

Fishmeal substitution with plant ingredients in shrimp feeds: A sustainability conundrum?

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A shift from fishmeal to plant ingredients should not be taken for granted as a sustainable solution to meeting a rapidly expanding shrimp aquaculture industry

By Wesley Malcorps and Björn Kok

Significant amounts of fishmeal are included in shrimp diets, causing a dependency on finite marine resources. Driven by economic incentives, terrestrial plant ingredients are widely viewed as sustainable alternatives. As the relative price of fishmeal increases, feed manufacturers have been decreasing inclusion rates of fishmeal in commercial diets and shifting towards crop-based ingredients such as soy protein concentrate, cereal and wheat gluten.

Substitution of fishmeal by plant ingredients is also considered to be environmentally sustainable, while the nutritional requirements of shrimp may limit the amount of fishmeal substitution. Additionally, substituting fishmeal by plant ingredients would shift resource demand from the oceans onto the land, potentially adding pressure to the land-based food production systems, affecting the environment, biodiversity, and availability and prices of crops.

Current knowledge suggests that aquaculture growth and its increasing demand for plant ingredients in aquafeed could affect agricultural supply and its resources, such as land, freshwater and fertiliser. However, the quantitative impact is relatively unknown.



Fish meal. Credit: Sadasivam Kaushik



Credit David Mark pixabay.com

Aquafeed interactions with marine and terrestrial resources

Aquaculture and capture fisheries are interdependent, as fishmeal and fish oil are used in many aquafeeds. Shrimp feed production uses 31% (approximately 1 million tonnes) of the fishmeal in aquaculture. Global fishmeal production is around 5 million tonnes annually and its future supply may be affected by an increasing demand, climate change, and variability.

Shrimp feed manufacturers have decreased the inclusion of fishmeal from a global range of 19–40% in 2000 to 11–23% in 2014, while the range for fish oil inclusion stabilised (around 0–2%). Future fishmeal inclusion in shrimp feeds is expected to further decline and stabilise at around 6% in 2025. However, total farmed shrimp production is expected to increase to approximately 8.6 million tonnes in 2025.

Plant meal alternatives come at a cost, as agricultural production for aquafeed ingredients (rapeseed/canola, soybean, corn and wheat) required a land area as large as Iceland (~10 million ha) in 2008. Some argue that there is insufficient land available for agricultural expansion, as 4.9 billion ha (which is approximately 40% of the total land surface in 2005) currently occupies 91% of the approximately 5.41 billion ha suitable for agriculture. It is estimated that animal feed crop production occupies around a third of global crop land.

An excessive dependency on plant ingredients for aquaculture could lead to deleterious effects on the environment and indirectly impact human health by altering the nutritional value of aquaculture products. In this respect, our principal objectives were to quantify firstly the resource implications (freshwater, land, nitrogen, phosphorus and wild fish) of soybean meal inclusion to reduce the dependency of marine sources, and secondly examine the inclusion of alternative plant ingredients typically included in modern shrimp feeds, such as rapeseed meal, pea meal protein and corn gluten meal.

Modelling the transition to plant-based ingredients

We modelled the natural resource demands of a transition to plant-based ingredients in shrimp feed formulations.



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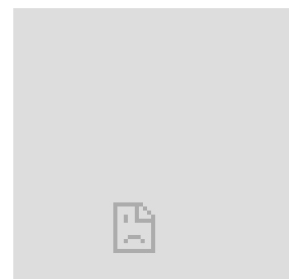
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In this study, feed formulation algorithms were used to create unique feed formulations for the two most dominantly produced shrimp species, with intermediate declining steps of 20% fishmeal substitution by plant ingredients, while accounting for the dietary requirements of individual shrimp species. These diets were modelled in combination with a comprehensive multifactorial assessment of marine and terrestrial resource demand for agricultural crop production and processed ingredients.

Feed formulations and scenarios

We estimated the impact of fishmeal substitution with plant ingredients by developing contemporary shrimp feed diets using the feed formulation software FeedSoft™. This software calculates the most cost-efficient feed formulation based on dietary requirement data and global market ingredient prices. Nutrient requirement data of shrimp were obtained from the National Research Council and global ingredient prices were from the International Hammersmith Commodity Index Database. These prices fluctuate; therefore, we selected the commodity prices of September 2018 and converted them to Euros for input into the feed formulation software.

We developed feed formulations for *Litopenaeus vannamei* (whiteleg shrimp) and *Penaeus monodon* (black tiger shrimp). Traditional shrimp feed formulations include between 20% and 30% fishmeal where 30% was commonly applied for *P. monodon*. Fishmeal inclusion differs per species: carnivorous *P. monodon* requires higher protein contents in their diets (36–42%) and *L. vannamei*, 18–35%. Therefore, we set baseline fishmeal inclusions at 20% for *L. vannamei* and 30% for *P. monodon*.

We developed 24 feed formulations for these two species (*L. vannamei* (LV) and *P. monodon* (PM)) and two scenarios: commonplant scenario (LV1, PM1) and alternative-plant scenario (LV2, PM2). Each combination of species and scenarios contained six feed formulations with intermediate steps of 20% fishmeal substitution by plant ingredients. Table 1 is available at <https://doi.org/10.3390/su11041212>

- The “common-plant scenario” with the lowest possible price used mainly soybean (Glycine soja) meal to substitute fishmeal.
- The “alternative-plant scenario” excluded economic incentives and included alternative plant ingredients suitable for fishmeal substitution based on their nutrient profile. Ingredients were pea protein concentrate, rapeseed meal, corn gluten meal and corn oil.

In order to ensure reliability of the model, we compared prices of our developed feed formulations with indicative prices per tonne of feed in Asia (USD 700–1100), China (USD 450–800), India (USD 844–956), and the Philippines (USD 876–967).

Model simulations and runs

The model ran six feed formulations per species and scenario with intermediate fishmeal substitution by plant ingredients. A shared common data set of multi-factorial resource demand was developed and used per ingredient for each feed formulation to account for the global variety of resource demands by crops and its derived ingredients (Table 1, freshwater, land, nitrogen, phosphorus and fisheries).

The main results in absolute and relative numbers are available in the full text of this paper. In summary, the complete substitution of 20–30% fishmeal could lead to increasing demand for freshwater (up to 63%), land (up to 81%) and phosphorus (up to 83%) while other substitution rates lead to proportionally lower impacts. These findings suggest that even though the production of shrimp feed utilises only a small percentage of the global crop production, the sustainability of substituting fishmeal by plant ingredients should not be taken for granted. For example, Figure 1 shows the relative (%) change in land demand as a result of complete fishmeal substitution with plant ingredients, highlighting one of the tradeoffs between marine and terrestrial resources.

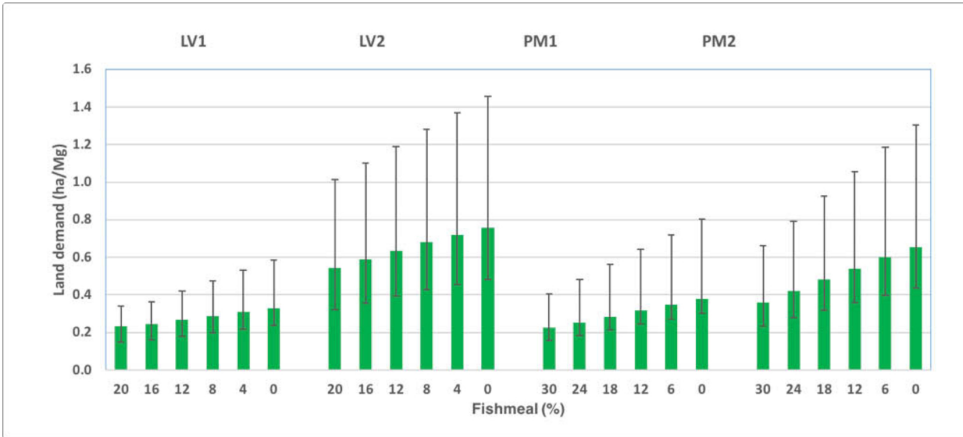


Figure 1. Minimum, mean, and maximum land demand (ha/tonne) for the baselines and five substitution levels in two scenarios and for two species. The y-axis represents the global mean land demand, and the bars indicate the range (min/max) in land demand of a combination of ingredients in the feed formulations.

The sustainability conundrum of fishmeal substitution

There is a global strategy to find alternatives to fishmeal in shrimp feed formulation. Our results show that although this strategy serves to mitigate marine protein and oil dependency, when used as a sole substitute, it shifts pressure to terrestrial resources. The modelling results show the intensity of the added pressure on freshwater, land and fertiliser, highlighting a shift in pressures in the longer term for using higher inclusions of plant ingredients in aquafeed.

The large difference in mean land demand between *L. vannamei* and *P. monodon* in both scenarios is caused by the higher inclusions of soybean meal, pea protein concentrate and corn gluten, and their relatively higher land use compared to other aquafeed ingredients (Table 1). Soy production requires more land compared to corn and wheat, while corn gluten meal requires relatively less land (0.2 ha/ tonne) compared to rapeseed meal (0.9ha/tonne), which has a higher inclusion (36.7%) in diet LV2 compared to 10.7% in diet PM2, Table 1). It is obvious that land demand is significantly higher in the alternative-plant scenario as a result of the higher inclusion of crops with a relatively higher land demand such as rapeseed, pea and corn compared to soybean and wheat in the common-plant scenario. (Table 1)

A shift from fishmeal to plant ingredients should not be taken for granted as a sustainable solution to meeting a rapidly expanding (shrimp) aquaculture industry.

Conclusions

Our model highlights the need for a paradigm shift in the definition of sustainable shrimp feed by presenting quantitative data on the consequences relating to sea-land linkages as a result of the substitution of fishmeal with terrestrial ingredients based on current resource demands. Our study has clearly demonstrated that complete fishmeal substitution by plant ingredients could lead to an increasing demand for freshwater (up to 63%), land (up to 81%), and phosphorus (up to 83%). These are significant increases, as only a share of 20-30% of the feed is substituted.

This is mainly caused by the inclusion of resource intensive crops and their derived ingredients to meet nutritional requirements, such as soybean meal concentrate, rapeseed meal concentrate, pea protein concentrate and corn gluten meal. A shift from fishmeal to plant ingredients should not be taken for granted as a sustainable solution to meeting a rapidly expanding (shrimp) aquaculture industry. The additional pressure on crucial terrestrial resources inflicted by the rapidly growing aquaculture sector may become more obvious over the next decades.

While the paper is focused on shrimp feeds, the model may be equally applicable to other intensively farmed species (for example, freshwater and marine finfish). However, more data on the origin and resource demand of ingredients are required in order to gain accurate insight into the optimal use of marine and terrestrial resources. This would enable the shrimp farming industry to operate and contribute in a sustainable manner to global food security and the economy, providing the much needed high nutritionally valuable seafood.

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