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# **The Economics of Aquaculture with respect to Fisheries**

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# BIOECONOMIC EVALUATION OF SUBSTITUTION OF BALANCED FEED WITH CHAYA (CNIDOSCOLUS CHAYAMANSA) LEAVES IN TILAPIA PRODUCTION

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## Abstract

*In Mexico, the culture of tilapia has developed in rural areas, where the main problem is low producer income. The state of Yucatan also experiences this situation, and scarcity of money needed to purchase inputs results in complementary feeding with chaya (Cnidoscolus chayamansa), whose leaves are edible for humans and animals. In this situation, CINVESTAV conducted experiments to determine the optimal level of substitution of balanced feed with raw chaya leaves. The tests with 25% and 50% reduced balanced feed complemented with chaya (*ad libitum*) did not show significant differences ( $P>0.05$ ) in growth compared to fishes fed with a complete ration of balanced feed (100% feed table). A bioeconomic model was developed, including a submodel of growth according to observed results in each test. The model was developed in Excel, considering economic and management components. In addition, the analysis was completed using the Marginal Rate of Technical Substitution (MRTS) to evaluate cost minimization. According to the MRTS results, it is necessary to add 2.4 units of chaya for each reduced unit of balanced feed, in order to maintain the same level of production. Substituting 50% of the recommended ration (feed table) with chaya resulted in lower production costs, generating profit maximization.*

**Keywords:** Bioeconomic model; Cost minimization; Tilapia

**JEL clasification:** O13, Q22.

## Introduction

By production volume, tilapia culture is the second largest aquaculture system in use worldwide in sweet-water and is mostly done using semi-intensive systems in developing countries (FAO, 2000). As in most fish culture systems, balanced feed is one the most significant inputs in tilapia culture, and accounts for 30% to 60% of production costs (El-Sayed, 1990; Goddard, 1996; Tudor *et al.*, 1996). However, as has been proved in a number of nutrition studies (Belal and Al-Jasser, 1997; Diana, 1997; Olvera-Novoa *et al.*, 1998), tilapia are also able to feed on vegetables, grains, algae, zooplankton, etc.

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Substitution of fish meal in balanced feed has been vital to reducing feed costs, and thus overall tilapia production costs. Efforts have been made to reduce feed cost by substituting fish meal with a wide variety of vegetables and meats (Olvera-Novoa *et al.*, 1990; Olvera-Novoa *et al.*, 1997; El-Saidy and Gaber, 2003; Richter *et al.*, 2003). Feed producers have also done economic analyses of substitution to reduce costs and offer better prices for this aquaculture input.

The possibility of using complements or substitutes (e.g. algae, zooplankton and agricultural products) for balanced feed in tilapia production is especially important for rural communities in developing countries. Rural producers often cannot buy inputs for lack of resources or simply because supply is sporadic. However, more attention has been dedicated to reducing the amounts of fish meal to reduce balanced feed costs, and thus less study has been done of potential complements or substitutes.

Inclusion of new inputs in culture systems requires economic evaluation to determine maximum-revenue or lowest-cost production (Meade, 1989). This has been done for tilapia given balanced feed complemented with organic fertilization, which reduces production costs versus exclusive use of balanced feed with 27 to 58% replacement possible without significantly affecting production (Green *et al.*, 1990). However, minimizing aquaculture production costs can be done more precisely by searching for optimal substitutions and studying the relationship between them, as has been done for channel catfish (*Ictalurus punctatus*) and sea bream (*Sparus aurata*). Producing catfish to 500 g size substituting protein amount with ration size provides a potential range of choice ranging from 26.5% to 34.2% and 0.79 to 1 ration size, with a minimum cost at 200 g of protein and 651 g of feed (Cacho *et al.*, 1990). In sea bream culture the substitution of ration size by harvest weight to produce 350 g sizes is potentially from 25 to 100% and 1200 g at 350 days, and minimum cost is had at 370 days and a 0.85 ration size (León *et al.*, 2001).

Very little research has been done on the use of potential local inputs as partial substitutes for balanced feed (El-Sayed, 1999). In Mexico, local plant species such as the leafy bush known as chaya (*Cnidoscolus chayamansa*) have been used traditionally in animal and human diets. Studies show it to have higher protein content than spinach and a generally high nutritional value (Ranhotra *et al.*, 1998; Kuti and Kuti, 1999). Because of this high value and its low cost, it has been studied for use in poultry feed and shown to offer good economic results when included in poultry diets (Aguilar *et al.*, 2000). Its leaves have been processed into meal for use in pig feed with no affect on apparent digestibility and good growth (Parra-Canto, 2000). It has also been used in balanced combination with alfalfa for experimental tilapia diets, though these results were not compared with a control diet (Rosado-Vallado, 1985). Currently, it is used as tilapia feed in rural areas of the state of Yucatan, Mexico, by tying the stems together and offering the fish the fresh leaves. However, this has been

totally empirical, and nothing is yet known about the amounts that can be complemented or substituted, or its effect on growth or costs.

The present study addressed substitution of balanced feed by chaya leaves to minimize costs in tilapia production. The amount of balanced feed that can be substituted by chaya leaves was determined through laboratory experiments, a bioeconomic model was developed based on these data, and then technical, biological and environmental tilapia production scenarios were analyzed.

## **Materials and methods**

### *Data for analysis*

Data for the bioeconomic analysis came from an experiment done at the CINVESTAV-Merida aquaculture laboratory using chaya as a substitute for balanced feed in tilapia diets. Five diets were tested: 100% balanced feed (100BF), the control with no other complement; 100% chaya (100CH), with no other complement; 75% balanced feed (25CH); 50% balanced feed (50CH); and 25% balanced feed (75CH). The chaya proportion in the latter three treatments was offered *ad libitum*.

The balanced feed was Tilapia Chow (Purina) with 30% protein content. Daily rations were determined using the manufacturer's feeding table with the recommended amount treated as 100% (100BF). The 25CH, 50CH and 75CH treatments were calculated based in this amount, reducing the balanced feed proportion from the 100%, and the chaya proportion was offered *ad libitum*. Weight gain, feed conversion rate and survival were calculated for each treatment. Weight gain results were statistically analyzed with a one-way ANOVA at a 95% confidence level.

### *Culture system model*

The developed culture system model simulates tilapia production in rural areas of Yucatan, Mexico, where producers are primarily agriculturalists and engage in aquaculture part-time. These systems usually include a tank (117.81 m<sup>3</sup> average capacity) used for both aquaculture and irrigation. Juvenile stocking density is approximately 21.2 fish/m<sup>3</sup>. Feed is offered twice daily, and three times daily if resources are available, following the feeding table provided by the feed producer. Water changes are dependent on agricultural cycles and are not completely aerated. Survival at the end of a culture cycle is about 90%. No gradations are made during a cycle, so the fish remain in a tank until average size is 400 g; from one to two harvests are produced annually.

### *Bioeconomic model*

The tilapia culture bioeconomic model was based on the system described above, and includes biological, management and economic models. Daily individual tilapia growth was analyzed with the following function:

$$W_t = B0 + B1 * e^{(B2*t)} \quad (1)$$

where  $W$  is average organism weight,  $B0$ ,  $B1$  and  $B2$  are parameters, and  $t$  is time in days.

Production system biomass ( $B$ ) was estimated using the average individual weight and total number of organisms:

$$B_t = W_t * N_0 * e^{(S*t)} \quad (2)$$

where  $N$  is the number of fish initially stocked and  $S$  is the survival rate. Production costs ( $PC$ ) were generated from the beginning of culture cycle (i.e. moment of stocking) to harvest:

$$PC_t = \sum_{t=0}^t (Cm_t + Ce_t + CA_t) + Ca * N_{t=0} \quad (3)$$

where  $Cm_t$  is labor cost,  $Ce_t$  cost of electricity,  $CA_t$  feed cost and  $Ca$  cost of fingerlings. The feeding cost ( $CA$ ) includes balanced feed and/or chaya, as the case may be.

Farm profits ( $\pi$ ) are generated by the difference between the price of the fish at harvest (biomass) and production costs:

$$\pi_t = N_t * P_t * W_t - \sum_{t=0}^t (Cm_t + Ce_t + CA_t) + Ca * N_{t=0} \quad (4)$$

where  $P_t$  = price of tilapia.

## **Results and discussion**

### *Fish growth*

Modeling of tilapia growth under the studied assumptions was developed from an experimental database, discussed here briefly. Input substitution for tilapia was analyzed for 174 days (October 2001 to March 2002) using four experimental diets and one control, all applied in triplicate. The fish fed diets 100CH and 75CH had higher survival rates than those fed the control diet (100BF), suggesting that mortality was caused by handling and not feed type (Table 1). Weight gain results for the 100BF, 25CH and 50CH diets exhibited no significant differences ( $P>0.05$ ), while the 75CH and 50CH were different from these treatments. As the proportion of chaya increased and that of balanced feed decreased, FCR generally rose, suggesting that the diets including chaya did not have the same nutritional efficiency as the balanced feed.



**Table 1: Experimental Tilapia Growth and Feed Conversion Rate Results**

Parameter	Unit Measure	Diet				
		100B	25CH	50CH	75CH	100CH
Initial weight	(g)	8.7	8.6	8.7	8.7	8.7
Final weight	(g)	130.9	111.7	105.6	49.8	12.5
Weight gain	(g)	122.1	103.0	96.9	41.1	3.7
Survival	(%)	88.4	65.3	86.5	94.2	94.2
FCR	Ratio	2.3	3.6	4.5	4.1	31.9

Diets 75CH and 100CH resulted in low weight gain, which can be attributed to their lack of essential nutrients for tilapia growth. Further detailed research on nutrition and histopathology is needed to determine the role which chaya plays as a complement to balanced feed in tilapia growth.

#### *Bioeconomic analysis parameters and assumptions*

The model was simulated using the Excel program 7.0 (Microsoft Corporation 1995). Model assumptions were based on experimental, market and environmental data for the Yucatan Peninsula. The experimental data (25CH, 50CH and 100BF) were used to fix the growth model parameters, using the STATISTICA program (Table 2). The Theil statistic was used to evaluate discrepancies between the observed and simulated data, and produced acceptable values (Barlas, 1989; Power, 1993; Hernández *et al.*, 2003).

**Table 2: Growth Function Parameters by Feed Combination**

Parameter	Feed Combination		
	100B	25CH	50CH
$B0$	-162.8496	-129.4693	-131.5333
$B1$	146.7147	109.4159	115.5267
$B2$	0.00311	0.00327	0.00305
$R^2$	99.69	99.68	99.55

The bioeconomic analysis included the two annual water temperature cycles in Yucatan: cold (November to March) and hot (April to October). Data calibration for the hot season scenarios was done using experiments carried out in this season to generate growth results while accounting for water temperature. Labor costs were determined considering that the worker is occupied only part-time with the aquaculture system and uses most of his time for agricultural work. The cost of electricity was calculated assuming the use of motorized pumps in system water changes during the culture cycle. Input costs were established based on the commercial price of each one. Cost of the chaya was calculated using the labor needed to harvest and prepare it for use. Product

sale price was treated as on-site (Table 3). All the cost and prices (\$) are in Mexican Pesos (MP) (1 USD = 10.6 MP).

**Table 3: Tilapia Production Bioeconomic Analysis Assumptions**

Parameter	Units measure	Amount	
Season		Cold	Hot
Water temperature	°C	[18, 25]	[26, 32]
Tank capacity	M <sup>3</sup>	117.81	117.81
Stocking density	Fish/m <sup>3</sup>	21.20	21.20
Survival	%	90.10	90.10
Approximate production	Kg/cycle	900.00	900.00
FCR (100B)	Ratio	2.29	1.70
FCR (25CH)	Ratio	3.62	2.68
FCR (50CH)	Ratio	4.57	3.38
Harvest size	Kg/fish	0.40	0.40
Costs:			
Fingerlings	\$/fing	0.80	0.80
Balanced feed	\$/Kg	6.30	6.30
Chaya	\$/Kg	0.4386	0.4386
Labor	\$/day	1.3159	1.3159
Electricity	\$/day	4.00	4.00
Tilapia price	\$/Kg	22.00	22.00

### *Bioeconomic results*

The overall bioeconomic model consisted of biological, management and economic models. The biological model included a fish growth function which serves as the base of the model since it is directly interrelated with fish management, inputs and costs. The characteristics of this function when generating daily biomass, which is the production function, allow for a real analysis (Bjørnal, 1990).

A good example of analysis with the experimental results is production of tilapia fed the balanced feed/chaya combinations for 107 g average size. The basic assumptions, excluding harvest size, are shown in Table 4, and include the two seasonal scenarios.



**Table 4: Economic Results of 107 g Harvest Size Production**

Parameters	Unit measure	Diets					
		Hot Season [26, 32]°C			Cold Season [18, 25]°C		
		100B	25CH	50CH	100B	25CH	50CH
Cycle duration	Days	101	110	112	147	167	174
Biomass	Kg /tank	255	255	255	247	244	243
FCR	Ratio	1.7	2.67	3.37	2.29	3.62	4.57
Production cost	\$/cycle	5094	5032	4519	6188	6125	5464
Unit cost	\$/Kg	19.9	19.6	17.7	24.9	25.0	22.4

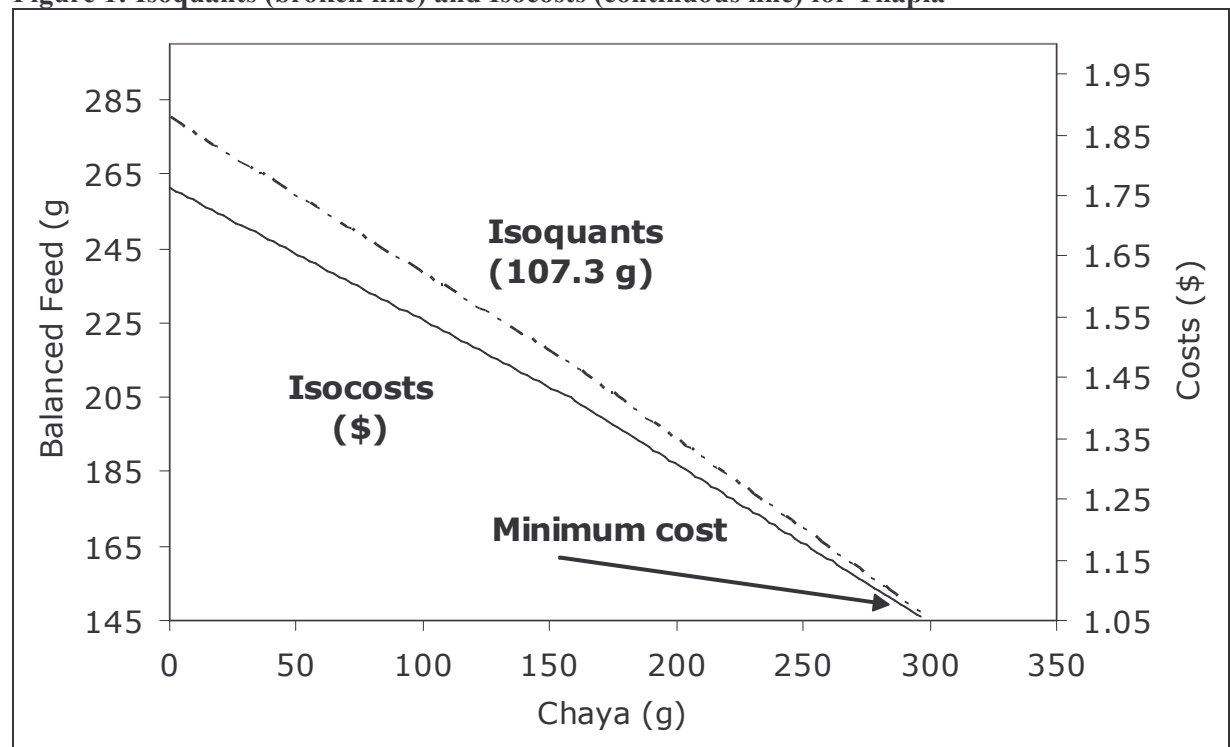
Water temperature has a clear effect on growth and biomass, with significant increases in culture days and FCR in the cold season, which directly affects costs. Harvesting 107 g sizes does not allow for decreasing yields to be reached which are needed to attain economic optimization (Curtis and Howard, 1993). Unit costs are higher than sale price during the cold season and lower during the hot season. Also, unit costs are generally higher when using balanced feed with no chaya complement, and decrease as chaya inclusion levels increase and the balanced feed proportion drops.

#### *Production isoquants and isocosts*

The isoquant and isocost curves show optimum inputs use and minimum cost. When analyzing inputs in a production system, the marginal rate of technical substitution (MRTS) provides a measure of the amount to be substituted of one factor versus another, if production is to remain constant (Pappas and Brigham, 1988). The isoquants curve was developed using tilapia feed intake data for the 25CH, 50CH and 100BF (control) treatments (Figure 1). This linear isoquant shows that these inputs function as perfect conditioned substitutes, the constant slope being an important characteristic. They are conditioned substitutes because they need at least 50% balanced feed for the diets including chaya to generate the desired growth. The MRTS for the 25CH treatment was 2.4 and that for the 50CH ranged from 2.4 to 2.06, meaning that these amounts of chaya must be added to replace each balanced feed unit to reach the 107.3 g size.

The isocost line is more horizontal than the isoquant line, indicating that the optimum choice is at the extremes of the lines, that is, a corner solution (Varian, 1999). This shows that the 50CH is the point at which costs are minimized when using both inputs (balanced feed and chaya) in tilapia production.

**Figure 1: Isoquants (broken line) and Isocosts (continuous line) for Tilapia**



### *Commercial size tilapia production*

Analysis of the substitution of balanced feed with chaya in production of commercial size (i.e. 400 g average weight) tilapia is potentially important in rural areas where chaya is grown, such as Mexico, Central America, the Caribbean, South America, Polynesia, Thailand and the USA (Sandoval *et al.*, 1991; Sarmiento-Franco *et al.*, 2003; Cámara-Cortazar, 2004). Among its other applications, chaya is seen as important in combating malnourishment in semi-arid tropical regions like some African countries (FAO, 1997).

The two seasonal scenarios were applied using the assumptions in Table 3. Cold season water temperatures last for seven months in Yucatan. Because the scenarios here are for comparative purposes, both possibilities are proposed. Production costs are significantly affected by BF when producing 400 g harvest size tilapia (Table 5) as this input accounts for the highest percentage within the production costs structure (76% in 100B; 71% in 25CH; 61% in 50CH) in both seasons. Consequently, other input costs such as fingerlings, electricity, chaya and labour account for a lesser proportion.

**Table 5: Bioeconomic Results of Tilapia Production during Hot and Cold Seasons**

Parameters	Unit measure	Diet					
		Hot Season [26, 32]°C			Cold Season [18, 25]°C		
		100B	25CH	50CH	100B	25CH	50CH
Cycle duration	Days	201	217	224	382	412	435
Biomass	Kg /tank	903	906	908	902	902	901
Sales income	\$/cycle	19879	19949	19987	19855	19848	19841
Production cost:							
Fingerlings	\$/cycle	2000	2000	2000	2000	2000	2000
Labor	\$/cycle	264	285	294	502	542	572
Electricity	\$/cycle	804	868	896	1528	1648	1740
Balanced feed	\$/cycle	9799	8868	6512	13273	11997	8789
Chaya	\$/cycle	0	462	908	0	626	1225
Total costs	\$/cycle	12868	12484	10611	17303	16814	14327
Net income	\$/cycle	7011	7466	9376	2552	3035	5514
Daily income	\$/cycle	34.8	34.4	41.8	6.6	7.3	12.6
Unit cost	\$/Kg	14.2	13.7	11.6	19.1	18.6	15.8

The lowest production cost is generated during the hot season with the 50CH combination, with a 18.3% drop in unit cost versus the 100BF treatment. This reduction results from the use of less balanced feed in the daily ration than is indicated in the manufacturer's feeding tables. The FCR is higher for this treatment since 66.7% of the ration is chaya. Because it is a vegetable, it has a higher fiber content and does not include all the nutrients essential to tilapia growth, resulting in a higher demand by the fish for this input. The 25CH combination has higher net income than the 100BF, also due to inclusion of chaya. However, daily income is higher with 100BF than with 25CH, which is explained by the fewer number of days needed to reach harvest size (400 g). The 25CH treatment requires 16 more days to reach harvest size, elevating labor and electricity costs and making the savings on balanced feed insignificant in comparison to the 50CH treatment.

The lowest production cost during the cold season is with the 50CH treatment, which is 17.2% lower than the 100BF treatment, consequently raising net income by 116% with the 50CH versus the 100BF. The 25CH treatment decreases production costs by 2.82% and increases net income by 19% versus the 100BF treatment. All the diets require more days to reach harvest size, considerably increasing FCR. This also causes daily income to be lowest with the 100BF treatment since this diet depends entirely on the most expensive input (balanced feed). Given this, substitution with chaya can be used to effectively counteract increases in production costs in the cold season as it lowers the amount of balanced feed used.

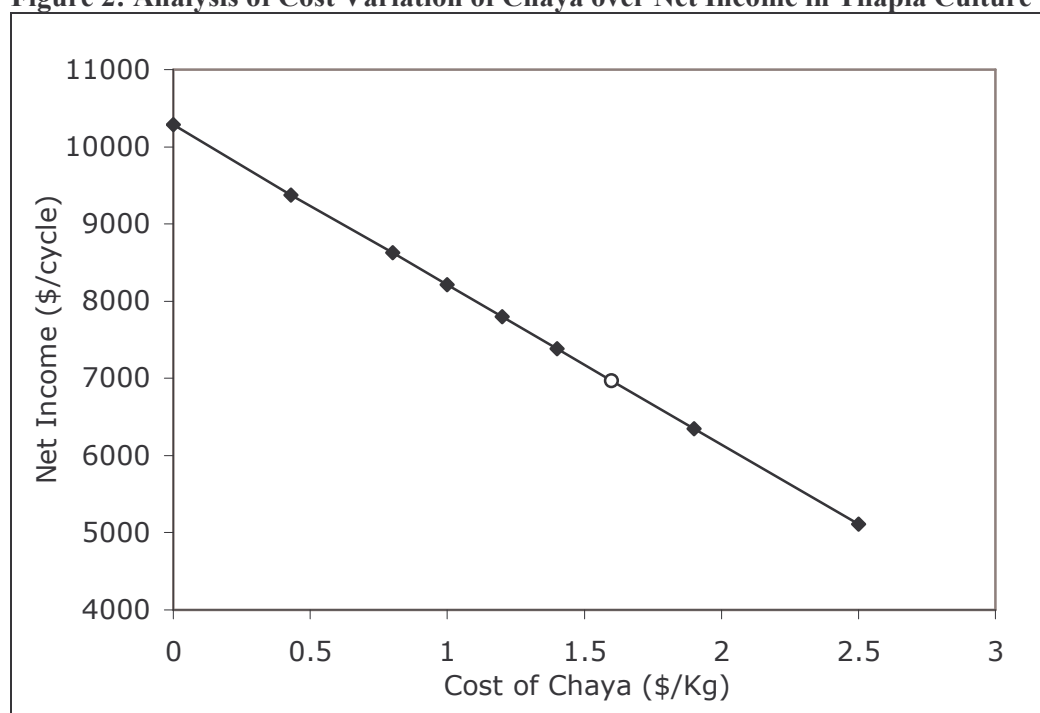
During the hot season, the 25CH, 50CH and 100BF diets all generate more net income than during the cold season (46%, 70% and 74%, respectively). This results from the time to harvest size being much less than during the cold season (from 181 to 211 days less), which lowers the amount of inputs used. Producers obviously need to take full advantage of the hot season's better water temperature conditions as they provide better results. Tilapia can also be grown during the cold season though production costs must be closely monitored to ensure profitability.

Finally, an analysis was done of the number of culture cycles that can be had over a 10-year period with each of the diets during the hot season. The 100BF diet allowed for 18.2 cycles and an income of \$127,329.20 MP, the 25CH diet provided for 16.8 cycles and an income of \$125,590.50 and the 50CH diet allowed for 16.2 cycles and an income of \$152,778.00. Cycle duration is a vital variable in tilapia culture and is closely linked to water temperature.

#### *Variations in cost of complementary input*

An analysis was done to determine the maximum cost that can be paid for chaya and still maintain an income greater than that generated when using the 100BF, all other costs being constant. Because it was shown to be the best option in the above analyses, the 50CH diet and its corresponding assumptions (Table 3) was used as the scenario. This diet is highly dependant on chaya (66.7% of ration) and is thus more susceptible to possible increases in the cost of chaya (Fig. 2). The cost of chaya that would make its use less feasible in tilapia production, versus the 100BF diet, was also determined.

**Figure 2: Analysis of Cost Variation of Chaya over Net Income in Tilapia Culture**



The maximum cost that can be paid for chaya and keep net income greater than when using the 100BF diet is 1.5 \$/Kg (Figure 2, unfilled circle). Use of balanced feed would be preferable if the cost of chaya surpasses 1.6 \$/Kg, a price only estimated for the 50CH treatment. This conclusion is valid when the 50CH combination is used and was done considering net income per culture cycle.

## Conclusions

Tilapia culture in rural areas of developing countries requires strategies for better performance. It is often done part-time by agriculturalists who do not have the resources to buy inputs and thus need alternatives. Tilapia feed in semi-intensive systems applied in poor communities allows the use of complementary inputs such as chaya. A study showed that use of this input is viable in combination with at least a 50% balanced feed ration based on feed producer recommendations. The balanced feed can be reduced to 50% of the daily ration, leading to reduced production costs. Chaya functions as a perfect conditioned substitute with a constant isoquant curve. The isocost line is more horizontal than the isoquant line and the optimum choice was a corner solution. A 50% reduction in balanced feed complemented with chaya *ad libitum* reduced production costs by 18.3% in the hot season and by 17.2% in the cold season, versus exclusive use of balanced feed. Maximum cost of the chaya to minimize tilapia culture production costs was 1.5 \$/Kg when used as a complement for 50% of the balanced feed. The results can be applied in regions

where chaya is grown, including Mexico, Central America, South America and some Asian countries.

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