the highest densities do not always result in improving financial returns.

Building earth ponds can represent 40% to 86% of the initial fixed capital (Barros et al., 2012; 2020a). The greater participation of the support infrastructure and low participation of earth ponds, as observed in this study, is related to the small size of the farm, because with the increase of the productive scale, it is expected that the cost of earth ponds will increase its participation in the investment (Barros et al., 2020b; Costa, J., 2016). This scenario indicates that the farm is operating with low-scale efficiency (Costa, J., 2016), where the increase in the number of ponds will require a lower investment in support infrastructure than initially required. J. Costa (2016) found a participation rate of 86.16% for the construction of nurseries (600m^2) and 13.84% for support infrastructure. This high participation was attributed to the construction of more nurseries per area when compared to larger nurseries.

In *A. gigas* production, feed costs can vary from 17% to 87% of the production cost, depending on the phase, density, cycle size, system, and cost of the structure adopted (Chu-Koo et al., 2017; Lopes, 2015; Munoz et al., 2016; Oliveira et al., 2012; Santana et al., 2020). Feed is usually the most expensive item of production, and producers must be aware of variations in their prices and the items that determine the diet (Asche and Roll, 2013; Costa, J. et al., 2017). In this study, although feed was supplemented with live fish, this was the most important production cost. This may be due to the demand for carnivorous species with greater quantities of crude protein, such as *A. gigas*, which is the most expensive ingredient in commercial diets (Aguinaga et al., 2015; Lopes, 2015).

The young fish were the second-most representative production cost. *Arapaima gigas* young fish have a high commercial value (US$ 0.25·cm^{-1}) because the demand is greater than the supply, and they are marketed according to their size in centimeters (Chu-Koo et al., 2017; Lopes, 2015; Oliveira et al., 2012). The high price of juveniles leads to their high share in the production cost (10.29% of TPC), even in a long production cycle (390 days). Santana et al. (2020) and Oliveira et al. (2012) reported higher costs of juveniles that represented 24% and 53.3% of the production cost, in both cases, the high participation was attributed to the short production cycle. Lopes (2015) observed that by increasing the production, the cycle reduces the participation of juvenile prices, representing, at the end of the 310-day production cycle, between 19 to 21% of the EOC, where the greater demand than supply for fingerlings raises the market price.

The production of *A. gigas* showed positive profits, with a profit margin of 21.30%. Chu-Koo et al. (2017), evaluating the cultivation of *A. gigas* in Peru, found profit margins ranging from 14.62% to 61.42%, depending on the size of the pond, production cycle, and initial weight of the animals. Munoz et al. (2016), evaluating production in Rondonia-Brazil found negative margins, which resulted in the migration of producers to other more attractive species.

In this study, low stocking densities provided good growth (Specific growth rate: 1.32%) but low productivity, which commonly results in economic losses in the farm (Gomes et al., 2006; Santana et al., 2020; Santos et al., 2007; Souza-Filho, 2003). This was not observed in this study, which proved feasibility even with low productivity, with high profit per cycle US$ 3,977.38. Similar results were observed by Oliveira et al. (2012) in the production of *A. gigas* during 140 days, where the best financial return was found at the lowest density (10 fish·m^{-2}), with an IRR of 34.4%, a NPV of 150,127.34, and a payback of 2.8 years. However, the authors showed that production was sensitive to variations in the feed cost and the selling price. In the larviculture of *A. gigas*, Santana et al. (2020) observed that low densities (<600 larvae·m^{-3}) generated economic losses, with the highest net revenue obtained at the highest density. These results show that density will impact the feasibility of production differently depending on the production phase. In the initial phases, higher densities generate greater returns; in the final phases, the densities that allow greater growth of the animals may be the most indicated.

CONCLUSION

Arapaima gigas has a good production performance in earth ponds in Peru, with a weight gain (kg) of 11kg in 390 days and a profit of 3,977.38 US$ in 0.3 ha ponds. The feed and fingerlings are the most representative items in the production cost. This production is a low-investment and high-profitable business. This could be a way of increasing the income of small producers through the diversification of their production.

ETHICAL APPROVAL

In this study there were not use any handling or sacrifice of the animals.

CONFLICT OF INTEREST

Nothing to declare.

DATA AVAILABILITY STATEMENT

All datasets were generated or analyzed in the current study.

AUTHOR CONTRIBUTIONS

Conceptualization: Costa JI; **Data curation:** Costa JI; **Formal analysis:** Costa JI; **Acquisition of funding:** Yunis-Aguinaga J; **Research:** Gonzalez-Callirgos L; **Methodology:** Gonzalez-Callirgos L; **Project administration:** Gonzalez-Callirgos L; **Software:** Gonzalez-Callirgos L; **Supervision:** Yunis-Aguinaga J; **Validation:** Yunis-Aguinaga J; **Visualization:** Yunis-Aguinaga J; **Writing - Preparation of original draft:** Yunis-Aguinaga J; **Writing - Proofreading and editing:** Yunis-Aguinaga J.

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