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Article

A value chain and SWOT analysis for optimizing the self-sufficiency of fish feed to strengthen freshwater aquaculture production in Indonesia

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Abstract: This study evaluates the aquafeed self-sufficiency sector in Indonesia, aiming to provide policy recommendations for optimizing freshwater aquaculture production. The study engaged 1005 participants, including 204 self-sufficient aquafeed producers and 801 fish farmers, covering 88% of the regions where the Ministry of Marine Affairs and Fisheries promotes aquafeed self-sufficiency, conducted in 30 Indonesian provinces. The majority of on-farm and small-scale feed manufacturers continue to operate successfully (91%), with a minor portion discontinuing (9%). Aquafeed products incorporating local ingredients prove cost-effective and receive high acceptance among fish farmers. The sustainability of the aquafeed self-sufficiency sector is closely linked to local ingredient availability, operational aquafeed manufacturing plants, product quality, human resource capabilities, and government policies. The study presents policy recommendations to address these issues, encompassing measures such as ensuring ingredient supply sustainability, providing a mobile laboratory for ingredient and feed analysis, enhancing human resource quality through training, facilitating easier access to financial support, and strengthening central-local government coordination to optimize the aquafeed self-sufficiency program. The rise of the national fish production target from freshwater aquaculture has attracted great attention in the improvement of the aquafeed sector since the sustainability of aquafeed supply is the main driver for the success of aquaculture production.

Keywords: aquafeed; aquaculture; sustainability; self-sufficiency; value chain

1. Introduction

Indonesia is one of the largest fish producers in the world (Food and Agriculture Organization of the United Nations, 2020a). As the production of food fish from capture fisheries has leveled off in the last decade (Gephart et al., 2021), the Ministry of Marine Affairs and Fisheries (MMAF) of Indonesia has ambitious targets for expanding fish production from aquaculture to be increased from 5.5 million tonnes in 2019 to 8.8 million tonnes in 2024 (Ministry of Marine Affairs and Fisheries, 2020a). Of this target, fish production in Indonesia that is contributed from freshwater

aquaculture production will be about 70%. Freshwater aquaculture products are currently increasing in demand and providing a significant contribution to food fish supply and overall food security for the country (Naylor et al., 2021). In addition, the freshwater aquaculture sector makes important contributions toward achieving the Sustainable Development Goals (SDGs) 2030. Despite the role of aquaculture part of the solutions to achieving the SDGs, it is also as dependent on good governance at all levels (local, national, regional and international) of decision-making (Farmery et al., 2021a, 2021b; Hambrey, 2017; Stead, 2019). Hence, various freshwater aquaculture development programs are still needed to strengthen their role toward the achievement of sustainability development goals as well as freshwater aquaculture sustainability itself.

Various freshwater aquaculture production might have different impacts on the sustainability pillars depending on its aquaculture program. The low environmental footprints of freshwater aquaculture programs support environmental sustainability. Nevertheless, it is also important to maintain the quality of aquafeed, which will support the economic and social benefits of freshwater aquaculture sustainability.

There are 2.6 million farmers currently involved in freshwater aquaculture (Ministry of Marine Affairs and Fisheries, 2020b), and predicted to increase as the government expands the freshwater aquaculture programs on fish commodity clusters based on local economy improvement called "the fish village program". There are five major freshwater commodities in Indonesian aquaculture including Nile tilapia, *Oreochromis niloticus*, African catfish *Clarias gariepinus*, common carp *Cyprinus carpio*, stripped catfish *Pangasianodon hypophthalmus*, and giant gourami *Osphronemus goramy,* which significantly contributed to the national fish production (Kurniawan et al., 2021; Tran et al., 2017). Thus, the programs have been initiated for further development of these commodities especially tilapia, catfish, and stripped catfish started at six areas in Sumatra and Java islands and will be followed by other freshwater commodities and regions.

Aquafeed is one of the essential factors in the success of aquaculture development (Davis, 2015; Tacon, 2019). It significantly contributes to the production input of freshwater aquaculture in Indonesia, which is estimated at around 50%–70% of total production (Aya, 2017; Sunarno, 2018). To support the national program in expanding freshwater aquaculture, the supply of aquafeed is urgently needed to achieve the fish production target. However, the national production of the aquafeed industry for aquaculture was around 3.25 million tonnes in 2020, which likely will not meet the demand for targeted production in 2024. The increase in freshwater fish production to 8.8 million tonnes indicates that aquafeed demand is also predicted to increase at about 11.09 million tonnes in 2024, a significant increase compared to the previous production (Ministry of Marine Affairs and Fisheries, 2020a). The significant increase in aquafeed demand requires comprehensive strategies to address the lack of production from commercially manufactured feed and provide alternative aquafeed resources. Aside from the aquafeed industry, the intensification of the aquafeed self-sufficiency program, which refers to on-farm aquafeed produced by fish farmers and small-scale aquafeed producers utilizing local raw materials resources, needs to be considered for national aquafeed production. The MMAF has initiated the promotion of the aquafeed self-sufficiency program as a national strategy for expanding aquafeed

production since 2015 (Sunarno et al., 2019). However, the project has not been well-evaluated regarding the status, value chain, and challenges. Understanding the status and value chains of the aquafeed sectors is essential in determining actions needed for mitigation, strengthening quality control, providing appropriate training and development for stakeholders, and improving the regulation and policy of the government (El-Sayed et al., 2015). This research aims to evaluate the status, value chain, and challenges of the aquafeed self-sufficiency sector in order to recommend strategic government interventions for optimizing freshwater aquaculture production in Indonesia.

2. Materials and methods

2.1. Study area

The study was carried out on five main islands of Indonesia, which covered 30 provinces where the MMAF has promoted the aquafeed self-sufficiency program. Some regions were the most important areas which contributed to more than half of national freshwater aquaculture production, such as West Java (27%), South Sumatra (13%), Central Java (9%), West Sumatra (8%), and East Java (7%). In addition, six areas were promoted as the pilot project of the fish villages program, including Banyuasin and Oku Timur, Magelang and Pati, and Banyumas and Bogor for stripped catfish, tilapia, giant gourami, and ornamental fish commodities, respectively.

2.2. Data collection and validation

Primary data were collected from two principal actors involved in the value chain of the aquafeed self-sufficiency sector by using two structured questionnaires based on Google forms distributed online (as a response to the COVID-19 outbreak situation) from March to June 2021. The unit analysis of this study is self-sufficient aquafeed producers and aquaculture farmers. Data collection was designed to cover geographical areas (including targeted areas for the fish villages program), business ownership (private, individual and group, and public sectors), and business scales for all participants. For self-sufficient aquafeed producers, obtained data were mainly related to the operational status of the aquafeed business, production performance, aquafeed raw materials, feed formulation and technology, and aquafeed quality. For fish producers, sampling was carried out to understand production performance, cultured fish commodity, fish farming systems, and aquafeed types used in fish production and their responses to homemade aquafeeds. Prior to data collection, selected participants were first contacted by phone, online message application, and trusted intermediaries. We also involved the staff projects who provided an online help desk. Informed consent was obtained from all individual participants included in the study. There were 1005 participants involved in this research, including 204 self-sufficient aquafeed producers (20%) and 801 farmers (80%) from five main islands over 30 provinces (**Figure 1**, **Tables 1** and **2**). After data collection, field trips were randomly carried out to validate self-sufficient aquafeed producers and fish farmers who fulfilled the questionnaires in 7 provinces (15 locations) (**Figure 1**).

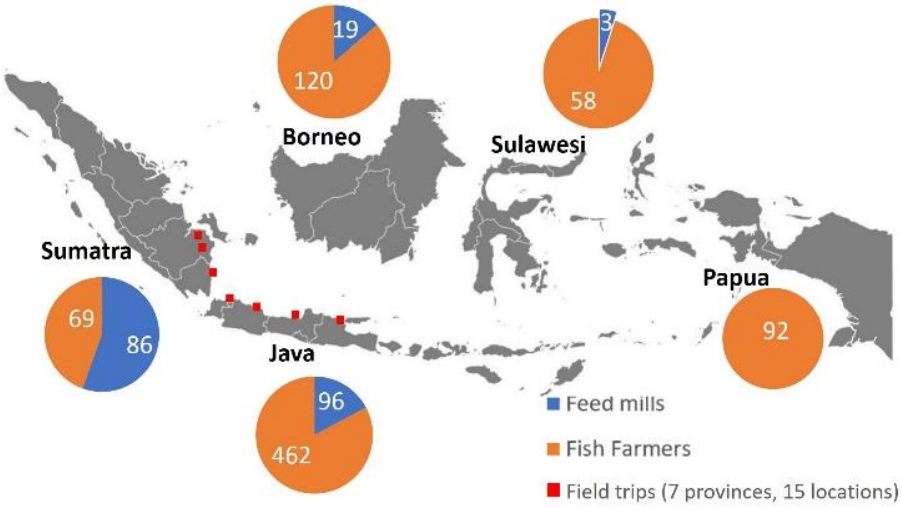

Figure 1. Map of Indonesia showing the proportion of respondents based on sampling sites and field trip locations.

Table 1. Distribution of self-sufficient aquafeed producer and fish farmer participants involved in the project based on main islands of Indonesia.

Islands	ProvinceNumber	Covered provinces	Aquafeed millsrespondents	Fish Farmerrespondents	Total participants
Sumatra	10	10	86	69	155
Java	7	7	96	462	558
Kalimantan	5	4	19	120	139
Sulawesi	6	3	3	58	61
Papua/Maluku/NT	6	6	0	92	92
Total	34	30	204	801	1,005

Table 2. Number of self-sufficient aquafeed producers interviewed according to ownership and production capacity.

Ownership	Production ranges (ton/year)					
	<20	20–40	40–60	60–80	>80	Total
Public company	7	1	-	-	-	8
Private company	68	26	9	3	10	116
Self-employed individual	31	21	14	8	6	80
Total						204

Secondary data are related to production of commercial feed, production of self-sufficient aquafeed, production of freshwater aquaculture and other related data, and the use of feed ingredients especially fish meal. Secondary data were also collected from various sources, including the statistical report of marine and fisheries production from the Ministry of Marine Affairs and Fisheries (MMAF), the Food and Agriculture Organization of the United Nations (FAO), focus group discussion, and aquafeed webinar which involved aquaculture and aquafeed farmers, aquafeed experts, and policymakers.

2.3. Data analysis

2.3.1. Value chain analysis (VCA)

The value chain analysis (VCA) framework was used to evaluate the performance of the aquafeed self-sufficiency sector in Indonesia. VCA refers to a diagnostic tool for assessing product and information flows, management, and control of the value chain performance (Taylor, 2005). In connection to freshwater aquaculture sustainability, the value chain development (VCD) system was an increasingly popular methodology for promoting growth and decent work subject to various environmental issues. VCD that addresses environmental considerations can play a vital role in promoting sustainable enterprise development and a just transition towards environmentally sustainable economies (International Labour Organization, 2021). With a good environment, the fish farming business using such environmentally friendly feed will be more sustainable and could generate more profits.

The implementation of VCA has been widely used in determining aquafeed and aquaculture value chain for the improvement of the sectors in many countries (Alemu and Azadi, 2018; El-Sayed et al., 2015; Goyal et al., 2021; Hasan et al., 2019; Islam and Hasan, 2020). Data and information collected for VCA consist of principal and supporting actors who conduct various activities commonly involving suppliers, producers, and consumers. The present study used descriptive and qualitative VCA approaches to evaluate essential factors affecting competitiveness, gaps/weaknesses, and potential factors for the improvement of value chain performances. Subsequently, we visualized existing and recommended VCA maps of homemade aquafeed for sustainability and improvement of the aquafeed sector.

2.3.2. SWOT analysis

SWOT analysis was aimed at evaluating the aquafeed self-sufficiency business based on the government's perspective. Data were collected from online questionnaire surveys, field observations, and a literature review of supporting references related to self-sufficient aquafeed manufacturers and freshwater aquaculture businesses in Indonesia. Focus group discussion (FGD) was also carried out to evaluate collected data and information for SWOT assessment. SWOT is an analysis to evaluate and develop strategic planning of an industry and particular business based on internal strengths and weaknesses, as well as external opportunities and threats of the operating environments (Helms and Nixon, 2010). Recently, it has been widely implemented in fisheries and aquaculture systems to propose strategic planning for better management and production of the sectors (Glass et al., 2015).

3. Results and discussion

3.1. Status of national aquafeed industry

The national aquafeed industry plays a pivotal role in the development of fish farming in Indonesia. National aquafeed production in Indonesia reached 1.58 million tonnes in 2017, 1.65 million tonnes in 2018, and increased significantly to 2.95 million tonnes in 2019, where most of the aquafeed was produced by 41 aquafeed private companies in 7 provinces (Ministry of Marine Affairs and Fisheries, 2017; Coordinating Ministry for Maritime and Investment Affairs, 2020). The feed mills are

mostly located in Java and Sumatra regions. In Java, East Java (12 companies) is the province with the largest number of commercially manufactured aquafeeds, followed by West Java (7 companies), Banten (6 companies), Central Java (3 companies), and Jakarta (1 company). In Sumatra region, aquafeed industries are established in North Sumatra (7 companies) and Lampung (5 companies). National aquafeed production currently reaches a total production capacity of 3.25 million tonnes, which indicates the increase of aquafeed production is urgently needed to support the MMAF fish production target at about 8.79 million tonnes, estimated to require 11.09 million tonnes of aquafeed in 2024 (**Figure 2a**). A significant challenge in the aquafeed industry is that the main ingredients of aquafeed largely depend on imports. Based on data collected by the Indonesian Feed Mill Association (GPMT), the content of imported ingredients in aquafeed contributes 75% depending on the quality of the feed. Aquafeed ingredients, including fish meal, soybean meal, and wheat, are currently imported **(Figure 2b**).

The recent study showed that most on-farm and small-scale feed manufacturers are were still operating well (91%), and the remaining was were discontinued (9%). Evaluation of aquafeed producers in understanding the aquafeed self-sufficiency program has been a minor improvement on the operational level of the business. There were no differences in the operational level between the group receiving government grants and the group without government grants (**Figure 3b**). The two groups have a similar pattern in terms of business level, which has a similar number of stagnant and developing business levels. Similarly, there are no differences in the business levels of the types of business ownership (private, public, and self-employed individuals) (**Figure 3c**). In terms of business development, the group that has operated small-scale aquafeed manufacturing plants for more than six years presented more developing levels compared to other groups. (**Figure 3d**).

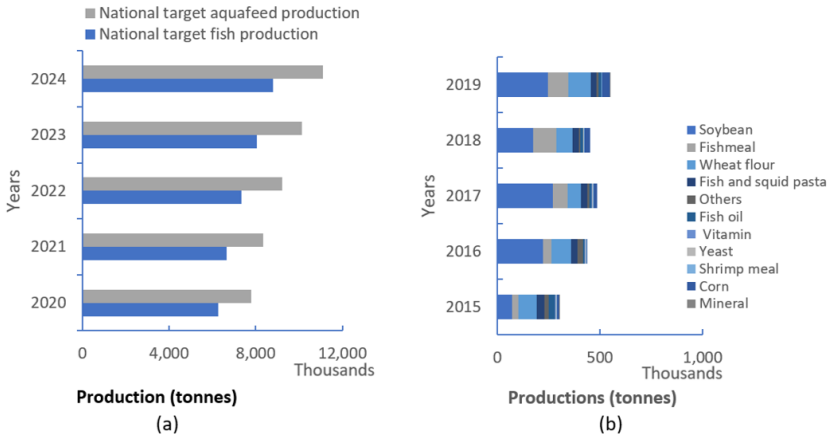

Figure 2. Production target of aquafeed and imported aquafeed ingredients. **(a)** Projection of aquafeed production for fish production 2020–2024; **(b)** Aquafeed ingredient resources used in commercially manufactured aquafeeds imported to Indonesia.

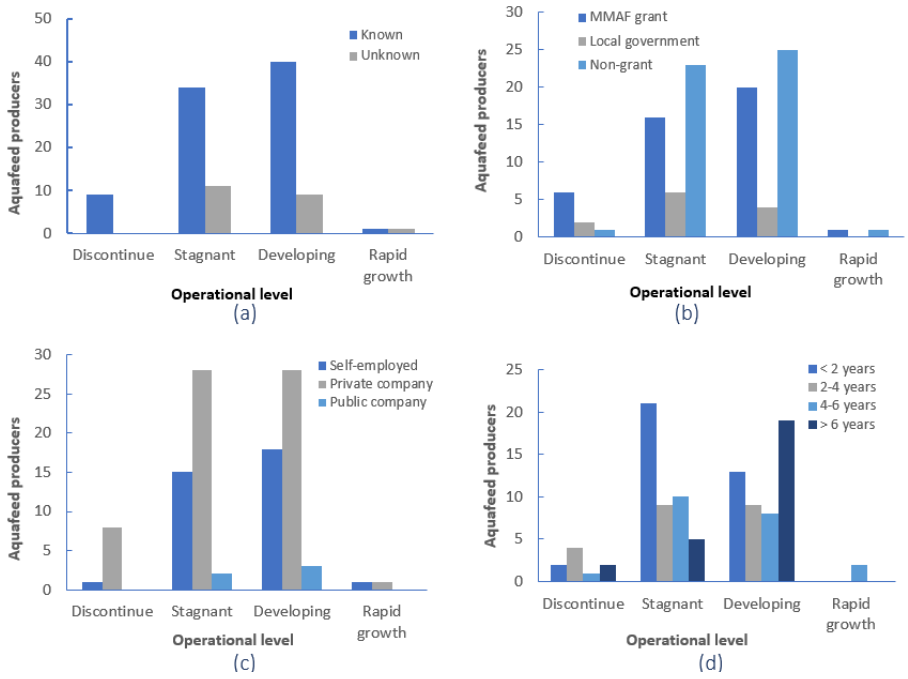

Figure 3. Operational level of aquafeed self-sufficiency producers. **(a)** Business level of self-sufficient aquafeed producers based on the understanding of the aquafeed self-sufficiency program; **(b)** types of government grants; **(c)** business ownership; **(d)** business periods.

3.2. Local ingredients

Five ingredient resources, including the source of protein, carbohydrates, fatty acids, vitamins, and minerals, are urgently required for high-quality aquafeed production (Gasco et al., 2018; Merrifield and Ringø, 2014). Similar to commercial aquafeed manufacturers, on-farm and small-scale aquafeed producers needed continuous availability of ingredients for business sustainability (Sunarno et al., 2017; Wardono et al., 2017). Fish meal is the largest source of local protein used for aquafeed, followed by fish by-catch, salted fish, soybean meal, shrimp head meal, maggot, and bone/meat meal (**Figure 4a**). Fish meal is also made from fish. Humans also consume this kind of ingredient. The availability of fish in nature tends to decrease. Meanwhile, human need for fish meal continues to increase along with the increase in population. Therefore, the use of fish meal in feed needs to be reduced because it competes with humans. The use of salted fish and fish by-catch as a source of aquafeed protein significantly contributes to the sustainability of the aquafeed businesses as these ingredients are cost-effective, continuously available, and more accessible than fish meal, which was considered to have higher prices and limited availability in the market (Hasan and Halwart, 2009). However, the use of salted fish and by-catch as the main source of aquafeed ingredients needs to consider the quality of protein content as the quality of these products is below the standard for high-quality aquafeed. According to proximate analysis, the protein content of most salted fish and by-catch was below 50%. Most aquafeed producers in Sumatra, Java, and Kalimantan utilized fish meal, by-catch, and salted fish as the main protein sources for aquafeed (**Figure 4a**). Maggot, the black soldier fly larvae, is one of the protein sources for cost-effective aquafeed (Goyal et al., 2021; Henry et al., 2015). The mass production of maggot for fish meal

substitution significantly increases the growth of cultured fish (Fawole et al., 2020). Recently, maggot has been a promising ingredient that is increasingly utilized for aquafeed and considered as high as the use of shrimp head meal and bone/meat meal in aquafeed formulation.

The largest source of fatty acid used in aquafeed is fish oil, followed by palm oil, squid oil, and corn oil (**Figure 4b**). However, about 28% of aquafeed producers did not require fatty acid resources for the aquafeed formulation. The use of vitamins and minerals was rarely implemented by on-farm and small-scale aquafeed producers. The most dominant source of carbohydrates used in self-sufficient aquafeed producers was rice bran (**Figure 4c**). It is used as the main ingredient of aquafeed and is widely distributed throughout regions. However, the use of bran in some groups of aquafeed producers reaches a proportion of 80%, which indicates a need for more knowledge of the aquafeed producers to understand the appropriate aquafeed formula. Other ingredients used as a source of carbohydrates are corn, coconut peel, wheat, cassava, beans, and tofu by-products (**Figure 4c**). For the mass utilization of local ingredients for aquafeed, the viability of ingredients needs to consider commercially available, adequate nutrition, easy handling and processing, and no or less competition for human food (Agboola et al., 2019). In addition, as local resources can be widely used for alternative ingredients, it would reduce the independence of the aquafeed sector to fish meal and oil to ensure sustainable production of aquaculture (Cottrell et al., 2020).

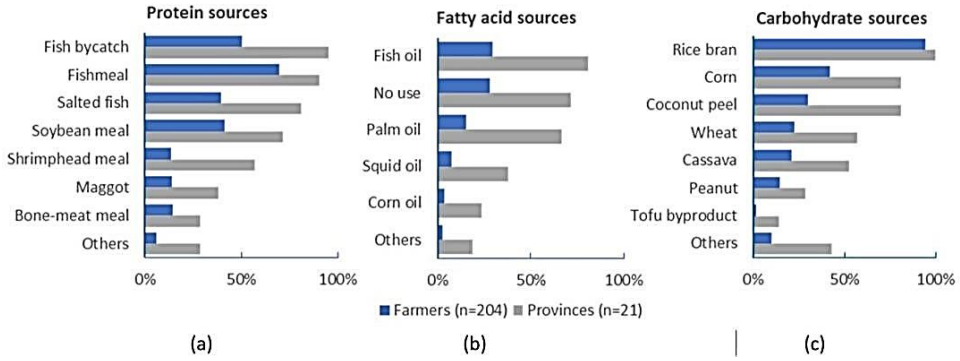

Figure 4. Corp distribution of the main aquafeed ingredient resources. **(a)** protein sources; **(b)** fatty acid sources; **(c)** carbohydrate sources used by small-scale feed manufacturing plants in Indonesia.

3.3. Aquafeed production system

The total production of aquafeed relied on the capacity of the machinery system and the different types of aquafeed products commonly based on different species and age groups (Hernandez et al., 2018). Based on the survey, there are five categories of machinery-based production capacity used in small-scale feed manufacturing plants, including ≤100 kg/hour, 100–200 kg/hour, 200–300 kg/hour, 300–400 kg/hour, and >400 kg/hour. Based on survey, the aquafeed plants mainly operated feed machinery with capacity at about ≤100 kg/hour (46.1%) followed by 100–200 kg/hour (33.3%), 200–300 kg/hour (12,3%), 300–400 kg/hour (6%) and >400 kg/hour (2.3%) with the mean production at about 20, 30, 50, 70, and 80 ton/year, respectively (**Table 3**).

Table 3. Existing production and prediction of aquafeed from the small-scale feed manufacturing plants for national target production.

Machinery capacity	Samples (n:204)	Mean production(Existing)	Total existing production
≤100 kg/hour	94 (46.1%)	20 ton/year	1881 ton/year
100–200 kg/hour	68 (33.3%)	30 ton/year	2038 ton/year
200–300 kg/hour	25 (12.3%)	50 ton/year	1255 ton/year
300–400 kg/hour	12 (6.0%)	70 ton/year	857 ton/year
>400 kg/hour	5 (2.3%)	80 ton/year	375 ton/year
Total samples	204 (100%)		6406 ton/year
Estimation of aquafeed production	1000 farmers		31,402 ton/year
Total prediction	100,000 farmers		3,140,200 ton/year

However, as the main aquafeed production is used for self-sufficient feed, the increasing production of aquafeed relies on the performance of cultured fish in the farms. The survey showed that about 62% of aquafeed was used as self-sufficient feed, and the remaining (38%) was sold to other customers. To increase the national production of aquafeed from the small-scale feed manufacturing plants, the aquafeed self-sufficiencyprogram needs to be widely expanded to include more farmers participating in this project. As the total production data from 204 respondents were used as a baseline for the projection, the total number of aquafeeds contributed from the small-scale feed manufacturing plants would be estimated at 3,140,200 tonnes/year. Thus, a total of 100.000 farmers would be included in the project (**Table 3**).

3.4. The price and quality of local aquafeed self-sufficiency product

Local self-sufficient aquafeed products are recommended for application in small-scale fish farms as they are more cost-effective than industrial aquafeed (Food and Agriculture Organization of the United Nations, 2020b). The cost-effective price of local self-sufficient aquafeed is the determinant factor for the sustainability of the business since the commercially manufactured aquafeed is the largest competitor (Sunarno et al., 2011). In general, the price of local self-sufficient aquafeed with a similar protein content was lower than that of commercially manufactured feed (**Table 4**).

Table 4. Comparison of local self-sufficient feed and commercially manufactured aquafeeds based on the protein content and aquafeed price.

Protein content	Local self-sufficient feed (IDR)/kg	Commercially manufactured feed (IDR)/kg	Remarks
>30%	8000–9000	12,500–15,500	The price was valid for June 2021
25–30%	7000–8000	10,000–12,500	
20–25%	6000–7000	9000–11000	
<20%	4000–5000	8000–10000	

The price of local aquafeeds ranged between IDR 4000 to IDR 9000/kg (USD 0.27–0.60/kg), while commercially manufactured aquafeeds ranged from IDR 8000–15,500/kg (USD 0.53–1.0). The calculation of aquafeed prices both for small-scale aquafeed producers and aquafeed industries (**Figure 5a**) depends on the protein

content targeted in aquafeed products (Sunarno, 2018). However, several challenges need to be addressed by the government since many small-scale aquafeed producers need to consider scientific formulation and laboratory analysis when calculating the ingredients used for targeted products (**Figure 5b**). This issue would generate an unstable quality of local aquafeed products.

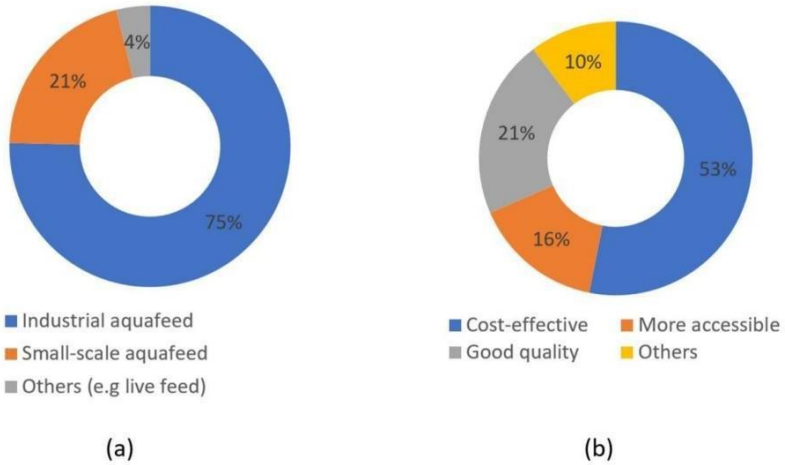

Figure 5. Usages and responses of fish farmers on aquafeed. **(a)** The source of aquafeed purchased by fish farmers; **(b)** Responses of fish farmers to small-scale aquafeed producers.
The number of participants were 801 respondents.

The responses of fish farmers to small-scale aquafeed producers are shown in **Figure 6**. The farmers predominantly used commercially manufactured feeds (75%) for the fish farms, while the remaining (21%) used aquafeeds produced from small-scale feed producers (**Figure 6a**). Cost-effective price (53%) was the key factor in the use of local aquafeed by the fish farmers, followed by good quality (21%), more accessible (16%), and other reasons (10%) (**Figure 6b**).

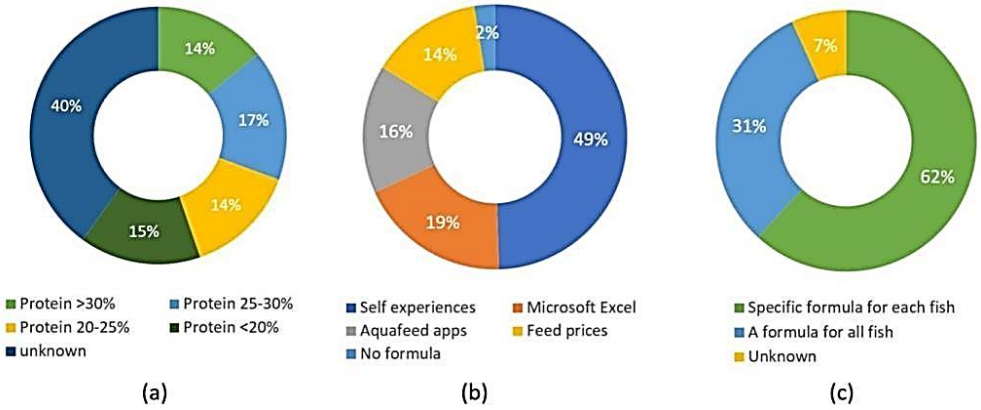

Figure 6. Responses of fish farmers to small-scale aquafeed producers. **(a)** Responses of small-scale aquafeed producers to the protein content of their aquafeed products; **(b)** the use of aquafeed formulation tools; **(c)** determination aquafeed formulation for fish.

Aquafeed is categorized as a good quality product when the protein content of the product is more than 25% (Sunarno, 2018). This research found that the aquafeed

products that met the requirement for the national standard were 31% (**Figure 6a**). On the other hand, a total of 40% of aquafeed producers did not calculate the protein content of the products, and 29% of aquafeed was found to be below standard. In addition, 38% of aquafeed producers likely did not consider protein requirements for each fish species (**Figure 6c**). Aquafeed formulation needs to be differentiated among cultured fish species based on the protein requirement of each species (Pahlow et al., 2015). For instance, tilapia has different protein requirements as compared with stripped catfish and other species (Kontara et al., 2013; Samsudin et al., 2013; Sunarno et al., 2014).

3.5. Value chain analysis for aquafeed producers

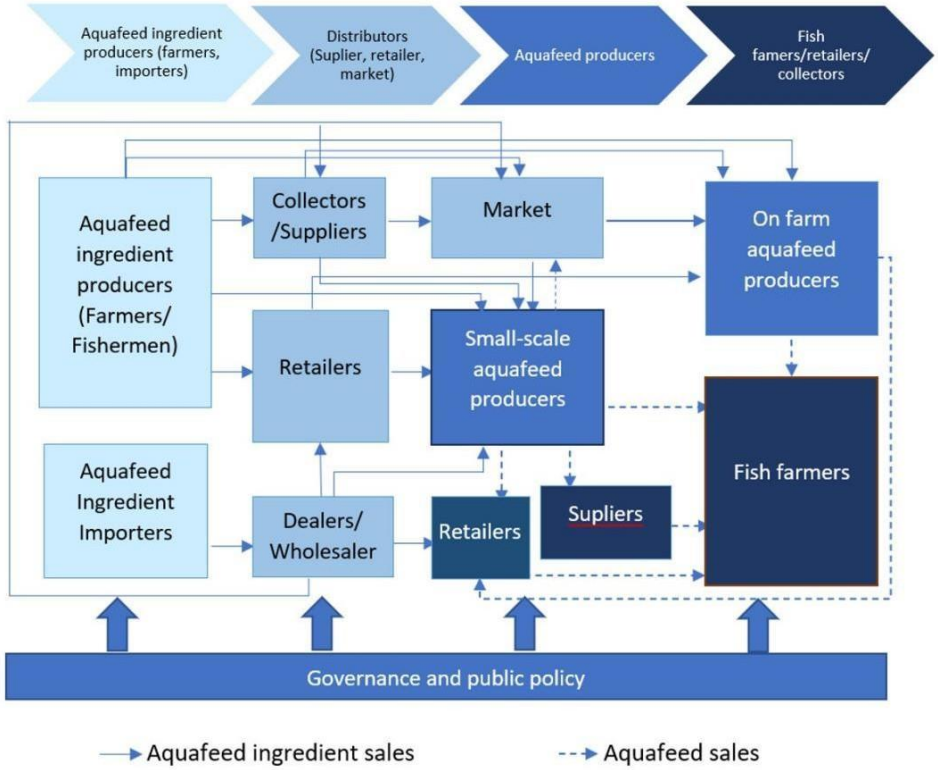

Figure 7. Value chain of self-sufficient aquafeed producers in Indonesia.

Understanding the value chain in the aquafeed sector is essential to determine critical factors affecting the sustainability of the business for further development (El-Sayed et al., 2015). Apart from the business aspect (business profits), sustainability is also related to environmental and social aspects. Environmental aspects relate to the use of raw materials such as fish meal in feed. The limited availability of fish, where these fish come into competition with humans, has prompted restrictions on the use of these ingredients in feed. Social aspects, self-sufficient aquafeed business and its derivatives will involve many people and open up new jobs. The principal actors involved in the value chain of local aquafeed self-sufficiency sectors in Indonesia consist of 3 main categories, including local ingredient producers, small-scale aquafeed producers, and fish farmers. Obtaining aquafeed ingredient resources was the key factor impacting business sustainability, and it involved many stakeholders such as suppliers, ingredient shops, markets, and distributors, which were mainly

involved in importing raw materials (Giri, 2017). This leads to the value chain of aquafeed business in the distribution of aquafeed products, and information tends to be complex (**Figure 7**).

In this study, the main aquafeed products and information were divided into two aspects, including fish farmers who have small-scale feed manufacturing plants (on-farm aquafeed producers) and small-scale aquafeed producers. The number of on-farm aquafeed producers reached 164 farmers (80%), and the remaining were small-scale aquafeed producers at about 40 entrepreneurs (20%). The main use of aquafeed produced by on-farm aquafeed producers was to provide feed for their farms and farming groups and the remainder for sale (**Figure 8b**). On the other hand, the aquafeed produced by small-scale aquafeed producers was the main income or additional income for their economy and livelihood.

An important aspect of the sustainability of aquafeed business sectors is aquafeed ingredient resources (Hasan et al., 2019). The feed ingredient collector (58%) was the largest ingredient provider, followed by feed shops (44%), farmers (41%), markets (23%), and the remaining other traders (4%) (**Figure 8a**). In terms of aquafeed sales distribution, the supply chain mainly involved fish farmers, markets, feed shops, and collectors. The largest customer for self-sufficient aquafeed products was fish farmers (63%) and self-utilization (62%), followed by feed shops (5%), markets (3%), and other sellers (1%) (**Figure 8b**).

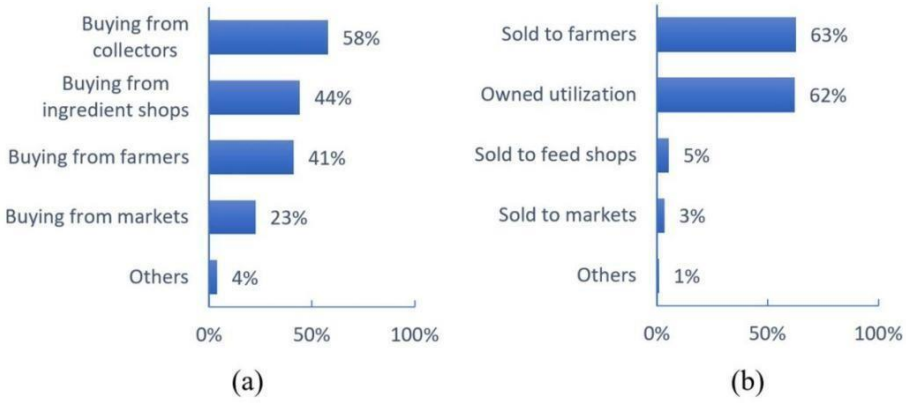

Figure 8. Sales distribution of local ingredient. **(a)** local aquafeed products; **(b)** in aquafeed self-sufficiency sector.

The number of participants was 204. Respondents can answer more than once choices (Multiple choices questions).

Feed ingredients are classified into five resource categories, including protein, fatty acids, carbohydrates, vitamins, and minerals. As there are no specific places that could provide all ingredient resources for aquafeed production, the aquafeed producers need to compete to obtain feed ingredients from various sources of suppliers. The challenges mainly relate to the expensive prices (27%), fluctuated price (24%), fluctuated quality (22%), the difficulty of accessing ingredients (19%), and other issues (2%). However, 6% of respondents reported that there were no issues in collecting aquafeed ingredients.

MMAF has played a significant role in the development of the local aquafeed self-sufficiency sector. Training and extension programs were the largest contributor

(34%) to the development of small-scale aquafeed producers. Transfer of knowledge and skill from aquafeed researchers and the Indonesian standard guide (SNI) for aquafeed were 12% and 11%, respectively. Small-scale aquafeed producers also independently learn the production of aquafeed based on their own experience (26%) and books/magazines/the internet (17%). The main target of the government is not only to increase the quantity of aquafeed production but also to initiate good manufacturing practice certification and feeding management for small-scale aquafeed producers. The certification programs for aquafeed and feeding management in aquaculture have been widely implemented in many countries to achieve sustainable aquaculture schemes (Hasan and New, 2013; Komatsu et al., 2019).

Therefore, for further improvement of this sector, the government needs to increase awareness of the importance of business legality to register small-scale feed manufacturing plants as well as their products. It would give beneficial aspects for monitoring and collecting data and information on the small-scale aquafeed sector for further evaluation. Based on the survey, it was about 55% of the small-scale feed manufacturing plants registered the business, while 40% of them have not registered the business, and the remaining (5%) are still in the process of registration (**Figure 9a**). In addition, most small-scale aquafeed products have yet to be registered (86%), and the remaining aquafeed products (14%) were registered (**Figure 9b**).

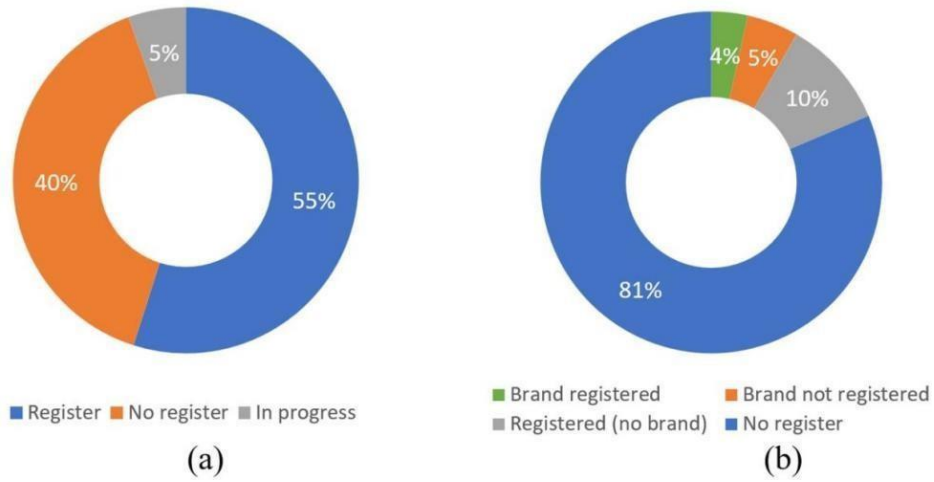

Figure 9. Aquafeed small-scale manufacturing plants and products status. **(a)** Legality aspect of local aquafeed self-sufficiency business; **(b)** the registration of aquafeed products.

Recently, 1506 aquafeed products have been registered to the government, including commercially manufactured feed products (1.472), small-scale aquafeed products (19), and public aquafeed products (15) (Ministry of Marine Affairs and Fisheries, 2020b). In addition to government institutions, the National Self-Sufficient Aquafeed Association (APMN) was established in 2015. APMN can facilitate a more comprehensive dialogue with the government in determining policies for the development of on-farm and small-scale aquafeed producers.

3.6. SWOT analysis

SWOT analysis was carried out based on data collected through online

questionnaire surveys, field observation, literature review, and focus group discussion (FGD) in determining strategic plans for improving the aquafeed self-sufficiency sector. A SWOT analysis includes the investigation of the strengths and weaknesses of the internal operating environment and the potential opportunities and threats from the external operating environment that could impact the sector. The FGD representatives included government agencies involved in policymaking, researchers, and on-farm and small-scale aquafeed producers. A summary SWOT analysis of aquafeed self-sufficiency sectors is presented in **Table 5**.

Table 5. Summary SWOT analysis for aquafeed self-sufficiency sectors development in Indonesia.

Strength (S)	**Weaknesses (W)**
• Aquafeed products based on local ingredients are cost-effective • Availability of local ingredients and by-catch • The quality of aquafeed is relatively good and accepted by the fish farmers • Availability of cheap labour for businessdevelopment • The local aquafeed self-sufficiency sector is already on the national strategic program • Good government supports	• Limited capability on aquafeed product quality analysis • Fluctuated cost and no standard price of local ingredients • Unsustainability supply of several aquafeed ingredients and additives • Limited labour capability (nutrition, feed formulation, machine, and finance management) • Underdeveloped workshop for machinery and spare parts market • Limited marketing access • The aquafeed value chain of small-scale aquafeed producers presents a complex business process • Several uncoordinated programs and initiatives by different authorities
Opportunities (O)	**Threats (T)**
• High market demand • Excellent support in research and development capability for improvement of aquafeed production • Availability of transfer technology, training, and extension for small-scale aquafeed producers • Availability of government grants for the improvement of aquafeed small-scale producers • Laboratory support for proximate analysis from the government • Product promotion and distribution through corporations with public and private sectors • Product registration is easily supported by the government	• Market competition with the aquafeed industry • Several main ingredients and additives still relied on imports • Competitive aquafeed import from other countries • Limited access to financial support and services for product development • Workshop and service of the aquafeed machinery are not available

3.7. Aquafeed contribution in Sustainability Development Goals

Aquafeed plays an important role in aquaculture, as it refers to any feed given to aquatic farmed animals as part of aquaculture. A study by Troell et al. (2023) stated that the possible aquaculture contribution to SDGs related to eliminating hunger and improving health (SDGs 2, 3), increasing environmental sustainability of oceans, water, climate, and land through responsible production/consumption (SDGs 6, 12, 13, 14, and 15), and reducing poverty, achieving gender equality, improving livelihoods, and reducing inequalities (SDGs 1, 5, 8, and 10). Feed is the main factor in fish farming, costing up to 70% of the total cost of fish farming. Feed prices that continue to increase without being followed by the increase of selling price of the fish will negatively affects fish production. Humans need these fish as a healthy food source. Self-sufficient aquafeed produces feed at an economical and efficient price. Therefore, self-sufficient aquafeed will continue to be developed in Indonesia as an effort to strengthen freshwater fish cultivation. Understanding sustainability pillars such as environmental, social, and economic characteristics of the multifaceted nature of

aquaculture provides more context-specific solutions for addressing both opportunities and challenges for its future sustainable development.

Meeting the 2030 global agenda toward freshwater sustainable development goals achievement will require partnership and innovation approaches and strategies at multiple scales. The SDGs 17 might need to be implemented to support the aquafeed value chain sustainability in the supply chain macro scope.

3.8. Policy recommendations

Policy recommendations were proposed referring to the critical factors investigated based on the recent status of aquafeed self-sufficiency sectors, value chain analysis, and SWOT table. It was proposed for improvement of government policy implemented for the sustainability of aquafeed self-sufficient businesses, which may support the increase of target fish production from inland aquaculture in Indonesia. We also proposed targeted value chain mapping for the development of aquafeed small-scale producer sales and distribution of both ingredients and aquafeed products (**Figure 10**). Ingredient shelters such as integrated feed machinery workshops and laboratory mobile can be managed by the public or private sector in each region. Here, we present the policy recommendations as follows:

1) Maintaining the stability of ingredients supply and standard price through:
    (a) Establishing local ingredients shelters in specific locations
    (b) Providing aquafeed ingredients database online as the standard guide for the appropriate aquafeed formula in accordance with the abundance of the ingredients in each location
    (c) Establishing local ingredients processing industries to optimize ingredient content supporting a good quality of aquafeed (e.g., water hyacinth and fish by-products) in collaboration with related stakeholders.
2) Maintaining and improving the aquafeed quality through
    (a) Providing mobile test laboratories for proximate testing of ingredients and feed products on a scheduled basis
    (b) Cooperation between government test laboratories and aquafeed entrepreneurs to monitor and provide feed-quality testing services at affordable prices
    (c) Providing helpdesk services for easy and continuous consultation with experts
3) Improving the quality of human resources in the technical and managerial aspects based on the aquafeed industry approach through:
    (a) Education and training in good manufacturing practices for ingredients and aquafeed managers
    (b) Technical workshop in maintenance and repair of aquafeed machinery systems
    (c) Technical workshop for aquafeed formulation
    (d) Training in finance management and marketing strategies
4) Providing access to a wide array of financial products and technical assistance for the aquafeed business actors who present potential growth

5) Improving coordination between the central government and regions (provinces, districts/cities) related to aquafeed self-sufficiency programs
6) Involving research institutions and/or universities to evaluate the government programs in aquafeed self-sufficiency sectors
7) Consistently refer to SDGs approach mainly through
   (a) Improving partnership (SDGs 17) SDGs strategy to strengthen the value chain. SDG contributions are usually achieved when aquaculture production is linked with distribution.
   (b) Minimize environmental impact as Life below Water SDGs strategy (SDGs 14) by maintaining aquafeed ingredients in a green strategy.
   (c) Reduced inequality (SDGs 10) to improve decent work and economic growth (SDGs 8)

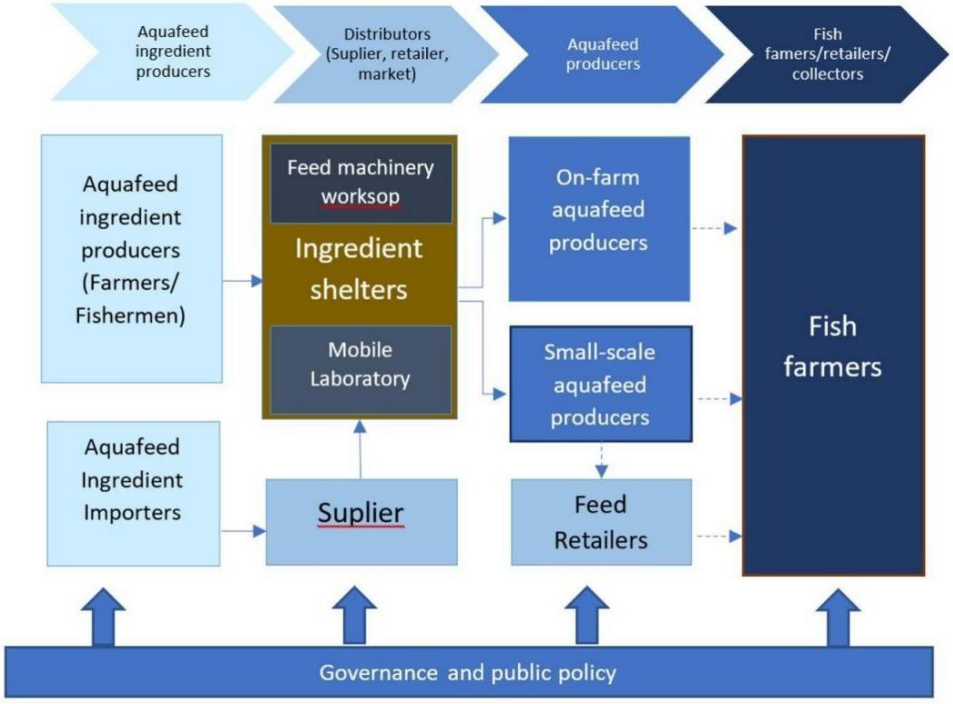

Figure 10. Targeted value chain mapping for development aquafeed self-sufficiency sector.

The sector includes on-farm aquafeed producers and small-scale aquafeed producers. Ingredient shelters integrated with feed machinery workshop and laboratory mobile can be managed by the public or private sector in each region.

4. Conclusions

Aquafeed products based on local ingredients were cost-effective and well-accepted by fish farmers. The sustainability of the aquafeed self-sufficiency sector significantly depended on local ingredients, operational aquafeed manufactured plants, the quality of aquafeed products, and the capability of human resources as well as government policies. Here, we propose policy recommendations to deal with these issues, including (1) maintaining the sustainability of ingredient supplies and price stabilities through establishing integrated ingredients shelters-machinery workshop-

field laboratory, providing local ingredients online database, and developing potential main ingredients of aquafeed. (2) providing a mobile laboratory for ingredients and feed analysis. (3) improving the quality of human resources through managerial and technical training (e.g., aquafeed technology, feed machine maintenance, and reparation). (4) providing easier access to financial support, and (5) enhancing the role and coordination between central and local governments to optimize aquafeed self-sufficiency program. (6). Consistently refer to the SDGs implementation.

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