Pertanika J. Trop. Agric. Sci. 49 (4): 1995 - 2010 (2026)

TROPICAL AGRICULTURAL SCIENCE

Journal homepage: http://www.pertanika.upm.edu.my/

Development and Evaluation of Fermented Sago-Based Poultry Feed Using Solid-State Fermentation with *Aspergillus niger*

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ABSTRACT

Sago pith is a locally available, energy-rich feed; however, its protein content is low, and thus it cannot be used in broiler feeds. This study aimed to assess the use of solid-state fermentation (SSF) using *Aspergillus niger* as an approach to enhance sago for poultry feed. Sago was fermented using *A. niger,* and diets of 10%, 20%, and 30% fermented sago and a commercial control were tested in a 42-day trial in comparison to a lower protein negative control. One hundred Cobb 500 chicks were randomly assigned to the five treatments, and growth, along with feed conversion and carcass characteristics, were recorded after 42 days. The crude protein increased to 12.4% while the crude fibre decreased to 5.2% after fermentation. There was no statistically significant difference was detected between the 20% diet and the commercial control in final body weight (2.42 kg and 2.50 kg, respectively), or in FCR (1.93 and 1.97, respectively). The 10% and 20% groups were about 73-74% dressed, whereas the lower-protein control was 72.3%. The nutrient balance was limiting at 30% inclusion due to nutrient limitation. Nutrient quality of sago was enhanced by the *A. niger* fermentation, and broiler performance was not significantly affected by the inclusion of fermented sago up to 20%. Economic benefits depend on the prices of ingredients and the production, sterilisation, drying, labour and quality control costs of inoculum.

Keywords: Aspergillus niger, alternative feedstuffs, broiler chickens, carcass yield, growth performance, sago pith, solid-state fermentation

ARTICLE INFO

Article history:
Received: 20 August 2025
Accepted: 07 August 2026
Published: 21 August 2026

DOI: https://doi.org/10.47836/pjtas.49.4.20

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e-ISSN: 2231-8542

INTRODUCTION

High feed prices and reliance on imported feedstuffs such as maize and soybean meal are ongoing challenges for poultry production in tropical regions. The use of locally available alternative feed resources may help reduce dependence on conventional ingredients and improve the sustainability of poultry production (Babatunde et al., 2021). The sago palm (*Metroxylon sago*) is widely grown in Southeast Asia, with its starchy pith, known as sago, being a potential local energy source for animal feeds. Sago is a very rich source of carbohydrates, but is very unbalanced in terms of nutritional composition. Ground sago pith has low crude-protein content and relatively high fibre, which limits its nutritional value as a poultry-feed ingredient (Ab Jalil et al., 2015). These nutritional limitations indicate that appropriate processing or supplementation is required before sago can be effectively incorporated into nutritionally balanced poultry diets.

One possible way to improve the nutritive value of low-quality feedstuffs like sago starch is the use of filamentous fungus in solid-state fermentation (SSF). SSF consists of growing microorganisms in moist solid media, which leads to growth and changes in the substrate due to enzyme activity. Previous studies have demonstrated the potential of fermentation to improve sago-derived feed materials. Ab Jalil et al. (2015) reported an increase in crude protein and a reduction in crude fibre following SSF of ground sago pith with *Rhizopus oligosporus*. Similarly, Lani et al. (2021) reported that mixed-culture fermentation of sago waste increased crude protein by approximately 1.3 percentage points and reduced crude fibre, with the fermented product subsequently used as a partial feed ingredient for red hybrid tilapia. These findings suggest that microbial fermentation can improve the nutritional characteristics of sago-based substrates.

Filamentous fungi such as *Aspergillus niger* are particularly suitable for SSF because they produce extracellular enzymes capable of degrading complex components of plant materials. During SSF, *A. niger* can produce enzymes including cellulases, xylanases, proteases and phytases, which may contribute to changes in substrate composition and nutrient availability (Shi et al., 2015). Fermentation may also generate organic acids and other metabolites that alter substrate pH. More broadly, studies of fermented poultry feeds have reported reductions in antinutritional factors and changes in gut microbial communities, with potential benefits for growth and health (Predescu et al., 2024; Zhu et al., 2023). These properties indicate that fermentation has potential to improve sago pith beyond its value as a carbohydrate source.

The present study aimed to develop a fermented sago-based poultry feed using *Aspergillus niger* for solid-state fermentation and to evaluate the performance of broilers and carcass characteristics when fed with this fermented poultry feed. We hypothesised that the fermentation of sago pith using *A. niger* would greatly improve the crude protein and nutritional value of the sago pith and that it could be incorporated into the diets at a moderate level (10-20%) without negative effects on growth performance and meat production. The feeding study was designed to evaluate the effect of fermented sago at different inclusion levels (0%, 10%, 20%, 30%) on broiler development, feed efficiency and carcass characteristics in comparison with a control (regular commercial diet) and a negative control (0% inclusion diet). This study combines the enrichment of a starch-based substrate with *A. niger* with the addition of graded amounts of fermented sago to broiler diets and the measurement of growth efficiency and carcass yield. This integrated design recognises a practical inclusion level and meets the requirement for locally available feed ingredients in the sago-producing areas.

MATERIALS AND METHODS

Sago Substrate and Inoculum Preparation

Sago pith was collected from the East Campus plantation of Universiti Malaysia Sarawak (UNIMAS), dried and milled. Distilled water was added progressively to achieve 50% moisture (w/w), after which the substrate was divided into 5-kg batches and sterilised at 121 °C for 20 min. *Aspergillus niger* PAN 1, supplied by the Molecular Genetic Laboratory, UNIMAS, was cultured on potato dextrose agar at 30 °C for 5-7 days. Conidia were harvested in sterile distilled water containing 0.1% Tween 80 and counted using a haemocytometer. Each 5-kg batch received 250 mL of spore suspension at 2×10^8 spores/mL.

Solid-State Fermentation

The inoculated substrate was spread in layers approximately 2-3 cm thick and incubated aerobically at 30 °C for five days. The material was mixed and aerated daily, while temperature and visible contamination were monitored. Fermentation was terminated by oven-drying at 60°C for 24-36 h. The dried product was milled and stored in sealed containers until analysis and feed preparation.

Experimental Diets and Feed Preparation

Five dietary treatments were evaluated: a commercial positive control (PC), a negative control (NC) without fermented sago, and diets containing 10%, 20% or 30% fermented sago (FS). The PC provided approximately 21% crude protein (CP) and 3100 kcal/kg metabolizable energy (ME), consistent with recommended broiler nutrient levels (National Research Council [NRC], 1994). The NC contained approximately 18% CP and 3000 kcal/kg ME and served as the lower-protein reference diet.

In the formulated diets, fermented sago progressively replaced yellow maize, while the fish meal/protein source, rice bran, vitamin-mineral premix and vegetable or palm oil were maintained at constant proportions. Previous studies have shown that solid-state fermentation can improve the nutritive value of sago pith for poultry feed and that fermented alternative feed ingredients can partially replace maize in broiler diets (Ab Jalil et al., 2015; Aladi et al., 2021). The diets were formulated using least-cost principles and standard amino-acid balancing practices (Moran et al., 1992).

All ingredients were mixed thoroughly and processed into a uniform physical form. Figure 1 shows the pelletizer used during feed preparation. The use of locally available alternative ingredients was also considered relevant to reducing reliance on conventional feed ingredients (Babatunde et al., 2021).

Figure 1. Pelletizer machine producing uniform feed pellets

Chemical and Nutritional Analyses

Representative samples of unfermented sago, fermented sago and each experimental diet were analysed in triplicate. Dry matter, crude protein, crude fibre, ether extract and ash were determined according to Latimer (2019). Crude protein, crude fibre, ether extract and ash followed AOAC methods 990.03, 978.10, 920.39 and 942.05, respectively. Ash was determined by incineration at 550°C for 4 h. Nitrogen-free extract (NFE) was calculated using Equation 1.

$$\text{NFE (\% DM)} = 100 - [\text{crude protein} + \text{crude fibre} + \text{ether extract} + \text{ash}] \quad [1]$$

For pH determination, 10 g of sample was suspended in 50 mL of distilled water and measured using a calibrated digital pH meter. ME was estimated from ingredient composition using poultry nutrient values reported by National Research Council (NRC) (1994). The analysed nutrient composition of the experimental diets is presented in Table 1.

Table 1
Proximate composition of experimental broiler diets (mean ± SD)

Diet Treatment	Crude Protein (%)	Crude Fibre (%)	Ether Extract (%)	Ash (%)	Moisture (%)	Calculated ME (kcal/kg)
Positive Control (Commercial)	21.0 ± 0.1	5.0 ± 0.1	8.0 ± 0.2	8.0 ± 0.1	13.0 ± 0.1	~3100
Negative Control (0% Sago)	18.2 ± 0.2	4.3 ± 0.1	6.0 ± 0.1	6.0 ± 0.1	11.3 ± 0.2	~3000
10% Fermented Sago Diet	19.0 ± 0.3	3.9 ± 0.2	6.2 ± 0.1	6.2 ± 0.2	10.5 ± 0.3	~3010
20% Fermented Sago Diet	19.4 ± 0.2	4.4 ± 0.2	6.3 ± 0.1	6.4 ± 0.1	10.6 ± 0.1	~3020
30% Fermented Sago Diet	19.4 ± 0.1	4.7 ± 0.1	6.4 ± 0.2	6.4 ± 0.1	10.6 ± 0.2	~3030

Note. FS = fermented sago; ME values were estimated from ingredient composition

Birds, Ethics and Experimental Design

One-hundred-day-old, unsexed Cobb 500 broiler chicks with an average initial body weight of approximately 42 g were individually tagged and allocated by weight-balanced randomisation to five treatments, with 20 birds per treatment. Birds were housed individually in partitioned wire-floored cages providing approximately 0.5 m² per bird. The protocol was approved by the UNIMAS Animal Ethics Committee (approval no. UNIMAS/AEC/R/F07/079), and all husbandry and slaughter procedures followed the approved animal-welfare requirements. Representative images of the chickens on Days 1, 4, and 11 are shown in Figure 2.

Figure 2. a) Day 1 chicks, b) Day 4 chicks, c) Day 11 chicks

Bird Management and Growth-Performance Measurements

Brooding temperature was maintained at 32 °C for the first 14 days, followed by ambient tropical temperatures of 25-32 °C with fan-assisted ventilation. Lighting was provided for 23 h/day. Birds received a commercial starter diet containing approximately 22% CP during the first seven days. Experimental diets were introduced from day 8 and fully provided from day 10 to day 42. Feed and water were offered *ad libitum*. Vaccinations against Newcastle disease and infectious bursal disease were administered on days 5 and 10, respectively, and no antibiotics or growth promoters were used.

Figure 3. Digital weighing scale

Individual body weight and feed intake were recorded weekly using a digital scale. Health, feeding behaviour and mortality were monitored daily. Body-weight gain, average daily gain (ADG) and feed conversion ratio (FCR) were calculated using Equation 2 and Equation 3. The digital weighing scale used for body-weight measurement is shown in Figure 3.

Body-weight gain = final body weight - initial body weight

ADG (g/bird/day) = body-weight gain (g) / 42 days [2]

FCR = total feed intake (g) / total body-weight gain (g) [3]

For mortality-adjusted FCR, partial intake and body-weight data from birds that died were excluded from the final endpoint calculation (Ramli et al., 2024).

Carcass Evaluation

On day 42, eight birds per treatment were fasted for 6 h and humanely slaughtered by neck incision and exsanguination. Live weight at slaughter, carcass weight, breast weight, thigh weight, drumstick weight and abdominal fat were recorded using standard procedures (Ghazi et al., 2024). Dressing percentage was calculated using Equation 4.

$$\text{Dressing percentage (\%)} = [\text{carcass weight} / \text{live weight at slaughter}] \times 100 \quad [4]$$

Statistical Analysis

Data are presented as mean ± standard deviation. The individual bird was the experimental unit for growth-performance data, and the individual carcass was the experimental unit for carcass traits. Final performance and carcass data were analysed using one-way analysis of variance, with dietary treatment as a fixed effect. Type III sums of squares were applied when unequal sample sizes resulted from mortality. Weekly body weight and feed intake were evaluated using one-way analysis of variance. When treatment effects were significant, means were compared using Tukey's honestly significant difference test. Normality and homogeneity of variance were assessed before analysis. Percentage data were arcsine square-root transformed when required, although untransformed means are reported. Analyses were performed using SPSS version 25 at $p < 0.05$.

RESULTS

Nutrient Enhancement through Fermentation

After five days of solid-state fermentation with *Aspergillus niger*, the crude protein content of sago pith increased from 3.8% to 12.4% on a dry-matter basis. Crude fibre decreased from 6.0% to 5.2%, whereas ether extract increased slightly from 0.5% to 0.7%. Ash increased from 2.3% to 5.1%, nitrogen-free extract decreased from approximately 87.4% to 76.6%, and pH decreased from 6.6 to 5.2. The dry-matter content of the fermented product after drying was 90.5%. The proximate composition of sago pith before and after fermentation is summarised in Table 2.

Table 2
Proximate composition of sago pith before and after A. niger fermentation (dry matter basis)

Component	Unfermented Sago	Fermented Sago (5 days)
Dry Matter (% as fed)	85.0%	90.5% (after drying)
Crude Protein (% DM)	3.8%	12.4%
Crude Fibre (% DM)	6.0%	5.2%
Ether Extract (% DM)	0.5%	0.7%
Ash (% DM)	2.3%	5.1%
Nitrogen-Free Extract (% DM)	~87.4%	~76.6%
pH (20% (w/v) suspension)	6.6 (neutral)	5.2 (slightly acidic)

Note. Values for unfermented sago represent the raw dried sago pith substrate; fermented sago values are after 5 days SSF and drying

Diet Composition and Nutrient Intake

The analysed composition of the experimental diets is presented in Table 1 in the Materials and Methods section. The commercial positive-control diet contained 21.0% crude protein and approximately 3100 kcal/kg metabolizable energy, whereas the negative-control diet contained 18.2% crude protein and approximately 3000 kcal/kg. The diets containing 10%, 20% and 30% fermented sago contained 19.0%, 19.4% and 19.4% crude protein, respectively, with calculated metabolizable-energy values of approximately 3010-3030 kcal/kg. Across the fermented-sago diets, crude fibre ranged from 3.9% to 4.7%, ether extract from 6.2% to 6.4%, ash from 6.2% to 6.4%, and moisture from 10.5% to 10.6%.

Growth Performance

Initial body weights were similar among treatments, ranging from 0.0415 to 0.0423 kg. At day 42, the positive-control group had the highest final body weight (2.500 +/- 0.050 kg), followed by the 20% fermented-sago group (2.421 +/- 0.054 kg) and the 10% fermented-sago group (2.310 +/- 0.052 kg). The negative-control group had the lowest final body weight (1.902 +/- 0.035 kg; $p < 0.001$), while no significant difference was detected between the 20% fermented-sago and positive-control groups ($p > 0.1$). Body-weight gain followed the same pattern, and the 20% fermented-sago group did not differ significantly from the positive control ($p = 0.15$).

Total feed intake was highest in the positive-control group (4.85 kg) and lowest in the negative-control group (4.10 kg). The 20% fermented-sago group consumed more feed than the negative-control group ($p < 0.01$). Feed conversion ratio was lowest in the 20% fermented-sago group (1.93), followed by the 10% fermented-sago (1.96) and positive-control (1.97) groups. The 30% fermented-sago and negative-control groups recorded FCR values of 2.13 and 2.20, respectively. Significant FCR differences were detected between the negative control and the 10% and 20% fermented-sago groups ($p < 0.05$). Two deaths were recorded in the negative-control group, whereas no mortality occurred in the positive-control or fermented-sago groups. No clinical signs of mycotoxicosis were observed during the trial. The growth-performance results for all treatment groups are summarised in Table 3.

Carcass Traits and Meat Yield

The positive-control group had the highest carcass weight (1940 +/- 45 g), whereas the negative-control group had the lowest (1376 +/- 35 g). Carcass weights for the 10%, 20% and 30% fermented-sago groups were 1707 +/- 50 g, 1775 +/- 55 g and 1489 +/- 35 g, respectively. The 10% and 20% fermented-sago groups had higher carcass weights than the negative control ($p < 0.05$). Dressing percentage was highest in the positive-control group (77.6%), compared with 72.3% in the negative control and 73.9%, 73.3% and 73.3% in the 10%, 20% and 30% fermented-sago groups, respectively.

Table 3
Growth performance of broiler chickens fed fermented sago diets vs. control diets (Day 0-42)

Performance Metric	Positive Control (21% CP)	Negative Control (18% CP)	10% Fermented Sago	20% Fermented Sago	30% Fermented Sago
Initial Body Weight (kg)	0.0423 ± 0.0020	0.0421 ± 0.0015	0.0415 ± 0.0017	0.0418 ± 0.0018	0.0417 ± 0.0016
Final Body Weight (kg)	2.500 ± 0.050	1.902 ± 0.035	2.310 ± 0.052	2.421 ± 0.054	2.033 ± 0.030
Body Weight Gain (kg)	2.458 ± 0.050	1.860 ± 0.035	2.269 ± 0.052	2.379 ± 0.054	1.992 ± 0.030
Total Feed Intake (kg)	4.85 ± 0.10	4.10 ± 0.08	4.45 ± 0.09	4.60 ± 0.10	4.25 ± 0.07
Feed Conversion Ratio (FCR)	1.97 ± 0.04	2.20 ± 0.05	1.96 ± 0.05	1.93 ± 0.04	2.13 ± 0.05
Mortality (out of 20 birds)	0	2	0	0	0

Figure 4. Representative broiler carcass cuts collected on day 42, showing breast, thigh, drumstick, and wing portions used for carcass-yield evaluation

Representative broiler carcass cuts collected on day 42 are shown in Figure 4. Breast-muscle weights were 620, 496, 550, 530 and 500 g in the positive control, negative control, 10%, 20% and 30% fermented-sago groups, respectively. Total leg weights were 620, 514.5, 550, 540 and 524.5 g, respectively. Abdominal fat ranged from 1.5% to 1.8% of carcass weight and did not differ among treatments. The carcass characteristics of broilers across all dietary treatments are summarised in Table 4.

Table 4
Carcass characteristics of broilers fed fermented sago diets vs. controls (n = 8 per treatment)

Parameter	Positive Control	Negative Control	10% FS Diet	20% FS Diet	30% FS Diet
Live Weight at Slaughter (g)	2500 ± 50	1902 ± 40	2310 ± 52	2421 ± 54	2033 ± 30
Carcass Weight (g)	1940 ± 45	1376 ± 35	1707 ± 50	1775 ± 55	1489 ± 35
Dressing Percentage (%)	77.6 ± 0.5	72.3 ± 0.6	73.9 ± 0.7	73.3 ± 0.5	73.3 ± 0.7
Breast Muscle Weight (g)	620 ± 10	496 ± 8	550 ± 10	530 ± 9	500 ± 10
Thighs (both) Weight (g)	330 ± 5	274.5 ± 5	290 ± 5	290 ± 5	279.5 ± 5
Drumsticks (both) Weight (g)	290 ± 5	240 ± 5	260 ± 5	250 ± 5	245 ± 5
Total Leg (Thigh+Drum) Weight (g)	620	514.5	550	540	524.5
Abdominal Fat (% of carcass)	1.8 ± 0.2	1.5 ± 0.2	1.6 ± 0.2	1.7 ± 0.2	1.6 ± 0.2

DISCUSSION

Nutritional Changes Following Fermentation

Solid-state fermentation substantially improved the protein value of sago pith. The increase from 3.8% to 12.4% crude protein represented an increase of 8.6 percentage points, or approximately 3.3 times the original concentration. This improvement is consistent with reports that solid-state fermentation with *Aspergillus niger* can increase crude protein and improve the nutritional quality of plant-based feed substrates (Shi et al., 2015). The increase observed in the present study was also greater than the 1.3% increase in crude protein reported by Lani et al. (2021) following mixed-culture fermentation of sago waste, which may reflect differences in fungal strain, inoculum density, substrate preparation and fermentation conditions. During solid-state fermentation, *A. niger* can produce enzymes such as endoglucanase, xylanase, acid protease and phytase that contribute to the modification of the fermented substrate (Shi et al., 2015).

The reduction in crude fibre is consistent with enzymatic degradation of structural carbohydrates during fermentation. *Aspergillus* species produce a broad range of enzymes capable of degrading plant cell-wall polysaccharides, including cellulolytic and xylanolytic enzymes (de Vries & Visser, 2001). Enzymatic hydrolysis of lignocellulosic components in sago pith residue has also been demonstrated using cellulolytic enzymes (Linggang et al., 2012). In addition, phytase produced by *A. niger* can improve the availability of phytate phosphorus and associated minerals (Gujar et al., 2013). The reduction in pH from 6.6 to 5.2 may reflect the production of organic acids, including citric acid, during *A. niger* fermentation (Lu et al., 1997). Although a lower pH may assist product preservation and could influence gastrointestinal conditions, storage stability and gut-health effects were not measured in this study.

Growth Performance and Nutrient Adequacy

Broilers receiving 10% and 20% fermented sago performed better than birds fed the lower-protein negative-control diet. The 20% fermented-sago diet produced final body weight, body-weight gain and FCR values for which no significant difference was detected relative to the commercial positive control. This finding should be interpreted as comparable performance under the tested conditions rather than proof of nutritional equivalence. The response may have been supported by the increased microbial protein content and enzymatic modification of the fermented substrate, which can improve nutrient availability in fermented feeds (Hombegowda et al., 2021).

Performance declined at 30% inclusion despite a calculated energy value similar to those of the lower-inclusion diets. Higher inclusion may have altered dietary bulk, palatability, nutrient density or amino-acid balance, although these factors were not measured directly. Ralahalu et al. (2021) similarly reported lower body-weight gain in native chickens receiving diets containing 5-15% fermented sago waste than in birds receiving the control ration, indicating that performance may depend on inclusion level and overall ration formulation. Lani et al. (2021) also demonstrated that fermented sago waste could be used as a partial feed ingredient in tilapia diets, with inclusion of up to 150 g/kg producing growth performance that did not differ significantly from the control.

The commercial starter diet supplied during the first seven days contained approximately 22% crude protein. Thereafter, the 10% and 20% fermented-sago diets contained 19.0-19.4% crude protein and approximately 3010-3020 kcal/kg metabolizable energy. These values were broadly comparable with phase-specific nutritional recommendations for Cobb 500 broilers. For example, Cobb-Vantress (2022) recommends approximately 21-22% crude protein for the starter phase, 19-20% for Grower 1 and 18-19% for Grower 2, with corresponding metabolizable-energy recommendations of approximately 2900, 2950 and 3020 kcal/kg, respectively. The poorer performance of the 30% group therefore suggests that total crude protein and calculated energy alone may not fully describe the nutritional limitations associated with a high fermented-sago inclusion level.

Carcass Responses

Carcass responses followed the pattern observed for growth performance. Birds receiving 10% and 20% fermented sago had greater carcass and muscle weights than the negative-control birds, while the 30% group showed a weaker response. The higher breast and leg weights at moderate inclusion levels may be associated with improved availability of dietary protein and amino acids following fermentation (Hombegowda et al., 2021). However, amino-acid digestibility and muscle-protein deposition were not measured directly. Differences from the commercial control may also reflect the lower crude-protein concentration and possible amino-acid limitations in the fermented-sago diets. Differences from the commercial control may also reflect the lower crude-protein concentration and possible amino-acid limitations of the fermented-sago diets. Reduced-protein broiler diets generally require careful amino-acid balancing to maintain performance and carcass development (Aftab et al., 2006).

Abdominal fat remained below 2% of carcass weight and did not differ among treatments. This indicates that the observed differences in body and carcass weight were not accompanied by detectable changes in abdominal-fat deposition. Improved nutrient use following microbial fermentation has been proposed as one mechanism supporting lean-tissue growth in animals fed fermented ingredients, although this mechanism requires direct confirmation in broilers fed fermented sago.

Economic and Practical Implications

The 20% fermented-sago diet reduced the proportion of conventional maize while maintaining performance that did not differ significantly from the commercial control. This result suggests potential for reducing dependence on imported feed ingredients in sago-producing regions. Malaysia's corn imports for 2025/2026 are forecast at approximately 3.8 million metric tonnes (Mohd Sait, 2025), while feed commonly accounts for approximately 60-70% of poultry-production costs (Wongnaa et al., 2023). Greater utilisation of locally available sago may therefore contribute to feed-supply resilience while supporting local livelihoods and rural development in sago-producing regions (Konuma, 2018).

Because contemporary ingredient and processing prices were not available, economic performance was evaluated using a break-even relationship based on feed conversion ratio. Feed cost per kilogram of gain is equal to diet cost per kilogram multiplied by FCR. Accordingly, the break-even relative diet price was calculated as the FCR of the commercial control divided by the FCR of each fermented-sago diet. This partial analysis does not include fermentation, drying, labour, transport, quality-assurance or capital costs and should not be interpreted as proof of commercial savings. Actual least-cost feed formulation should consider current ingredient prices while meeting specified nutrient requirements (Pesti & Choct, 2023). The performance-adjusted break-even diet prices relative to the commercial positive control are summarised in Table 5.

Table 5
Performance-adjusted break-even diet price relative to the commercial positive control

Diet	FCR	Break-even price (% of PC price)	Interpretation
Positive control	1.97	100.0	Reference
10% fermented sago	1.96	100.5	Cost-neutral if diet price is no more than 0.5% above PC
20% fermented sago	1.93	102.1	Cost-neutral if diet price is no more than 2.1% above PC
30% fermented sago	2.13	92.5	Cost-neutral only if diet price is at least 7.5% below PC

Note. Break-even price (%) = FCR of positive control / FCR of treatment x 100. PC, positive control; FCR, feed conversion ratio

Limitations and Future Research

The findings were obtained under a single set of fermentation and feeding conditions. The study did not directly measure amino-acid composition, nutrient digestibility, enzyme activity, antinutritional factors, mycotoxin concentrations, gut histology, microbiota, meat sensory properties or consumer acceptance. The absence of clinical signs of mycotoxicosis is encouraging but does not replace chemical safety testing. Future work should validate the 20% inclusion level using larger replicated trials, current ingredient and processing costs, digestibility measurements and detailed meat-quality and safety assessments. Mixed-culture fermentation with yeast or other beneficial microorganisms may also be investigated to determine whether further nutritional improvement is achievable.

CONCLUSION

Solid-state fermentation using *Aspergillus niger* successfully enhanced the nutritional value of sago pith, demonstrating its potential as an alternative feed ingredient for broiler production. This study highlights the value of utilising locally available resources to reduce dependence on imported feed ingredients while supporting improved feed security and more sustainable poultry production systems. Further research should focus on evaluating the effects of fermented sago on sensory properties such as taste and texture, as well as investigating intestinal histology and gut microbiota characterisation to better understand its influence on broiler health and overall production performance.

ACKNOWLEDGEMENT

The authors thank Universiti Malaysia Sarawak (UNIMAS) and the Animal Biotech Laboratory for facilitating the resources for this research. The authors also extend appreciation to personnel who supported the feeding trial and laboratory analyses. This research was supported by the UNIMAS Tun Haji Openg Grant (grant no. UNI/F07/TOC/85601/2023).

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