Supporting ASEAN Good Aquaculture Practices:
Utilization of Alternative Protein Sources for Aquafeed to Minimize Pressure on Fishery Resources

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Aquaculture industry of Southeast Asia has been expanding steadily as a result of an increasing demand of food fish in the region as well as in the global scale. Aside from its contribution to the world's fisheries, the aquaculture industry creates employment opportunities and provides income for the region's fish farmers, as well as produces fish which is a major component in the diets of peoples in Southeast Asia. However, the fast development of aquaculture had been viewed as threat to sustainable capture fisheries production as the widespread use of fish by-catch in aquaculture feeds results in over-exploitation of the fishery resources and to certain extent degradation of the resources. Recognizing the importance and urgency of addressing such concern, the Senior Officials of the ASEAN Member States responsible for fisheries adopted in June 2011, the Plan of Action on Sustainable Fisheries for Food security for the ASEAN Region Towards 2020 which includes provision on the need to "improve the efficient use of aquatic feeds by strictly regulating the quality of manufactured feed and feed ingredients and support continued research for developing suitable alternative protein sources that will reduce dependence on fishmeal and other fish-based products." Along with such declaration, the SEAFDEC Aquaculture Department has been enhancing its R&D activities aimed at finding alternatives to fishmeal as feed ingredients in aquaculture feed formulations.

Many ASEAN Member States (AMSs) are top producers of aquatic products from aquaculture, *e.g.* Indonesia, Viet Nam, Myanmar, Thailand, and the Philippines altogether contribute about 16% of the total finfish (inland aquaculture) and 19% of the total finfish (mariculture) production in the world (**Table 1 & 2**). Given the land resource and access to improved technology, Cambodia, Lao PDR and Singapore would be fast catching up in terms of aquaculture production and can become major players in the coming decades. Supporting this upward direction entails the reliance of aquaculture on efficient and sustainable aquafeed production.

Issues and Concerns

Reducing aquafeed dependency on fishmeal is a key for a sustainable development of aquaculture. Towards this end and guided by the various agreements and declarations of the ASEAN-SEAFDEC Member Countries, the Aquaculture Department (AQD) of SEAFDEC launched a program on Healthy and Wholesome Aquaculture since the late 1990s, which is a holistic approach to address issues on fish nutrition and aquatic disease management for food security and sustainability of the aquaculture industry. Going along the direction towards sustainability, the AMSs took notice of the need to source aquafeed ingredients from other sources aside from wild-caught fish in order to minimize pressure on the fishery resources which had undergone severe deterioration. Thus, the AMSs heeded the call for States to "*support research and development on potential feed ingredients and alternative protein sources to minimize the use of fishmeal and food fish in aquaculture*" (SEAFDEC, 2001a). Such objective had been

Table 1 & 2. World's top 10 producers by selected measurements of aquatic production, 2013 (FAO, 2015)

1. Finfish - Inland Aquaculture

Country	Production (metric tons)	%
China	24,817,311	60.1
India	4,148,407	10.0
Indonesia	2,459,418	6.0
Viet Nam	2,369,903	5.7
Bangladesh	1,647,827	4.0
Egypt	1,091,688	2.6
Myanmar	869,384	2.1
Thailand	467,249	1.1
Brazil	388,700	0.9
Philippines	318,798	0.8
Others	*2,713,481*	*6.6*
World	**41,292,167**	**100.0**

2. Finfish - Mariculture

Country	Production (metric tons)	%
Norway	1,245,399	21.6
China	1,123,576	19.4
Chile	736,310	12.7
Indonesia	720,545	12.5
Philippines	375,735	6.5
Japan	242,905	4.2
United Kingdom	156,220	2.7
Greece	124,740	2.2
Canada	122,024	2.1
Turkey	110,845	1.9
Others	*820,088*	*14.2*
World	**5,778,387**	**100.0**

intensified when the ASEAN-SEAFDEC Member Countries again agreed to "*improve the efficient use of aquatic feeds by supporting research into developing suitable alternative protein sources to reduce dependence on fishmeal and other fish-based products*" (SEAFDEC, 2001b).

Recognizing the urgency and severity of the aforesaid concern, the ASEAN-SEAFDEC Member Countries reiterated their declaration to "*consider aquafeed ingredients not derived from wild-caught fish, encourage the culture of species requiring no or low fishmeal content in their feed and apply effective feeding management practices, taking into consideration the need for cultural and social acceptance of alternative feed ingredients*" (SEAFDEC, 2011). Therefore, it has also become imperative for SEAFDEC to support the objective of achieving sustainable aquaculture by doing its part in searching for suitable and cost-effective substitutes for fishmeal and fishery products in aquaculture feeds or aquafeeds. Platon *et al*. (2007) suggested that in order to support R&D initiatives to reduce dependence on fishmeal for aquafeeds, it is necessary to intensify research on the use of low-cost agricultural products or plant-based ingredients for aquafeeds. Through SEAFDEC's Philippine-based AQD, R&D on fish nutrition has been sustained focusing on alternative protein sources that could be used as fishmeal substitutes in the formulation of aquafeeds for various aquaculture species.

Fishmeal Substitutes

Although most omnivorous fish species feeds are now devoid of fishmeal such as tilapia, carp, catfish, and milkfish, reduction of fisheries-based products in the diets of carnivorous aquaculture species still poses a huge challenge. Feed accounts for 50% of the total operational costs in

Box 1. Locally-available ingredients as fishmeal substitutes

Plant protein

Feed ingredients derived from plants are the most abundant substitutes for fishmeal. However, their characteristics of having high variability of nutrient profile, inadequacy of essential amino acids (EAA), and the presence of anti-nutritional factors are aspects that still need thorough examination and research.

Oil seeds such as soybean meal, cotton seed meal, rapeseed (**Fig. 1**) meal, and sunflower meal have competitive prices and protein content ranging from 38 to 52%. Soybean meal is the most available and commonly-used plant ingredient in aquaculture. Fishmeal replacement by oil seeds is only limited to 20-40% and mean incorporation of 10-20% for carnivorous fish species. Oil seeds are characterized to be deficient in EAA, particularly methionine and lysine, and could also contain several anti-nutritional factors that can be inactivated by heat processing or solvent extraction. Palatability is compromised when plant ingredients are incorporated in the diets of the fish, thus the addition of feed stimulants is needed.

Fig. 1. Rapeseed
www.bdtdc.com

Pea seed meal *Pisum sativum* and lupin *Lupinus*, and other beans could contribute to the research on substitution of fishmeal. However, due to their minimal protein content (22-30%), its incorporation has become limited due to the presence of anti-nutritional factors. It can replace fishmeal at a level of 10-30% of the ingredient. Its incorporation has become limited due to the presence of anti-nutritional factors, poor EAA profile, presence of non-starch polysaccharides and a high content of starch which should be taken into consideration when formulating the diet.

Cereals which include maize, rice and wheat could be incorporated in the diets to be used as an energy source (carbohydrates). It is low in protein (8-12%) but is a rich source of carbohydrates in the form of starch (about 60%). Cereal incorporation in the diets of carnivorous fish is limited at 10-20% which provides 5% of the dietary protein. It is also deficient in EAA especially lysine.

Leucaena leaf ("ipil-ipil" leaf meal) with an analyzed crude protein of 34.38% could be a supplement in the diets of tilapia. However, this plant protein source contains mimosine and tannin which are toxic that can affect the digestive process of the fish and eventually leads to poor fish growth.

Groundnut cake, *Arachis hypogaea* which contains 31.6% crude protein, is an alternative protein source which is highly palatable and have acceptable odor. It has better binding properties compared to soybean. In spite of its positive characteristics, it is deficient in some EAA (methionine and lysine) and can be exposed to aflatoxin which is toxic. Results from previous studies suggested that groundnut cake can replace 10% of fishmeal in the diets of catfish *Heterobranchus longifilis*.

The sweet potato, *Ipomoea batatas* is an important food crop in the tropical areas. The leaves of this plant have been used as a cheap protein source as ruminant feeds. The leaf meal has protein content between 26 to 33%, good amino acid, minerals and vitamin profile. However, it contains anti-nutritional factors that can significantly affect fish growth. Tilapia growth trials have suggested an up to 15% inclusion level of sweet potato leaves in tilapia diets.

The identification and removal of anti-nutritional factors through heat treatment has improved the potential of taro, *Colocasia esculenta* as a protein ingredient in fish feeds. Taro leaves have a high amount of protein (31.5%) and high level of vitamins and minerals which are needed in fish feed formulation. Growth experiment has indicated that a complete replacement of fishmeal with taro can be achieved in the diets of tilapia cultured in ponds with high natural productivity.

Harvested duckweed, *Lemna* spp. (**Fig. 2**) plants contain up to 43% protein on a dry weight basis and may be utilized without further processing as a complete food for fish. The amino acid profile of duckweed is relatively better than most of the plant protein sources and it contains high concentration of trace minerals. Studies have indicated that tilapia fed with duckweed at a feeding rate of up to 30 g dry matter/kg resulted in a higher survival rate and weight gain.

Fig. 2. Duckweed
www.duckweedbioponica.com

Box 1. Locally-available ingredients as fishmeal substitutes (Cont'd)

Coconut meal (copra), *Cocos nucifera* is made from the processed by-product of coconut oil extraction. It contains approximately 22% crude protein. Copra contains no known anti-nutritional factors and has a high protein digestibility. But relative to fishmeal and soybean meal it is deficient in all the essential amino acids required by fishes. Nevertheless, copra is a useful diet ingredient in areas where it is locally available in quantity.

The leaves of water hyacinth, *Eichhrornia crassipes* (**Fig. 3**) contain 20% protein and relative to other plant, its essential amino acid profile is relatively balanced. However, it has a high fiber content which limits the utilization of this ingredient. Reports have suggested that processing the water hyacinth as concentrates can improve its nutrient profile and can be fed to white shrimp, *Litopenaeus vannamei* at 25% level.

Fig. 3. water hyacinth

Terrestrial animal protein

Rendered protein or animal by-product, which comprises meat meal, poultry meal (**Fig. 4**), meat and bone meal, feather meal, blood meal, has high potential as alternative to fishmeal. However, these types of ingredients are heterogenous in nutrient profile, limited EAA and prone to bacterial contamination. The protein content of these animal by-products ranges from 50 to 80% and can replace fishmeal at a level of 20-40%. These types of ingredients have good palatability and do not contain anti-nutritional factors similar to plants. However, it contains high levels of ash and saturated lipid. High inclusion level of animal by-product meal in fish feed can cause excess dietary phosphorus which is harmful to the environment and could have deleterious effect on the nutritional health of the fish.

Fig. 4. Chicken by-product meal
www.saragingerich.com

Fisheries co-products

Shrimp by-products, *e.g.* heads and shells (**Fig. 5**) are produced in large quantities from processing plants and are commonly used as ingredients in shrimp diets. Head meal, processed residue and waste of shrimp by-products has an average crude protein of 40%. Studies have indicated that *L. vannamei* growth and survival was significantly improved when shrimp by-product was included in the feeds of up to 18% level. Fish, *e.g.* humpback grouper growth experiments suggested that with increased level of shrimp head meal (SHM) inclusion in the diets, growth and feed efficiency were adversely affected. High chitin and ash content of SHM pose as main constraints in the performance parameters of the fish fed the experimental diets. Studies also suggest that a maximum of 10% SHM inclusion could be included in the diet of the fish.

Fig. 5. Shrimp head meal
www.hxcorp.com

By-products from the fish processing industry, *i.e.* milkfish and tuna (**Fig. 6**), could be utilized as ingredient in fish feeds. On average, derivatives from fish processing has crude protein of 60% and several essential amino acids are not limiting. Research trials have shown that these ingredients have performed well when fed to grouper, *Epinephelus coioides* and red sea bream, *Pagrus major* at an inclusion level of up to 25%. However, products obtained from the processing plants do not ensure the homogeneity and freshness of the ingredients.

Fig.6. Fish processing by-product
www.addcon.com

Microbes

Single cell proteins (SCP), such as yeast are rich in protein source (>50%), high levels of nucleotides, palatable and devoid of anti-nutritional factors commonly found in plants. Studies have indicated that these ingredients can replace protein from fishmeal by as much as 50% (corresponding to a dietary incorporation of 30-55%). These types of ingredients are mostly incorporated in the diets as potential probiotics which can improve the health condition, health resistance, microbiota balance, and gut physiology of the fish.

Unconventional sources

Earthworm (**Fig. 7**) can also be used as protein source in fish feed. It has amino acid profile similar to that of fishmeal and can be easily propagated in culture conditions. Replacement of up to 20-30% earthworm (*Eisenia foetida*) has improved the growth performance of several fish such as tilapia, rainbow trout and common carp which could be attributed to its palatability and high protein content of 60% crude protein.

Considered as pest, the golden snail (*Pomacea* sp.) is easy to cultivate and has a huge potential to become a source of protein in fish diets. It is characterized with high protein content however it has low levels of specific essential amino acid (methionine + cystine) relative to fishmeal values. Results from experiments have suggested maximum inclusion level of 30% GSM to replace fishmeal in the diets of tiger grouper (*Epinephelus* spp.).

Frog meal contains 58% of crude protein and amino acids close to the ideal profile of an animal feed. It contains a high proportion of essential fatty acid as good source of vitamins and minerals. However, scientific studies on its utilization as ingredient in fish feeds had been very limited.

Tilapia fed with maggot meal of up to 30% substitution level resulted in good overall growth performance and health status of the fish. Based on cost effectiveness, availability and nutrient profile, the housefly larvae grown on animal waste seem to have an immensed potential as an alternative source of protein in the diets of the fish. Maggot meal has a range of protein content of 39-55%, a rich source of phosphorus, trace elements, B complex vitamins and an excellent essential amino acid profile.

Fig.7. Worm meal
www.mazuri.com

Table 3. Protein and limiting amino acid profile of selected alternative protein ingredients (A. Oliva-Teles *et al.*, 2015)

Feedstuffs	% Protein	Limiting amino acids		
		1°	2°	3°
Maize distillers wet grains and solubles	44.0	Lys	Tyr	Arg
Maize distillers dried grains and solubles	29.5	Lys	Tyr	-
Brewer's yeast, dehydrated	48.6	M+C	His	-
Earthworm, dehydrated	61.0	Lys	-	-
Feather meal	87.5	Lys	His	Trp
Blood meal	94.1	Ile	Trp	His
Poultry offal meal	60.2	Lys	Trp	His
Meat and bone meal, low fat	62.0	Lys	M+C	Trp
Meat and bone meal, high fat	54.9	Trp	M+C	Lys
Fishmeal, 60-68% protein as fed	70.6	-	-	-
Fishmeal, high protein	75.4	-	-	-
Maize gluten meal	67.3	Lys	Trp	Arg
Maize grain, Europe	9.4	Lys	Tre	-
Wheat grain	12.6	Lys	Tre	-
Faba bean (*Vicia faba*)	29.0	M+C	Trp	-
Lupin (*Lupinus angustifolius*), blue seeds	33.8	M+C	Lys	Trp
Pea seeds	23.9	M+C	-	-
Linseed meal, expeller-extracted	34.2	Lys	-	-
Cottonseed meal, low fiber, low oil	45.0	Lys	M+C	Tre
Sunflower meal, solvent extracted, dehulled, partially dehulled	37.7	Lys	-	-
Canola meal, solvent extracted	39.0	Lys	-	-
Rapeseed meal, solvent extracted, low erucic, low glucosinolates	38.3	Lys	-	-
Soybean meal, high oil (expeller)	49.3	M+C	-	-
Soybean meal, high protein (dehulled)	53.5	M+C	-	-

Note: 1° - First limiting amino acid; 2° -Second limiting amino acid; 3° -Third limiting amino acid
Arg - Arginine; His - Histidine; Ile - Isoleucine; Lys -Lysine; M+C -Methionine + Cysteine; Tre - Threonine; Trp - Tryptophan; Tyr - Tyrosine

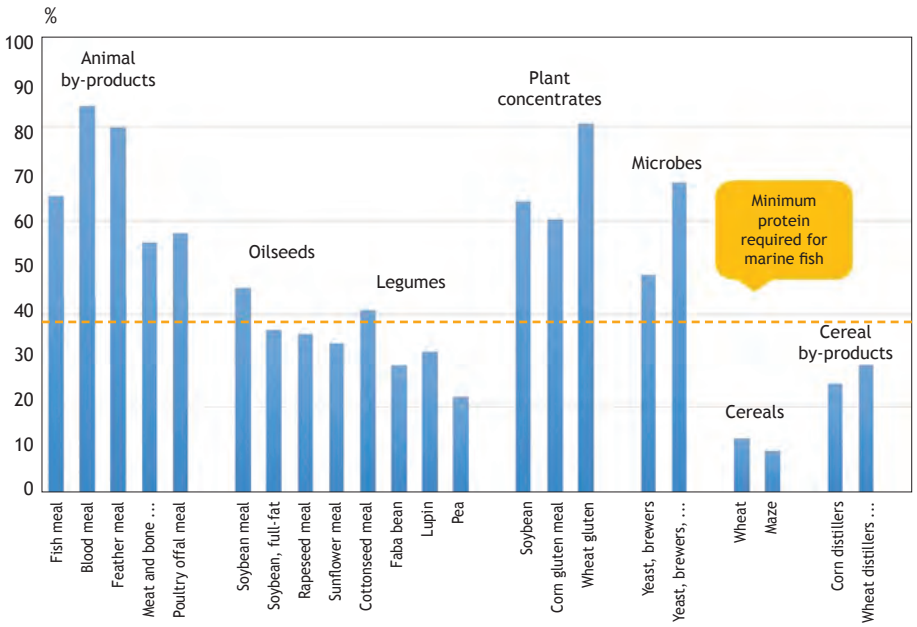

Fig.8. Protein composition of alternative protein sources (A. Oliva-Teles *et al.*, 2015)

aquaculture with fishmeal as the main protein source (average inclusion level of 24% in the diets). The supply of wild-caught fish in the Southeast Asian region including by-catch or trash fish had been dwindling while the same fishery resource also serves as protein source for peoples in the region. Thus, the aquaculture industry is beset with increasing operational costs in feed formulations, shortage of fish-based ingredients, and increasing conflict with human consumption. This has driven the AMSs to seek the assistance of SEAFDEC/AQD in exploring the use of unconventional ingredients in aquafeeds. Therefore, SEAFDEC/AQD with inputs from the AMSs, has been examining the utilization of locally available ingredients as fishmeal substitutes, *e.g.* plant protein, protein from terrestrial animals, fisheries co-products, microbes, unconventional sources (**Box 1**).

Processing of the Ingredients

Although indigenous and alternative protein sources are encouraging, high levels of inclusion has been hampered by various constraints as mentioned above, which could include: deficiencies in nutrient composition (protein and essential amino acids) as shown in **Fig. 8** and **Table 3**, complex carbohydrates, high fiber, anti-nutritional factors and even contamination. Advances in feed processing which comprise extrusion cooking, pre-enzyme treatment, use of protein concentrates, hydrolysis and solvent extraction have been undertaken to improve the nutrient profile of the ingredients.

For AMSs that produce palm oil, lessons could also be learned from Indonesia's research on "converting waste to wealth" through the natural process of bioconversion to produce aquafeeds from oil palm kernel (Hem *et al*., 2008).

Recommendations and Way Forward

Acceptability of these alternative protein ingredients mainly depends on its nutrient and phytochemical profile. Previous growth experiment resulted in poor performance parameters when using these crude alternative ingredients. With the advent of new feed processing technology, these protein substitute ingredients could be incorporated in the fish diets at a higher level without significantly affecting growth. Blending two or more processed alternative ingredients in fish diet formulations has been currently pursued in experimental growth trials.

SEAFDEC/AQD has embarked on nutritional studies which involve applying fish protein substitutes (plant, terrestrial animals and fish by-products) in fish diets. Over the past decade, several results have shown prospects that some ingredients could be applied in a commercial scale without affecting fish growth and revenue from the farmed fish. At present, laboratory results from the evaluation of recently introduced ingredients (Distiller's dried grains with soluble (DDGS), hydrolyzed milkfish offal, mungbean as well as new variety of soybean meal) in the region had shown positive

Box 2. Regional Policy Recommendations for the Development and Use of Alternative Dietary Ingredients or Fishmeal Substitutes in Aquaculture Feed Formulations

Issues/Gaps	Regional Policy Recommendations
Knowledge & Technology Nutritional profiles of feed ingredients (amino acid/fatty acid profile)	• Create a network/regional forum for exchanging and sharing of information on R&D on feed formulation and improving feed efficiency • Technical support to improve farmer knowledge on feed and feeding management, hygiene and sanitation • Information exchange and cooperation with other regions
Status of the aquafeeds	• Assess the capacity of feed milling companies, status of import - export of the raw materials for feed ingredients
Raw materials from IUU fishing activity/GMO	• Traceability system of raw materials • Apply the Catch Documentation system
Efficiency of Feed Formulation	• R&D on aquafeeds quality, formulation and use of alternative dietary ingredients
Sustainability of supply of alternative dietary ingredients to replace fishmeals	• Need government program to increase production and centralized supply of feed ingredients in each local government • Develop techniques for mass production of high quality alternative ingredients • Establish the local ingredients supplier networks
Creation of regulations/fishery acts to manage the development of Aquafeeds	• Establish the national Aquafeeds Quality Standards (control) to ensure that feed milling companies comply with the regulation/fishery acts
Center of ASEAN Program	• SEAFDEC/AQD to work closely with ASEAN Member States, R&D institutions, the academe, Industry and inter-regional organizations as a center of ASEAN programs on Development and Use of Alternative Dietary Ingredients in Aquaculture Feed Development • Establishment of the ASEAN Network on Development and Use of Alternative Dietary Ingredients in Aquaculture Feed Development
Regional Cooperation	• Develop the National Action Plan on Development and Use of Alternative Dietary Ingredients in Aquaculture Feed Development • Increase the awareness of importance of reducing dependence of aquaculture on marine animal origin feed and ingredients

Agricultural wastes and by-products currently being converted into valuable protein sources in tilapia diets (Photos: F. Aya)

results as well. Information that could be gathered from this article could serve as basis to further improve the utilization of these ingredients by other fish species as well as the search for new ingredients to lessen the dependence of fishmeal in the formulation of aquaculture feeds.

Along with such foresights, SEAFDEC in collaboration with the Department of Fisheries of Myanmar with funding support from the Government of Japan through the Japan-ASEAN Solidarity Fund, convened the ASEAN Regional Technical Consultation on Development and Use of Alternative Dietary Ingredients or Fishmeal Substitutes in Aquaculture Feed Formulations in Myanmar in December 2014. The Consultation came up with Regional Policy Recommendations for the Development and Use of Alternative Dietary Ingredients in Aquaculture Feed Formulations (**Box 2**) which had been endorsed by the SEAFDEC Council during its Forty-seventh Meeting in Thailand in April 2015 (Catacutan *et al*., 2015). Therefore, SEAFDEC/AQD would continue to pursue its technical works as well as information compilation on the aforementioned aspects as these could serve as basis for countries in the region to develop strategies to reduce dependence of fish-based materials as ingredients in aquaculture feeds, as recommended by the SEAFDEC Council of Directors (SEAFDEC, 2015).

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