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Technical and Economical Feasibility of On-farm Fish Feed Production Using Fishmeal Analogs*

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ABSTRACT

Ten experimental diets and one control diet were fed to 720 tilapia (20 fish × 12 cages × three replicates) in a recirculating aquaculture system to determine the economic significance of replacing fishmeal with fishmeal analogs if the fishmeal analogs were processed on-site by the producer. All experimental diets were produced at Illinois State University using an Insta-Pro Model 600 Jr. extruder plus grinding, weighing and mixing equipment commonly found on commercial livestock operations. Primary diet protein sources included corn gluten meal, corn gluten feed and distillers dried grains. All diets were balanced for amino acid requirements of the fish, and both 32 and 36% crude protein diets were fed. There was no significant difference in feed conversion ratio (FCR) between diets with fishmeal and diets without fishmeal. There was no significant difference in FCR between 32 and 36% crude protein diets. An economic engineering model which included all equipment necessary for extruding and handling pelleted feed on-site was developed. Annualized investment and operating costs were estimated to determine the total cost of processing each of the 10 experimental diets. There was a significant difference in cost of gain among the 10 experimental diets and the control diet. Cost of production was highly sensitive to volume of feed extruded.

*Mention of a proprietary product or a vendor does not constitute a guarantee or warranty of the product by Illinois State University or the U.S.D.A. and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

INTRODUCTION

A primary factor in the profitability of tilapia production is the cost of feed which may account for 20–40% of production costs. Sources of protein in fish feed include animal sources, typically fishmeal, and plant sources such as corn and soybeans. Both fishmeal and grain-based rations provide adequate sources of protein for tilapia produced in recirculating systems; however, plant protein sources, especially grain by-products, may prove more cost effective. Additional research and economic analysis are needed to determine if tilapia producers who feed fish in recirculating systems can decrease feed costs and increase net income by processing their own corn and soybean-based rations using an extrusion process.

Biological studies of fish nutrient requirements, including protein requirements, are numerous (Cacho *et al.*, 1990; Clark *et al.*, 1990; Davies *et al.*, 1990; Hughes, 1991; Lim *et al.*, 1993; Moshen and Lovell, 1990; Olvera-Novoa *et al.*, 1990; Shiau and Huang, 1990). On the other hand, studies of the economics of protein sources, particularly for tilapia produced in recirculating systems, are scarce. Research on the growth effects of plant proteins vs. fishmeal in fish diets seems to indicate that soybean meal, corn and grain by-products can be substituted for fishmeal as long as sufficient amino acids are provided. If all protein is provided by soybean meal, for example, the diet may be deficient in methionine, cystine or threonine (Lovell and Smitherman, 1993) and should be supplemented with more expensive synthetic amino acids. Distillers dried grain, on the other hand, is low in lysine. Consideration must also be given to the impact of diet ingredients on the appearance of the final product and appeal to consumers. For example, corn should not exceed 35% of diet composition because it is high in xanophyll and creates a yellow color in the flesh (Lovell and Smitherman, 1993).

Tacon *et al.* (1983) studied the effects of replacing 75% of the brown fishmeal in a diet with puffed full-fat soybean meal supplemented by 0·5% DL-methionine when fed to *Oreochromis niloticus* fingerlings and fry. The soybean diet provided the same growth and feed conversion ratios as the fishmeal diet, but body fat percentage was higher with the soybean diet. Researchers in Taiwan (Shiau *et al.*, 1987) substituted commercial hexane-extracted soybean meal for fishmeal in a 32% protein diet and concluded that growth and feed conversion were reduced significantly when the diet was fed to tilapia without methionine supplementation. Methionine was sufficient in a 24% protein diet, but 24% protein is sub-optimal in a tilapia diet and is not commercially feasible. Subsequent research indicated that full-fat soybean meal can be substituted for blue whiting fishmeal in a low (24%) protein diet fed to tilapia fingerlings for 9 weeks (Shiau *et al.*, 1990). Researchers concluded that further study of soybean meal as a replacement for fishmeal in the grow-out stage of tilapia is essential. Keembiyehetty and De Silva (1993) concluded that approximately 33% of fishmeal in test diets could be replaced with cowpea and black gram seed without any adverse effect on the growth rates of *Oreochromis niloticus* (L.). Robinson (1990) stated that practical feeding studies of fish under commercial growing conditions are scarce because of excessive capital investment requirements and lack of appropriate facilities. He emphasized a need for more nutritional data from practical research.

Tilapia producers should have greater flexibility in diet formulation and reduced feed costs if they process their own feeds on-site using an extruder and locally available grains and soybeans. Livestock farmers in the Midwest began adopting extruders in the 1960s to take advantage of plentiful supplies of soybeans and feed grains (Said, 1992). The impacts of various extrusion and non-extrusion processes on nutritional content of feed and growth rates of livestock have been documented (Hancock *et al.*, 1991a, b; McNab, 1989; Newcomb *et al.*, 1988; Sell, 1984; Socha and Satter, 1991; Waldroup, 1985; Waldroup and Hazen, 1978; Wiseman, 1983). These studies focused almost exclusively on biological aspects and did not address the impact of processes on cost of production.

Applications of extrusion technology in the aquaculture industry have been limited mainly to commercial operations that manufacture feed for aquaculture producers. The economic benefits of extrusion for some aquatic species is known, however. Shrimp feeds, for example, can be produced more cheaply with an extruder because the extrusion process requires fewer 'starch-bearing' ingredients than pelleting, and lower cost plant proteins can partially replace the starch bearing ingredients and fishmeal in the formulation. The average protein content of shrimp feed can be reduced from 60% with pelleting to 50% with extrusion. Extrusion also increases the digestibility of raw materials and increases the water stability of shrimp feed (Kearns, 1989).

MATERIALS AND METHODS

Biological analysis of rations

Seven hundred and twenty sub-adult tilapia weighing 30·0 ± 0·4 g were placed into 36 polyethylene mesh cages each measuring 0·61 ×

0·61 × 1·22 m. The sides and tops of the cages consisted of 1·91 cm mesh, and the bottoms consisted of 0·32 cm mesh covered with a solid piece of plastic. The cages were suspended into the culture water of an 18 500 liter, modified Red Ewald-style recirculating system at the Illinois State University farm.

Three replicates of fish were fed one of 10 experimental diets and six replicates of fish were fed a commercial control diet for 103 days (26 March–6 July 1993). Prior to the trial, the fish were conditioned on a 36% crude protein, 0·62 cm floating pellet commercial ration developed for recirculating systems. During the trial, fish were fed twice daily at a rate of 3% of body weight or as dictated by water quality conditions. Weight of feed fed was recorded daily, and total weight of fish in each cage was recorded every 2 weeks.

The 10 experimental diets were produced at Illinois State University using a Model 600JR INSTA-PRO Extruder capable of producing 272–365 kg of extruded product per hr. Prior to the beginning of the feeding trial, the extruder was adjusted to produce a satisfactory extruded pellet feed. Extruded pellets were air-dried overnight at room temperature to reduce moisture content to 7–9%. Diets were stored in a freezer prior to feeding to assure consistent quality throughout the trial.

Experimental diets contained varying combinations of plant and animal proteins (Table 1). Corn gluten meal, corn gluten feed and distillers dried grains were obtained from Brown-Forman Corp. (Louisville, KY). Soy flour and soy oil were obtained from Archer Daniels Midland Corp. (Decatur, IL). Menhaden fishmeal and menhaden fish oil were obtained from Zapata Haynie Corp. (Hammond, LA). Soy lecithin was obtained from Riceland Foods, Inc. (Stuttgart, AR), and yellow corn was obtained from a local commercial source. All diets contained 51% protein soy flour for convenience in processing. Soy lecithin, a co-product of soy oil extraction, was included in two diets to investigate the previously unknown effects of lecithin on tilapia growth.

Utilizing ingredients in Table 1, all diets were balanced for amino acid requirements of tilapia (National Research Council, 1983; Santiago, 1985). Nutritional composition of ingredients, nutritional composition of each diet (Table 2), and amino acid balance of each diet, including the control diet, were determined by the U.S.D.A. National Center for Agricultural Utilization Research in Peoria, Illinois.

All experimental diets contained vitamin pre-mix for warm water fish from Hoffman-LaRoche (Paramus, NJ) and catfish trace mineral

TABLE 1
Ration Formulations[a] and Costs of Ingredients

Ingredient	Ration code[b]										cost ($)/kg[c]
	361	361L	362	363	321	321L	322	323	325	326	
Yellow corn	35	35	25	18	42	42	25	25	25	23	0·093
Corn gluten meal	18	18	16		16	16					0·358
51% protein soy flour	40	40	39	56	35	35	52	46	43	35	0·240
Corn gluten feed			13				16		19		0·094
Distillers dried grains				19				22		29	0·138
Fishmeal (menhaden)									6	6	0·452
Soy oil	2	1	2	2	2	1	2	2	2	2	0·573
Fish oil (menhaden)	2	2	2	2	2	2	2	2	2	2	0·507
Soy lecithin[d]		1				1					0·600
Vitamin/mineral mix	3	3	3	3	3	3	3	3	3	3	0·948

[a]Percent of ration by weight. [b]Ration codes beginning with 36 and 32 represent 36 and 32% crude protein rations, respectively; L indicates that a ration contained lecithin. [c]Prices quoted on 8 December 1993 and printed in 13 December 1993 issue of *Feedstuffs*. [d]Liquid lecithin with soybean oil.

TABLE 2
Nutritional Composition of Experimental Diets[a]

Diet	Dry matter	Crude protein	Fat	Crude fiber	Total ash
361 and 361L	89·4	35·9	5·9	2·4	3·3
362	89·4	35·9	5·8	3·1	3·9
363	90·0	36·1	6·8	3·8	4·3
321 and 321L	88·8	32·4	6·0	2·4	3·1
322	89·7	32·4	5·8	3·6	4·6
323	89·9	32·2	7·2	4·0	3·9
325	89·8	31·9	6·4	3·5	5·4
326	90·1	31·9	8·2	4·2	4·6

[a] Percent as fed basis.

pre-mix from Triple F Products (Des Moines, IA). The vitamin and mineral pre-mixes provided the following per kg of diet: vitamin A, 9900 international units (IU); vitamin D, 2200 IU; vitamin E, 82·5 IU; vitamin B_{12}, 0·014 mg; riboflavin, 18·2 mg; niacin, 107 mg; pantothenic acid, 37 mg; choline, 715 mg; folic acid, 6·1 mg; biotin, 0·17 mg; ascorbic acid, 220 mg; menadione (K_3), 9 mg; thiamine, 16·2 mg; calcium, 4·3 g; phosphorous, 2·6 g; copper, 5·0 mg; iron, 41 mg; manganese, 120 mg; zinc, 115 mg; iodine, 2·5 mg; cobalt, 1·0 mg; and sulfur, 153 mg. The control diet was a 36% crude protein commercial fish ration which contained soybean meal, fishmeal, wheat middlings, blood meal, feather meal, fish oil, and vitamin and mineral mix.

Biological filtration in the system was provided by an aerated, submerged fixed film 2·7 m^3 vertical screen filter with eight screens and 328·6 m^2 total surface area. The biological filter was housed in a fiberglass tank 1·22 m wide × 1·22 m deep × 2·44 m long. Filter plates were made of perforated fiberglass covered with two layers of polyethylene mat. Oxygenation was provided by a 1·12 kW (1·5 hp) blower which was also used to power airlift pumps for water movement. A second water circuit was installed in the system to pump water through an oxygen cone. Oxygen was injected into the tank through the oxygen cone from a liquid oxygen tank which was powered by a 0·56 kW pump. Solids were separated into a PVC-lined wooden settling tank 1·22 m wide × 2·44 m long × 0·61 m deep. Water in the settling tank had a 6-min retention time.

Water temperature, dissolved oxygen (DO) and pH were recorded daily. Total ammonia-N (TAN), un-ionized ammonia and nitrite-N (NO_2) concentrations were recorded four times per week. Alkalinity, and concentrations of nitrate-N (NO_3), phosphorous and carbon dioxide (CO_2), were recorded weekly.

At the conclusion of the feeding period, a feed conversion ratio (feed fed in g/biomass increase in g) was calculated for each cage. One-way analysis of variance was used to determine statistical differences among diets at the 5% level of significance.

Economic analysis of rations and ration processing

An economic engineering model was developed to determine the cost of extrusion processing for the various diets fed during the trial. The objective was to determine the potential reduction in cost for tilapia producers who processed locally available plant proteins on-site. All equipment and structures necessary to extrude feed, handle raw ingredients, and handle and feed processed rations were included in cost analysis. Cost data were prepared from price information and estimated operating costs provided by vendors, and data collected from 80 hr of extruder operation at Illinois State University (Tables 3 and 4). The extruder was assumed to operate at a rate of 272 kg/hr and produce 90·7 tons (100 short tons) of feed per year, which would represent output for a tilapia producer of moderate size in the Midwest. Depreciation was calculated using the straight-line method over the estimated life of depreciable assets; the amount depreciated

TABLE 3
Investment and Annual Costs for Extrusion System, Equipment and Structures

Item description	Initial investment ($)	Estimated life (years)	Salvage value 5 years ($)	Annual repair and maintenance ($)	Annual SL depreciation ($)	Annual interest on investment[a] ($)
7-ton bins (3)[b]	4410·00	15	0·00	100·00	294·00	154·35
Grinder/mixer	4500·00	10	500·00	500·00	400·00	157·50
Extruder[c]	19 200·00	10	2000·00	1200·00	1720·00	672·00
Drier	4000·00	15	500·00	500·00	233·33	140·00
Auger wagon	2500·00	15	200·00	500·00	153·33	87·50
12-ton bulk bin (1)	4000·00	15	0·00	200·00	266·67	140·00

[a]Calculated at 7% per annum. [b]Bin volumes are stated in short tons. [c]Includes $18 000 for extruder and $1200 installation costs.

TABLE 4
Fixed and Variable Costs for Items other than Equipment, Structures and Feed Ingredients

Cost category	Price/unit	Units per ton of feed	Units per hour	Units per year	Cost per year ($)
Water	$0·0005/liter	27·82	7·57	2523·58	1·33
Electricity	$0·07/kWh	202·09	55·00	18 333·33	1283·33
Labor wages	$10·00/hr	3·67	1·00	333·33	3333·33
Labor fringe benefits	23% of wages				766·67
Property insurance					200·00
Property tax					100·00
Interest on operating capital	7% × non-depreciation expenses				Variable[a]
Miscellaneous expenses	1% × cash expenses				Variable[a]

[a]These costs vary directly with the cost of feed ingredients.

was equal to original cost less estimated salvage value. The opportunity cost of capital was included at 7% since the addition of extrusion equipment to an existing firm producing tilapia in a recirculating system would not significantly add to the firm's risk and could possibly reduce total firm risk.

Per unit prices of feed ingredients (Table 1) are subject to variability over time and across geographic regions. Specific prices utilized were Chicago cash prices quoted on 8 December 1993.

TABLE 5
Costs per Ton of Prepared Feed ($)

Ration code	Fixed costs	Variable costs excluding feed ingredients	Feed ingredients	Total costs
361	68·54	85·26	242·88	396·69
361L	68·54	85·91	266·25	420·71
362	68·54	85·07	236·25	389·87
363	68·54	84·83	227·30	380·68
321	68·54	84·91	230·17	383·64
321L	68·54	85·55	253·55	407·66
322	68·54	84·43	212·98	365·96
323	68·54	84·45	213·88	366·89
325	68·54	84·66	221·28	374·49
326	68·54	84·69	222·36	375·60

Estimated total processing and handling costs for all experimental rations are provided in Table 5. Fixed costs include depreciation, maintenance of equipment and structures, property insurance, property tax and interest on investment. Variable costs, excluding feed ingredients, include labor wages, labor fringe benefits, water, electricity, repairs of equipment and structures, miscellaneous expenses, and interest on operating capital.

The impact of feed production volume on cost per ton of feed was analyzed. One-way analysis of variance and Duncan's multiple range test were utilized to determine differences in cost of gain [(feed fed in g $\times$ cost of feed per kg)/(biomass increase in g)] among diets at the 5% level of significance.

RESULTS AND DISCUSSION

Biological analysis of rations

There were no significant differences (5% level) in feed conversion ratios (FCR) among the 11 diets (Table 6). Average ($\pm$ standard error) weight per fish at the end of the trial was 134·7 $\pm$ 12·7 g compared to 30·0 $\pm$ 0·4 g at the beginning of the trial. Average biomass increase per cage was 1959·4 $\pm$ 301·9 g, and average feed fed per cage was 5587·7 $\pm$ 609·8 g. Average FCR per cage was 2·9 $\pm$ 0·3. Average number of fish per cage from 26 March to 6 July was

TABLE 6
Feed Conversion Ratios (FCR) and Costs of Gain

Ration code	FCR[a]	±	SEM[b]	Cost of gain[cd]	±	SEM[b]
Control	2·88	±	0·22	1·30[e]	±	0·10
Control	2·82	±	0·17	1·27[e]	±	0·08
361L	2·90	±	0·35	1·22[ef]	±	0·15
321	3·16	±	0·54	1·21[ef]	±	0·21
361	3·05	±	0·13	1·21[efg]	±	0·05
362	3·03	±	0·08	1·18[efgh]	±	0·03
321L	2·83	±	0·18	1·16[efgh]	±	0·07
323	2·92	±	0·42	1·07[fgh]	±	0·15
363	2·77	±	0·15	1·05[fgh]	±	0·06
326	2·79	±	0·25	1·05[fgh]	±	0·10
325	2·70	±	0·10	1·01[gh]	±	0·04
322	2·70	±	0·14	0·99[h]	±	0·05

[a]Feed fed in g/biomass increase in g. [b]SEM = standard error of the mean. [c](Feed fed in g × cost of feed per kg)/biomass increase in g. [d]Values in column with different superscripts are statistically different at 5% level.

TABLE 7
Water Quality Parameters

Measure	No. of observations	Mean	±	SEM[a]	Maximum	Minimum
Temperature (°C)	97	27·07	±	0·09	30·20	25·60
DO (mg/liter)	97	10·30	±	0·23	16·70	2·40
pH	97	7·11	±	0·01	7·50	6·59
TAN (mg/liter)	63	2·47	±	0·14	7·65	1·24
Un-ionized ammonia (mg/liter)	63	0·024	±	0·004	0·208	0·002
NO_2 (mg/liter)	63	1·70	±	0·17	7·18	0·37
NO_3 (mg/liter)	13	142·00	±	16·3	222·00	32·00
Alkalinity (mg/liter)	13	176·90	±	10·58	220·00	110·00
Phosphorous (mg/liter)	13	89·01	±	19·10	268·00	31·00
CO_2 (mg/liter)	13	22·26	±	1·38	29·55	11·70

[a]SEM = standard error of the mean.

18·7 ± 1·6. Water quality parameters remained within acceptable ranges for commercial production in a recirculating system throughout the trial (Table 7).

FCRs from the trial exceeded commercially accepted standards for undetermined reasons. Poor palatability of experimental diets has been ruled out since there was no significant difference in FCR between commercial and experimental diets. Mesh cage design could have allowed some feed to be lost into the culture water outside the cages. Future trials will compare FCR for fish fed in aquaria with FCR for fish fed in suspended cages to determine the impact of cage design.

Economic analysis of rations

There were significant differences (5% level) in cost of gain among the 11 diets (Table 6) when the commercial ration was analyzed at its actual cost of $451·82 per ton. These results indicate that there can be a significant economic difference between purchasing and feeding a commercially prepared ration and on-site processing and feeding of locally available grains and grain by-products. Of the five experimental diets that did not differ significantly from the commercial diet (361, 361L, 362, 321 and 321L), all contained corn gluten meal and two contained soy lecithin. Alternatively, of the lowest cost diet (322) and the six experimental diets that did not differ significantly from the lowest cost diet (362, 363, 321L, 323, 325, 326), three contained corn gluten feed and three contained distillers dried grains. Corn gluten meal and soy lecithin did not appear to be economically beneficial at prices utilized in the analysis, whereas corn gluten feed and distillers dried grains did appear to be economically beneficial. Soy flour is more expensive per ton than 44% protein soybean meal; however, the quantity of soybean flour present was not a critical factor in the relative cost of diets.

The total processing and handling costs for the 10 experimental diets (Table 5) ranged from $366 per ton (322) to $421 per ton (361L). These figures are in contrast to commercially prepared rations suitable for tilapia which can cost $450 per ton. On the other hand, local feed processors have quoted prices for bulk-delivered, custom processed tilapia rations ranging from $340 to $353 per ton. Given the comparability of the latter prices to the cost of on-site processing, scale of production was an important factor to analyze.

When total volume of production for the low cost diet (322) was allowed to vary from 90·7 tons (100 short tons) to 544·3 tons (600 short tons) per year, cost per ton processed ranged from $366 per ton to $294 per ton (Fig. 1). Between production of 90·7 tons and 181·6 tons, there was a substantial decrease in cost from $366 per ton to $321 per ton. At 181·6 tons per year, tilapia producers would accrue feed costs below the competitive prices offered by local feed

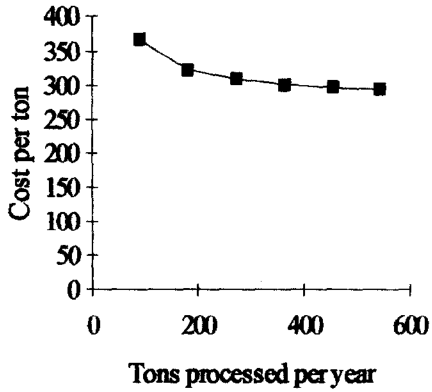

Fig. 1. Volume of feed processed and cost per ton in dollars.

processors. Few tilapia producers, however, would be able to take advantage of the economies of scale available at 544·3 tons. Lovell and Smitherman (1993) have estimated that the entire weight of feed fed to tilapia in the US in 1990 was 2778 tons, and 544 tons represents almost 20% of that amount.

CONCLUSIONS

Depending upon the cost of commercial feed, prices of feed ingredients and scale of production, tilapia producers may be able to reduce feed costs by utilizing locally available plant proteins and on-site extrusion processing. Feed conversion ratios were not significantly affected when fishmeal was replaced with combinations of corn, corn gluten feed, corn gluten meal, distillers dried grains and soy flour. There was a significant difference in cost of gain among commercial and experimental diets when cost of extrusion was included as a component of feed cost. Lower cost diets contained varying amounts of distillers dried grains and corn gluten feed, whereas higher cost diets contained varying amounts of corn gluten meal and soy lecithin. Cost per ton of feed was affected by annual feed output; therefore, substantial cost reductions can be realized by increasing the scale of production.

Application of results to other geographic areas will require adjustment for availability and cost of plant proteins. Producers who will be required to make a substantial investment in long-lived assets should analyze the risk of the investment over its expected life using simulation analysis.

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