PARTIAL SUBSTITUTION OF BALANCED FEED BY CHAYA LEAVES IN NILE TILAPIA PRODUCTION: A BIOECONOMIC ANALYSIS

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ABSTRACT

Tilapia culture in Yucatan State, Mexico, is largely semi-intensive. The producers are mostly poor farmers who receive government subsidies for purchase of fingerlings and balanced feed. Feeding practices are often inadequate (satiety rations), moreover, producers frequently suffer financial and resource shortfalls. During feed shortages producers are known to use empirical application of chaya (*Cnidoscolus chayamansa*) leaves, used traditionally in human and animal nutrition. A study was done of growth in juvenile tilapia using diets containing balanced feed with chaya (25 and 50% of substitution), complete, half-complete and satiety rations of balanced feed, during the warm season. The results were used to develop a bioeconomic model and implemented in MS Excel program, with a one-day time step. In order to minimize the cost of tilapia feeding, and maximize the benefits by using a limited amount of balanced feed per cycle. In addition the analysis was completed using the Marginal Rate of Technical Substitution (*MRTS*). According to results from *MRTS*, it is necessary to add 2.51-3.91 units of chaya for each reduced unit of balanced feed, to maintain the same level of production. In a resource limited situation, substitution of 50% of balanced feed for raw chaya leaves generates a harvest size greater than complete and satiety rations of 24.8 and 28.8% respectively. When considering sale prices that are consistent with size at harvest and costs, treatments with chaya considerably maximized profits.

Keywords: tree spinach, temperature, maximize profits

INTRODUCTION

The development of aquaculture has been severely retarded in developing countries by the failure of agencies, governments and farmers to appreciate its basic requirements, which must be integrated with the rural development [18]. In Mexico the aquaculture has been promoted as occupational option in coastal zones affected by the overfishing and as a technological innovation in rural areas to make the agricultural activity more productive, where the tilapia culture has taken great social relevance [7]. The state of Yucatan is one of the poorest in Mexico. Rural economies are based on small family farms producing vegetables, citrus products and poultry. In response, the Mexican government has included Yucatan in high-priority economic support programs, like tilapia culture [8], constructing 116 concrete tanks (1 tank/farm) for this purpose. Sometimes, the rural producers receive government subsidies for purchase fingerlings and balanced feed, although this is not constant, due to the sexennial duration in development programs [15]. In addition, management systems in Yucatan are often inadequate since feeding to satiety is a common practice and it has not been proven to be the best option.

When rural producers suffer financial and resource shortfalls, they are forced to feed tilapia with alternative materials such as raw spinach tree leaves (*Cnidoscolus chayamansa*), locally known as chaya. In the Yucatán Península and Central America, chaya has been used traditionally for human and animal consumption. Principally indigenous Maya people have used chaya given its high nutritional properties, in addition, chaya also has many applications in traditional medicine [5, 12]. This shrub is distributed in México, Central America and Cuba and has been introduced in southern Texas, Florida, the Marshall

Islands and Polynesia [2, 5, 11, 17, 22, 23]. Use of these nutrient sources in their natural form as complements or substitutions for balanced feed in tilapia production is potentially significant for culture systems located in rural communities in developing countries. These potential complements or substitutions are under-researched because emphasis has more frequently been placed on reducing the proportion of fish meal in feed and thus reducing costs. Past studies have demonstrated that chaya can partially substitute balanced feed offering the same growth outcome as with complete rations; however, this has only been proven at low cultivating temperature (24ºC), thus obtaining small harvest size [16].

Implementation of new inputs or resources into a culture system requires economic evaluation to determine maximum income and lowest production cost [14]. This can be obtained by two related ways, maximizing production with given resources or achieving a given level of production with the least possible resources [20]. Bioeconomic studies have been done to minimize aquaculture production costs by analyzing the relationships between inputs and determining optimum scenarios. The marginal rate of technical substitution (*MRTS*) refers to the amount of a resource that may be decreased as use of another resource is increased by one unit without affecting output [10]. One such study of catfish culture showed that when producing 500 g catfish with substitution of protein in the balanced feed with feed ration, minimum cost was reached at 651 g of feed, which contained 200 g of protein [6]. In another example, in a study of feed ration size and culture days in production of 350 g gilthead seabream it was found that minimum costs were reached at 370 days and with a ration 5% higher than that recommended in feed tables [13].

In an effort to minimize costs in tilapia feeding, the present study's aim was to evaluate substitution of balanced feed with chaya and different balanced feed rations. A bioeconomic model was produced based on experimental data, and diverse technical, biological and environmental scenarios were evaluated for use of chaya in tilapia culture. Profit maximization was analyzed considering a regular production of chaya and a limitation in the amount of balanced feed per cycle.

MATERIALS AND METHODS

Experiment and data synopsis

The data analyzed here are from an experiment carried out in the Aquaculture Laboratory of CINVESTAV-Merida, between the months of May and October, when water temperature is warmer than in the rest of the year (27.9±0.8). The experimental system consisted of 12 round fiberglass tanks of 0.75 m^3 volume subject to ambient environmental conditions. The treatments were based on a 27.8 % protein commercial balanced feed and chaya. The complete ration or control diet was 100% balanced feed (100BF) (recommended ration by the manufacturer), the treatments: 50% of control diet or half-complete (50BF), balanced feed satiety, 75% (25CH) and 50 % (50CH) of chaya substitution. Daily rations for 25CH, and 50CH diets were calculated based on the 100BF diet, while the chaya where offered *ad libitum*. All treatments were done in triplicate. Data for growth, survival, feeding and water temperature were used in the present bioeconomic analysis.

Culture System Model

The culture system model applied in the analysis simulates tilapia production in rural areas of Yucatan State, Mexico. All assumptions used in the analysis consider the technical and biological aspects of the semi-intensive system used in this location. Producers in these areas are primarily farmers and engage in aquaculture as a part-time activity. The culture system used in the region generally consists of a 117.8 m^3 water tank (usually built by the government) used for both culture and irrigation. Producers receive government subsidies (1,125 kg of balanced feed). Producers administered balanced feed at satiety rations divided in two to three portions daily. Generally, chaya was provided when the balanced feed was consumed because their financial resources are limited to buy more balanced feed. Water changes are done depending on the agricultural cycle and the tanks do not have complementary aeration. The water used is generally hard with high calcium carbonate a level, meaning no fertilization is used due to the consequently low primary production levels. No gradations are made during the cycle and therefore the fish remain in the tank until harvest. Size at harvest varies depending on demand. Local buyers acquire sizes from 100 to 500 g individual weight. Wholesalers do occasionally buy harvests, but are mainly interested in production and sizes between 250 and 400 g individual weight.

Production Isoquants and Isocosts

When analyzing inputs in a production system, the Marginal Rate of Technical Substitution (*MRTS*) is used to represent the isoquant slope (Appendix Eq. 1), in this case the amount of chaya (Δx_1) that must be used to substitute balanced feed (Δx_2) if production is to remain constant [1].

Bioeconomic Model

A fish growth function forms the foundation of the biological model since it interrelates organism management, inputs and costs [4]. A Von Bertalanffy-type growth function was integrated into biological sub-model to describe growth in each treatment. The tilapia bioeconomic model was implemented in MS Excel program with a one-day time step, and it includes biological, management and economic sub-models, the most significant of which are explained below.

A thermal correction function was integrated to include the effect that temperature had on tilapia growth [15] (Appendix Eqs. 2-3). [16]. The management sub-model contains the main culture control variables, including density, tank capacity, feed quantity, etc., which are closely linked to organism growth and consequently to farm economic results. A function was included over consumption and survival according to temperature variation using growth data from tilapia fed with a control diet (100BF) at a temperature of 24.05ºC (Appendix Eqs 4-8). A one year production cycle was considered with a limitation of balanced feed per cycle (1,125 kg), similar to the government subsidies.

The economic sub-model included those variables with the greatest impact on the economic results by using Model input variables included on-site wholesale price for tilapia, costs of fingerlings, feed, electricity (for pumping) and labor (man hours) (Appendix Eqs. 9-11). Depreciation was calculated using the straight line method for one horizon (30 years) over the value of the concrete tanks. The discount rate was assumed to be the interest paid on 28-day Federal Treasury Certificates (CETES) in Mexico. The model was estimated in Mexican pesos (MXP 11=USD 1).

Pattern prediction tests were done to validate the growth model and confirm that the simulated data matched the observed data as treated with the Theil *U* statistic [3, 9]. This non-parametric statistic measures unevenness between observed and simulated values in relation to the mean square error (*MSE*) for each data pair.

Bioeconomic Analysis Assumptions

Model assumptions were based on experimental, commercial, market and environmental data for the Yucatan Peninsula, Mexico. No charge for land was included in the cost estimates since it was assumed that the land was owned and was being used for both aquaculture and agriculture. Labor costs considered that tilapia culture is a part-time activity in this system. Electricity costs were calculated based on use of a pump for water replacement in the system during the culture cycle, although this depends on agricultural irrigation cycles. Input costs were established according to the market price of each one. A regular production of chaya and a limitation in the amount of balanced feed per cycle (similar to the government subsidies) was assumed, therefore, every fish has already been harvested and sold by the time balanced feed was run out. The cost of chaya was established based on the time (labor) required to harvest and prepare it for use. This was considered an opportunity cost, which refers to the money that could have been earned (labor) in the second best economic option or alternative, which is treated as a cost attributable to the activity or work done [19].

RESULTS AND DISCUSSION

Experimental results

According to the one-way ANOVA, growth results for diet treatments 100BF, 25CH and Satiety were not different ($p<0.05$) (Figure 1), whereas diet treatments 50BF, 50CH and satiety were different ($p>0.05$) from each other. The treatments of satiety, 100BF and 50BF generated a Feed Conversion Ratio (FCR) of 1.82, 1.69 and 1.28, respectively. Treatments 75CH and 50CH generated an FCR of 2.5 and 2.72, however breaking down balanced feed values (1.83 and 1.01) and chaya values (1.22 and 1.71) an important reduction of consumption of balanced feed can be observed. These indicators show that the tilapias can grow in production systems on a small scale, using fresh vegetables available locally (such as chaya), with the purpose of minimizing the costs of feed.

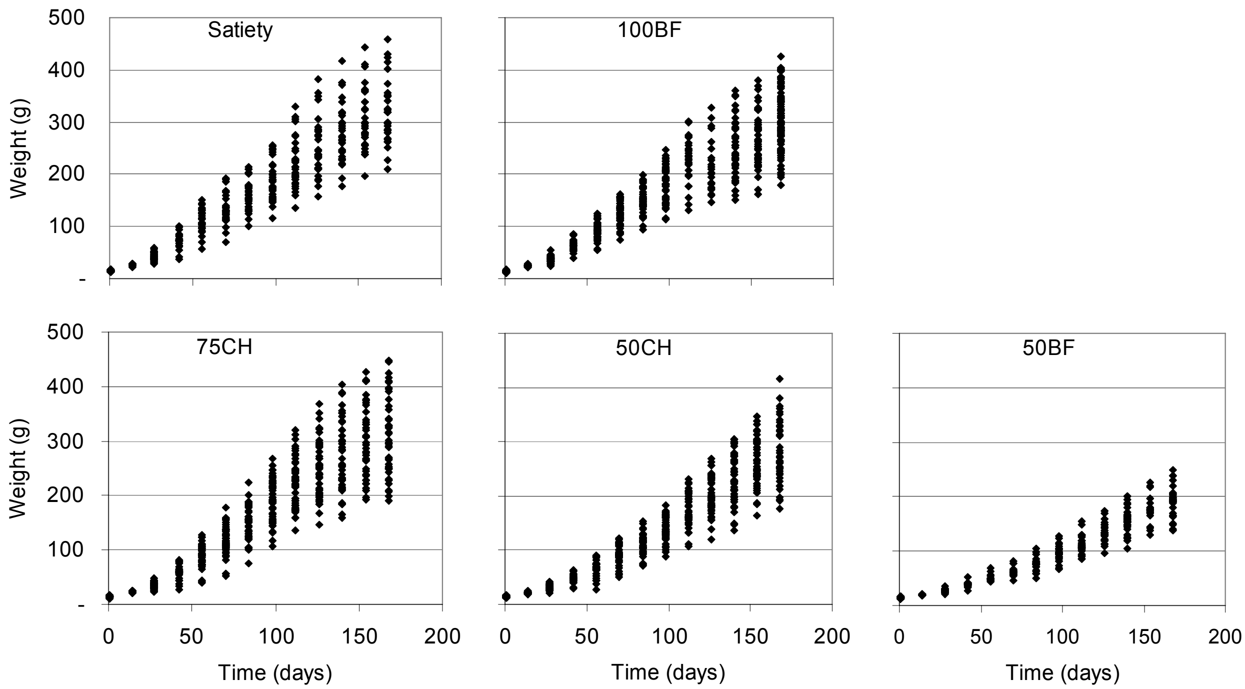

Fig. 1 Results of growth in each treatment

Contribution of chaya to tilapia growth can be observed by comparing treatments 50BF (50% ration) and 50CH (50% ration + chaya), where the weight obtained was of 284.4 and 355.8g respectively (Table II), with an increment of 71.4g (25.1% greater), attributed to the nutritional contribution of chaya, which demonstrates that this vegetable can be an adequate partial substitute of balanced feed when combined with 50% of the recommended ration.

Previous studies with this input had demonstrated that chaya by itself does not contribute with the necessary nutrients for optimum tilapia growth [16]. These authors observed that feeding tilapia using 100% chaya in a period of six months at a cold temperature results in a minimum weight gain, in a similar to a ration of maintenance, where no weight is gained or lost. However, the results of the present study indicate that chaya can efficiently contribute to fish development when used as a supplement of balanced feed, which is supported by the results in growth and efficiency in feed use.

Production isoquants and isocosts

The isoquant and isocost curves indicate optimum input use and minimum cost. The isoquant fixes the amounts to be used of each input and the isocost indicates the cost or budget each will engender. The isoquant slope (*MRTS*) was generally linear, and between the 100BF and 50CH treatments it was 2.51, meaning that for substitution 2.51 units of chaya would be needed for every unit of balanced feed. However, the *MRTS* between the 100BF and 75CH treatments it was 3.91. To attain a 300 g size fish using only balanced feed would require 482.5 g of feed whereas using only chaya it would require 4,300 g. The isocost line shows the cost (or budget) of the feed to be used as well as that of the best option [24]. Use of only balanced feed produces a cost of 4.82 MXP. By comparison, the minimum cost (300 g size) was produced by a combination of 545.4 g chaya and 322.6 g balanced feed, in other words, the 50CH scenario is the input combination which minimizes costs most in this tilapia production system (Figure 2).

Input levels above those for the two inputs alone (i.e. 482.5 g BF and 4,300 g CH) would not increase production and would therefore result in an unnecessary cost (i. e. satiety ration). In addition, it would lead to a high probability of mortality due to excess nitrogenated wastes, pH changes, etc. caused by decomposed balanced feed or unconsumed chaya.

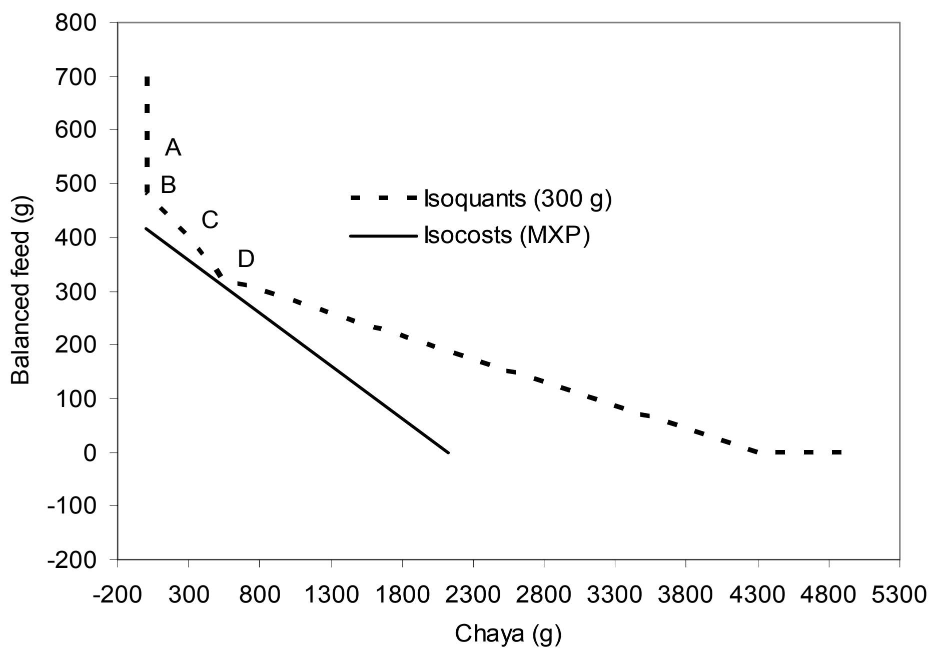

Fig. 2. Isoquant (dotted) and isocost (solid) lines for tilapia production to 300 g average size, A) satiety, B) 100BF, C) 75CH and D) 50CH

Using the isoquant can help in determining proper input levels for use of balanced feed alone, and/or the extent to which it can be substituted, depending on producer needs. As the proportion of balanced feed is reduced, the proportion of chaya would need to be increased for the fish to reach the size, although culture time can increase substantially if the optimum feed input combination is surpassed.

Bioeconomic analysis with balanced feed limitation

The von Bertalanffy growth model parameters are summarized in Appendix Table AI. The statistical results show that the model accurately reproduces the observed data within the average Theil *U* values (i.e. < 0.20), with the highest bias in the covariance (Appendix Table AIII).

Taking into account the basic assumptions (Appendix Table AIII), the simulation results show that 276.2-355.8 g harvest sizes can be obtained at the same time depending on the feeding scenario used (Table I). In the scenario where 75CH was used a greater size was achieved with respect to 50BF (13.0%), 100BF (16.3%) and satiety (12.7%), meanwhile, with 50CH, increment was greater in 25.1% (50BF), 24.8% (100BF) and 28.8% (satiety). All scenarios (50CH, 75CH, complete and satiety) achieve profit (50BF was the exception), even when there is a limitation of balanced feed in each cycle. However, the scenarios satiety and 100BF have very low remuneration versus 50CH and 75CH. This is due to the restriction of the balanced feed/cycle in combination with a higher FCR and low stocking density, characteristic of the cultivation system (without aeration). This is important, because poor farmers who receive government subsidies (fingerlings and balanced feed) don't make periodic biometrics therefore they don't know the economic impact of the satiety rations. The 75CH and 50CH scenarios, reach the biggest harvest sizes, considering limitations in amount of balanced feed per cycle reducing the unit cost and maximizing profits.

Table I. Economic results for production of tilapia using five feeding scenarios, with a balanced feed limitation of 1,125 kg per cycle

		Satiety	100BF	75CH	50CH	50BF
Cycle duration	Days	141	149	165	210	218
Harvest size	g	276.2	285.0	321.3	355.8	284.4
Biomass	MXP/cycle	744.3	767.2	863.1	950.0	759.9
Price	MXP/Kg	22.7	23.1	24.7	26.0	23.07
Total Income	MXP/cycle	16,881	17,718	21,300	24,699	17,530
Variable costs (VC)						
Fingerlings	MXP/cycle	2,436	2,436	2,436	2,436	2,436
Labor	MXP/cycle	1,692	1,788	1,980	2,520	2,616
Electricity	MXP/cycle	443	459	515	581	489
Balanced feed	MXP/cycle	8,922	8,923	8,926	8,980	8,998
Chaya	MXP/cycle			473	848	
Interest on VC	MXP/cycle	386	411	478	654	643
Total VC	MXP/cycle	13,879	14,017	14,772	16,019	14,539
Fixed cost	MXP/cycle	2,804	2,804	2,804	2,804	2,804
Total costs	MXP/cycle	16,683	16,821	17,576	18,823	17,986
Profit	MXP/cycle	198	897	3,724	5,876	-456
Unit costs	MXP/cycle	22.4	21.9	20.4	19.8	23.5

The simulation also indicated that culture cycle duration is longer in the scenario 50CH than 100BF and satiety. Chaya does not have all the nutritional elements contained in balanced feed and therefore the organisms would require more time to reach a given weight. The longest cycle for 50CH directly influences variable costs, labor is specially incremented as well as energy by a 20.7% and 14.4%, as compared with 100BF and 25.9% and 19.4% with respect to the satiety scenario. However, with the same amount of balanced feed/cycle 50CH achieves greater harvest sizes. Long culture cycles entail risks because during this time the water temperature can fluctuate considerably, having a direct impact on the daily survival and FCR.

Given the above, use of chaya as a partial substitute for balanced feed can substantially reduce tilapia production costs by significantly decreasing use of balanced feed, and maximize profits when this resource is limited, a common characteristic in developing countries. These results are potentially applicable in regions where chaya is produced, such as Mexico, Central America, South America and some Asian countries.

CONCLUSIONS

Tilapia culture in the rural zones of developing countries requires strategies that promote improved performance. Producers frequently undertake tilapia culture only part-time, often do not have the resources to buy inputs and therefore need alternatives. Tilapia feeding in semi-intensive systems in poorer communities can benefit from the use of complementary inputs such as chaya. The present results indicate that tree spinach leaves can be used to replace balanced feed in small-scale tilapia culture at a level up to 50 %, with a concomitant reduction in production costs. According to results from Marginal Rate of Technical Substitution, it is necessary to add 2.51-3.91 units of chaya for each reduced unit of balanced feed, to maintain the same level of production. Achieving biggest harvest sizes when the commercial feed is limited, maximizing profits. In Yucatan, the warm season should be thoroughly exploited since lower unit costs are generated during this season, using only balanced feed or in combination with chaya. The feeding to satiety and with half-complete rations must be avoided, since it offers the greater unit costs of production. These results are potentially applicable in regions where chaya is produced, such as Mexico, Central America, South America and some Asian countries.

APPENDIX A

The Marginal Rate of Technical Substitution (*MRTS*)

The isoquant was developed using the tilapia feed intake data for the 100BF, 25CH and 50CH experimental diets

$$MRTS\ x_2\ \ for\ x_1 = \frac{\Delta x_2}{\Delta x_1} \qquad \text{(Eq. 1)}$$

Biological sub-model

$$W = W\infty * \left(1 - e^{-k*(t-t_0)*(\theta)}\right)^3 \qquad \text{(Eq. 2)}$$

Where:
W is average organism weight,
$W\infty$ is asymptotic organism weight,
k determines growth rate, t is time (in days),
t_0 is a theoretical value representing the day on which the fish had a weight of 0,
θ is estimated mean water temperature, calculated as follows:

$$\theta = \left[\alpha + \beta_1 * Sin(2 * \frac{\pi}{365} * (t' - \gamma)) + \alpha + \beta_2 * Cos(\frac{\pi}{95} * (t' + 9 - \gamma))\right] / 2 \qquad \text{(Eq. 3)}$$

α is mean temperature,
β is variance,
γ is seasonal phase and
t' is the stocking date (1-365).

Management sub-model

In order to calculate the variation in the rate of survival according to the water temperature, data of survival to 24ºC were used [17]. System biomass (B_t) during culture was estimated using individual fish weight and the total number of fish:

$$B_t = W_t * N_{t_{-1}} * S_{V\,t} \qquad \text{(Eq. 4)}$$

N_{t-1} is the number of fish in the time -1, starting to count from N_0 (the number of fish initially stocked)
S_{Vt} is the variable daily survival rate (%/day). The variable daily survival rate depends on a fixed rate of survival and the water temperature, when the water temperature (θ) is lower than 25 ºC, the *Svt* falls:

$$S_V = \left[(\theta_R - \theta) * -\delta\right] + S_F \qquad \text{(Eq. 5)}$$

θ_R is the reference temperature (25 ºC),
δ is a change factor
S_F is a fixed rate of survival at 25 ºC.

In the same way, the percentage of daily feed offered (*feed%*) is based on the strategy of feeding, the weight of the fish and the water temperature

$$feed\% = (\varphi_A * W_t^{\varphi_B}) * (r) + \left[(\theta_R - \theta) * \varphi_C)\right] + \Gamma \qquad \text{(Eq. 6)}$$

Where:
r is the ration size in each treatment (0.5, 0.75, 1 and 1.12),
φ_A, φ_B, and φ_C are parameters
Γ is the adjustment factor

The consumed feed is from the FCR

$$FCR = \frac{\sum_t^0 (B_t * feed\%)}{B_t - B_0} \qquad \text{(Eq. 7)}$$

Consumption of chaya was calculated by multiplying the *TMST* of 50CH and 75CH, by the differences in consumption of feed (*feed%*) of the complete ration 100BF (r =1), with respect to 75CH (r = 0.75) y 50CH (r = 0.50).

Intake at time t (I_t) of balanced feed and chaya was calculated based on the feed conversion ratio (*FCR*), biomass (B_t) and expected change in individual weight:

$$I_t = \sum_{t=0}^{t} FCR * B_t \qquad \text{(Eq. 8)}$$

Economic sub-model

Fixed Costs (*FC*) were based only on depreciation of the tank and pump equipment, and included interest on investment. Variable Costs (*VC*) were generated from initial stocking (i.e. beginning of the culture cycle) to harvest:

$$VC_t = \sum_{t=0}^{t}\left[\left(Lc_t + Ec_t + Fdc_t\right) + (fc * N_0)\right] * (i) \qquad \text{(Eq. 9)}$$

Lc_t is labor costs,
Ec_t is electricity costs,
Fdc_t is feed costs,
fc is cost of fingerlings and
i is interest on Variable Cost (Discount rate). Feed costs (FC_t) included balanced feed and/or chaya, as the case may be. The Profits in the different treatments were calculated using a simple equation:

$$P = TI - (FC + VC) \qquad \text{(Eq. 10)}$$

P, is the Profits;
TI, is total income from tilapia sale;
FC, is fixed costs and
VC is variable costs.

The on-site wholesale price per kilogram (p/kg) of tilapia was calculated:

$$p/kg = \rho * (1 - e^{(\sigma * W_t)}) \qquad \text{(Eq. 11)}$$

ρ, is the maximum tilapia price,
σ is a constant and
W_t is the tilapia weight in g.

Von Bertalanffy function's parameters

Table AI. Growth and temperature function parameters according to feed input combination					
Growth parameters	Satiety	100BF	25CH	50CH	50BF
$W\infty$	650	650	650	650	650
k	0.0002658	0.0002662	0.0002732	0.0002456	0.0001872
t_0	-48.3177	-43.9578	-40.6143	-38.1751	- 53.5774
Temperature parameters (θ)					
α	26.78				
β_1	3.31				
β_2	1				
γ	170				

Statistics results

Table AII. Statistical results for each observed/simulated data combination, according to feed input combination

	Satiety	100BF	75CH	50CH
Theil *U* Coefficient	0.098	0.095	0.108	0.091
Mean (U^M)	0.000	0.000	0.000	0.001
Variance (U^S)	0.035	0.030	0.034	0.015
Covariance (U^C)	0.965	0.970	0.966	0.984

Table AIII. Assumptions used in bioeconomic analysis

	Unit measure	Amount
Water temperature	ºC	
Tank capacity	m^3	117.81
Stocking density	Fish/m^3	24
Initial weight	g/fish	8.7
Balanced feed restriction	Kg/Cycle	1,125
Costs:		
Fingerlings	MXP/fing	0.80
Balanced feed	MXP/Kg	8.00
Chaya	MXP/Kg	0.495
Labor	MXP/day	1.983
Electricity	MXP/day	4.00
Investment		
Tank, pump and accessories	$	25,200
Discount rate (*i*)	%	7.3
Survivor parameters		
Constant rate of survival (S)	%/day	99.9730
Survival factor change (δ)	Calibration	$7.1443*e^{-5}$
Reference water temperature (θ_R)	ºC	25
Feeding parameters		
φ_A	Calibration	0.11093
φ_B	Calibration	-0.33808
φ_C	Calibration	0.0056
Γ (Satiety)	Calibration	0.0009
Γ (100BF)	Calibration	0.0021
Γ (75CH)	Calibration	0.0035
Γ (50CH)	Calibration	0.0040
Γ (50BF)	Calibration	0.0060
Tilapia price parameters		
Maximum tilapia price (ρ)	MXP/kg	36
σ	Calibration	0.0036

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