Biomass Utilization and Biorefinery By-Product from Palm Oil and Marine Resources for Animal Feed and Feed Additive

Ahmad Sofyan, Hendra Herdian, and Agung Irawan

Abstract Indonesia is the largest producer of palm oil. Biorefinery by-products from palm oil can be classified into lignocellulosic and fiber-rich biomass. Palm kernel meal (PKM), a by-product from palm kernel oil extraction contains crude protein (13–16%) and there have been ongoing efforts to improve its utilization as animal feed. The restriction of PKM used in animal feed is linked with the imbalance of amino acids, high fiber content, shell, and other physical characteristics. On the other hand, Indonesia is among the leading countries in marine industry, by-products of fish, shrimp, crustaceans, and other marine processing industries are of high potency for animal feedstuff. Chitin, the dominant by-product of shrimp production, has ahead popularity in the last decade due to its large spectrum functions, especially as antimicrobial agent, non-toxic, biodegradable, and biocompatible. This chapter discusses the recent advances in PKM and marine industry by-products availability status and utilization, and novel technologies to improve their quality for animal feed and feed additive. A practical and conceptual development of the bioproducts for implementation, especially in the context of Indonesia and other countries with similar characteristics of nature. Biological processes including solid-state fermentation, mechanical processing, and valorization techniques can be integrated to process the biomass from palm oil industry. Chemical treatments including green chemistry techniques could improve chitosan functionality. Implementation of biorefinery techniques of biomass and by-products of palm oil and marine resources promise supporting raw material stock and sustainability for the feed and feed additive of animals.

Keywords Agroindustrial by-product · Biorefinery · Feed technology · Livestock · Palm oil

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1 Introduction

Availability of feed ingredients in terms of quality, quantity, and continuity (sustainability) is the key in supporting livestock productivity. Therefore, efforts to continuously increase the availability of feed ingredients are paramount to support national meat self-sufficiency. This is in line with the national program "Efforts for the Special Acceleration of Increasing the Population of Pregnant Cattle and Buffalo (Upsus Siwab)" in increasing the national livestock population. However, the problem arises when conversion of land-producing forages or feedstock is continuously occurring. On the other hand, increasing effluent residues is identified to be a major problem in the biomass-generating industry (biorefinery). Therefore, integrating biorefinery industries into the livestock industry coupled with implementing novel technologies can help to aid the problem for both.

There are many underutilized biomass or waste generated from agricultural processing and biorefinery industry that are plenty and economical. Based on the biomass characteristics, they can be classified into lignocellulosic and non-lignocellulosic biomass. It is well known that Indonesia is the leading producer of palm oil (Safi et al. 2022). Many by-products of palm oil biorefinery are left-over including oil palm trunks, empty fruit bunches, oil palm fronds, palm kernel shells, and palm kernel meal, that can be classified into lignocellulosic and fiber-rich biomass (Kahar et al. 2022). Those biomasses are produced up to 70 tons per hectare of palm oil. Among those biomass, palm kernel meal (PKM), a by-product generates from the extraction of palm kernel oil, receives growing interest due to its potential quality and quantity, particularly in Indonesia and Malaysia that contributes to over 80% of the world's PKM supply (Safi et al. 2022). PKM contains moderate crude protein (13–16%) and there have been ongoing efforts to improve its utilization as animal feed. The problem associated with palm kernel meal is related to the imbalance of amino acids, high fiber content, and physical characteristics (Sundu et al. 2008). Lack of access to technology is a key problem to optimally utilize the PKM. At present, most of them are exported to European countries and used as an economical feed ingredient for livestock (Azizi et al. 2021). For other biomasses of palm oil biorefinery as mentioned above, they are generally burned and used as fertilizer in the plantation which can increase pollution to the air (Kahar et al. 2022).

Valorization of PKM is a critical point to enhance the quality of valuable animal feed. Several strategies that can be used to improve the nutritive value of PKM include mechanical, biological, and chemical treatments. Using multiple alternative processing technologies, PKM can be processed as a whole biomass or subjected to protein extraction to obtain various functional protein concentrate. In addition, integrating livestock into the palm oil crop system has also been introduced in Indonesia as this approach is potentially more economically and environmentally beneficial (Agus and Widi 2018). However, much more effort is needed to valorize the low-quality biomass using novel technologies that can be implemented in the plantation area, together with the livestock.

On the other hand, reflecting that Indonesia is among the leading countries for its aquaculture industry, by-products of the fish processing industry are of high potency for feed of livestock. In particular, Indonesia is the leading country for shrimp production and is becoming the top five exporter countries for fresh shrimp in the world due to the large production volume supported by nature and available resources (Aneesh et al. 2020). Chitin is a major by-product of shrimp production and a primary source of chitosan, biopolymer obtained from diacylation of chitin (Shan et al. 2012). Chitosan is gaining popularity in the last decade due to its large spectrum of functions, especially as antimicrobial agent. It is also considered non-toxic, biodegradable, and biocompatible (Anggraeni et al. 2022). In addition, chitosan has been widely used in various industries including pharmaceuticals, foods, textiles, and agriculture. Recently, the use of chitosan as an additive for livestock has been extensively investigated for its potential as rumen modulator and methane suppressor (Harahap et al. 2022).

Optimization of extraction process and efforts for improving the functionality of chitosan have been introduced in the last decade, in addition to undergoing efforts to optimize the bio-functionality. To produce chitosan, chitin is commonly subjected to different steps including demineralization, deproteinization, and deacetylation. Recent advances in processing chitin into chitosan using novel technology can provide insight into the progress of technological development and future priorities of product development, especially in the context of feed additives for livestock.

In this chapter, we discuss the recent advances of PKM and fish industry by-products availability status and utilization, their potency, and novel technologies to improve the quality of by-products as an animal feed. In addition, we provide practical and conceptual development of the bioproducts for implementation, especially in the context of Indonesia and other countries with similar characteristics of nature. Collaborative framework among stakeholders should be established to take full advantage of such bioresources as a feedstock and to connect the farmers with industry.

2 Biomass and By-Product Characteristic and Potency

As a country with comparison of the ocean and land area of 6.3 versus 1.9 M km^2 makes Indonesia known as the largest archipelagic country in the world (Indonesian Geospatial Information Agency 2013). So it is not surprising that Indonesia has great potential for marine resources. Crustacean as one of the marine products has an important meaning for Indonesia's economic growth. No less than US $ 1.55 billion in year 2021 the export values of crustacean products from Indonesia that make Indonesia the sixth largest country as crustacean producer in the world, while the total sales of crustacean products in the world reach US $ 33.2 billion (OEC 2023). As much as 40–50% of these crustacean products can end up as waste (Muthu et al. 2021), so, the potential to disturb the environment is massive if there is no further utilization process. Likely, waste from crustaceans still has the potential to be reused

Table 1 Chemical composition of shrimp shell (Rødde et al. 2008)

Compound	Concentration (dry weight)
Protein	33 and 40%
Chitin	17 and 20%
Mineral ($CaCO_3$)	34 ± 2%
Lipid	0.3–0.5%
Astaxanthin	14–39 mg kg^{-1}

either as food or feed (Senel and McClure 2004; Özogul et al. 2019). Crustacean shell waste (lobster, shrimp, crab) generally contains protein parts, chitin minerals, lipids, and a small portion of astaxanthin (Table 1). This part of waste has a number of potentials that can lead to certain functions either as human food or animal feed (Özogul et al. 2019; Suryawanshi et al. 2018).

Protein portions from crustacean skin waste can be obtained through the fermentation of lactic acid bacteria to the cephalothorax and exoskeleton sections, resulting in hydrolysates ranging in proteins from 8.43 ± 0.22 to 46.73 ± 1.29 (Bueno-Solano et al. 2009), using protease (alcalase) enzyme following pH-stat method (Dey and Dora 2014). Crustacean skin extraction using the alcalase enzyme (Mizani et al. 2005) is described in Fig. 1. Protein sources from hydrolysate crustacean skin waste have the potential in addition to provide a source of nitrogen from crude protein also has the potential to contain amino acids that are quite complete for animal feeds Penaeus shrimp shells have a fairly complete amino acid balance and this is almost equivalent to soybean meal (Yan and Chen 2015). The use of hydrolysate protein in addition to supplying protein and amino acids also improves other functions because there is a compensatory bioactive peptide (Alvarez et al. 2015). Chitin is a polysaccharide found in the exoskeleton of an insect, crustaceans, mushroom structures, fungi, and yeast (Pighinelli et al. 2019), this condition causes chitin to be the most common polysaccharide found after Cellulosa (Senel and McClure 2004).

Chitin is a polymer of d-glucosamine while its deacetylated form is known as chitosan polymer N-acetyl-d-glucosamine monomers (Amiri 2022). Chitosan has a higher binding activity with several molecules compared to chitin. As a natural biopolymer, chitin is a material that has biocompatibility, biodegradability, and non-toxicity, has antibacterial properties, and anti-coagulant, absorbent molecules in nature, the form of chitin consists of αchitin, β chitin and ϒ chitin (Pighinelli et al. 2019). Conventionally to recover chitin and chitosan from the crustacean shell the extraction process by the chemical compound is described in Fig. 2. In ruminants, chitosan has extensive biological functions including antimicrobial, and protein-protecting agents to improve silage quality with various mechanisms of action (Fig. 3).

Although not made de novo by crustaceans, the pigment substance astaxanthin is obtained by crustaceans from the supply of feed material that contains a lot of carotenoids and astaxanthin, in crustacean astaxanthin obtained in free form or binds to proteins in the form of carotenoproteins (Özogul et al. 2019). The astaxanthin extraction method using acetone solvents yields the best results compared to

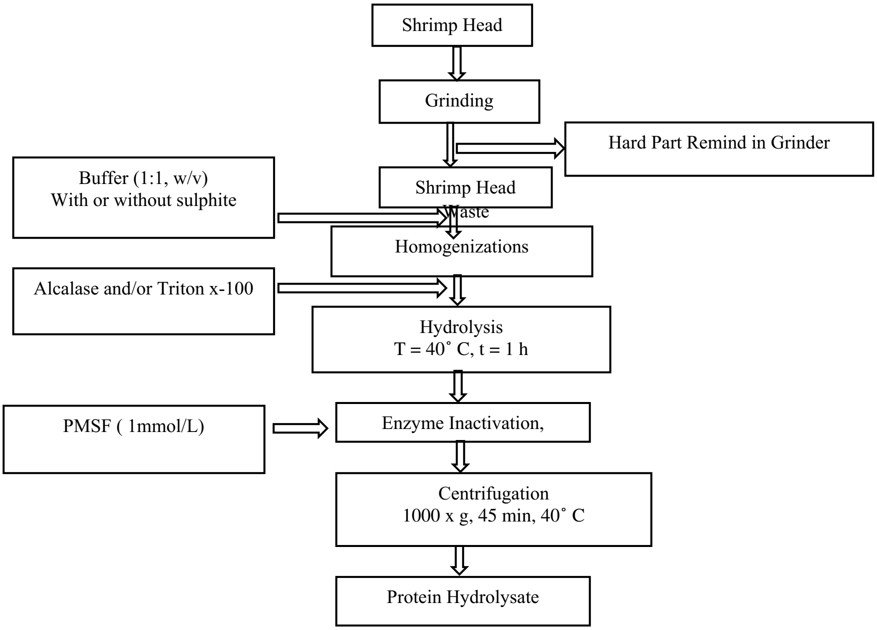

Fig. 1 Scheme of extraction crustacean shell protein procedure (Mizani et al. 2005)

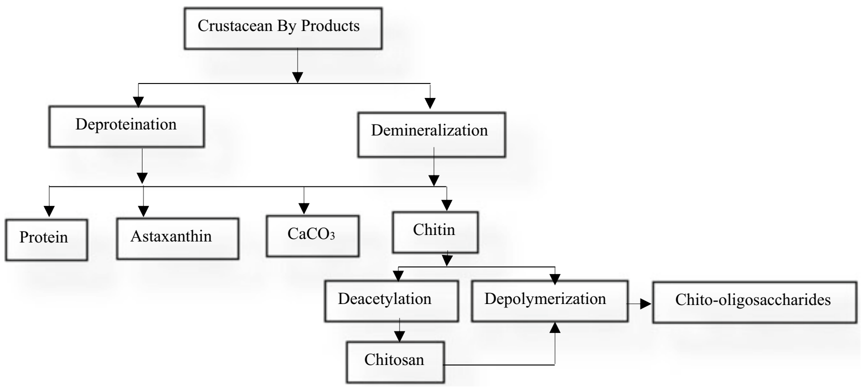

Fig. 2 Biorefinery of crustacean by-product to valuable compound (Özogul et al. 2019)

other conventional polar solvents (Dalei and Debasish 2015). Giving astaxanthin to Holstein Friesian dairy cows that are lactating can improve immune function and livestock reproduction (Da Costa et al. 2021).

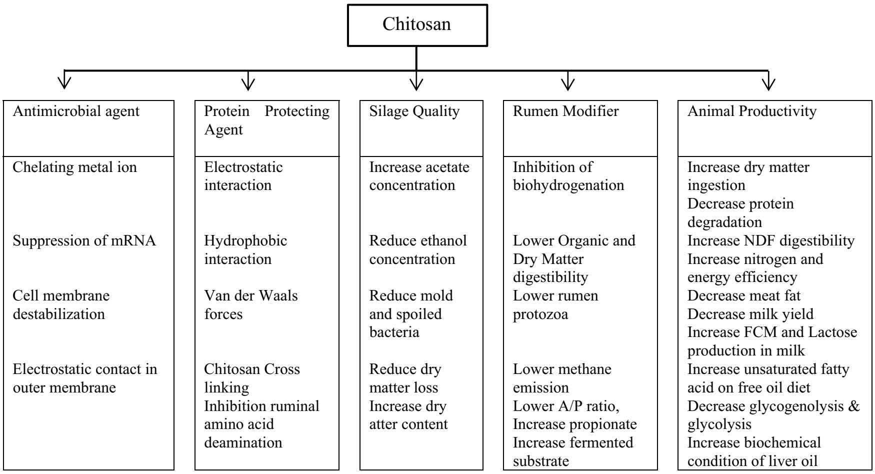

Fig. 3 Applications and effect of chitosan as feed additive in ruminants (Anggraeni et al. 2022)

3 Method for Improving Quality

3.1 By-Product of Palm Oil Processing Industry

Major limitation of PKM as a feedstuff for both poultry and ruminants is related to the imbalance of amino acids and high fiber content (Sundu et al. 2008). For ruminant animals, such high fiber content is not an issue. Several studies have demonstrated that inclusion of PKM or palm kernel cake in ruminant diets did not affect nutrient utilization, ingestive behavior, growth performance, and meat quality (da Silva et al. 2020, 2021). However, pretreatment processing is needed when it is used as a feed for poultry animals. The high content of cellulase is co-limiting the availability of amino acids by blocking the access of enzymes to utilize them especially when fed to poultry. Amino acid (AA) digestibility is considered as moderate in broiler chickens (Suprayogi et al. 2022). Replacement of a soybean meal-corn-based diet with 25% PKM resulted in low crude protein digestibility (41.6%) and moderate AA digestibility (averaged 75%) (Reza Abdollahi et al. 2015). The average essential and non-essential AA digestibility commonly falls into the value between 80 and 85% (Kim et al. 2022). The low CP digestibility is particularly a problem that can impair the growth of broiler chickens. To this end, methods to aid the low nutrient profile of PKM are of prime importance. Multiple strategies can be used to improve the nutritive value of PKM, such as fermentation, thermomechanical, thermochemical treatments, and their combinations.

3.1.1 Enzymatic Treatment

Enzymatic hydrolysis is more practical when compared to protein isolation in the context of its utilization as an animal feed. The main purpose of enzymatic treatment is to break down resistant starch of the PKM mainly lignin, cellulose, and β-mannan. PKM contains considerable amounts of β-mannan (up to 30%) (Navidshad et al. 2016) that can cause hyperplasia due to the high viscosity characteristics. A growing number of studies have been performed for this purpose. For instance, treatment with a mixture of *Aspergillus niger* and β-mannanase was reported to increase the true metabolizable energy (TME) by 32.1% and crude protein by 9% and concomitantly decrease the crude fiber content by 48.3% (Navidshad et al. 2016). Other carbohydrase enzymes such as xylanase, α-galactosidase, and β-mannosidase were also demonstrated to effectively enhance the molecular structure of protein of PKM (Moreira and Filho 2008; Álvarez-Cervantes et al. 2013; Chen et al. 2013).

A comprehensive review is available for the enzymatic treatment effect of PKM (Alshelmani et al. 2021). Overall, enzymatic treatment either using crude enzyme or microbial fermentation resulted in significant improvement in the quality of PKM, especially most of AA components. Compared to direct enzyme supplementation to the feed, enzymatic treatment to the PKM is more effective to increase the value of PKM which subsequently can improve productive performance of poultry. When these above enzymes were supplemented to broiler feed, no improvement was observed (Aftab and Bedford 2018; Chen et al. 2019). On the other hand, weight gain of broiler chickens was improved when fed with PKM treated enzyme compared to untreated PKM (Navidshad et al. 2016).

3.1.2 Solid-Sate Fermentation

Solid-state fermentation has gained more attention in the last few years due to its ability to improve the value of biomass, including feed ingredients for poultry. The main advantages of SSF are its effect to enhance protein quality, produce functional peptides, decrease antinutritional properties, and thus increase functionality (Suprayogi et al. 2021, 2022). SSF is known to enhance antioxidant activity of the substrate. There are not many available reports regarding the application of SSF to improve the value of PKM. There is a huge opportunity to implement this technology for PKM. The process of SFF is generally consisted of several steps including (1) preparation of microbial culture; (2) substrate incubation; and (3) harvesting. The schematic process of the SSF is provided in Fig. 4.

To date, several reports related to the effect of SFF were available on the quality of palm kernel cake (PKC) while the study on PKM is scarce. Alshelmani et al. (2017) reported that SSF of PKC using cellulolytic bacteria *Paenibacillus polymyxa* ATCC 842 and *P. curdlanolyticus* DSMZ 10248 resulted in significant decrease of NDF (−12.9%) and hemicellulose (−20.7%) and also increased several AA contents such as isoleucine, histidine, phenylalanine, threonine, methionine, arginine, and glycine. SFF of PKC using four fibrolitic bacteria *Bacillus amyloliquefaciens* DSMZ 1067,

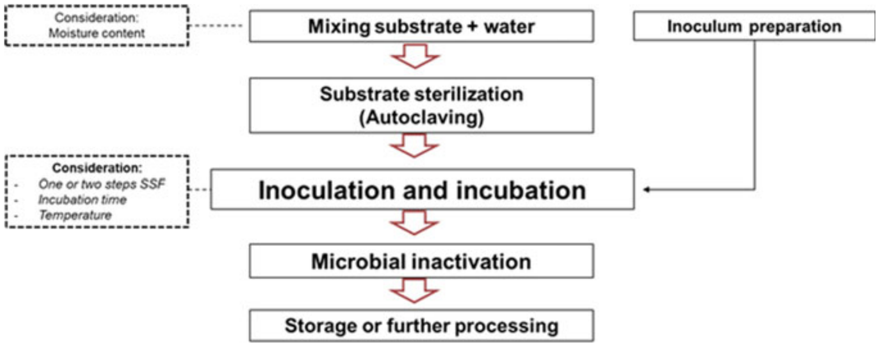

Fig. 4 Schematic representation of solid-state fermentation to enhance quality of PKM

Paenibacillus curdlanolyticus DSMZ 10248, *P. polymyxa* ATCC 842, and *B. megaterium* ATCC 9885 showed similar trends of nutritional profile enhancement (Alshelmani et al. 2014). In addition, PKC was also suggested as an economical substrate for enzyme production through SFF process, as reported in Ong et al. (2004). Another study reported that *Aspergillus niger, Aspergillus oryzae,* and *Aspergillus awamori* were able to grow in PKC, and xylanase was successfully produced. The obtained enzyme was able to improve the nutritive value of PKC as shown by the increase of CP and NFC and the decrease in the non-starch polysaccharides (Mohamad Asri et al. 2020). Studies in this area using PKM and also various by-products generated from palm oil biorefinery are worth investigating.

Different from PKM which is generated from solvent extraction process in palm oil processing, PKC is obtained from expeller press to extract the oil. Nevertheless, the characteristics of PKM and PKC are relatively similar. They contain considerable amounts of antinutritional factors (ANFs) such as β-mannan, cellulose, arabinoxylan, and glucuronoxylan (Alshelmani et al. 2021), while the first was considered as a prebiotic and is beneficial when added to the diet in low amount (Salami et al. 2022). Results of SFF are different depending on the type of substrate, inoculants, water-to-substrate ratio, temperature, and incubation time. To obtain the best conditions of SFF for PKM, a response surface model is the best starting point.

3.1.3 Valorization of PKM into Concentrated Protein

Although the percentage is considerably low, the protein quality of PKM is highly attractive. Various methods can be used for protein extractions from PKM including fractionation or using alkaline solution to extract and separate soluble and non-soluble protein contents. A series process of enzymatic treatment is effective to extract and purify soluble protein from PKM. The hydrolysis can be conducted in a reactor by utilizing 5–10% dry weight of PKM at 60 °C using a certain level of proteolytic enzymes for up to 4 h of stirring. After enzyme inactivation, centrifugation is needed to obtain the supernatant-containing protein. Next, the supernatant is purified using ultrafiltration to eliminate non-protein components using a specific membrane size with the aid of pressure and continuous stirring. Using this technique, soluble protein fraction is obtained (Safi et al. 2022). Known for different hydrolysis capabilities, selecting highly effective enzyme is an important decision. In their work, Safi et al. (2022) reported that alcalase is the most superior enzyme producing the highest purity and yield of protein from PKM, up to >50% and 70% of the supernatant, respectively. They also reported that using this technique, protein with high solubility was obtained. In addition, characterization of protein isolates and protein hydrolysate of PKM processed using the Osborne-type method have demonstrated a significant AA profile improvement than unprocessed PKM. In their study, protein fraction of the PKM was obtained by extracting the PKM using cold distilled water at room temperature with continuous stirring for 1 h.

After a series of extraction processes, supernatant and soluble protein from residue were dialyzed where the hydrolysate (protein concentrate) was obtained. Protein isolate, on the other hand, is obtained by further processing the protein concentrate. The protein concentrate is obtained using a dispersion method in a NaOH solution for 2 h stirring to obtain supernatant. The supernatant is then filtered, and the filtrate is subjected to protein precipitation in pH 4.6 and the precipitate is centrifuged to obtain protein concentrate. Protein hydrolysate can also be produced using microbial hydrolysis, as described in Aluko and Monu (2003) and Chang et al. (2014). Protein isolate from PKM can contain up to 75.6% protein with 15–50 kDa of polypeptide mass (Chang et al. 2014). Such protein isolate can be used as a highly valuable protein for poultry feed. Additionally, SSF can also be employed to produce low molecular weight functional peptides by using PKC as the main substrate. The peptides exhibit antifungal activity as shown in the inhibitory activity against *Aspergillus flavus*, *Aspergillus niger*, *Fusarium* sp., and *Penicillium* sp. (Mohamad Asri et al. 2020).

3.2 By-Product from Marine Industry

The increase in the human population increases the need for food consumption, one of which is the increase in crustacean consumption. This problem certainly has a linear value with the increasing waste by-product of this product. The challenge is how to increase reuse without increasing disruption to the environment. The conventional Chitin chitosan manufacturing process always involves the use of chemical reagents which besides being expensive can also interfere with the environment. The approach is carried out using a number of enzymatic, physical, and biological processes.

3.2.1 Biological Process

Lactobacillus acidophilus SW01 from shrimp waste for deproteinated fermentation of shrimp wastewas used. As a result, the minerals and protein were quickly removed with their contents decreasing to 0.73% and 7.8%, respectively, after 48 h fermentation (Duan et al. 2012). A protease-producing strain, *Exiguobacterium profundum*, and a lactic acid-producing strain, *Lactobacillus acidophilus,* were used to extract the chitin. The yields for the chitin were 47.82 and 16.32%, respectively (Xie et al. 2021). Two strains of bacterial BAO-01 and BAO-02 were isolated and observed for the chitinase activity. These *Salinivibrio* spp. did not show bioamine production, hemolytic activity, and mucin degradation. Therefore, the in vitro screening results suggested that these bacteria could be widely used as new candidates for chitin hydrolyzation and seafood fermentation (Le et al. 2018).

3.2.2 Physical Treatment

The extraction process could use ball milling processes combined with steam explosion that worked for woody biomass or biorefinery action, or other uses converting chitin into small nitrogen-containing chemicals—such as derivatives of ETA and of the widely used organic solvent furan (Yan and Chen 2015).

4 Feed and Feeding Containing Biomass

As a feed additive in ruminants, chitosan administration has two functions, namely directly affecting the microbial fermentation process of the rumen, digestive system, and livestock metabolism and indirectly, namely improving the quality of feed to be consumed by livestock.

4.1 Direct Effect

4.1.1 Anti-Inflammatory and Immunomodulator

The intrauterine infusion of a chitosan solution could speed up the healing process of uterine after parturition in dairy cows (Okawa et al. 2021). It happened because of the antimicrobial effect of chitosan. Diet supplementation of chitosan in dairy cows diet reveals the response of suppressed the activity and expression level of gene and protein of inducible nitric oxide synthase, and linearly decreased interleukin-1 content and gene expression. The supplementation of CHI linearly increased the proportion of CD4+ and CD3+ (T lymphocytes). The supplementation of CHI linearly down-regulated the expression of nuclear factor-κBp65 gene and phosphorylation level in peripheral blood mononuclear cells and linearly inhibited the activity of inducible nitric oxide synthase and the production of nitric oxide (Zheng et al. 2021). The infusion of Chito-oligosaccharides on peripheral blood mononuclear cells (PBMCs) in dairy cows at a concentration of 160 μg/mL exhibited the strongest effect decreased the content and gene expressions of interleukin-1β and tumor necrosis factor-α, the mRNA and protein expression and activity of the inducible nitric oxide synthase, and NO production compared with the values observed in the control group (Zheng et al. 2020).

4.1.2 Protecting Agent

Rumen-protected amino acid coating chitosan on the particles of hydrogenated fat entrapping amino acid could protect arginine particles coated with chitosan by the coacervation using NaOH could retain about 80% of arginine, with the addition of ethanol employed, the chitosan-coated particles could retain even 97% of arginine, and the chitosan-coated methionine particles prepared by addition of ethanol led to 85% (Chiang et al. 2009). Minimizing the ruminal biohydrogenation process of unsaturated fatty acids by the use of encapsulation of flaxseed oil with chitosan (14 and 7%) to encapsulate fats and their effect on in vitro fermentation and fatty acid biohydrogenation with the result increased oleic unsaturated fatty acid significantly compare to control (Besharati et al. 2022).

4.1.3 Methane Reducer and Rumen Modulator

Related to the metabolism of energy supply from crude fiber sources, normally CH_4 gas is releaseed from the rumen, losses in the form of loss energy and emission of greenhouse gas causing this process to be attempted to be reduced. chitosan addition was able to reduce enteric methane emissions such decrease was accompanied by a decline in the protozoa population and a tendency of methanogen reduction also (Harahap et al. 2020). The methanogens could react with the chitosan as the result of different cell charges leading to leakage of the cell (Zanferari et al. 2018). The proportion of VFA was affected by the addition of chitosan. While dry matter intake was not affected the addition of chitosan changed the carbohydrate fermentation resulting in the increase of propionate and decrease of acetate (Araujo et al. 2015) this condition was the same result as monensin was used (Goiri et al. 2010; Zanferari et al. 2018).

4.2 Indirect Effect

Chitosan has a function as an antimicrobial, based on this concept, the addition of chitosan is given to the silage-making process to control fermentation processes that are not desired by microbes. Chitosan addition at 4.47–7.47 g/kg of dry matter (DM) increased the efficiency process by reducing the fermentation losses and increasing the nutritional content of sugarcane silage (Del Valle et al. 2022). The infusion of chitosan and a microbial inoculum to soybean whole plant silage enhances nutritional and fermentative quality, increases all bacteria, and decreases yeast and mold on the silage product (Gandra et al. 2018). The addition of 2% chitosan on the alfalfa silage Neutral detergent fiber (NDF), neutral detergent insoluble crude protein (NDICP) values increase a lactic acid and butyric acid contents decreased, in conclusion, chitosan negatively influenced fermentation quality of alfalfa silage, but reduced mold and clostridial development (Sırakaya and Büyükkılıç-Beyzi 2022).

5 Future Strategy for Biomass Utilization

Biomass transformation via novel bioconversion technology is new frontiers for biorefinery concept, with the main objective to produce value-added underutilized by-products. At present, large volume of palm oil and fish processing by-products need a serious attention for further processing. Solid evidence from the capability of various technological approaches to increase the quality of by-products provides a realistic target for future implementation. From an industrial and economic point of view, there is a need to design a business model for palm kernel cake and palm kernel meal, prior to the implementation of technological processing. At this step, identification of stakeholders that are in need of the final products and potential market volume is fundamental. Next, re-routing the biorefinery process can be determined by considering the industrial-consumer chain characteristics.

For the palm oil processing industry, integrated applications of novel technology to process PKC, PKC, and other potential biomass is the first critical step to produce competitive products. Solid-state fermentation, coupled with mechanical processing, and various valorization techniques can be integrated to process the biomass from palm oil industry. Meanwhile, chemical treatments to improve chitosan functionality are now promising. At the same time, on-farm trials are needed to generate data and validate the quality of the products, that may also help with future improvement strategy. In addition, life cycle assessment may also help to assess the economical, environmental, and social impacts of the implementation of biorefinery technologies for palm oil and fish processing industries. The successful implementation of integrated biorefinery technology to produce valuable by-products from these industries is promising to establish a better livestock industry that is environmentally friendly while decreasing the demand for imported raw materials.

6 Conclusion

Utilization of biomass and biorefinery by-products as feedstock is emerging as a potentially viable alternative to support livestock development and sustainability. Feed ingredients in terms of quality, quantity, and continuity (sustainability) is the key in supporting livestock productivity. Implementation of technology for improving biomass and by-product quality could be carried out by several techniques. Biological processes including solid-state fermentation, mechanical processing, and valorization techniques can be integrated to process the biomass from palm oil industry. Chemical treatments including green chemistry technique could improve chitosan functionality. Consequently, utilization of biomass and by-products of palm oil and marine resources promises supporting raw material stock and sustainability for the feed and feed additive of animals. Further, life cycle assessment should be carried out to evaluate the economic, environmental, and social impacts of the implementation of biorefinery technologies for palm oil and marine processing industries and their relationship with the livestock industry.

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