Utilization of Agro Wastes into Animal Feed through Solid-State Fermentation

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Abstract— *The regions of Southeast Asia generate significant quantities of underused agro-industrial residues that include sago hampas and rice bran and palm kernel cake (PKC) and cassava peels while these materials hold substantial nutritional value. This review is prepared in accordance with PRISMA guidelines examines current research (2015–2025) about transforming agricultural leftovers into improved animal feed through solid-state fermentation (SSF). Thirty-three relevant studies examined microorganisms such as Aspergillus, Trichoderma and Bacillus and lactic acid bacteria together with fermentation conditions that improved animal nutritional quality alongside performance outcomes. During SSF the protein content increased by up to 30–35% in PKC while fiber fractions decreased specifically cellulose and hemicellulose and anti-nutrient effects were observed with cyanogenic glycosides and phytates reduction. The study identified fermented PKC together with rice bran as protein concentration feeds which benefit both monogastric and ruminant animals and fermented cassava peels alongside sago hampas function as digestible energy sources through supplementary nitrogen use. The fermentation process through SSF led to various co-benefits which improved digestive capacities and gut health together with elevated feed conversion for poultry, swine, fish and ruminant livestock. The utilization of SSF faces ongoing operational hurdles because fermentation needs scale-up alongside microbial safety controls and feed maintenance stability. The sustainability solution of SSF meets circular agriculture's criteria through waste transformation for animal feed production while decreasing imported ingredient use and protecting the environment. The research evidence indicates that implementing SSF technology throughout Southeast Asia requires government backing together with staff training sessions and the establishment of scalable technological solutions to support broader adoption.*

Keywords— Agro-industrial Waste, Animal Feed, Protein Enrichment, Sago Hampas, Solid-State Fermentation (SSF).

I. INTRODUCTION

Extensive crop production in Southeast Asia yields huge amounts of agro-industrial residues (agro-wastes) [1]. Some of the common examples include sago hampas (the fibrous by-product of the pith after sago starch extraction), rice bran (a by-product of rice milling), palm kernel cake (PKC, a by-product of palm oil extraction), and cassava peels [2]. Such materials, which are often discarded or underutilized, have significant nutrients. For example, palm kernel cake offers 14–18% and 12–20% crude protein (CP) and crude fiber (CF), whereas cassava peels also offer only ~4–6% CP but are high in fibre (≈34% hemicellulose & cellulose) but contain anti-nutrients such as cyanide [3]. Direct use of such agro wastes in animal feeds are limited due to low protein content, high fibre or starch content and anti-nutritional factors [4].

The solid-state fermentation (SSF), a promising bioprocess to convert these wastes into more nutritious feed ingredients, has gained attraction [5]. In SSF, a solid substrate (fungi, yeasts, or bacteria) is moisture, so that there is little free water, which allows the metabolism of complex plant polymers into more digestible molecules [6]. SSF can degrade the fibrous matter of agro wastes and enrich it with microbial biomass, therefore detoxifying toxic compounds. This tackles both feed- and environmental-related issues: it supplies alternative feed sources that can partly untether from expensive conventional feeds (e.g. soybean meal or fishmeal) and minimizes pollution from agro-waste disposal by repurposing them in a circular bioeconomy [7]. Many studies on SSF have been conducted in Southeast Asia in recent times, especially within the last ten years, targeting local agro wastes as feed for wide range of animals (poultry, ruminants, fish, and shrimp) [8]. This systematic review summarizes recent information about the utilization of sago hampas, rice bran, palm kernel cake, cassava peels and other similar wastes using SSF in animal nutrition.

II. METHODOLOGY

2.1 Research Design:

This study utilized a systematic literature review (SLR) technique that followed PRISMA criteria to identify and analyze relevant studies from approximately the last ten years (2015–2025) focusing on solid-state fermentation of agro-wastes for animal feed in Southeast Asia [9].

2.2 Search strategy:

A comprehensive search strategy was created in collaboration with a medical librarian to identify relevant studies from electronic databases such as PubMed, Scopus, Web of Science, IEEE Xplore, and the Cochrane Library [10]. The search phrases included keywords such as "solid-state fermentation", "agro-industrial waste", "animal feed", combined with specific terms like "*sago hampas*", "rice bran", "palm kernel cake", and "cassava peel". The entire search method for each database was described and provided in the supplemental materials. The search was limited to articles published in English between 2015 and 2025, to ensure the inclusion of the most recent and relevant studies.

2.3 Inclusion and Exclusion Criteria:

Inclusion criteria were studies that involved SSF processing of these substrates with the aim of improving their feed value, and which evaluated either the fermentation process (microbial/enzymatic changes) or the feeding outcomes in animals (nutrition or performance). Both experimental research articles and relevant review papers from the last decade were included to ensure coverage of up-to-date findings. Preference was given to studies conducted in or relevant to Southeast Asian conditions, although insightful research from other tropical regions was also considered when applicable.

Studies were included in this review if they investigated SSF as a processing method for agro wastes intended for animal feed and provided detailed information on fermentation parameters, including microbial strains, substrate modifications, and changes in nutritional composition. Additionally, only studies that evaluated the impact of fermented agro wastes on animal performance, digestibility, or feed efficiency were considered. To ensure the inclusion of high-quality and up-to-date research, only studies published in peer-reviewed journals or credible scientific sources between 2015 and 2025 were selected. The geographical focus was on research conducted within Southeast Asia or in tropical regions with comparable agro-climatic conditions. Studies that exclusively examined submerged fermentation (SmF), lacked experimental data, or did not provide sufficient methodological details were excluded from this review.

A systematic approach was employed to extract key data from the selected studies, ensuring consistency and relevance to the research objectives. The extracted information included details on microbial inoculants used in fermentation, such as *Aspergillus spp*., *Trichoderma spp*., *Bacillus spp*., and lactic acid bacteria, as well as fermentation conditions, including duration, temperature, moisture content, and the presence of additives [11,12]. Changes in the chemical composition of agro-wastes post-fermentation were recorded, focusing on crude protein enhancement, fibre reduction, and detoxification of anti-nutrients. Additionally, animal performance indicators such as feed intake, weight gain, digestibility, and overall health parameters were documented. The experimental design and methodological approaches used in each study were also analysed to understand variations in experimental setups and their impact on the findings.

2.4 Data Synthesis and Analysis:

The findings from the included studies were synthesized through a thematic analysis approach, allowing for an organized evaluation of SSF applications. Studies were categorized based on the type of agro waste fermented, the microorganisms utilized, and the observed effects on feed composition and animal performance. A comparative analysis was conducted to identify emerging patterns and trends in SSF application across different substrates and animal species. Furthermore, variations in fermentation efficiency, microbial effectiveness, and feed conversion outcomes were examined to draw broader insights into the potential of SSF as a bioprocessing technique for animal nutrition.

2.5 Quality Assessment:

To ensure the reliability and validity of the included studies, a rigorous quality assessment was performed. Factors such as experimental design quality, sample size, and methodological rigor were critically evaluated [13]. Preference was given to studies with well-defined fermentation protocols and controlled animal feeding trials to ensure that the reported outcomes were robust and replicable. Additionally, any potential biases or inconsistencies in data reporting were noted, allowing for a balanced and objective interpretation of the results.

III. RESULTS

3.1 Study Selection:

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram presented in Figure 1 illustrates the systematic process undertaken to identify, screen, and include studies for the review. The process began with the identification phase, where a total of 1,185 records were retrieved from various academic databases. Prior to screening, 821 records were removed, comprising 534 duplicate records and 287 records that were excluded for other reasons, such as irrelevance to the research topic or incomplete data.

Following the removal of these records, 364 studies proceeded to the screening phase, during which their titles and abstracts were reviewed for relevance. At this stage, 216 records were excluded as they did not meet the inclusion criteria. Subsequently, 148 full-text reports were sought for retrieval to facilitate a more detailed assessment. However, 97 of these reports could not be retrieved, likely due to access restrictions or unavailability of full-text versions.

In the eligibility assessment phase, 51 full-text reports were evaluated against the predefined inclusion criteria. During this assessment, 18 reports were excluded because they originated from countries that were not within the geographical scope of the study. Consequently, only 33 studies met the eligibility requirements and were included in the final review. Among these, 24 reports were considered as primary sources for data extraction and synthesis.

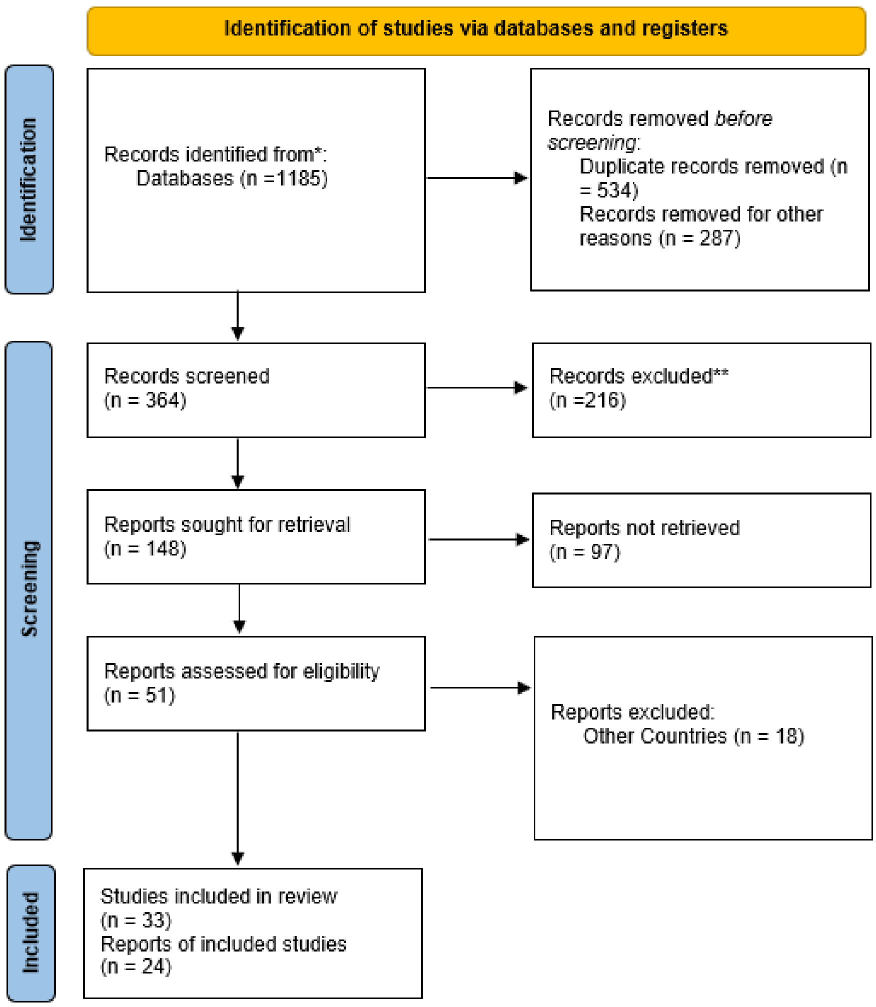

FIGURE 1: PRISMA Flow Diagram (n= number)

3.2 Microbial Strains and Fermentation Conditions:

Various strains of microbes have been used in SSF of agro-wastes, broadly categorized as filamentous fungi, yeast, and bacteria (mostly Bacilli and lactic acid bacteria) [14,15]. Fungal strains are ubiquitous; they produce robust quantities of extracellular enzymes on solid substrates. Aspergillus spp. (e.g., *A. niger*, *A. oryzae*) and *Trichoderma* spp. (e.g. *T. longibrachiatum, T. pseudokoningii*) are commonly utilized because they degrade fibrous ingredients, and protein is enriched in their mycelial [8]. The protein content of palm kernel cake was significantly enhanced (~18.8 – 32.8% CP) and cellulose was reduced from 28% to 12% through fermentation with *Trichoderma longibrachiatum* [16]. Likewise, SSF of PKC with *Aspergillus oryzae* is reported to reduce hemicellulose content by nearly 50% [17].

Edible fungi such as *Pleurotus* (oyster mushroom) have also been evaluated; fermentation of rice bran with *P. sapidus* under SSF conditions (generally ∼25–30 °C for 6–10 days) almost doubled protein from 7.4% to 12.8% [18]. Bacterial inoculants include *Bacillus* spp. (e.g. *B. subtilis, B. amyloliquefaciens, B. licheniformis*), which produce fiber-degrading enzymes, and lactic acid bacteria (e.g., *Lactobacillus plantarum, Weissella confusa*), which ferment carbohydrates and produce organic acids [19]. A study conducted using *Weissella confusa* involved SSF of PKC, coupled with optimized conditions for improving its nutritive value for broilers [20]. Mixed-culture fermentations have also been described (e.g., *B. amyloliquefaciens, B. licheniformis, A. niger,* and *A. flavus*), which ferment sago hampas by exploiting the synergetic enzyme activities of bacteria and fungi [15]. Some methods even rely on naturally derived consortia; for example, cassava peels were fermented using a palm wine culture (a natural mixed yeast/bacteria source) to produce a protein-rich ingredient for fish feed [21].

These studies optimize fermentative conditions specific to the microbes chosen and the characteristics of the substrate. Temperature is usually maintained in the mesophilic range (≈25–40°C). Fungi thrive well at around 28–30°C, while some bacterial fermentations (e.g., *Bacillus* spp.) may be carried out at slightly lower temperatures (above 30°C) [17]. Dry fermentations (like *Trichoderma* and *Aspergillus* on agro-wastes) have been achieved at ~28–30°C for 1–3 weeks or at 40°C for 9 days (*Bacillus amyloliquefaciens* with sago hampas) [19]. SSF produces substrates for palatability, and initial protein levels when fermentation (24–48h) is of short duration, whereas longer durations (5–12 days, sometimes even 3 weeks at room temperature) allow substantial fiber degradation and high biomass accumulation [14]. *T. pseudokoningii* needed 12 days of SSF on cassava residue to achieve a substantial protein level, while a mixed probiotic inoculum on sago hampas showed a continuous decrease in fiber content over 7 days but had progressively decreasing returns at 21 days [8].

For SSF, moisture content is an important parameter; it should be sufficiently high to allow for microbial growth but without excess water [18]. Most studies keep 60–75% moisture in the substrate. For optimal microbial activity, sago waste was fermented with a substrate moisture content of approximately 75% w/w (with mineral solution added in a small quantity). Cassava peel fermentations also did well at 60–70% initial moisture [16]. This is usually done by moistening and either sterilizing or pasteurizing substrates before inoculating them with the culture. Another common method is nutrient supplementation: many agro-wastes are often carbon-rich but protein-deficient in nature, so adding a nitrogen source such as urea or ammonium sulphate greatly enhances microbial protein synthesis [21]. One study reported that adding 1% urea to cassava residues in SSF increased protein by 48% (8.4% to 12.5% CP), as fungi had more nitrogen available to incorporate into their biomass [15]. However, some fermentations also require extra mineral salts or co-substrates (i.e., bran or molasses) to facilitate microbial growth [20]. Fermentation is generally done using trays, flasks, or bioreactors, under aerobic conditions (for fungi and *Bacillus*) or in anaerobic/semi-anaerobic conditions for lactic acid bacteria [19]. The process is monitored for temperature (as heat buildup can be an issue in large-scale SSF due to poor heat dissipation), and endpoints are determined by either maximal enzyme activity or nutrient improvement [15]. In general, successful SSF of agro wastes demands careful control of these conditions to stimulate the proliferation of beneficial microbes and degradation of fibrous matter without spoilage.

3.3 Nutritional Improvements in Fermented Agro-Wastes:

Across diverse substrates, SSF has consistently been shown to enhance the nutritional profile of agro wastes [22]. A primary outcome is protein enrichment. As microbes grow on the waste, they assimilate carbon (e.g., fiber, starch) and minerals and incorporate nitrogen (either from the substrate or supplemented) into microbial protein, thereby raising the overall crude protein content of the feed [23]. For example, fermentation of palm kernel cake (PKC) by various microbes often yields a substantial protein boost [24]. Trichoderma-fermented PKC increased crude protein (CP) from approximately 18% to 33% [25]. Similarly, *Aspergillus niger*-fermented PKC has demonstrated improved protein quality and amino acid profiles [26]. Research has also shown that SSF converts rice bran into a higher-protein product, with one study reporting an increase from 7.4% to 12.8% CP using *Pleurotus sapidus* [19]. Furthermore, SSF has been utilized in aquaculture feed formulation, where it was observed to increase protein content, reduce fiber, enhance the amino acid profile, and improve digestibility. Fermented rice bran (FRB) has been recognized as a high-protein feed ingredient capable of partially replacing soybean meal in shrimp diets without compromising growth [16].

In the case of cassava by-products, which typically have very low protein content, SSF can raise protein levels significantly [27]. Fermenting cassava flour or pulp with Aspergillus strains has been shown to increase protein content from approximately 1–4% to over 10% through the production of single-cell protein, representing a 200–300% relative improvement [28]. For cassava peels, *Trichoderma pseudokoningii* SSF resulted in a protein increase of about 48%, from 8.4% to 12.5% CP, under optimal conditions [29]. Though fermented cassava retains a moderate protein level (~12% CP), this still represents a substantial upgrade over the nutritional value of the unfermented peel. Sago hampas, which has an initially low protein content (often 1–4% CP), cannot reach high absolute protein levels through SSF alone unless additional nitrogen is supplied. However, SSF of sago waste has been shown to approximately double its protein content on a percentage basis. For instance, the use of *Aspergillus niger* with 5% urea increased sago hampas' crude protein by about 15% [15].

In addition to protein gains, fiber reduction is a crucial benefit of SSF. Filamentous fungi and some bacteria produce cellulases, xylanases, mannanases, and other fiber-degrading enzymes that break down complex carbohydrates into simpler forms. Studies consistently report decreased crude fiber or structural polysaccharides in fermented products. In fermented PKC, fiber fractions decrease substantially; *Trichoderma longibrachiatum* not only boosted protein content but also reduced cellulose levels from 28.3% to 12.1% [30]. Other work on PKC fermentation with *Paenibacillus* bacteria and fungi found significant reductions in fiber content and concurrent improvements in metabolizable energy [31]. Fermented sago hampas shows a consistent decline in crude fiber content, regardless of the inoculum used. One study observed that mixing sago hampas with rumen liquor and fermenting with *Bacillus amyloliquefaciens* (2% inoculum) for 9 days at 40°C led to a one-third reduction in crude fiber. Another study using a multi-microbe probiotic mix (plus 30% urea) over 21 days achieved approximately a 15% reduction in fiber [32]. In cassava peels, fermentation helps to break down fibrous cell wall components and reduces certain anti-nutrients bound to fiber, improving mineral availability. As fiber is degraded, the fraction of easily digestible components (such as soluble carbohydrates and microbial biomass) increases, enhancing feed energy value and digestibility. In fermented rice bran, for example, total carbohydrate content increased from 36.6% to 50.2% due to fibre breakdown [14].

Another key improvement associated with SSF is increased digestibility and bioavailability of nutrients. By breaking down fibre and anti-nutritional factors, SSF makes more nutrients accessible to animals. In ruminants, whose microbiomes can ferment fibre, SSF-treated agro-waste has been linked to higher feed intake and improved dry matter digestibility. For example, including up to 50% fermented sago hampas in a ruminant diet resulted in approximately 68% digestibility—significantly higher than diets with unfermented hampas [33]. In non-ruminants, including poultry, fish, and pigs, fibre removal and carbohydrate breakdown are particularly beneficial. Poultry studies have noted improved energy metabolizable and amino acid digestibility when PKC or rice bran undergo SSF. For instance, broilers fed diets containing fermented PKC exhibited better nutrient digestibility than those consuming raw PKC diets [15]. In aquaculture, apparent digestibility coefficients for protein increased when fermented ingredients replaced raw agro-wastes in feed formulations [19].

The SSF process also aids in the degradation of specific anti-nutrients. Fermentation tends to reduce phytic acid levels in fibrous residues, as seen with cassava peels, where phytate phosphorus content dropped from approximately 1% to 0.7% (Abu Yazid et al., 2017). Similarly, rice bran, which is rich in phytate, undergoes partial phytate hydrolysis by microbial phytases during SSF. In cassava, cyanogenic glycosides (which release toxic hydrogen cyanide) are significantly reduced through fermentation and drying, as these processes facilitate cyanide evaporation and microbial enzymatic degradation of linamarin. Consequently, fermented cassava products are safer for animal consumption than raw peels, which pose a risk of cyanide poisoning [32].

Additionally, SSF can enhance beneficial compounds. Some fermentations increase vitamin levels (e.g., B-vitamins produced by yeasts or bacteria) or introduce enzymes and metabolites that act as digestive aids or probiotics. Fermented feeds often contain lactic acid and other organic acids, which lower pH and improve gut health. There is evidence that fermented liquid feeds can reduce pathogenic bacterial loads in poultry. For example, one study found that feeding fermented diets reduced broiler susceptibility to Salmonella infections [14]. While the primary focus of SSF research is on nutritional enhancements, these health benefits represent valuable secondary advantages.

3.4 Comparative Analysis of Different Substrates:

Due to their different compositions, different agro-waste substrates respond to SSF in different ways. A summary comparation of 4 major substrates (sago hampas, rice bran, palm kernel cake, cassava peels). Sago Hampas are high in fiber (lignocellulose) and also has residual starch, it has very low native protein (1–3% CP) and high crude fiber (generally >30%) because of its low protein, unmodified sago hampas is still lacking in protein compared to more common feeds, and this is also true for fermented sago hampas unless external nitrogen is introduced [34]. Reducing fiber content and improving digestibility is the main advantage of using SSF on sago. Multi-strain fermentation considerably reduces fibre content (by up to 33% reduction on total fibre) [35]. Sago hampas also contains a high amount of non-fibrus carbohydrate (NFE) (starch), which is a good energy source for ruminants, but at the same time, the starch can support microbial growth during SSF [25]. According to comparative studies, fermented sago hampas can replace some of the commonly used energy feed, as long as it is supplemented with protein sources (as in the case of ruminants, urea). Fermented sago waste showed potential in aquaculture and ruminant systems in feed trials. And in a test on fish diets, inclusion of 15% fermented sago waste (150 g/kg) in a tilapia feed produced statistically equivalent growth rates to a control diet containing fishmeal [36]. This shows that fermented sago hampas is an efficient supplier of energy and nutritional sources including vitamins, even at very low protein levels, making it an appropriate practical step when properly balanced. Sago hampas can be a source of basal roughage for ruminants and it has been concluded in one review that fermented sago hampas in cattle feed (up to around 50% of diet dry matter) would still allow reasonable growth and digestibility, although raw hampas in high proportions would grossly limit performance [37].

Rice bran (10–15% CP) is moderately nutrient-dense, when it comes to a high fat (15–20% ether extract) and 8–12% fiber it plus starch residues [38]. The major concerns are rancidity (from lipase activity in the oil) and phytate and other inhibitors that can lower the bioavailability of minerals and proteins [39]. SSF acts to stabilize the rice bran by eliminating or reducing lipid content and serve to enhance protein and digestibility in rice bran. Lipid content decreased (possibly from 48.5 to 27.8 % of DM) in the case of rice bran in SSF with Pleurotus indicating oil utilization as an energy source by the organism, preventing rancidity and increasing other nutrients. In parallel, dietary protein was increased to 13% [40]. Fermentation improves the amino acid balance of rice bran: feeding it to microbes increases the protein content, and the microorganisms produce high-quality protein that can be used to supplement the low-lysine protein found in rice [41]. Compared to other commonly used feed ingredients, fermented rice bran is relatively well-balanced, with moderate protein (lower than fermented PKC, but more than fermented cassava or fermented sago), moderate fiber, and a bit of residual oil for energy [42]. It has been extensively tested for use in monogastrics and aquaculture. For instance, fermented rice bran completely replaced soybean meal at 25–50% in shrimp (Penaeus monodon) feeding trials and had no adverse effect on either growth performance or carcass composition [43].

At 25% replacement, shrimp growth even improved, likely due to enhanced palatability or micronutrients from the fermentation. This indicates fermented rice bran can partially substitute expensive protein sources [44]. In poultry and pig diets, fermented rice bran is often included at 5–15% as an energy-protein source with positive results on feed efficiency compared to raw bran [45]. Thus, relative to other wastes, rice bran under SSF becomes a high-quality feed ingredient with a balance of protein and energy, suitable for all animal categories (and especially valuable in non-ruminant diets where raw bran's utility is limited by anti-nutrients).

Palm Kernel Cake (PKC) is a fibrous residue which is high in protein (14–18%) and fiber (up to 20% CF) with mannan-rich polysaccharide. PKC is among the substrates for which SSF provides some of the largest gains [46]. Fermentation can elevate its CP to oilseed meal level, to begin with, being richer in protein. All fungal treatments (e.g. Aspergillus, Trichoderma) significantly increased PKC protein to the 25–30% range so "fermented PKC" could be used as a local replacement for soybean meal, a common ingredient in poultry diets [47]. The fiber (mostly mannans and cellulose) is highly degraded, a key factor because raw PKC's high fiber content makes it less suited for use in non-ruminants. In one comparative study, the hemicellulose content of Aspergillus oryzae-fermented PKC was found to be markedly lower compared to the corresponding unfermented PKC (~19% vs 37% originally) [48]. Additionally, fermentation is a unique opportunity for PKC, to develop value-added end-products, *Paenibacillus,* and other inoculants, can be utilized to convert fibre from PKC to mannan-oligosaccharides (MOS), which although used as a prebiotic in animal feedings have their own benefits [49]. When compared across wastes fermented PKC is particularly advantageous to poultry and pigs as it changes PKC from a primarily ruminant feed (in raw form) to a more universally digested feed [50]. When PKC is fermented and incorporated at levels of 10–20% of a broiler's diet, the quality of performance based upon weight gain and feed conversion is remarkably improved compared to that of raw PKC included at levels which would suppress performance if fed. Reduced fiber and beneficial fermentation metabolites in fermented PKC contributed to enhanced growth and gut health of broilers in heat-stressed tropical climates. Fermented PKC has higher protein and bypass nutrients that could benefit ruminants, which can also utilize raw PKC. More specifically, studies conducted in dairy cattle showed an increase in milk yield and quality when some of the concentrate was exchanged for fermented PKC (due to increased undegradable protein and nutrient density) [51]. Hence PKC through SSF becomes a high digestibility, protein-rich feed when you compare it. It also has a higher baseline content of the nutrient in question, so unless it's otherwise counter-intuitive, it will typically produce the most nutritious product, it had the highest absolute protein.

Cassava Peels (and Pulp) remains are basically energy-dense, protein-poor substrates. Peels contain 5% of CP and more than 50–60% of carbohydrates (mostly starch and fiber) [52]. They also have anti-nutritional cyanogenic glycosides that should be reduced. SSF provides moderate protein enrichment, often elevating CP into the 10–15% range upon N, supplementations and acts to detoxify the cassava waste; Though fermented cassava peels have lower protein compared to fermented PKC or rice bran, this feed has the advantage of being a safe and appetizing energy source that can become a partial substitute for the inclusion of grains [53]. For instance, fungi- or rumen-microbe-based fermentation of cassava peels improves their nutrition with lots of microbial protein and reduces the content of cyanide to safe levels (far below 50 mg/kg) [54]. This means cassava peel–based feeds could be used much more widely. A fermented cassava peel product (sometimes referred to as cassava peel silage or SCOB – single cell protein biomass) has been tested and successfully replaced maize or other energy sources in feeding trials in swine and poultry in proportions of ca. 20–30% inclusion, usually with positive or no negative effect on growth [55]. In one study in broilers, a mixture of fermented cassava pulp and PKC fully replaced maize without a drop in weight gain, as long as amino acids were balanced [56]. Use of dried fermented cassava peels (sometimes fermented with yeast from palm wine or with rumen fluid) as a protein/carbohydrate source in fish has also been investigated [57]. In tilapia fishes feed, this type of diet outperformed raw cassava peel and even fishmeal alone and displayed slightly lower performance than a soybean meal diet. Implying that fermented cassava can serve as a source of energy and a fair amount of protein [58]. Cassava wastes may need more attention than others to become detoxified, as SSF represents a biological detox method (especially with select bacteria). They generally require nitrogen supplements (e.g., urea, soybean waste, etc.) to ensure that fermentation produces a viable protein feed. However, the transformation of cassava peels into feed would have a considerable impact due to the large number of cassavas in Southeast Asia (Thailand, Indonesia, etc.) and Africa. Economically, it makes what is fundamentally a disposal problem a feed resource [59]. Overall, fermented cassava peels are a decent energy feed and, with some protein supplementation, are better than raw peels, but nutritionally they are a step down from fermented PKC or rice bran as they have less protein.

Higher initial protein substrates (such as PKC, rice bran) generally produce fermented products that can be used as protein concentrates. Those that are very low in protein (i.e., sago, cassava) are essentially enhanced energy sources but with some additional protein and highly- fibrous substrates (PKC, sago) experience the most skilled reduction of fiber in terms of the fiber, which better locates its usage into a non-ruminant animal [60]. Substrates with a high starch content (cassava, sago etc.) readily support mycelium growth and can, therefore, grow microbial protein if nitrogen is not limiting. Each substrate can be metabolized by different microbes: *Neurospora crassa* has been traditionally used in Indonesia as a means of fermenting cassava waste into high-protein biomass ("oncom" feed), while things like white-rot fungi such as *Pleurotus* can flourish on high-fat rice bran because they can metabolize lipids [61]. These differences highlight the need to optimize SSF conditions for each individual waste. However, all these agro wastes can be bioconverted using SSF to become more nutrient-rich, using less conventional feed ingredients in the poultry, ruminants, and aquaculture species that previously could not properly use the raw forms. In practice, the choice of fermented substrate may be determined by local availability and the animals targeted, a farmer in Malaysia, for example, might use fermented PKC for chickens (taking advantage of the country's abundant palm oil wastes), while an Indonesian farmer might use fermented cassava peels and sago hampas for cattle in an area where those substrates are available in abundance.

IV. DISCUSSION

The above results demonstrate that solid-state fermentation is a powerful tool for valorising agro waste into animal feed, but realizing its full potential involves understanding its benefits and challenges in practical contexts, as well as its broader impact on sustainability and economics. The benefits of solid-state fermentation (SSF) for animal feed production are numerous, beginning with nutrient enhancement. SSF significantly improves the nutritional profile of agro-waste-derived feed by increasing protein content and enhancing fiber digestibility, which directly contributes to better animal growth performance and overall health [62]. Fermented palm kernel cake (PKC) and rice bran can partially replace imported soybean meal in livestock diets, while fermented sago and cassava can serve as substitutes for a portion of cereal grains, thus diversifying protein and energy sources. Additionally, microbial fermentation enriches the feed with B-vitamins, enzymes, and amino acids, improving its overall nutritional balance. Studies have shown that livestock and fish fed fermented feed exhibit equal or superior weight gains and feed conversion ratios compared to those on unfermented counterparts, further validating the benefits of SSF in vivo [63,64].

Another significant advantage of SSF is its ability to utilize locally abundant, low-cost resources. Southeast Asia produces large quantities of agro-industrial by-products such as PKC in Malaysia and Indonesia and rice bran in rice-producing countries. By transforming these materials into animal feed, SSF reduces reliance on costly imported feed ingredients such as soybean meal and corn [1,46]. This process not only lowers production costs for farmers but also enhances feed security by leveraging readily available agricultural residues. Fermented agro-waste feeds are often cheaper per unit of nutrient compared to conventional commercial feeds, making them an economically viable solution for sustainable livestock production [65].

Beyond economic benefits, SSF promotes environmental sustainability by mitigating waste disposal challenges. Large-scale agricultural operations generate significant amounts of by-products that, if left unused, can contribute to environmental pollution [66]. For example, PKC and sago hampas in Malaysia and Indonesia pose major waste management challenges, but SSF enables their reintegration into the farm production cycle. By converting these residues into nutritious feed, SSF reduces open dumping and burning, which can cause environmental hazards such as methane emissions and soil degradation. Furthermore, by replacing a portion of conventional feed ingredients, SSF reduces the need for additional cropland for feed cultivation or wild fish harvesting for fishmeal, thereby alleviating land use pressure and contributing to more sustainable food systems [67].

Animal health and feed safety also benefit from SSF, as fermentation can improve gut health and inhibit pathogens. Organic acids such as lactic and acetic acids lower feed pH, creating an unfavorable environment for harmful bacteria, including *Salmonella* and *E. coli*. Studies indicate that fermented feed in poultry and swine diets can significantly reduce the incidence of these pathogens while promoting beneficial gut microbiota [68,69,70]. Additionally, some fermented feed products act as natural probiotics or prebiotics, as seen with mannan-oligosaccharides (MOS) derived from fermented PKC, which support gut health and immune function. Fermentation can also detoxify harmful compounds, breaking down mycotoxins, cyanogenic glycosides, and other anti-nutritional factors, thereby improving overall feed safety. These effects contribute to healthier animals, potentially reducing the need for antibiotics and chemical additives in livestock diets.

Moreover, SSF-derived feeds demonstrate remarkable adaptability across various animal production systems. Ruminants benefit from increased rumen-degradable protein and improved fiber digestibility in fermented roughages, allowing for better nutrient absorption and growth performance. Non-ruminants, such as poultry and pigs, benefit from reduced fiber and anti-nutritional content in fermented feeds, enabling higher inclusion rates of agro-waste-derived ingredients without compromising performance. In aquaculture, fermented plant-based ingredients are more readily accepted by fish and shrimp due to improved palatability and reduced off-flavors. For instance, the fermentation of rice bran has been shown to enhance its "umami" amino acid content, potentially improving shrimp feed acceptability and growth outcomes. The versatility of SSF feeds makes them well-suited for integrated farming systems, where a single waste stream can be processed and utilized across multiple animal species [71]. A farm practicing SSF, for example, could ferment agro-waste and use the resulting feed for both cattle and fish in a polyculture setup, maximizing resource efficiency and minimizing wastePreparation of inoculum and substrates are another critical challenge in SSF. While a reliable inoculum is important, it may pose a challenge, particularly to smallholders. Some fermentations use naturally occurring microbes, as with rumen fluid or palm wine starters, but pure or well-defined mixed cultures (e.g., specific *Aspergillus* or *Bacillus* species) are often needed to achieve reproducible results. These starter cultures might have to be prepared in a lab, which necessarily is less accessible. Moreover, a number of substrates need to be pretreated to achieve optimal fermentation efficiency. This includes drying, grinding to create surface area, altering pH or adding nutritional additives, all of which add labor and cost. Cassava peels, for instance, usually need being chopped and soaked prior to being fermented in order to drop cyanide ranges. For small-scale farmers, however, these preparatory steps can be cumbersome without adequate training or equipment.

V. CONCLUSION

Solid-state fermentation has emerged as a viable strategy to transform Southeast Asia's abundant organic residues into premium livestock feed ingredients. Throughout the past decade, widespread investigation has demonstrated that prevalent local wastes – like sago filter cakes, rice bran, palm kernel cake, and cassava peels – can be biologically processed with molds and microbes to significantly better their nutritional worth. This thorough review highlighted that SSF generally heightens crude protein (through microbial biomass formation) and reduces fibrous portions, thereby enhancing the digestibility and feed value of these materials. A variety of microbial strains (for example, Aspergillus, Trichoderma, Bacillus, Lactobacillus) have effectively been utilized, under conditions of fermentation usually surrounding 28–37°C, 60–75% moisture, and 5–14 days duration, regularly with nutrient supplementation to optimize growth. The fermented products have displayed promising outcomes across animal types: poultry diets with fermented PKC or cassava have boosted development and feed proficiency, ruminants have superior digestibility and performance on diets containing fermented sago or rice bran, and fish/shrimp feeds incorporating fermented rice bran or cassava peels can partly change traditional ingredients without loss of productivity.

Comparative analysis sheds light on how varied agro-waste responses can be – for instance, palm kernel cake experiences major boosts to protein content and digestibility, allowing its use as a protein-packed feed for non-ruminants. Meanwhile, cassava peels become safely used for energy once cyanide levels reduce, though they enrich less dramatically. These insights permit targeted applications: utilizing fermented rice bran or palm kernel cake to replace costly concentrates, and high-fiber fermented refuse like *sago hampas* fulfilling roughage and energy roles in ruminant rations. Embracing SSF for feed brings manifold advantages – it fosters waste reuse and environmental sustainability, lessens feed expenses and reliance on imports, and may enhance animal gut wellness through probiotic effects. However, maintaining fermentation quality, confirming economic feasibility, and scaling the process beyond labs to farms remain challenges. Addressing such hurdles will prove pivotal to broader industry adoption. Developing starter culture kits, modular fermenters like bags or silos, plus merging SSF into prevailing agro-industrial operations can smooth practical implementation.

In conclusion, solid-state fermentation offers a compelling pathway to enhance feed security and sustainability in Southeast Asia. By transforming diverse agro-wastes into nutritious feed, it recycles environmental burdens into economic gains – aligning precisely with aims of circular agriculture and zero-waste goals. Experiments over the past decade prove conclusively that animals can thrive on diets incorporating sizable portions of fermented by-products. Moving forward, efforts must optimize fermentation techniques, conduct extensive on-farm tests to calibrate suitable inclusion levels for various species, and carry out cost-benefit analyses in real settings. With persistent innovation and assistance, SSF of agro wastes is well-positioned to shift from exploration studies into standard agricultural practice, contributing importantly to a more resilient and sustainable animal agriculture sector in Southeast Asia and beyond. Evidence compiled herein serves as a knowledge base to propel this transition, confirming that residual materials from one process indeed represent "treasure" as healthy animal nourishment.

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REFERENCES

[1] Wan-Mohtar, W. A. A. Q. I., Khalid, N. I., Rahim, M. H. A., Luthfi, A. A. I., Zaini, N. S. M., Din, N. A. S., & Mohd Zaini, N. A. (2023). Underutilized Malaysian agro-industrial wastes as sustainable carbon sources for lactic acid production. Fermentation, 9(10), 905.

[2] Mirnawati, M., Ciptaan, G., & Ferawati, F. (2019). Improving the quality and nutrient content of palm kernel cake through fermentation with Bacillus subtilis.

[3] Zubair, J. B. (2024). Effect of Lactic Acid Bacteria Treated Gliricidia-Cassava Peels Mixtures Silage on Performance Characteristics and Blood Profile of West Africa Dwarf (WAD) Goats (Master's thesis, Kwara State University (Nigeria)).

[4] Kundmann, A. C., Flynn, A., Wood, D. F., Orts, W. J., & Hart-Cooper, W. (2024). Animal feed production and analysis from egg and almond hull agricultural waste. Journal of Applied Animal Research, 52(1), 2426984.

[5] Bamidele, M. O., Bamikale, M. B., Cárdenas-Hernández, E., Bamidele, M. A., Castillo-Olvera, G., Sandoval-Cortes, J., & Aguilar, C. N. (2025). Bioengineering in solid-state fermentation for next sustainable food bioprocessing. Next Sustainability, 6, 100105.

[6] Postigo, L. O. C., Jacobo-Velázquez, D. A., Guajardo-Flores, D., Amezquita, L. E. G., & García-Cayuela, T. (2021). Solid-state fermentation for enhancing the nutraceutical content of agrifood by-products: Recent advances and its industrial feasibility. Food Bioscience, 41, 100926.

[7] Perwez, M., & Al Asheh, S. (2024). Valorization of agro-industrial waste through solid-state fermentation: Mini review. Biotechnology reports (Amsterdam, Netherlands), 45, e00873. https://doi.org/10.1016/j.btre.2024.e00873

[8] Yafetto, L., Odamtten, G. T., & Wiafe-Kwagyan, M. (2023). Valorization of agro-industrial wastes into animal feed through microbial fermentation: A review of the global and Ghanaian case. Heliyon, 9(4).

[9] Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... & Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. bmj, 372.

[10] Gusenbauer, M., & Haddaway, N. R. (2020). Which academic search systems are suitable for systematic reviews or meta-analyses? Evaluating retrieval qualities of Google Scholar, PubMed, and 26 other resources. Research synthesis methods, 11(2), 181-217.

[11] Díaz-Rodríguez, A. M., Parra Cota, F. I., Cira Chávez, L. A., García Ortega, L. F., Estrada Alvarado, M. I., Santoyo, G., & de Los Santos-Villalobos, S. (2025). Microbial Inoculants in Sustainable Agriculture: Advancements, Challenges, and Future Directions. Plants, 14(2), 191.

[12] Dong, M., Li, Q., Xu, F., Wang, S., Chen, J., & Li, W. (2020). Effects of microbial inoculants on the fermentation characteristics and microbial communities of sweet sorghum bagasse silage. Scientific Reports, 10(1), 837.

[13] Shaheen, N., Shaheen, A., Ramadan, A., Hefnawy, M. T., Ramadan, A., Ibrahim, I. A., Hassanein, M. E., Ashour, M. E., & Flouty, O. (2023). Appraising systematic reviews: a comprehensive guide to ensuring validity and reliability. Frontiers in research metrics and analytics, 8, 1268045. https://doi.org/10.3389/frma.2023.1268045

[14] Sadh, P. K., Duhan, S., & Duhan, J. S. (2018). Agro-industrial wastes and their utilization using solid-state fermentation: a review.

[15] Bibi, F., Ilyas, N., Saeed, M., Shabir, S., & Shati, A. A. (2023). Innovative production of value-added products using agro-industrial wastes via solid-state fermentation.

[16] Selo, G., Planinić, M., Tišma, M., & Tomas, S. (2021). A comprehensive review on valorization of agro-food industrial residues by solid-state fermentation.

[17] Ametefe, G. D., Lemo, A. O., Orji, F. A., & Lawal, A. K. (2022). Pectinase activities of selected fungi grown on agrowastes via solid-state fermentation.

[18] Alpers, T., Kerpes, R., Frioli, M., Nobis, A., Hoi, K. I., Bach, A., ... & Becker, T. (2021). Impact of storing condition on staling and microbial spoilage behavior of bread and their contribution to prevent food waste. Foods, 10(1), 76.

[19] Kumar, V., Naik, B., Choudhary, M., & Kumar, A. (2022). Agro-waste as a substrate for the production of pullulanase by Penicillium viridicatum under solid-state fermentation.

[20] Mahmoud, E., Ramadan, M., & Ismail, M. M. (2022). Production of flavors from agro waste of Ocimum basilicum L. by different microorganisms using solid-state fermentation. Egyptian Journal of Chemistry.

[21] Naik, B., Goyal, S. K., Tripathi, A. D., & Kumar, V. (2019). Screening of agro-industrial waste and physical factors for the optimum production of pullulanase in solid-state fermentation from endophytic Aspergillus sp.

[22] Bajić, B., Vučurović, D., Vasić, Đ., Jevtić-Mučibabić, R., & Dodić, S. (2022). Biotechnological production of sustainable microbial proteins from agro-industrial residues and by-products. Foods, 12(1), 107.

[23] Rasool, K., Hussain, S., Shahzad, A., Miran, W., Mahmoud, K. A., Ali, N., & Almomani, F. (2023). Comprehensive insights into sustainable conversion of agricultural and food waste into microbial protein for animal feed production. Reviews in Environmental Science and Bio/Technology, 22(2), 527-562.

[24] Zeng, H., Miao, J., Liao, J., Sui, Z., Hou, M., & Hang, S. (2024). Palm Kernel Cake Extracts Obtained from the Combination of Bacterial Fermentation and Enzymic Hydrolysis Promote Swine Small Intestine IPEC-J2 Cell Proliferation and Alleviate LPS-Induced Inflammation In Vitro. Antioxidants, 13(6), 682.

[25] Wardono, H. P., Agus, A., Astuti, A., Ngadiyono, N., & Suhartanto, B. (2022, February). The effect of fermentation time on the nutritional value of sago hampas. In 9th International Seminar on Tropical Animal Production (ISTAP 2021) (pp. 97-102). Atlantis Press.

[26] Uche, F. O., Eggbune, E. O., Anigboro, A. A., & Tonukari, N. J. (2024). Assessment of Biochemical Potential of Rhizopus oligosporus as Starter Culture to Enhance the Nutritional Value of Palm Kernel Cake for Animal Feed Formulation. Journal of Applied Sciences and Environmental Management, 28(9), 2887-2903.

[27] Vandenberghe, L. P., Pandey, A., Carvalho, J. C., Letti, L. A., Woiciechowski, A. L., Karp, S. G., ... & Soccol, C. R. (2021). Solid-state fermentation technology and innovation for the production of agricultural and animal feed bioproducts. Systems Microbiology and Biomanufacturing, 1, 142-165.

[28] Sathya, R., Varghese, R., & Arasu, M. V. (2023). Vágvölgyi Csaba, Pankaj Kumar, RC Dubey 14 Agro-food industrial residues into enzymes and other products using solid-state fermentation. Microbial Oxidative Enzymes: Biotechnological Applications, 281.

[29] Inga, M., Betalleluz-Pallardel, I., Puma-Isuiza, G., Cumpa-Arias, L., Osorio, C., Valdez-Arana, J. D. C., & Vargas-De-La-Cruz, C. (2024). Chemical analysis and bioactive compounds from agrifood by-products of peruvian crops. Frontiers in Sustainable Food Systems, 8, 1341895.

[30] Yafetto, L. (2022). Application of solid-state fermentation by microbial biotechnology for bioprocessing of agro-industrial wastes from 1970 to 2020: A review and bibliometric analysis.

[31] Abu Yazid, N., Barrena, R., Komilis, D., & Sánchez, A. (2017). Solid-state fermentation as a novel paradigm for organic waste valorization: a review. Sustainability, 9(2), 224.

[32] Murugesan, G., & Shenpagam, D. N. H. (2015) Synthesis And Characterization Of Neutral Protease From Agro Waste By Solid State Fermentation. Pharmanest - An International Journal Of Advances In Pharmaceutical Sciences, 6(6)

[33] Wardono, H. P., Agus, A., Astuti, A., Ngadiyono, N., & Suhartanto, B. (2021). Potential of sago hampas for ruminants feed. In E3S Web of Conferences (Vol. 306, p. 05012). EDP Sciences.

[34] Fetriyuna, F., Letsoin, S. M. A., Jati, I. R. A., & Purwestri, R. C. (2024). Potential of Underutilized Sago for Bioenergy Uses. International Journal on Advanced Science, Engineering & Information Technology, 14(1).

[35] Sandar, S. (2022). Potential of neglected biomass and industrial side-streams utilization in biofuels production.

[36] Lani, N., Husaini, A., Ngieng, N. S., Lee, K. S., RAHIM, K. A. A., Roslan, H. A., & Esa, Y. (2021). Solid substrate fermentation of sago waste and its evaluation as feed ingredient for red hybrid tilapia. Malaysian Applied Biology, 50(1), 85-94.

[37] Tiro, B. M. W., Beding, P. A., & Baliadi, Y. (2018, February). The utilization of sago waste as cattle feed. In IOP Conference Series: Earth and Environmental Science (Vol. 119, No. 1, p. 012038). IOP Publishing.

[38] Sapwarobol, S., Saphyakhajorn, W., & Astina, J. (2021). Biological Functions and Activities of Rice Bran as a Functional Ingredient: A Review. Nutrition and metabolic insights, 14, 11786388211058559. https://doi.org/10.1177/11786388211058559

[39] Sahini, M. G., & Mutegoa, E. (2023). Extraction, phytochemistry, nutritional, and therapeutical potentials of rice bran oil: A review. Phytomedicine Plus, 3(2), 100453.

[40] Omarini, A. B., Labuckas, D., Zunino, M. P., Pizzolitto, R., Fernández-Lahore, M., Barrionuevo, D., & Zygadlo, J. A. (2019). Upgrading the nutritional value of rice bran by solid-state fermentation with Pleurotus sapidus. Fermentation, 5(2), 44.

[41] Seyoum, Y., Humblot, C., Baxter, B. A., Nealon, N. J., Weber, A. M., & Ryan, E. P. (2022). Metabolomics of Rice Bran Differentially Impacted by Fermentation With Six Probiotics Demonstrates Key Nutrient Changes for Enhancing Gut Health. Frontiers in nutrition, 8, 795334. https://doi.org/10.3389/fnut.2021.795334

[42] Manlapig, J. J. D., & Matsui, H. (2025). Production and Utilization of Fermented Rice Bran as Animal Feed. Animal science journal = Nihon chikusan Gakkaiho, 96(1), e70037. https://doi.org/10.1111/asj.70037

[43] Huervana, F. H., Traifalgar, R. F. M., & Dionela, C. S. (2024). Solid-state fermentation converts rice bran into a high-protein feed ingredient for Penaeus monodon. Frontiers in Marine Science, 11, 1384492.

[44] Wang, Y., Zheng, W., Deng, W., Fang, H., Hu, H., Zhu, H., & Yao, W. (2023). Effect of fermented heat-treated rice bran on performance and possible role of intestinal microbiota in laying hens. Frontiers in Microbiology, 14, 1144567.

[45] Haryati, T., Susanti, T., & Susana, I. W. R. (2015). Nutritional value of rice bran fermented by Bacillus amyloliquefaciens and humic substances and its utilization as a feed ingredient for broiler chickens. Asian-Australasian journal of animal sciences, 28(2), 231.

[46] Azizi, M. N., Loh, T. C., Foo, H. L., & Teik Chung, E. L. (2021). Is palm kernel cake a suitable alternative feed ingredient for poultry?. Animals, 11(2), 338.

[47] Abdeltawab, A. M., & Khattab, M. S. (2018). Utilization of palm kernel cake as a ruminant feed for animal: A review. Asian J. Biol. Sci, 11(4), 157-164.

[48] Gomez-Osorio, L. M., Nielsen, J. U., Martens, H. J., & Wimmer, R. (2022). Upgrading the Nutritional Value of PKC Using a Bacillus subtilis Derived Monocomponent β-Mannanase. Molecules (Basel, Switzerland), 27(2), 563. https://doi.org/10.3390/molecules27020563

[49] Tiwari, U. P., Fleming, S. A., Rasheed, M. S. A., Jha, R., & Dilger, R. N. (2020). The role of oligosaccharides and polysaccharides of xylan and mannan in gut health of monogastric animals. Journal of nutritional science, 9, e21.

[50] Ong, W. L., Chan, K. L., Suwanto, A., Li, Z., Ng, K. H., & Zhou, K. (2024). Hydrolysis of palm kernel meal fibre using a newly isolated Bacillus subtilis F6 with high mannanase activity. Bioresources and bioprocessing, 11(1), 113. https://doi.org/10.1186/s40643-024-00826-9

[51] Ferreira, F. G., Leite, L. C., Alba, H. D. R., Pina, D. D. S., Santos, S. A., Tosto, M. S. L., Rodrigues, C. S., de Lima Júnior, D. M., de Oliveira, J. S., de Freitas Júnior, J. E., de C Mesquita, B. M. A., & de Carvalho, G. G. P. (2022). Palm Kernel Cake in Diets for Lactating Goats: Intake, Digestibility, Feeding Behavior, Milk Production, and Nitrogen Metabolism. Animals : an open access journal from MDPI, 12(18), 2323. https://doi.org/10.3390/ani12182323

[52] Lomwongsopon, P., & Aramrueang, N. (2022). Mild chemical pretreatment of cassava pulp for enhancing high-load anaerobic digestion. Bioresource Technology Reports, 17, 100896.

[53] Godoy, Mateus & Freire, Denise. (2018). Agricultural Residues as Animal Feed: Protein Enrichment and Detoxification Using Solid-State Fermentation.

[54] Gunun, P., Cherdthong, A., Khejornsart, P., Wanapat, M., Polyorach, S., Kaewwongsa, W., & Gunun, N. (2023). Replacing concentrate with yeast-or EM-Fermented cassava peel (YFCP or EMFCP): Effects on the feed intake, feed digestibility, rumen fermentation, and growth performance of goats. Animals, 13(4), 551.

[55] Heuzé, V., Tran, G., Archimede, H., Regnier, C., Bastianelli, D., & Lebas, F. (2016). Cassava peels, cassava pomace and other cassava by-products.

[56] Chang'a, Edwin & Abdallh, Medani & Ahiwe, Emmanuel & Mbaga, Said & Zhu, Ze & Fru, Fidelis & Iji, Paul. (2019). Replacement value of cassava for maize in broiler chicken diets supplemented with enzymes. Asian-Australasian Journal of Animal Sciences. 33. 10.5713/ajas.19.0263.

[57] Andriani, Yuli & Pratama, Rusky & Harlina, Putri. (2023). POTENTIAL UTILIZATION OF CASSAVA PEEL WASTE FOR FISH FEED. 21-27. 10.5281/zenodo.8137841.

[58] Talukdar, Anik & Rahman, Md & Islam, Md & Alam, Mohammad & Rahman, Flura. (2023). Alternative protein sources as a replacement of fish meal in the diet of Oreochromis niloticus: A review. Archives of Agriculture and Environmental Science. 8. 442-451.

[59] Jumare, Fatimah Ibrahim & Salleh, Madihah & Ihsan, Nurashikin & Hussin, Huszalina. (2024). Cassava waste as an animal feed treatment: past and future. Reviews in Environmental Science and Bio/Technology. 23. 1-30. 10.1007/s11157-024-09701-7.

[60] Djulardi, Ade & Mirnawati, Mirnawati & Ciptaan, Gita & Kurnia, Ridho & Srifani, Anifah & Adriani, Lovita & Makmur, Malik. (2023). Improving the Quality and Nutritional Value of a Mixture of Sago Pith and Indigofera Leaves Fermented with Rhizopus oligosporus. World s Veterinary Journal. 13. 580-586. 10.54203/scil.2023.wvj62.

[61] Karimi, S. (2024). Filamentous Fungi as a Sustainable Ingredient for Fish Feed (Doctoral dissertation, Högskolan i Borås).

[62] Sousa, D., Moset, V., del Carmen López-Luján, M., Salgado, J. M., Dias, A., Belo, I., ... & Cambra-López, M. (2024). Potential of solid-state fermentation to enhance the nutritional value of oilseed cakes for poultry. *Animal Feed Science and Technology*, *316*, 116056.

[63] Jiang, W., Jia, X., Xie, N., Wen, C., Ma, S., Jiang, G., ... & Liu, W. (2023). Aquafeed fermentation improves dietary nutritional quality and benefits feeding behavior, meat flavor, and intestinal microbiota of Chinese mitten crab (Eriocheir sinensis). *Animal Nutrition*, *14*, 1-19.

[64] Lambo, M. T., Ma, H., Zhang, H., Song, P., Mao, H., Cui, G., ... & Zhang, Y. (2024). Mechanism of action, benefits, and research gap in fermented soybean meal utilization as a high-quality protein source for livestock and poultry. *Animal Nutrition*, *16*, 130-146.

[65] Riseh, R. S., Vazvani, M. G., Hassanisaadi, M., & Thakur, V. K. (2024). Agricultural wastes: A practical and potential source for the isolation and preparation of cellulose and application in agriculture and different industries. *Industrial Crops and Products*, *208*, 117904.

[66] Adejumo, I. O., & Adebiyi, O. A. (2020). Agricultural Solid Wastes: Causes, Effects, and Effective Management. Chapter 10. *Saleh, HM, Strategies of Sustainable Solid Waste Management. IntechOpen. doi*, *10*.

[67] Albrektsen, S., Kortet, R., Skov, P. V., Ytteborg, E., Gitlesen, S., Kleinegris, D., ... & Øverland, M. (2022). Future feed resources in sustainable salmonid production: A review. *Reviews in aquaculture*, *14*(4), 1790-1812.

[68] Peng, W., Talpur, M. Z., Zeng, Y., Xie, P., Li, J., Wang, S., ... & Zhang, H. (2022). Influence of fermented feed additive on gut morphology, immune status, and microbiota in broilers. *BMC Veterinary Research*, *18*(1), 218.

[69] Sugiharto, S., & Ranjitkar, S. (2019). Recent advances in fermented feeds towards improved broiler chicken performance, gastrointestinal tract microecology and immune responses: A review. *Animal nutrition*, *5*(1), 1-10.

[70] Ji, M., Rong, X., Wu, Y., Li, H., Zhao, X., Zhao, Y., ... & Li, B. (2025). Effects of Fermented Liquid Feed with Compound Probiotics on Growth Performance, Meat Quality, and Fecal Microbiota of Growing Pigs. *Animals*, *15*(5), 733.

[71] Elhalis, H. (2024). Expanding the Horizons of Saccharomyces cerevisiae: Nutrition, Oenology, and Bioethanol Production. *Sustainability*, *16*(24), 11151.