The Aquafeed Journal

Peer Reviewed article

FISH FARMING TECHNOLOGY

INTERNATIONAL AQUA FEED

This new peer-reviewed scientific journal will serve academia and the commercial aquaculture industry with high-quality papers relating to aquafeed science and technology for different species of farmed fish and crustaceans. It is envisaged to address fundamental nutritional requirements for effective and optimal production and applications to advanced feed formulations.

The manuscripts will be fully peer-reviewed by appropriate members of our editorial board and approved finally by the Editor-in-Chief. These published papers will be available on our official website aquafeed.co.uk and in print as well as being downloadable.

Please do not hesitate to contact us with your queries at journal@perendale.co.uk and visit https://www.aquafeed.co.uk/aquafeed-journal/author-guidelines/.

Volume 1 - 2023

Perendale Publishers Ltd

Find out more at:

www.aquafeed.co.uk/category/journal-articles/original-research

Peer Reviewed article

Potential for producing tilapia (*Oreochromis niloticus*) feed using locally sourced ingredients in resource-poor farming systems: A case study from Timor-Leste

Jharendu Pant[1]*, Ramesh Perera[2], Dedi Jusadi[3], Shwu Jiau Teoh[1], Silvino Gomes[4], Narayan Prasad Pandit[5], Ram C. Bhujel[6] and Jagadish Timsina[7]

[1] WorldFish, Jalan Batu Maung, 11960 Bayan Lepas, Penang, Malaysia

[2]Canberra, Australia

[3]Department of Aquaculture, Faculty of Fisheries and Marine Science, Bogor Agricultural University, Indonesia

[4]WorldFish Timor-Leste, Ministerio de Agricultura no Pesca, Avenida Nicolau Lobato, No. 5, Comoro, Dili, Timor-Leste

[5]Department of Aquaculture, Agriculture and Forestry University, Rampur, Chitwan, Nepal

[6]Asian Institute of Technology, Bangkok, Thailand

[7]Institute for Study and Development Worldwide, Sydney, and Global Evergreening Alliance, Melbourne, Australia

*corresponding author :

Jharendu Pant

WorldFish, Jalan Batu Maung, 11960 Bayan Lepas, Penang, Malaysia

Email: j.pant@cgiar.org

Introduction

Widespread poverty and malnutrition continue to be major impediments to recovery and growth of Timor-Leste since its independence in 2002 (UNDP, 2007; WFP, 2010; SDP, 2011; NDFA, 2012). Increasing availability of and access to animal-source food is vital to the improvement of the nutritional status of a large proportion of the population deprived of a nutritionally balanced diet. Aquaculture has been identified by the Government of Timor-Leste as a means of improving food and nutrition security situation in the country, which can also contribute to the expansion of economic activities in coastal and inland areas (NDFA, 2012). The Timor-Leste National Aquaculture Development Strategy (2012-2030) aims to produce 30,000 tonnes of fish by 2030 to maintain 15.0 kg annual per capita fish consumption from current consumption of 6.1 kg. Of the total fish production, 12,000 tonnes (40%) is expected to come from aquaculture, and the remainder from capture fishery mainly from marine waters. To achieve the above fish production target through aquaculture at least 18,000 tonnes of feed is required annually assuming 1.5 feed conversion ratio (FCR). Therefore, it would depend largely on the availability of and access to locally available and cheap feed ingredients to produce good quality feed.

Feed cost is the single most important factor in determining the economic viability of aquaculture operations – be they small- or large-scale. Feed typically makes up over 50% (Rana et al, 2009) and sometimes as much as 90% (El-Sayed et al, 2015) of the total cost of production of intensive and semi-intensive commercial aquaculture operations. Making high quality feed easily accessible to farmers at low price is; therefore, the most important intervention for the development and long-term sustainability of the aquaculture industry in Timor-Leste, and more so in rural aquaculture, where the profit margins often tend to be rather marginal. There is potential for reducing feed cost by reducing the cost of feed ingredients per se as well as through the adoption of prudent feed management strategies (De Silva, 2006). The most obvious approach is to decrease the amounts of expensive ingredients in the feed, e.g., fish meal, through substitution with a suitable, low-cost alternatives, while ensuring that this will not compromise the quality of feed thereby the growth and quality of the cultured stock. Research investigating cheaper alternative protein and energy feedstuffs for the development of low-cost pelleted feed suitable for use by resource-poor small-scale farmers has become a priority in developing countries, where there are acute shortages of animal protein in the diets. There is, therefore, the need to exploit cheaper and locally available, environmentally benign, and socially acceptable fish ingredients to replace expensive fish meal in feed formulation (Perera and Bhujel, 2022). Since locally available feed ingredients, mostly of plant origin contain low protein and high fibre, developing high-quality feeds using local ingredients alone would not be a feasible option. However, low-input and low-cost fish culture utilising fertilizer-based green water technology, where a significant portion of fish nutrition is derived from the 'natural' productivity of the water could be a viable and sustainable option for resource-poor situations (Almazan and Boyd, 1978; Boyd, 1976; Diana et al., 1991; 1996; 2007; Pant et al., 2002).

Tilapia (Oreochromis niloticus) is one of the major species identified as suitable for Timor-Leste (NDFA, 2012, Salvador et al., 2022). It is a fast-growing tropical fish, low on food chain, and can be farmed successfully in various management conditions ranging from low-input backyard ponds to large-scale intensively managed commercial production systems (Bhujel, 2014;). The government as well as I/NGOs in Timor-Leste are endeavoring to promote tilapia aquaculture for almost a decade now with a view to solving the malnutrition problem (Salvador et al., 2022). Further, WorldFish headquartered in Penang, Malaysia, with its country office in Timor-Leste, has also introduced the genetically improved farmed tilapia (GIFT) in the country in 2015 (Pant et al., 2019). However, its expansion is largely constrained by the lack of cost-effective feed technology and feed production in the country. In response, this study seeks to develop tilapia feed formulations for on-farm feed production for small-scale, resource-poor farmers relying exclusively on locally available ingredients but also provide various options for cost-effective commercial feed formulation using locally available and imported ingredients which could be the basis for establishment of a fish feed plant in the country.

Materials and Methods

This study consisted of three components: (i) survey of locally available ingredients for formulation of fish feed; (ii) evaluation of fish feed formulation options for on-farm and commercial-scale manufacturers; and (iii) macro-level assessment of the availability of fish feed ingredients to support the 2030 fish production target.

Feed ingredients survey

A key informant survey was conducted from November 2015 to January 2016 in three municipalities identified as suitable for freshwater aquaculture development by NDFA based on agro-ecological environments and accessibility (NDFA, 2012). The survey covered four sucos (villages), namely, Fatuquero and Poetete in Ermera, Gariuai in Baucau, and Batugade in Bobonaro municipalities.

A semi-structured checklist was used to interview key informants representing farmers, and private, public and I/NGO sectors across the study villages. Twenty-four small-scale farmers (engaged in farming crops and fish), four village market vendors, three Ministry of Agriculture and Fisheries (MAF) Extension Officers, two Municipality Fisheries Officers, three Senior Municipality-level MAF Officers, five INGO representatives (World Vision, Catholic Relief Services, Mercy Corps, Institutu Matadalan Integradu (IMI)), three business sector buyers of bulk agricultural products (KMANEK, Farm Pro, Timor Global), and an agriculture teacher at the Don Bosco Technical School, Fatumaca were interviewed. Information was collected on the kind of crops and fish farmed, production volumes (products and by-products), costs of and access to ingredients to use as fish feed, alternative uses of ingredients, off-farm and non-farm activities, and existing aquaculture practices in the area. The survey checklist was simplified upon consultation with National Directorate of Aquaculture, MAF to avoid ambiguity and improve clarity. The MAF Extension Officers were requested to locate the farmers and verify the information collected from the field. Data were also gathered by visiting local markets and shops using a separate checklist, which focused on the availability, source, purchase cost, and the selling price of ingredients.

Ingredients for on-farm feed use were selected based on their availability within the locality, production volume, price, and their competing uses. Ingredients for feed formulation for commercial manufacturing, however, were identified based on their availability across the country. Ingredients were selected based on seasonality, production volume and bulk purchase cost, and avoided those that were considered to be critical for food security. For the purpose of balanced feed formulation, potential nutritional value of the ingredients was also considered in terms of carbohydrate, protein and lipid source (Rotarian Action Group, 2015). Importantly, the seasonal availability reported here refers to the current status; however, improved irrigation in the future is expected to increase the availability of most crops such as rice and maize and hence feed ingredients.

Design of feed formulation options

Feed formulation options based on locally available ingredients were designed for on-farm manufacturing in the form of pellets or dough/mass balls, the latter to accommodate households where the purchase of a small manual/electric pelletizer was beyond their reach. Commercial feed formulation option was designed to make best use of locally available as well as imported ingredients. Various options that were developed and proposed for use in tilapia aquaculture based on data gathered through the ingredients survey were verified through a stakeholders' workshop held on 26-27 April 2016 in Dili, the capital of Timor-Leste. The workshop was attended by 30 staff from MAF and its Municipality-level officers, as well as WorldFish staff and field officers. The availability of ingredients, and seasonality, price and practicality of proposed feed formulation methods were then scrutinized against ground reality by the workshop participants, culminating in a refined, simpler set of feed formulations. The participants also provided feedback on competing uses of feed ingredients with a view to verifying the survey findings on wider food security impacts of fish feed manufacturing in Timor-Leste.

Macro level assessment of the availability of feed ingredients

The Timor-Leste NADS Implementation Plan has aimed to achieve annual fish production target of 12,000 tonnes by 2030. Hence, potential availability of feed ingredients to realise this target was assessed based on data/information collected from the secondary sources. Demand for feed ingredients against fish production target was estimated under a range of feed conversion ratio (FCR) scenarios using the following formula:

Apparent FCR = Feed used by fish / Fish weight gain

The lower the FCR, higher the weight gain from the feed.

Potential feed demand scenarios based on likely FCR of a given feed were developed to gauge the extent to which Timor-Leste could realistically support aquaculture growth with the feed made using mainly local ingredients. Given the limited availability of animal-source feed ingredients in the country, combinations of locally available ingredients as well as imported ones were proposed for semi-commercial fish feed formulation options.

Results

1. Potential feed ingredients

The main plant- and animal-source ingredients for formulation of on-farm feed and commercial manufacturing identified from the feed availability survey across the three municipalities were almost same, except for a few products such as candlenut (Aleurites moluccanus), coconut (Cocos nucifera) and breadfruit (Artocarpus camansi), which were common in Baucau (Ministry of Finance, 2010). Another notable exception was the large

amount of soybean production in Bobanaro, not seen elsewhere (Tables 1 and 2).

2. Feed formulation options

Feed formulations were developed with the consensus of the workshop participants by considering the eight specifications: (i) Feed ingredients are readily and locally available; (ii) Feed meets basic nutritional requirements (particularly protein and essential fatty acid) of farmed tilapia for their efficient growth; (iii) Feed contains sufficient amounts of binder to make pellets or dough balls with adequate water stability; (iv) Feed is palatable to tilapia; (v) Feed does not contain anti-nutritional factors such as cyanide, phytic acid and mimosine; (vi) On-farm feed manufacturing process, including pre-treatment of ingredients, is not too complex, time-consuming, or onerous; (vii) Feed ingredient costs for on-farm and commercial manufacturing are below US$0.50/kg and US$0.70/kg, respectively; and (viii) Feed does not contain ingredients likely to undermine food security, i.e., should have no competition against ingredients that are used for direct human consumption.

To develop the on-farm feed formulations, two feed characteristics were considered to be important: (i) sufficient levels of essential fatty acids to achieve a more nutritious fish product for the consumers, and (ii) adequate levels of binder in order to give water stability to the pellets or dough balls. A simple Microsoft Excel spreadsheet-based tool was used to explore and develop feed formulation options, especially in view of the regional and seasonal variations in ingredient availability. The tool was quite efficient and flexible providing a relatively easy means of balancing feed nutrients and calculating the ingredient costs of each formulation.

For the purpose of mathematically balancing the relative amounts of key nutrients in feed formulations, moisture, protein, fat, fibre, ash and nitrogen free extract contents for each ingredient were derived from scientific literature (FAO, 1997). In intensive culture, tilapia feed for small-scale on-farm feed manufacture should ideally contain crude protein >20%, gross energy > 280 kcal/100 g feed, fiber < 8%, ash < 12%, moisture < 12%, and essential fatty acids (e.g., linoleic acid) (Li et al, 2012) .

2.1 On-farm feed formulation options

The proposed feed formulations agreed by workshop participants were plant-source (rice bran, corn bran, leucaena leaf meal, and taro/cocoyam leaves), and animal-source (blood meal) ingredients (Tables 3-5). Rice bran and corn bran are the only ingredients that contain the essential fatty acids for an efficient growth of tilapia (de Silva and Senaarachchi, 2021). Leucaena leaf meal and taro/cocoyam leaves serve as the main source of protein (De Angelis et al., 2021). Leucaena leaf meal and cassava meal require pre-treatment to eliminate toxic compounds. The former contains mimosine (Wee and Wang, 1987; Xuan et al., 2006), while the latter contains linamarin/cyanide (Padmaja, 1995; Cereda and Mattos, 1996). Cassava meal serves as a source of carbohydrates (energy) and as a binder. Blood meal is used as the source of animal protein, which is relatively easier to process. It also improves feed palatability.

The workshop participants proposed two sets of feed formulations for on-farm feed production, first, using only plant source ingredients (Table 4); and second also including animal source ingredient, i.e., blood meal (Table 5). The formulations were made deliberately simple (3-4 plant ingredients) based on availability of ingredients and without including vitamins and minerals. It is however expected that deficiencies of vitamins and minerals would be compensated by natural food (phyto- and zooplanktons) available in the green water in ponds and low demand for nutrients due to low stocking density (approx. 3.5 fish per m2). Use of only plant-based ingredients resulted in feeds with low crude protein (13-15%) with the possibility of high crude fiber content. Therefore, the participants agreed that feeding only the plant-based diet might not be adequate for good growth of tilapia unless pond water is rich in natural food. Augmentation by protein-rich ingredients such as soybean meal, bloodmeal or fishmeal is needed. As bloodmeal is locally available across Timor-Leste, albeit in smaller amount, four options were tried using bloodmeal to achieve 5% protein source, which resulted in relatively higher level of crude protein (17-18%) in options 1 and 3 (Table 5). Increasing the amount to 15% or so, protein requirement could be fulfilled. However, bloodmeal is not easy to obtain in such a large volume.

2.2 Commercial feed formulation options

Ingredients for semi-commercial feed manufacturing must be ones that can be obtained in large volumes for economy of scale. Workshop participants developed four feed formulation options ranging from one using locally sourced ingredients to one using predominantly imported ingredients, such as fish meal, soybean meal, vitamin and mineral pre-mix, and essential fatty acids (Table 6). The addition of phytase enzyme (at a rate of 0.5 g/kg ingredient) was included to improve the digestibility of plant ingredients, especially phosphorus, which eliminates the need to add inorganic phosphorus and reduces the phosphorus release via faeces into the water. Leaf-based ingredients used for on-farm feed production were excluded for semi-commercial feed manufacturing (Table 6).

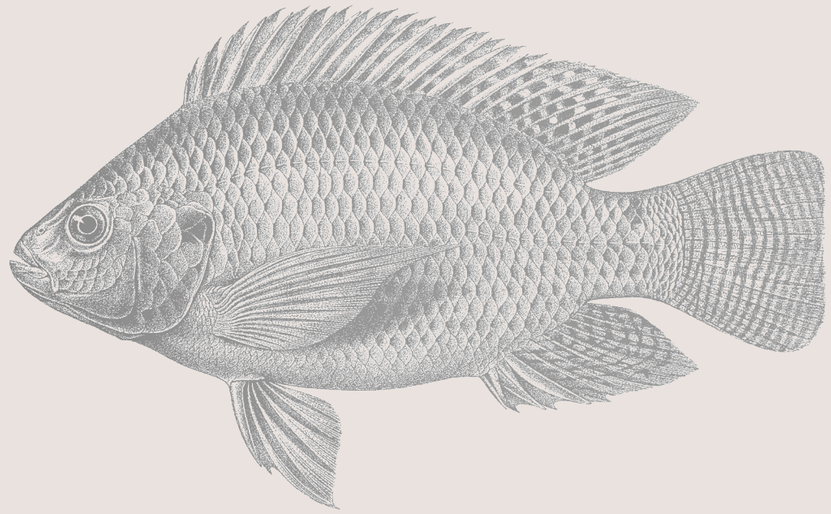
While protein content of all formulations was adjusted to around 26-27%, cost and quality varied across the options. Option 1 is considered inferior as it has sub-optimal amounts of n-3 fatty acids, vitamins and minerals. Option 2 is a more complete diet but has higher ingredient cost. Options 3 and 4 are complete diets but they use several imported ingredients from neighbouring Indonesia, although the total ingredient cost is less than those for options 1 and 2. Hence, for costing purpose, bulk price of ingredients in Indonesia was used. It is worth noting that cassava meal, which is needed as a binder in commercial feed, has an estimated bulk price of US$0.25, although its production in Timor-Leste has just started and its actual price is yet to be set.

3. Macro-level analysis

3.1 Fish feed demand

Timor-Leste's NADS Implementation Plan aims to realise an annual fish production target of 12,000 tonnes through aquaculture (presumably based on a range of species, but dominated by tilapia) by 2030 (NDFA, 2012). If aquaculture in Timor-Leste expands in pond area and increases in productivity and remains on track to meet the 2030 production target, the demand for fish feed will be dictated primarily by the feed conversion ratio (FCR) achieved on-farm. Assuming the FCR of 1.5, total annual feed demand by 2030 will be 18,000 tonnes. Aquaculture in the country is expected to be of a semi-intensive nature using pond fertilization. Hence, in addition to use of formulated feeds, FCR estimations need to be considered on a culture system basis that takes into account the contribution of naturally available food in green water ponds.

The FCR that might be achieved in Timor-Leste aquaculture in the coming years is uncertain. Thus, when modelling future demand for feed, it is useful to consider a range of FCRs to allow for any uncertainty. El-Sayed et al. (2013), for example, reported



FCRs of 1.7-2.5 for Nile tilapia farmed in fertilized ponds and supplemented with pelletized commercial feed. Bhujel (2013) reported FCR of 1 or less in supplementary fed tilapia farming with very high natural productivity. Researchers from Asian Institute of Technology, Thailand and University of Michigan achieved FCRs of 0.83 to 1.28 in experimental trials in Thailand, where ponds were fertilized with chemical fertilizers throughout the culture cycle with supplementary feeding of commercial feed pellets from day 80 (Thakur et al., 2004).

3.2 Feed ingredient demand

The percentage composition values for each of the key feed ingredients used throughout the year were used to calculate the total amount of each ingredient needed in 2030 if all feed was either farm- or commercial-made (Table 7). In order to capture the uncertainty in the performance of locally made feed, FCRs ranges (3.0-4.0 for farm made and 1.5-2.0 for commercially made feed) were used in the calculations.

3.3 Feed ingredient supply and competing uses

3.3.1 Plant source ingredients

Production data on all but the major crops in Timor-Leste are scant. Data on cassava, rice and corn were available through various sources but no reliable data was found on banana, leucaena meal, taro/cocoyam or palm kernel press cake (residue from palm oil extraction).

Cassava (Manihot esculenta)

Cassava is an important energy source for the people's diet and animal feed (Oke, 2007). Its use as a substitute of cereals in fish feed has been reported by Abu et al. (2010), Ufodike and Matty (1984), and Faturoti and Akinbote (1986). Cassava is a popular plant throughout Timor-Leste with a planted area of 10,757 ha and production of 94,834 tonnes in 2010 (NSD, 2011). An estimated 125,000 cuttings were grown in 2013-14 and another 93,000 cuttings distributed to INGOs for seed multiplication (SOL, 2014). Cassava roots are rich in starch and are normally consumed by humans when other staples like rice and maize are depleted (MDF, 2013) and normally fed to pigs. Cassava leaves, relatively high in protein content, are also consumed by humans as a vegetable. No information was however found on the availability of cassava meal or processed to flour for Timor-Leste. Commercial processing into cassava flour has just started, and product is expected to be used for human consumption. Cassava tubers could also be processed on-farm. To reduce the food-feed competition between human and animal, and for profit maximization, cassava could play an important role in Timor-Leste.

Taro (Colocasia esculenta)

Taro (cocoyam) is commonly available in Timor-Leste. Taro corms can be used by households as food, but the leaves are thrown or discarded, or sometimes used as animal feed. It is planted alongside with cassava and sweet potato. It has protein content of about 7% in root and 23% in leaves and is rich in essential amino acids (Saenphoom et al., 2016). Rodriguez et al. (2006) reported that fresh taro leaves can replace soybean meal by up to 50% in young pigs. Bunta et al. (2008) showed that taro leaf silage could replace up to 70-75% of the fish meal protein.

Leucaena (Leucaena leucocephala)

Leucaena (ipil-ipil) is an important fodder crop. Farinu et al. (1992) reported that leucaena leaves make a high-protein feed containing 21.7-34.0% crude protein. It can also be included in tilapia feed (Osman et al., 1996). In Timor-Leste, leucaena is commonly planted alongside coffee plants to fertilize the soil and is also promoted for reforestation. The plant is not used as food and the production data are not available.

Corn (Zea mays)

Corn is a popular cereal grown across Timor-Leste, with an annual production of 102,473 tons from 215,747 hectares. In 2012, Bobonaro produced 30,481 tons, Baucau 7,582 tons and Ermera 4,944 tons (MDF, 2013). Maize bran is used both as food for human and feed for animals by some households.

Rice (Oryza sativa)

In 2012, 51,358 tons of paddy rice was produced by 45,673 households from a total of 81,022 hectares in Timor-Leste (MDF, 2013). Baucau (18,311 tonnes), Bobonaro (6,073 tonnes) and Ermera (3,561 tonnes) municipalities produce over half of country's total rice production. There are large milling companies operating in the major rice production areas such as Lautem, Baucau, Bobonaro and Manatuto. Baucau (9,300), Viqueque (5,883) and Bobonaro (5,219) have the highest numbers of households involved in rice cultivation. Rice paddy is mostly grown for household consumption and just around a quarter of

the harvest is traded in the local market. The surplus is also sold to neighbours during the hungry months. Rice is sold as paddy with bran on. After milling, the miller keeps the bran and sells it in bulk. Rice bran can be used as fishmeal.

3.3.2 Other sources

There is no indication that farm-based ingredients (e.g., banana, cassava, taro, sweet potato) would be limiting at least to meet current demands. Fresh cassava demand projected for 2030 under a worse-case FCR scenario would be about 5% of the current supply. However, more information on crop production at national and suco levels, and also on national production of other crop by-products (e.g., cassava leaves) is needed before a meaningful estimate on the availability of ingredients can be made. This is also essential for making any judgment about whether local ingredients alone could meet the 2030 feed production target. In addition, studies on by-product yield of various crops are necessary. For example, estimated amounts of leaves that could be harvested annually would be required to estimate supply tonnages accurately.

It is reemphasised that the 2030 ingredient demands would require a significant increase in the production of the associated crops at farm level. Whether such demands can be met depends on a range of factors, such as irrigation and land availability, and importantly, the relative profitability of aquaculture compared to other competing land uses.

3.3.3 Animal source ingredients

Of the 221,767 heads of cattle in Timor-Leste, 37,052 are in Bobonaro, 14,172 in Ermera and 11,593 in Baucau (MoF, 2015). About 89% of the households in Bobonaro are involved in cattle raising and 84% in Lautem, with these two municipalities accounting for a quarter of the country's pasture land. Two to three cattle are slaughtered every week in Ermera and Baucau, and 1-2 cattle slaughtered every day in Bobonaro. Although cattle are raised for meat, neither blood nor intestines are used as food by locals. There are some uses of meat and bone meal as food but these by-products are usually discarded. More information is needed on the amount of blood meal, meat and bone meal, and cattle (and poultry) stomach meal that can be generated annually. Among these, animal blood has a potential to use as a source of protein for the manufacturing of commercial fish feed. Assuming that 30 animals are slaughtered each day, each producing 40 litres of blood (which is reduced to 4 kg of blood meal), then theoretically, current production would only satisfy 5% of the 2030 ingredient demand. We suggest for a comprehensive study exploring data on animal production, slaughtering, and animal blood extraction and their potential for fish feed in various municipalities.

3.4 Food security risks

Food security risks should be considered in the context of type and amount of ingredients available and in recognition that fish farming itself represents a potential mean of addressing food security concerns by improving household nutrition through increased consumption of fish. Although overall food security condition in Timor-Leste is improving, there still remains localised food insecurity issues, particularly in Ainaro (southwest), Ermera and Liquica (north) (FAO, 2015). Hence, an understanding of the macro-level ingredients demand for fish feed manufacturing in 2030 against their availability and potential risk of compromising food security by competing against ingredients intended for direct human consumption is important.

This study showed that of all the ingredients assessed, only soybean meal is considered to be a high-risk crop with potential for compromising food security. The rest are considered to pose low or moderate risk as they are neither eaten by humans or nor their production can be readily increased to accommodate farm-based feed manufacturing (Table 8). Based on this assessment, demand of individual ingredients for commercial feed manufacturing in 2030 is generally higher than for on-farm feed ingredients. This is because the commercial formulations assume that the purchase of ingredients is made in bulk and that a single formulation would be used throughout the year, with the end result being demand for greater quantities of fewer ingredients. Thus, there would be even greater limitations in meeting demand for ingredients for commercial manufacturing compared to on-farm feed production to meet the 2030 feed production target. On the other hand, commercial feed producers can import some or all ingredients (from Indonesia or elsewhere), and hence purchasing in bulk from large-scale suppliers can pass on savings from economies of scale in the form of lower ingredient costs. Commercial manufactures need not be solely reliant on locally sourced ingredients.

Discussion

This study aimed at developing and testing on-farm feed formulations for tilapia for small-scale resource-poor farmers relying exclusively on locally available ingredients and providing potential commercial cost-effective feed formulation options using locally available and imported ingredients. The study also aimed at assessing whether the ingredients available in Timor-Leste can fulfill the feed demand to achieve the fish production target of 12,000 tonnes through aquaculture by 2030. There is insufficient data available to make an accurate estimation; however, at a macro level, this analysis has shown that if the underlying assumptions hold true, there are enough raw materials to make sufficient on-farm feed to achieve the 2030 target 18000 tonnes of feed based on FCR of 1.5. The key underlying assumptions included: (i) the requisite ingredients would be available at the farm level, and (ii) FCR of 3.0-4.0 using farm made feed could be achieved in fertilised pond culture systems (Yi et al., 2008). This is particularly important due to the limited availability of animal-based raw material for fish feed manufacturing. Using solely plant-based ingredients available in the country means that protein levels in feed will be compromised. Protein level in feed that includes animal-based ingredients (blood meal and stomach meal) is approximately 20% as against the same feed made solely with plant-based ingredients of around 15%. What effects protein level will have on fish growth rates in the context of the overall FCRs that can be achieved in fertilised pond systems remains to be seen, but clearly, protein sources for feed manufacturers will pose a serious challenge to Timor-Leste meeting its aquaculture production goals. Complete substitution of fish meal in the feed has been demonstrated only in a few cases. Still, almost every ingredient tested – ranging from oil seed meals, pulses and leaf meals to various agricultural by-products (for example, Tacon, 1987; Hertrampf and Pascual, 2000), as well as aquatic food product wastes (e.g., Rathbone and Babitt, 2000; Gunasekera et al., 2002) - tested in laboratory has been proved capable of replacing fish meal to varying degrees, but mostly to about 40%, without compromising the performance and flesh quality.

Achieving the 2030 fish feed production requirement necessitates a significant increase in feed ingredients and an associated quantum increase in the number of farmers and or size of farms. The challenges described above will be exacerbated in the future and hinder the development of the aquaculture sector unless the availability of raw materials increases keeping pace with the demand. Testing the assumptions on the ground is a priority next step in determining the viability of on-farm feed manufacturing to support the Timor-Leste aquaculture, and for doing this, ongoing farm trials conducted by WorldFish across Ermera, Baucau and Bobonaro municipalities provide an opportunity to test and validate the effectiveness of the feed at the farm level (Pant et al., 2023).

Aside from the inherent lack of data on several raw materials to base an accurate estimation of the supply, the survey described in this paper had limitations of its own in terms of the time allocated on the ground. The geographical coverage and the number of key informant farmers interviewed in any one locality were limited and not randomly selected, and as such, there is uncertainty in the conclusions regarding estimation of the availability of raw materials at the national or municipality level, or the availability of ingredients in any one farm within a village. Thus, it is important to undertake a more comprehensive and randomised household survey to obtain a more realistic situation of fish ingredients availability across the country. A more comprehensive and detailed understanding of the potential ingredients for fish feed manufacturing that are available across the country will help better serve the national policy setting.

Importantly, this assessment has not considered whether small-scale pond aquaculture (encompassing farmer capability and access to natural resources) would be sufficiently profitable to attract the more farmers required to meet the production targets set in the aquaculture strategy. The feed cost typically makes up a significant portion of the overall production cost in aquaculture worldwide. In this study, we aimed to develop a farm-made feed of reasonably good quality based on plant ingredients at a cost of US$0.50 per kg or less (Tables 4 and 5). Ingredient cost varied significantly but was clearly much less for formulations that did not include animal-based materials with much lower protein levels. For example, in Poetete and Fatuquero villages, on-farm feed using plant-only ingredients cost only US$0.11-0.15 per kg, whereas feed that included animal ingredients cost US$0.26-0.34 per kg, reflecting the scarcity of high-protein raw materials that are suitable for diversion to fish feed manufacturing. As discussed previously, the assumptions about FCR are critical to these calculations and they must be verified through trials. Detailed information from on-ground trials is also necessary to determine the true cost of feed manufacturing, which must also take into account a range of other inputs (including time and labour costs). These inputs are difficult to model with confidence without on-ground trials.

Beyond determining the actual cost of feed, it is crucial to undertake enterprise-level economic (benefit-cost) modelling to evaluate the overall economic feasibly of small-scale fish farming (tilapia and other species) in Timor-Leste. The on-going PADTL2 WorldFish Project and USAID Project trials provide an excellent opportunity to collect data needed to support such a modeling (Pant et al., 2023). As part of a modelling exercise, it would be prudent to undertake parallel modelling of medium- and large-scale aquaculture, and of cluster or cooperative farming systems. This sort of modelling can generate information that will place policy makers in a better position to set future directions.

This analysis also looked at the potential impact of diverting raw materials to aquafeed manufacturing on food security. To a great extent, the choice of ingredients guarded against serious food security issues. Increasing lands allocated primarily to produce raw materials for fish feed as well as those allocated to building ponds needs to be monitored carefully to detect these indirect impacts on food security, especially in poor and vulnerable communities. Such analyses should also consider the benefits of aquaculture from the food security perspective.

In recent years, an animal feed company has already started producing fish feed in small batches and has shown its willingness to expand the production based on the commercial feed formulation options proposed in this paper (Pant et al., 2023). This analysis found the costs of ingredients for semi-commercial aquaculture to be higher than those for on-farm feed formulation although the feed for the former would be of superior quality. However, if productivity gains to meet fish demand are a priority, there may be a greater role for commercial-scale feed manufacturing. As mentioned before, it is paramount that economic modelling needs to be conducted to determine the feasibility of setting up and operating large-scale commercial feed mills. Such a modelling should incorporate comparisons between importing commercial feed pellets and importing ingredients for manufacturing feed in Timor-Leste, and policy setting options that would lower the costs of importation, for example, through reducing import duties.

Conclusions

Feed is the most important input for the development of aquaculture industry. Formulating quality feed containing high protein is not possible using ingredients of only plant origin. Feed quality can be improved by including ingredients with high protein content, especially of animal origin, e.g., fishmeal, animal bloodmeal. However, virtually all of the plant- and animal-based ingredients are in short supply in Timor-Leste. Hence, establishment of a fish feed industry is necessary. For this, in-country production of plant-based ingredients (e.g., corn, rice bran, soybean) have to be substantially increased and made available first at modest prices so that import could be restricted to fishmeal and/or soybean meal only. While aquaculture in Timor-Leste is just emerging, low demand for fish feed might constrain the economic viability of in-country feed manufacturing industry. Therefore, supporting private sector for the import of high-quality feed in bulk may serve as an alternative for scaling of aquaculture in a more efficient and cost-effective way until the time when the country starts producing feed itself. In recent years, attempts have been made elsewhere to explore alternatives to fish or soybean meals to enhance the quality of feed, which have emerged as potential sources of protein, such as black soldier fly and other insect meals (Bhujel and Perera, 2023; Galecki and Golaszewski, 2023). These alternatives may work in homestead small-scale production systems. Hence, future study should also address the technical feasibility, economic viability, and environmental aspects of their mass-scale production.

(References available upon request)

The Aquafeed Journal
Peer Reviewed article

For supporting tables and references please visit the article page on the online document repository at aquafeed.co.uk

Article 23.v1.1
bit.ly/23aquajournal1

Table 1. Availability of potential plant- and animal-source ingredients for on-farm formulation of tilapia feed in three municipalities of Timor-Leste.

SN	Ingredients	Ermera	Baucau	Bobonaro
I	Plant-source			
1	Banana leaves	Year-round	Year-round	Year-round
2	Banana/plantain meal	Year-round	Year-round	Year-round
3	Breadfruit	No data	Year-round	No data
4	Candlenut	No data	September and February	No data
5	Cassava fresh	June-July	June-July	June-July
6	Cassava leaves	June	June-July	June-July
7	Coconut	June-July	July-August	June-July
8	Coconut (copra) meal	No data	July-August	No data
9	Coffee pulp	May-July	May-July	May-July
10	Corn meal/ground corn	Feb-March	Feb-March	Feb-March
11	Corn/maize bran	Feb-March	Feb-March	Feb-March
12	Crushed beans and field peas	No data	Feb- March	March-April
13	Kangkong (water spinach)	Year-round	Year-round	Year-round
14	Leucaena leaf meal	Year-round	Year-round	Year-round
15	Mung beans	May-June	May-June	May-June
16	Palm kernel press cake	No data	Year-round	No data
17	Peanut	April-May	April-May	April-May
18	Peas (crushed/ground)	No data	June-July	March-April
19	Rice bran	April-May	April-May	April-May
20	Rice/paddy (ground)	April-May	April-May	April-May
21	Soybean			March-April
22	Sweet potato fresh	August-September	April-May	May
23	Sweet potato leaves	Year-round	Year-round	Year-round
24	Taro/cocoyam leaf	Year-round	February	May
25	Vegetable by product (mixed)	Year-round (monthly)	Year-round (monthly)	Year-round (monthly)
26	Yellow yam leaves	Year-round	Year-round	Year-round
II.	Animal-source			
1	Earthworm, fresh	Year-round	Year-round	Year-round
2	Fish (dried)	Year-round (February*)	Year-round (February*)	Year-round (February*)
3	Fresh blood (coagulated)	Year-round (monthly)	Year-round (monthly)	Year-round (monthly)
4	Cattle/poultry stomach meal	Year-round (weekly)	Year-round (weekly)	Year-round (weekly)
5	Snail meat, fresh	Year-round (December*)	Year-round (December*)	Year-round (December*)
6	Trash fish, raw	Year-round (Jan to Feb*)	Year-round (Jan to Feb*)	Year-round (Jan to Feb*)
7	Meat/bone	Weekly	Weekly	Weekly

*peak supply period
Source: Key Informants Interviews, 2016

Table 2. Availability of potential plant- and animal-source ingredients for commercial manufacture of tilapia feed in various municipalities in Timor-Leste.

Feed Ingredients	Potential source areas
Banana/plantain meal	Dili, Manatuto, Manufahi, Aileu, Ainaro, Baucau
Candlenut	Viqueue, Ainaro, Lautem, Manufahi, Baucau
Cassava meal	Covalima, Manufahi, Aileu, Manatuto, Ermera, Baucau, Bobonaro
Coconut/copra meal	Viqueque, Lautem, Bobonaro, Baucau
Coffee pulp	Liquica, Aileu, Maubisse, Letefoho
Corn meal/ground corn	Lautem, Viqueque, Oecusse, Baucau, Bobonaro, Ermera
Corn/maize bran	Lautem, Viqueque, Oecusse, Baucau, Bobonaro, Ermera
Rice bran	Manatuto, Viqueque, Covalima, Oecusse Baucau, Bobonaro, Ermera
Soybean by product	Bobonaro, Ermera (Atsabe and Letefoho), Ailue, Viqueque
Fish (dried)	Atambua (at cheapest price)
Fresh blood (coagulated)	Available at slaughterhouses in all municipalities
Trash fish, raw	Liquica
Meat and bone meal	In small quantities in all municipalities

Sources: Consultation meetings with NDA, MAF staff and local farmers at various times, Timor-Leste; Feedback from Feed Consultation Workshop, 2016.

Table 3. Proximate nutrient compositions of selected ingredients for tilapia feed formulation and their prices (US$/kg) in Timor-Leste.

Ingredients	Composition (%)						
	Moisture	Protein	Fat	Fiber	Ash	NFE	Price (US$/kg)
Taro/cocoyam leaves	9.31	16.48	9.68	8.99	11.82	43.73	0.10
Leucaena leaf meal	7.89	21.09	10.57	13.17	5.93	41.36	0.10
Corn bran	9.81	8.91	7.31	0.84	2.72	70.42	0.50
Rice bran	7.88	7.03	4.95	20.79	16.59	42.78	0.50
Blood meal	11.00	76.70	1.10	1.20	4.00	5.96	2.50

NFE: nitrogen free extract; Source: Tacon (1987).

Table 4. Evaluation of on-farm tilapia feed formulation options using locally available plant-based ingredients in Timor-Leste.

Ingredients	Composition (%)			
	Option 1	Option 2	Option 3	Option 4
Corn bran	32	29	-	-
Rice bran	-	-	26	25
Leucaena leaf meal	57	-	63	-
Taro/cocoyam leaves	-	60	-	64
Cassava Fresh	10	10	10	10
NaCl (salt)	1	1	1	1
Total	100	100	100	100
Protein (%)	15	13	15	13
Fat (%)	9	8	8	8
Fiber (%)	8	6	8	8
Gross energy (kcal/100 g)	385	370	347	332
Price (US$/kg)	0.27	0.26	0.24	0.24

Table 5. On-farm tilapia feed formulation options using locally available plant- and animal-based ingredients in Timor-Leste

Ingredients	Composition (%)			
	Option 1	Option 2	Option 3	Option 4
Corn bran	40	34	-	-
Rice bran			30	27
Leucaena leaf meal	44	-	54	
Taro/cocoyam leaves	-	50	-	57
Cassava Fresh	10	10	10	10
Blood meal	5	5	5	5
NaCl (salt)	1	1	1	1
Total	100	100	100	100
Protein (%)	17	15	18	15
Fat (%)	8	8	7	7
Fiber (%)	7	5	14	11
Gross energy (kcal/100 g)	391	377	346	336
Price (US$/kg)	0.42	0.40	0.38	0.37

Table 6. Commercial tilapia feed formulation options using local and imported ingredients in Timor-Leste.

Ingredients	Option 1	Option 2	Option 3	Option 4
Fish meal			15.00	10.00
Soybean meal			-	10.00
Wheat bran			29.48	21.77
Cattle/poultry stomach meal	25.00	25.00	10.00	10.00
Blood meal	5.00	5.00	5.00	5.00
Palm kernel press cake	5.00	5.00	5.00	5.00
Rice bran	20.00	20.00	22.00	24.41
Corn bran	30.48	30.08		
Cassava meal	13.52	10.00	10.00	10.00
Fish oil		1.70	0.30	0.60
Crude palm oil		-	-	-
Dicalcium phosphate		2.00	2.00	2.00
Vitamin and mineral mix		0.10	0.10	0.10
Vitamin C (l-ascorbic palmitate)		0.06	0.06	0.06
α-tocopherol acetate		0.03	0.03	0.03
Phytase enzyme (0.5 g/kg plant)		0.03	0.03	0.03
NaCl (salt)	1.00	1.00	1.00	1.00
Total	100.00	100.00	100.00	100.00
Price (US$/kg)	0.56	0.69	0.55	0.55
Nutrient content (%)				
Crude protein	26.4	26.3	27.1	27.2
S w-6	2.4	2.7	1.8	2.5
S w-3	0.1	0.6	0.6	0.6
Fiber	7.3	7.1	6.9	6.6

The Aquafeed Journal
Peer Reviewed article

For supporting tables and references please visit the article page on the online document repository at aquafeed.co.uk

Article 23.v1.1
bit.ly/23aquajournal1

The Aquafeed Journal

Peer Reviewed article

FISH FARMING TECHNOLOGY
INTERNATIONAL AQUA FEED

Perendale Publishers Ltd

Volume 1 - 2023

Find out more at:

www.aquafeed.co.uk/category/journal-articles/original-research