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RELEVANCE OF A RAPID APPRAISAL APPROACH TO IDENTIFY LOCALLY AVAILABLE FEED INGREDIENTS TO SMALL-SCALE NILE TILAPIA (*Oreochromis niloticus* L.) AQUACULTURE

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☐ *Applications of a rapid appraisal approach to identify locally available feed ingredients in feed formulation, production, and socio-economics of Nile tilapia aquaculture in Bangladesh are discussed. Three diets of 35%, 30%, and 25% crude protein were formulated using locally available ingredients, and their essential amino acid profiles were assessed for Nile tilapia. Six production scenarios were constructed using these diets and two culture periods of 100 and 150 days were considered. The production scenarios with 35% protein yielded the highest productivity and profitability over the 150-day culture period followed by the 30% protein scenario. Identification of locally available ingredients and their application in small-scale Nile tilapia aquaculture may lead to: (1) increased availability of inexpensive sources of fish production for poor people; (2) increased fish consumption; (3) increased self employment and involvement of women in productive activities; and (4) increased household income to reduce poverty.*

Keywords Bangladesh, feed formulation, local ingredients, Nile tilapia, poverty alleviation, rapid appraisal, socio-economics

INTRODUCTION

Nile-tilapia (*Oreochromis niloticus*) has long been known to aquaculturists as a species that can adapt to many environments and culture systems. It has also become well known to fish consumers across the world. Recent statistics show that tilapia is cultured worldwide in over 100 countries (FAO, 2004). They can be raised in a wide range of production systems from

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small-scale, low-input, rural ponds to large-scale, intensive, and commercial operations (Chowdhury et al., 2006). Tilapia has the potential to be the tropical fish of choice to meet the future demand for animal protein for marginal populations (Little et al., 1994), and to improve the livelihood of resource-poor farmers and rural women (Chowdhury & Rahman, 1998; Brugere et al., 2001).

The commercial feeds are cost-intensive and often beyond the capacity of small-scale farmers, as such feed comprises more than 60% of the production costs of a farming operation (Chowdhury, 1997; Brugere et al., 2001; Edwards & Allan, 2004). Alternatives to high cost commercial diets have been investigated, and include: (1) periphyton-based systems in cages (Huchette & Beveridge, 2002), (2) fertilization, and (3) use of aquatic plants e.g., *Lemna* sp., green vegetables and rice bran as supplemental feed (Morrice, 1998). However, low growth of Nile tilapia and of the filter feeding fishes (Indian and Chinese carps) in these systems observed raise questions regarding feasibility of these technologies to alleviate poverty through income generation (Azim et al., 2004).

Another alternative to reduce cost without sacrificing productivity is to prepare a diet compatible to commercial feed using locally available ingredients (Chowdhury & Bureau, 2006; Chowdhury et al., in press). A combination of low-cost diet and feed optimization techniques could provide farmers with an effective tool to minimize cost and reduce dependency on external resources. Therefore, it is important to develop a method to identify locally available feed ingredients that could be used to formulate a diet for Nile tilapia aquaculture. Rapid appraisal methodologies have been widely used in techno-socio-economic studies related to aquaculture and fisheries (Ofori & Prein, 1996; Pido et al., 1997; Chowdhury & Yakupitiyage, 2000; Pitcher & Preikshot, 2000) and recently, to identify locally available ingredients for cage aquaculture (Chowdhury & Bureau, 2006; Chowdhury et al., in press).

Objectives of this study are to: (a) formulate three low-cost diets of different protein content from locally available ingredients identified through a rapid appraisal process; (b) assess the ability of these ingredients to meet the nutritional requirements of Nile tilapia; and (c) compare the economic benefits of different production scenarios based on these three formulated feeds. This article . . . the study with "This article is organized into six sections including introduction. Other sections are: description of the rapid appraisal process; identification of locally available feed ingredients; formulation of three diets of different protein contents and their essential amino acid profiles; productivity and profitability of Nile tilapia aquaculture for different management practices and their possible impact on poverty alleviation; and conclusions and implications."

THE RAPID APPRAISAL PROCESS

The rapid appraisal approach (RAA) to identify locally available feed ingredients was established by Chowdhury and Bureau (2006) for low-input cage aquaculture and Chowdhury et al. (in press) for small-scale cage aquaculture. Figure 1 exhibits a flow diagram of the rapid appraisal process. The rapid appraisal approach (RAA) was divided into three sections: (1) household and physical resource mapping; (2) resource survey and

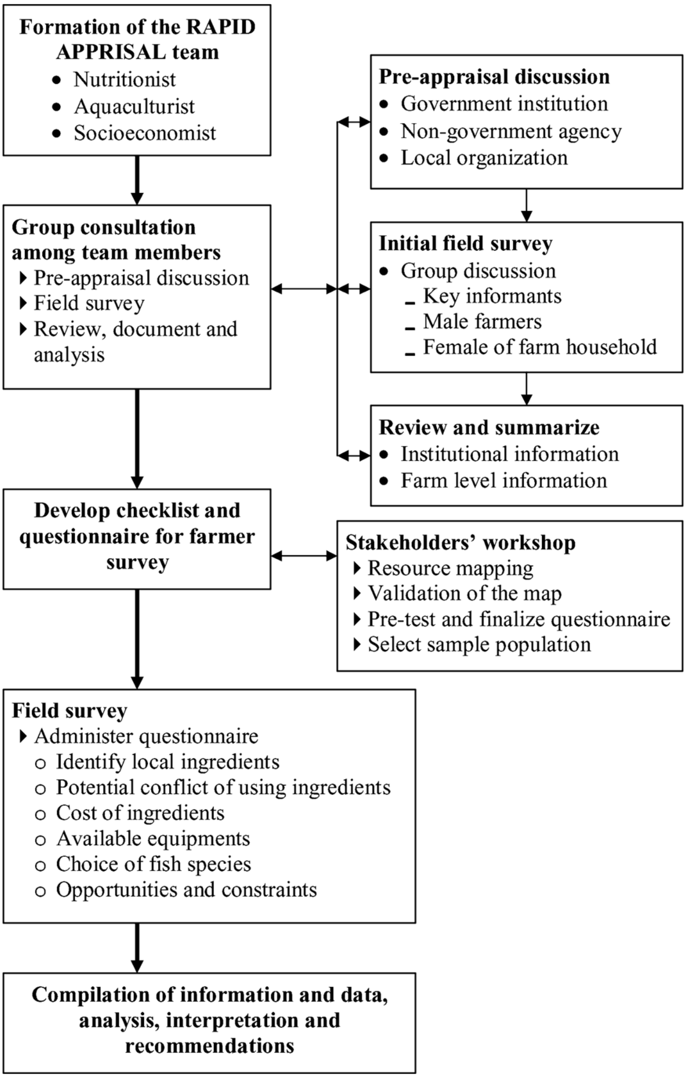
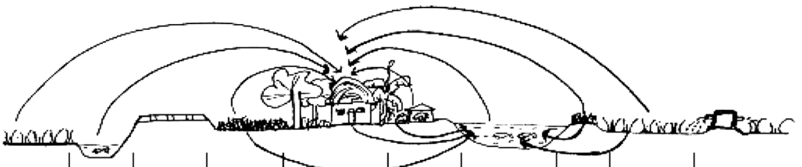


FIGURE 1 A flow-diagram of the rapid appraisal process (adopted and modified from Chowdhury et al. in press).



Crop field	Road side ditch	Road	Vegetable garden	Trees	House	Livestock & poultry shed	Pond and water	Vegetable garden	Crop field	Irrigation pump
Rice, wheat, corn, mustard, pulses and vegetables	Trapped wild fish and drainage	Transportation and marketing	Household consumption, women involvement in homestead agriculture	Perennial fruit, fuel and timber	Dwelling, processing, storage	Milk, meat, egg, fuel, nutrients for crops & pond	Bathing, cleaning, household consumption and irrigation for homestead vegetables	Household consumption and occasional marketing	Rice, wheat, corn, mustard, legumes and vegetables	Water marketing and community irrigation

FIGURE 2 A transect of the resources around a village household in Bangladesh. Flow of the resources is also indicated on transect.

identification of fish feed ingredients; and (3) compilation of data, interpretation and diet formulation. It includes a multidisciplinary team approach covering aquaculture, animal or fish nutrition, and socioeconomics disciplines.

The study was conducted in two field visits through focus group discussions of fishers, resource mapping by the local participants and administering a structured questionnaire. A separate list of locally available ingredients was prepared from secondary sources before initiating the field survey. During the initial field visit, a model transect of the study area was constructed (Figure 2) and the resource mapping was conducted during the focus group discussions (Figure 3). During the second phase of field visits, the questionnaire was administered through random sampling of the fishers and women living in the study area. Data on demographic information, socioeconomic conditions (includes assets and the capital base) of farmers, types of feed used for livestock, poultry and fish and their seasonality and producer price were collected from the respondents. The information on existing aquaculture practices, availability of food and feed processing equipment at the household level were also collected during the survey.

FEED INGREDIENTS: COLLECTION METHOD, SOURCES AND SEASONALITY

Data were collected from the three districts (*Jhenidah, Jessore* and *Chuadanga*) in the south-western part of Bangladesh. At each location, all male

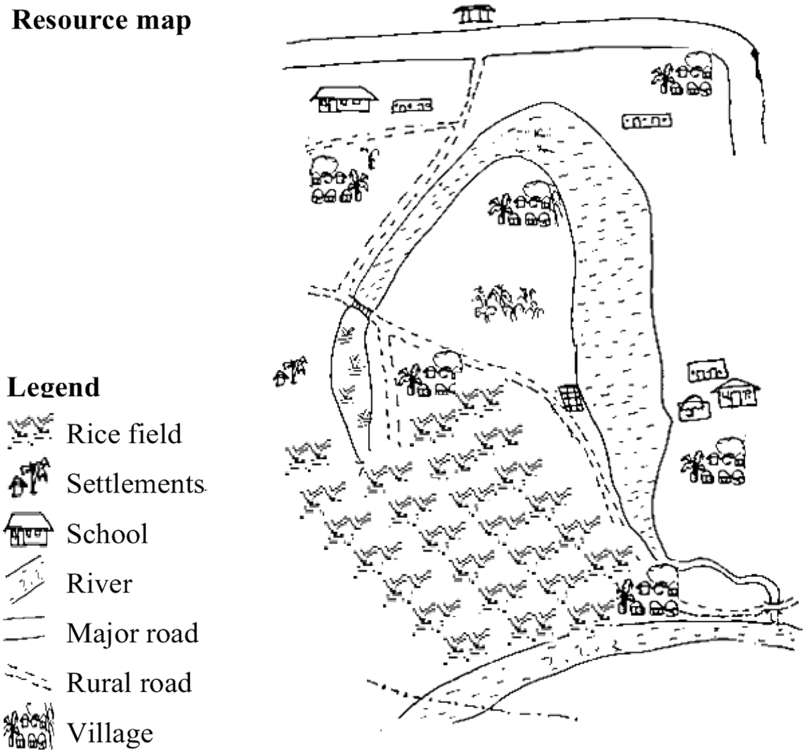


FIGURE 3 A resource map of the study area drawn by the workshop participants (Chowdhury et al. (in press)).

focus group discussions were conducted with the active participation of 20–25 local key informants. A total of 40 male and 20 female respondents were interviewed using the structured questionnaire and out of all respondents, 30 males were chosen randomly from the focus group participants. The list of local feeds was validated by the respondents during the focus group discussion and by each interview. The summarized information on feed ingredients is presented in Table 1 with opportunity costs calculated based on the time required to collect and process specific ingredients.

FEED FORMULATION AND PRODUCTION SCENARIOS

Feed formulation was guided by estimated nutrient requirements of Nile tilapia based on the National Research Council (1993). Amino acid profiles of selected ingredients were taken from Tacon (1987). Profiles of similar ingredients were used when information was unavailable. Nutritional composition and essential amino acid profiles of selected locally available ingredients are provided in Tables 2 and 3, respectively. Only two ingredients (mustard oil cake and duckweed) of plant origin have

TABLE 1 List of Selected Ingredients Available in the Studied Regions

Source of ingredient	Seasonal availability	Local market price (US$/per kg)	Opportunity cost (US$/per kg)	Import/ local
Plant source				
Rice bran	Year round	0.025	—	Local
Wheat bran	Year round	0.025	—	Local
Broken rice	Year round	0.125	—	Local
Mustard oil cake	Year round	0.100	—	Local
Dry duckweed	July to October	—	0.25	Local
Defatted rice bran	Year round	0.035	—	Local
Water hyacinth	Year round		0.05	Local
Animal source				
Dry blood	Year round	—	0.125	Local
Fish meal	Year round	0.500	—	Import
Poultry viscera	Year round	0.030	—	Local
Snails	July to October	—	0.20	Local
Shrimp head meal[a]	Year round	0.200	—	Local
Bone meal[b]	Year round	0.050	—	Local
Other source				
Household waste	Year round	—	0.05	Local
Egg shell	Year round	—	0.05	Local

Source: Chowdhury et al. (in press).

[a] Available in areas where shrimp processing plants are established.

[b] Available in urban or semi-urban areas where slaughter house wastes are sold (no established market).

very high protein content. High protein content was found in most ingredients of animal origin even though their "protein to lipid" ratios vary noticeably. Higher lipid content was found in poultry viscera while dry blood had very high protein content in comparison to other sources.

TABLE 2 Nutrient Composition of the Selected Locally Available Ingredients (Source: National Research Council, 1993)

	Nutrient composition (%)					
Source of ingredient	Moisture	Crude protein	Crude lipid	Nitrogen free extract	Crude fiber	Ash
Plant source						
Rice bran	8.7	1.40	5	48	20.19	11.31
Broken rice	11.4	8	0.9	83.46	6.1	0.91
Wheat bran	9.3	1.17	0.7	9.77	2.36	86
Mustard oil cake	10	33	5.4	33	13	15.6
Duckweed	96.5	32	6.9	27.3	17.6	16.2
Animal source						
Fish meal	14	46	5	25.6	3.6	19.8
Dry blood	79.8	35	4	39	4	18
Poultry viscera	73.7	40	12	33	4	11
Shrimp head meal	8.2	41	5	10.63	11.28	32

TABLE 3 Essential Amino Acid[a] Profiles (%g) of Selected Locally Available Ingredients (Source: Tacon 1987)

Source of ingredients	Arg	Cys	Met	Thr	Iso	Leu	Lys	Val	Tyr	Try	Phe	His
Plant source												
Rice bran	0.69	0.10	0.21	0.42	0.43	1.04	0.50	0.65	0.60	0.10	0.43	0.24
Wheat bran	0.86	0.28	0.2	0.45	0.57	0.95	0.50	0.67	0.29	0.26	0.59	0.33
Mustard oil cake	2.12	0.92	0.82	1.67	1.62	2.46	3.64	1.90	0.00	0.48	1.43	0.93
Duckweed	3.93	0.24	0.85	2.79	3.63	4.84	2.79	3.95	2.42	0.85	3.02	1.09
Animal source												
Fish meal	4.76	0.84	4.03	3.89	3.89	7.23	7.06	6.48	2.43	0.86	3.6	2.12
Dry blood	4.47	1.94	1.14	4.35	1.6	13.4	9.03	8.46	3.00	1.80	7.0	6.58
Poultry viscera	3.77	0.92	1.06	1.94	2.38	4.00	2.89	2.86	0.94	0.46	1.84	1.01
Shrimp head meal	6.80	2.40	1.70	4.30	6.30	6.80	9.30	5.50	3.70	0.60	4.7	0.00

[a] Standard abbreviation used worldwide: Arg – Arginine, Cys – Cystine, Met – Methionine, Thr – Threonine, Iso – Isoleucine, Leu – Leucine, Lys – Lysine, Val – Valine, Tyr -Tyrosine, Try – Tryptophen, Phe – Phenylalanine, His – Histidine.

Formulation of Feeds

Three feeds of 35%, 30%, and 25% crude protein (henceforth leveled as P1, P2 and P3) were formulated to assess their essential amino acid compositions to satisfy the requirements of Nile tilapia. Fish meal content was kept at 15% and 10% in the 35% and 30% crude protein feeds, respectively (Table 4), but totally excluded from the 25% protein feeds. Reduction in fish meal use from the feeds was guided by high costs, limited supply and poor accessibility of this ingredient for poor farmers. The assumptions used to formulate the diets were:

1. 35% protein feed assumed that all ingredients were available in the locality at any time;
2. 30% protein feed excluded duckweed and shrimp heads and assumed that duckweed was only available in the monsoon season; and

TABLE 4 Ingredients Used in the Formulation of Feeds of Different Crude Protein Content

Source	Ingredient (g/kg)	35% protein	30% protein	25% protein
Plant origin	Rice bran	150	190	150
	Wheat bran	190	200	300
	Mustard oil cake	160	250	250
	Duckweed	30	—	—
Animal origin	Fish meal	150	100	—
	Dry blood	130	100	100
	Poultry viscera	100	100	100
	Shrimp head meal	40	—	—
Supplement	Starch	50	60	100
Total (g)		1000	1000	1000

3. 25% protein feed excluded fishmeal because availability of fishmeal depends mostly on external markets and is deemed costly for poor farmers.

Two non-traditional ingredients, dry blood and shrimp head meal were added in formulating the feed due to the higher protein content and superior essential amino acid profiles. Dry blood is available in areas where animal slaughter houses are available, and shrimp head meal is available in areas where shrimp processing plants are located. Considering the required level of essential amino acids, only 35% protein feed contains more than 50% of the required essential amino acids by the Nile tilapia. While in the 30% and 25% protein feeds, seven of the essential amino acids were less than 50% of the required level (Table 5).The energy contents of 13.23 KJ/g (35% protein feed), 13.05 KJ/g (30% protein feed) and 12.41 KJ/g (25% protein feed) of the feeds were within the acceptable range (between 10.5 and 14.7 KJ/g, Sweilum et al., 2005) for Nile tilapia. Required methionine content was reduced to 75%, as cystine content in all three diets was greater than 0.54 (Hasan, 2001). It is assumed that partial fulfillment ($>50\%$) of the required essential amino acids is sufficient for Nile tilapia because of their ability to consume and synthesize nutrients from plankton from a well-fertilized pond.

TABLE 5 Essential Amino Acids Requirement for Nile Tilapia According to National Research Council (1993) and Percent of Required Essential Amino Acids in the Formulated Diets

Amino acid profile[a]	Essential amino acids requirement % of protein	% of EAA required at different protein levels		
		35%	30%	25%
Arg	4.20	61.1	47.7	38.4
Cys[b]	0.54	143.3	121.5	111.1
Met[b]	2.68	149.5	115.7	64.7
Thr	3.75	52.0	40.7	31.5
Iso	3.11	56.5	42.0	31.3
Leu	3.39	124.3	96.3	77.8
Lys	5.12	71.4	56.8	44.0
Val	2.80	111.7	85.3	64.6
Tyr	1.79	62.8	38.8	26.9
Try	1.00	58.5	48.4	42.4
Phe	3.75	60.1	45.9	37.8
His	1.72	88.3	47.7	63.4
Energy (KJ/g)	10.5–14.7	13.23	13.05	12.41
Cost (US$/kg)		0.16	0.12	0.07

[a] Arg – Arginine, Cys – Cystine, Met – Methionine, Thr – Threonine, Iso – Isoleucine, Leu – Leucine, Lys – Lysine, Val – Valine, Tyr – Tyrosine, Try – Tryptophen, Phe – Phenylalanine, His – Histidine.

[b] Required Methionine content is reduced to 0.75%g as Cystine content in all three diets are >0.54 (from Hasan 2001).

TABLE 6 Characterization of Six Production Scenarios with Respect to Three Levels of Crude Protein Feed Formulation

	35% crude protein		30% crude protein		25% crude protein	
Fixed parameters	100 days	150 days	100 days	150 days	100 days	150 days
Crop cycles/year	3	2	3	2	3	2
Mortality rate (%)	5.0	7.5	5.0	7.5	5.0	7.5
Protein deposition (%)	60	60	55	55	50	50
Average daily gain (g/d)	1.50	1.50	1.25	1.25	1.00	1.00

Production Scenarios

Two production scenarios were hypothesized for each feed based on crop duration in days, number of crop cycles, mortality rate as a percent, protein deposition as a percent and average daily gain in grams of fish body weight. The detail description of these scenarios are provided in Table 6.

Costs, production and economic performances of each feed for two sets of culture periods (100 and 150 days) were analyzed. Assumptions included: stocking density of 24,700/ha, protein deposition (PD) rate of 50 to 60% of protein in the diet/day, average daily gain of 1.0–1.5 g/day, initial body weight of 5 g, and the mortality was assumed to be 5% and 7.5% for the culture periods of 100 and 150 days, respectively. Table 7 presents the predetermined primary factors and the derived secondary factors considered in estimating costs of production of tilapia aquaculture for the 6 scenarios at three protein levels (35%, 30% and 25%) and the 2 culture periods (100 and 150 days). The protein deposition rate was predicted from the average daily gain (g) or the growth pattern of the species as proposed by Bureau et al. (2000). Mortality rate and average daily gains were derived from El-Sayed et al. (1996). Slightly higher average daily gains (1.0–1.5 g/day) were assumed because of the significantly lower stocking density and higher protein levels in 2 of the 3 feeds than in the study of El-Sayed et al. (1996).

TABLE 7 Factors Derived from the Fixed Parameters for Production and Costs of Tilapia Culture in Six Production Scenarios at a Stocking Density of 10/m^3

	35% crude protein		30% crude protein		25% crude protein	
Factors	100 days	150 days	100 days	150 days	100 days	150 days
Stocking density no./pond[a]	24700	24700	24700	24700	24700	24700
Initial body weight (g)	5	5	5	5	5	5
Final body weight (g)	241.1	362.1	201.2	301.8	160.9	241.4
Feed conversion ratio	1.71	1.83	2.54	2.71	4.02	4.31

[a] Stocking density is given by Binh (1998) for tilapia pond aquaculture.

The following equations were used to estimate the parameters:

$$\mathrm{FBW} = Ln\ (\mathrm{IBW})^{*}\mathrm{ADG}^{*}\mathrm{Days} \tag{1}$$

where FBW is the final body weight (g), IBW is initial body weight (g), ADG is average daily gain (g), and Days represents the culture period.

$$\mathrm{Pg} = \mathrm{FBP} - \mathrm{IBP} \tag{2}$$

where Pg is protein gain, FBP is the final body protein and IBP is the initial body protein content. Body protein contents are calculated as follows:

$$\mathrm{BP} = \mathrm{BW}^{*}0.1607 + 0.2272 \tag{3}$$

where BP is the body protein content and BW is the body weight. A linear equation ($0.1607X + 0.2272$) was constructed and used to calculate body protein from a dataset developed using information on 224 experiments on Nile tilapia published between 1984 and 2005. The following are the other calculations made to estimate the required parameters:

For the protein requirement,

$$\mathrm{PR} = \frac{\mathrm{Pg}}{\mathrm{PD}} \tag{4}$$

where PR is the protein requirement, Pg is for protein gain, and PD is protein deposition. For the feed requirement,

$$\mathrm{FR} = \frac{\mathrm{PR}}{\mathrm{PC}} \tag{5}$$

where FR is the feed requirement, PR is the protein requirement, and PC is the percent protein content in the feed. For feed conversion ratio,

$$\mathrm{FCR} = \frac{\mathrm{RAF}}{\mathrm{BWG}} \tag{6}$$

where FCR is the feed conversion ratio, RAF is the required amount of feed, and BWG is the body weight gain.

The average daily gain value of 1.50g/day for the first two scenarios were higher than those for scenarios 3 and 4 (1.25 g/day) followed by the values for scenarios 5 and 6 (1.00 g/day). The final body weights ranged from 201.2 g to 362.1 g. Culture period was a major determinant for the final body weight because a shorter culture period (100 days) produced significantly smaller fish than the longer culture period of 150 days fed a diet of similar crude protein content.

COSTS, PRODUCTIVITY, PROFITABILITY, AND POVERTY ALLEVIATION

Benefit-cost analysis was conducted to identify the unit cost of production which is the best indicator of profitability of a production system. Cost of production (inputs and services required) was estimated considering a hectare of pond area. We also analyzed the cost, productivity and profitability of 400 m^2 ponds in the proposed scenarios to accommodate the analysis for the average household pond size in Bangladesh.

Production Costs

Costs per kg of 35%, 30%, and 25% protein feeds were calculated as US$0.16, US$0.12, and US$0.07, respectively. The fixed parameters for the cost calculation were infrastructure development and pond rental. Infrastructure development includes repairs or reconstruction of dikes, building fences, cleaning aquatic weeds, and seining ponds to remove all fishes. Dependent parameters are fingerlings, feed, fertilization, and labour. We also considered the seasonal cost of labor in calculating the average cost of labor/man-day as it fluctuates from high during planting and harvesting seasons to low in the growing season of agricultural crops specifically of rice production. Prices of fingerlings and fertilizers were taken from Hussain (2004). Fertilization rates for aquaculture ponds were also calculated from Hussain (2004). Cost of feeds was calculated from the total production and feed conversion ratio (FCR) values (Table 7) derived for each scenario. In Bangladesh, functionally landless (less than 0.2 ha) households comprised 65% of the poor, while the marginal landowners (with between 0.2 and 0.6 ha) accounted for another 21% (FAO, 2004). This is one of the major reasons to include rental cost in the analysis.

In our analysis, the scenarios with 35% and 30% protein feed for the culture period of 100 days showed the highest cost per year for tilapia production, and the lowest cost was derived for the scenario with 25% protein feed for 150 days culture period (Table 8). In general, costs of production were always lower for the 150 day culture period than that of the 100 day production cycle in all three protein scenarios. Despite the lack of significant differences, slightly higher productions were achieved in the scenarios with three crop cycles than with two crop cycle scenarios (Table 9). Feed costs per kg of fish were higher in the scenarios with 150 day culture period. However, these scenarios also produced fish that were significantly larger ($P < 0.01$) that would normally yield a higher sale price than the smaller fish.

TABLE 8 Analysis of Costs per Production Cycle for a Hectare Pond Size of Tilapia Culture at Different Scenarios and Annual Cost of Production

Description	35% protein–100 days	35% protein–150 days	30% protein–100 days	30% protein–150 days	25% protein–100 days	25% protein–150 days
Infrastructure development (12 man-days)	12.30	12.30	12.30	12.30	12.30	12.30
Fingerling (on site price) (US$19.23/1000)	474.98	474.98	474.98	474.98	474.98	474.98
Feed	1478.06	2324.12	1425.34	2246.92	1085.07	1716.25
Labor[a]						
Pond preparation (5 man-days)	235.54	359.72	280.01	430.60	342.61	530.87
Pond management (2hr/day)	25.63	38.44	25.63	38.44	25.63	38.44
Feed preparation (50kg/manday)	194.54	305.90	239.01	376.78	301.61	477.06
Harvesting (10 man-days)	10.25	10.25	10.25	10.25	10.25	10.25
Fertilization						
Manure @ US$0.02/kg (1000 kg at preparation & 50 kg/week)	34.29	41.43	34.29	41.43	34.29	41.43
Urea @ US$0.09/kg (50 kg at preparation 14 Kg/week)	22.50	31.50	22.50	31.50	22.50	31.50
TSP @ $0.18/kg (50 kg at the beginning 7 kg/week)	27.00	36.00	27.00	36.00	27.00	36.00
Lime @ 0.06/kg (100 kg at prep. & 10kg/wk thereafter)	6.15	6.16	6.22	6.23	6.34	6.37
Pond rental @ $320.00/year	106.67	160.00	106.67	160.00	106.67	160.00
Miscellaneous	25.64	38.46	25.64	38.46	25.64	38.46
Total Costs/production cycle	2431.50	3497.30	2423.30	3491.00	2145.60	3060.60
Total Costs/year	7294.60	6994.70	7269.80	6982.00	6436.80	6121.30

[a] Assumed labor cost 1.025 US$/man-day.

TABLE 9 Per Hectare Annual Cost of Production, Productivity and Returns from Tilapia Culture at Different Scenarios

Description	35% protein–100 days	35% protein–150 days	30% protein–100 days	30% protein–150 days	25% protein–100 days	25% protein–150 days
Production (kg/year)	16994.5	16547.2	14162.0	13789.4	11329.6	11031.5
Farm gate price/kg (US$)	1.12	1.35	0.90	1.35	0.90	1.12
Gross Return (US$/year)	19064.30	22275.12	12709.53	18562.60	10167.62	12375.07
Total cost (US$/year)	7294.63	6994.73	7269.89	6982.08	6436.88	6121.31
Unit cost (US$/kg of fish)	0.43	0.42	0.51	0.51	0.57	0.55
Net Return (US$/year)	11769.66	15280.39	5439.64	11580.52	3730.74	6253.76
Net Return (US$/day)	39.23	50.93	18.13	38.60	12.44	20.85
Costs (US$/day)	24.32	23.32	24.23	23.27	21.46	20.40
Benefit/cost ratio[a]	2.61	3.18	1.75	2.66	1.58	2.02
Productivity and profitability from a 400 m^2pond[b]						
Production (kg)	566.5	661.9	566.5	551.6	453.2	441.3
Total cost (US$)	291.79	279.79	290.80	279.28	257.48	244.85
Cost per day (US$)	0.97	0.93	0.97	0.93	0.86	0.82
Gross return (US$)	762.57	891.00	508.38	742.50	406.70	495.00
Net return (US$)	470.79	611.22	217.59	463.22	149.23	250.15
Net return (US$/day)	1.57	2.04	0.73	1.54	0.50	0.83

[a] Benefit-cost ratio is calculated from FPF/UCP; where FPF is the farm-gate price (US$/kg) of Nile tilapia and UCP is unit cost of production (US$/kg).

[b] An average pond size assumed for a Bangladeshi farmer.

Productivity and Profitability

Highest annual tilapia production was achieved in scenario 1, followed by scenario 2. Scenario 6 produced the lowest gain of all (Table 9). Fish size at harvest was a major determinant of profitability. The farm-gate price of fish varies with the size of the fish from \$0.90 US/kg for the smaller size to \$1.35 US/kg for the larger fish (Table 9). Scenario 2 (35% protein feed for 150-day production cycle) had the highest return followed by scenario 1 (35% protein for 100-day cycle) (Table 9). This increase in the net return of the longer production cycle was due to the larger fish size at harvest. The average fish size was 362 g at harvest for scenario 2, while as the average fish size for scenario 1 was 241 g.

For an average homestead pond of 400 m^2, yields increased from 441.3 kg/year (25% protein, 150-day) to 661.9 kg/year (35% protein, 100-day). The highest net return of \$2.04 US/day was obtained for scenario 2 (35% protein, 150-day production cycle). Two other scenarios, 35% protein for 100 day and 30% protein for 150 day production cycle also produced net returns of \$1.57 and \$1.54 US/day, respectively. These net returns were significantly higher than the daily income of an agricultural laborer in Bangladesh (US\$1.03/day). Net returns per day in the rest of the scenarios were significantly lower, but they would provide additional household income to a resource-poor farmer, who cannot afford higher costs of production for other scenarios.

This study showed the possibility of generating income from underutilized and unutilized household and locally available resources by Nile tilapia aquaculture. The retail market price of Nile tilapia is much higher (\$1.28 US/kg to \$1.92 US/kg) than the average fish price of \$1.22 US/kg in Bangladesh (Dey et al., 2005). The average farm-gate price of tilapia ranges from \$0.90 to \$1.35 US/kg depending on their size. Net returns from Nile tilapia aquaculture in the current exercise has shown that it requires 21 times higher investment than the investment required for high-yielding modern *Boro* rice cultivation in the dry season (Hossain, 2003). However, a 27-fold higher net return could be achieved yielding six times more gain indicating that the higher the investment, the higher the profit.

The findings on production and economic performance could raise concerns regarding the involvement of resource-poor farmers in the semi-intensive or intensive pond aquaculture of Nile tilapia in a country like Bangladesh. One critical observation is that the initial investment and cost of production seems very high if one considers the cost of other agricultural activities. Perhaps the cost of production for 400 m^2 ponds would be much higher than the annual income of an average person from the household of a resource-poor farmer. Looking at the lucrative profit margin from this production business, poor farmers need financial and insurance support from government institutions and non-government organizations. If we assume that fish feed ingredients and labor are available at the household level, and the farmers do not have to pay for the pond rental, the cost of production would be much lower than estimated. If the cost of family inputs is not considered, then the total cost of production will fall drastically, and profit margins will increase proportionately.

Poverty Alleviation

Fish production is generally a profitable business, but for a long period did not receive much attention in the development agenda of the government. In Bangladesh, poor farmers have become involved in fish polyculture in some areas in recent years with government and non-government support. Absence of cash flow may have prevented the poor from engaging in semi-intensive or intensive tilapia aquaculture that requires a substantial amount of initial investment. A joint effort must be made by the government, non-government organizations, and financial institutions to facilitate and ensure a supply of initial credit. While the net return of $0.83 US/day (Table 9) for the lowest amount of investment is a modest gain, for resource-poor farmers this extra cash-flow is a substantial financial gain allowing them to access better food, health and education for their children, to achieve better quality of life, and social and economic empowerment.

Apart from increasing income and improving household food security, tilapia aquaculture in homestead ponds will enhance women's participation. Women typically manage in-house resources and, along with the children, perform everyday management tasks for tilapia production in the homestead ponds. Women family members could save cash costs for labor use in pond preparation, input use and management practices, which would be a way to reduce costs. This will also involve rural women in income-generating activities who otherwise do not have access to external income resources. Improved cash flow normally brings social and political empowerment in societies where women are left behind to manage non-income generating resources.

CONCLUSIONS AND IMPLICATIONS

The study found seven plant and six animal ingredients available year-round in the local area with the exception of duckweed and snails. However, these availabilities remain questionable as there is no large-scale intensive aquaculture and a very insignificant proportion of farmers adopted the technology through local knowledge. Rice, however, is the exception that is grown in all seasons. Poultry also are available all the time (but limited at the household level). Although the areas have high potential for seasonal and perennial aquatic resources suitable for aquaculture, proper knowledge of fish feed and species culture technologies were not available to farmers due to lack of extension services.

Results show that 2 ingredients from plant origin (mustard oil cake and duckweed), and 3 from animal sources (dry animal blood, poultry viscera, and shrimp head meal) have higher protein content than other ingredients available locally. Caution must be taken in formulating fish feed from mustard oil cakes because of the presence of anti-nutritional factors which could reduce the overall digestibility of the feed. Common processing techniques can effectively remove the deleterious effects of anti-nutrients from feed materials (Francis et al., 2001). Utilization of dried duckweed in feed is an important natural alternative but its availability is limited to four months of a year, particularly in the monsoon season. It will require large scale production to ensure year-round availability of duckweed and to keep the price level affordable for small farmers. Among the animal sources, high fiber and chitin content in shrimp head meal and the high fat content in poultry viscera is a constraint for these ingredients to be used as the sole protein source in feed formulation. Dry blood is one of the alternatives for its high protein content, and perhaps its social acceptability could be a major constraint because of religious barriers of different customs among communities.

Production scenarios of feed with 35% protein showed superior results in terms of food conversion ratio, productivity, and benefit-cost ratio. Only one other production scenario (30% protein, 150-day production cycle) showed similar economic performance despite a low feed conversion ratio and fish production. This study shows that formulating a low cost diet from locally available ingredients for Nile tilapia is possible and could increase production significantly. It has the potential to improve economic performance that could attract marginal and small farmers, entrepreneurs and investors. However, different alternative technology packages should be developed and disseminated in a precise way so that these can be adopted easily by the resource-poor farmers and local entrepreneurs.

Identification of locally available ingredients and its application to low-cost low-input tilapia aquaculture in small aquatic bodies has the following social and economic implications:

1. Better utilization of household and locally available resources;
2. Incorporation and improvement of indigenous technical knowledge (ITK);
3. Better watershed management and increase water productivity;
4. Increase inexpensive sources of fish production for poor people;

5. Increase fish consumption to meet the demand for animal protein;
6. Development of small-scale feed producing entrepreneurship in rural area;
7. Increase self employment and involvement of women in productive activities;
8. Increase household income to reduce poverty; and
9. Enhance the capacity for household food security.

Combinations of the above explicit advantages have multiplier effects and impacts on the other basic needs of resource-poor households and to improve their assets and capital wealth (social, physical, financial and human). However, to achieve these, a well-equipped field training and extension service, proper market infrastructure, and adequate on time supply of inputs by establishing backward linkage industries are essential. It also requires adequate institutional support from government and non-government agencies.

Research conducted in laboratories of academic and research institutions seldom end up in the farmers' field within a short period of time. Such research and development of improved fish production technologies cannot bring fruits of the technologies until properly disseminated to the farmers. Finally, the present study emphasized that, to develop and disseminate aquaculture technology, fabrication of feed for fish food production is needed to improve livelihoods and food security of the poor with major consideration for low-cost locally available ingredients. Identification and utilization of locally available ingredients for small-scale aquaculture would also encourage individual entrepreneurs and cooperative based agriculture and animal by-product processing industries, feed mills and nursery operations to grow fry to fingerling. This would create further employment and will help to enhance the overall rural economy in developing countries.

However, further in-depth research across different agro-ecological environments with locally available feed ingredients is needed. Research on feed processing and production technologies of local ingredients needs to be translated clearly using simple local language expressions. Finally, development of plant layouts to process and formulate feeds suitable for small-scale processing units to encourage local entrepreneurs should be developed.

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REFERENCES

Azim, M.E., Rahman, M.M., Wahab, M.A., Asaeda, T., Little, D.C. & Verdegem, M.C.J. (2004) Periphyton based pond polyculture system: a bioeconomic comparison of on-farm and on-station trials. *Aquaculture*, **242**, 381–396.

Brugere, C., McAndrew, K. & Bulcock, P. (2001) Does cage aquaculture addresses gender goals in development? Results of a case study in Bangladesh. *Aquaculture Economics and Management*, **5**(3–4), 179–190.

Bureau, D.P., Azevado, P.A., Tapia-Salazar, M. & Cuzon, G. (2000) Pattern and cost of growth and nutrient deposition in fish and shrimp: Potential implications and applications. In: *Avances en Nutricion Acuicola V* (eds D. Ricque-Marie, M. Tapia-Salazar, M.A. Oivera-Novoa & R. Civera-Cerecedo), Memorias del V Simposium Internacional de Nutricion de Acuicola, Mexico.

Chowdhury, M.A.K. (1997) *Techno-socio-economic aspects of developing cage aquaculture in oxbow lakes of Bangladesh.* MSc Thesis, Asian Institute of Technology, AS-97–17, 127 p.

Chowdhury, M.A.K. & Bureau, D.P. (2006) A rapid appraisal approach to identify feed ingredients for low-input cage aquaculture: A case from Bangladesh. *International Aquafeed*, **9**(1), 14–18.

Chowdhury, M.A.K., Bureau, D.P. & Ponniah, A.G. (in press) July, (2006) A rapid appraisal approach to identify feed ingredients for small-scale cage aquaculture. In: *Proceedings of the Second International Symposium on Cage Aquaculture in Asia* (ed S.S. De Silva), pp 3–8. Hangzhou, China.

Chowdhury, M.A.K. & Rahman, S. (1998) Women's participatory role in oxbow lake fisheries management: A case from Bangladesh. *Aquaculture Asia*, **3**(2), 3–7.

Chowdhury, M.A.K. & Yakupitiyage, A. (2000) Efficiency of the existing oxbow lake management systems in Bangladesh to introduce cage culture for resource poor fishers. *Fisheries Management and Ecology*, **7**(1–2), 65–74.

Chowdhury, M.A.K., Yi, Y., Lin, C.K. & El-Haroun, E.R. 2006. Effect of salinity on carrying capacity of Nile tilapia *Oreochromis niloticus* L. in recirculating systems. *Aquaculture Research*, **37**, 1627–1635.

Dey, M.M., Rab, M.A., Paraguas, F.J., Bhatta, R., Alam, M.F., Koeshendrajana, S. & Ahmed, M. (2005) Status and economics of freshwater *aquaculture* in selected countries of Asia. *Aquaculture Economics & Management*, **9**(1–2), 11–37.

Edwards, P. & Allan, G. (2004) Fish feed and feeding in the countries of the lower Mekong Basin. *World Aquaculture*, **35**(3), 30–32.

El-Sayed, A.F.M., El-Ghobashy, A. & Al-Amoudi, M. (1996) Effects of pond depth and water temperature on the growth, mortality and body composition of Nile tilapia, *Oreochromis niloticus* (L.). *Aquaculture Research*, **27**(9), 681–687.

FAO (2004) Gateway to land and water information. Country report: Bangladesh. <http://www.fao.org/ag/agl/swlwpnr/reports/y_sa/z_bd/bd.htm>. Accessed on June 21, 2006.

Francis, G., Makkar, H.P.S. & Becker, K. (2001) Antinutritional factors present in plant-derived alternate fish feed ingredients and their effects in fish. *Aquaculture*, **199**, 197–227.

Hasan, M.R. (2001) Nutrition and feeding for the aquaculture development in the third millennium. In: *Aquaculture in the Third Millennium* (eds R.P. Subasinghe, P. Bueno, M.J. Phillips, C. Hough, S.E. McGladdery & J.E. Arthur), pp 193–219. Technical Proceedings of the Conference on Aquaculture in the Third Millennium, Bangkok, Thailand, pp 20–25. February 2000. NACA, Bangkok and FAO, Rome. 471 p.

Hossain, M. (2003) Development of Boro rice cultivation in Bangladesh: Trends and policies. In: *Boro Rice* (eds R.K. Singh, M. Hossain & R. Thakur), pp 25–42, International Rice Research Institute (IRRI), India.

Huchette, S.M.H. & Beveridge, M.C.M. (2002) Technical and economical evaluation of periphyton-based cage culture of tilapia (*Oreochromis niloticus*) in tropical freshwater cages. *Aquaculture*, **218**, 219–234.

Hussain, M.G. (2004) *Farming of Tilapia. Breeding Plans, Mass Seed Production and Aquaculture Techniques.* Mymensingh, Bangladesh, 149 p.

Little, D.C., Siakaw, D. & Juntana, J. (1994) Commercial production and marketing of Nile tilapia (Oreochroniis niloticus) fry in Chonburi and Chachoengsao provinces, Thailand. *Naga, The ICLARM Quarterly*, **17**(2), 14–17.

Morrice, C.P. (1998) A trial to test the suitability of a low-cost, silver barb *Puntius gonionotus*-baed polyculture model for seasonal ponds in northwest Bangladesh. *Asian Fisheries Science*, **11**(2), 121–132.

National Research Council—NRC. (1993) *Nutrient Requirements of Fish.* National Research Council, National Academy Press, Washington, DC.

Ofori, J.K. & Prein, M. (1996) Rapid appraisal of low-input aquaculture systems. In: *Research for the Future Development of Aquaculture in Ghana* (eds M. Prein, J.K. Ofori & C. Lightfoot), pp 31–36. ICLARM Conference Proceedings 42, Manila, 94 p.

Pido, M.D., Pomeroy, R.S., Garces, L.R. & Carlos, M.B. (1997) A rapid appraisal approach to evaluation of community-level fisheries management systems: Framework and field application at selected coastal villages in the Philippines and Indonesia. *Coastal Management*, **25**(2), 183–204.

Pitcher, T.J. & Preikshot, D. (2000) RAPFISH: A rapid appraisal technique to evaluate the sustainability status of fisheries. *Fisheries Research*, **49**, 255–270.

Sweilum, M.A., Abdella, M.M. & Salah El-din, S.A. 2005 Effect of dietary protein-energy levels and fish initial sizes on growth rate, development, and production of Nile tilapia, *Oreochromis niloticus L. Aquaculture Research*, **36**, 1414–1421.

Tacon, A.G.J. (1987) *The nutrition and feeding of farmed fish and shrimp—A training manual.* FAO GCP/RLA/075/ITA Field Document 5/E.