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