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Valorization of Fishmeal Processing Sludge and Cassava Pulp as Sustainable Feed Ingredients for Broiler Production

Badat Muwakhid[1]*, Djoko Subagyo[2]
[1]Faculty of Animal Husbandry, Universitas Islam Malang, East Java, Indonesia
[2]Animal Science Study Program, Faculty of Agriculture, Universitas Jabal Ghafur, Pidie, Aceh, Indonesia.
*Corresponding Author's: badatmuwakhid@unisma.ac.id

Abstract— *Feed cost accounts for the largest proportion of broiler production expenses, creating a need for sustainable alternative feed resources derived from agro-industrial by-products. This study evaluated the effects of partially replacing commercial feed with a mixture of fishmeal sludge and cassava pulp (STIO) on growth performance, carcass characteristics, nutrient digestibility, and economic efficiency of broiler chickens. A total of 168 broiler chickens were randomly allocated to seven dietary treatments in a completely randomized design consisting of seven treatments, four replicates, and six birds per replicate. The dietary treatments comprised 0%, 5%, 10%, 15%, 20%, 25%, and 30% substitution of commercial feed with STIO. Parameters evaluated included feed intake, body weight gain, feed conversion ratio, carcass yield, abdominal fat percentage, organic matter digestibility, apparent nitrogen digestibility, and economic efficiency. Data were analyzed using analysis of variance (ANOVA). Dietary substitution with STIO significantly affected ($P < 0.05$) all measured variables. The 10% STIO inclusion level produced the best biological performance, as indicated by the highest body weight gain, carcass yield, organic matter digestibility, and apparent nitrogen digestibility, together with the lowest feed conversion ratio and abdominal fat percentage. Meanwhile, the 15% substitution level generated the highest economic efficiency. Furthermore, dietary inclusion of STIO up to 30% maintained acceptable productive performance, demonstrating that fishmeal sludge and cassava pulp can be utilized as sustainable alternative feed ingredients. These findings highlight the potential of agro-industrial by-products to improve feed efficiency, reduce feeding costs, and support environmentally sustainable broiler production*.

Keywords— *Agro-industrial by-products; broiler chicken; cassava pulp; feed efficiency; fishmeal sludge; nutrient digestibility*.

I. INTRODUCTION

The poultry industry has experienced rapid growth over the past decades in response to the increasing demand for high-quality animal protein. This expansion requires continuous improvements in productivity, which are highly dependent on the availability of nutritionally balanced and economically affordable feed ingredients. Feed remains the largest component of broiler production costs, accounting for approximately 60–70% of total production expenses (Surisdiarto and Koentjoko, 1990). This challenge is still relevant today because fluctuations in feed ingredient prices continue to affect poultry profitability worldwide. Consequently, the exploration of sustainable alternative feed resources has become an important strategy to improve production efficiency while reducing dependence on conventional feed ingredients. Recent reviews have emphasized that the utilization of agro-industrial by-products not only lowers feed costs but also supports circular bioeconomy practices through waste valorization and improved resource-use efficiency (Simmons et al., 2023).

According to Rasyaf (1992), alternative feed ingredients should be inexpensive, readily available, nutritionally adequate, safe for animal consumption, and should not compete directly with human food resources. This concept remains highly applicable in modern poultry nutrition, where agricultural and food-processing residues are increasingly recognized as valuable feed resources. Simmons et al. (2023) further reported that properly processed agro-industrial by-products can successfully replace a proportion of conventional feed ingredients without compromising broiler growth performance, provided that dietary nutrient balance is maintained.

Fishmeal sludge (STI) is one of the by-products generated during the fishmeal manufacturing process. It originates from the liquid fraction released during the mechanical pressing process and contains suspended solids, soluble proteins, lipids, minerals, and water (Hermanto and Chong, 1988; Moeljanto, 1992). Although fishmeal sludge possesses considerable nutritional value due to its relatively high protein content, it is still underutilized and is frequently discarded as industrial waste. Recent studies have demonstrated that fish-processing by-products represent promising alternative protein sources because they contain highly digestible protein, essential amino acids, and bioavailable minerals capable of supporting broiler growth and nutrient utilization while simultaneously reducing environmental impacts associated with waste disposal (dos Reis et al., 2025).

Cassava pulp (onggok), a by-product of tapioca processing, contains relatively low crude protein but abundant digestible carbohydrates, making it a promising alternative energy source for poultry diets (Rasyaf, 1996). Ogbuewu and Mbajiorgu (2023) reported that cassava-derived feed ingredients can partially replace conventional energy sources in broiler diets without negatively affecting productive performance when dietary formulations are nutritionally balanced. Furthermore, their meta-analysis demonstrated that cassava-based ingredients have considerable potential to reduce feed costs

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while maintaining acceptable growth performance, particularly when supplemented with high-quality protein sources.

The nutritional characteristics of fishmeal sludge and cassava pulp are complementary. Fishmeal sludge supplies high-quality protein and essential amino acids, whereas cassava pulp primarily contributes digestible carbohydrates as an energy source. According to the Food and Agriculture Organization (FAO, 2023), cassava-based feed ingredients require supplementation with high-quality protein sources to optimize nutrient utilization and animal performance. Therefore, combining fishmeal sludge with cassava pulp represents a promising strategy to produce a nutritionally balanced feed ingredient while simultaneously supporting sustainable waste valorization and reducing dependence on commercial feed ingredients.

Despite the growing interest in utilizing agro-industrial by-products as poultry feed, most previous studies have evaluated fish-processing by-products and cassava-derived ingredients separately. Comprehensive studies investigating the combined effects of fishmeal sludge and cassava pulp on growth performance, carcass characteristics, nutrient digestibility, and economic efficiency remain limited. Therefore, this study aimed to evaluate the effects of partially replacing commercial broiler diets with a mixture of fishmeal sludge and cassava pulp on feed intake, body weight gain, feed conversion ratio, carcass percentage, abdominal fat percentage, organic matter digestibility, nitrogen digestibility, and economic efficiency. The findings are expected to provide scientific evidence supporting the utilization of agro-industrial by-products as sustainable alternative feed ingredients for environmentally responsible and economically efficient broiler production.

II. Materials and Methods

Experimental Materials

The experiment utilized fishmeal sludge obtained from a fishmeal processing industry located in Muncar, Banyuwangi, East Java, Indonesia. Cassava pulp (onggok) in flour form was used as the carbohydrate source, while a commercial broiler diet (Japfa Comfeed, Indonesia) served as the basal diet. A total of 168 broiler chickens were used as experimental animals and reared in battery cages equipped with individual feeders, drinkers, and standard management facilities. Fishmeal sludge was selected as a potential alternative protein source because it is a by-product of the fish-processing industry containing valuable nutrients, whereas cassava pulp is an abundant agro-industrial by-product that provides digestible carbohydrates suitable as an alternative energy source (Hermanto and Chong, 1988; Ogbuewu and Mbajiorgu, 2023).

Experimental Design and Dietary Treatments

The experiment was conducted using a Completely Randomized Design (CRD) consisting of seven dietary treatments with three replicates, each replicate containing six broiler chickens. Commercial feed (Japfa Comfeed) was partially replaced with a mixture of fishmeal sludge and cassava pulp (STIO) at different inclusion levels as follows:

R0 = 100% commercial feed
R1 = 95% commercial feed + 5% STIO
R2 = 90% commercial feed + 10% STIO
R3 = 85% commercial feed + 15% STIO
R4 = 80% commercial feed + 20% STIO
R5 = 75% commercial feed + 25% STIO
R6 = 70% commercial feed + 30% STIO

The STIO mixture was formulated to provide a protein content comparable to that of the commercial diet. Feed and drinking water were supplied ad libitum, with feed offered twice daily in the morning and afternoon throughout the experimental period.

Growth Performance and Digestibility Measurements

The feeding trial was conducted for 42 days. Parameters evaluated included feed intake (g/bird), body weight gain (g/bird), feed conversion ratio (FCR), carcass percentage (%), abdominal fat percentage (%), organic matter digestibility (%), apparent nitrogen digestibility (%), and economic feed efficiency (Indonesian Rupiah/bird). Feed intake and body weight gain were recorded throughout the experiment and subsequently used to calculate feed conversion ratio. Carcass and abdominal fat percentages were determined at the end of the feeding period, whereas digestibility variables were evaluated using measurements of organic matter and apparent nitrogen digestibility. Economic feed efficiency was calculated based on the relationship between feed cost and production output, reflecting the economic value of each dietary treatment (North, 1987; Leeson and Summers, 2009).

Statistical Analysis

Data obtained from all experimental variables were subjected to analysis of variance (ANOVA) according to the Completely Randomized Design. Differences among treatment means were considered statistically significant at $P < 0.05$.

III. Results and Discussion

The effects of partially replacing commercial feed with a mixture of fishmeal sludge and cassava pulp (STIO) on the productive performance of broiler chickens are presented in Table 1. Dietary substitution with STIO significantly affected ($P < 0.05$) feed intake, body weight gain, feed conversion ratio (FCR), carcass percentage, abdominal fat percentage, organic matter digestibility, apparent nitrogen digestibility, and economic efficiency. Overall, moderate inclusion levels of STIO improved productive performance compared with the control diet, whereas higher substitution levels tended to reduce several performance indicators. Among the dietary treatments, the 10% STIO substitution (R2) consistently produced the most favorable biological responses, including the highest body weight gain, the lowest feed conversion ratio, the highest carcass yield, and the greatest nutrient digestibility. In contrast, the highest economic efficiency was achieved at the 15% substitution level (R3), indicating that a moderate increase in STIO inclusion could reduce feeding costs while maintaining satisfactory production performance. These findings demonstrate that the combined use of fishmeal sludge and cassava pulp has considerable potential as an alternative feed ingredient capable of improving both biological performance

and economic efficiency in broiler production while supporting the sustainable utilization of agro-industrial by-products.

Feed Intake

The analysis of variance showed that partial substitution of commercial feed with a mixture of fishmeal sludge and cassava pulp (STIO) significantly affected ($P < 0.05$) feed intake in broiler chickens (Table 1). The highest feed intake was observed in birds receiving the 10% STIO diet (R2), whereas feed consumption gradually declined as the substitution level increased to 20–30%. These results indicate that moderate inclusion of STIO maintained diet palatability and nutrient balance, while excessive substitution tended to reduce voluntary feed intake.

TABLE 1. Effects of dietary substitution with fishmeal sludge and cassava pulp (STIO) on feed intake, body weight gain, feed conversion ratio, carcass yield, abdominal fat percentage, organic matter digestibility, apparent nitrogen digestibility, and economic efficiency of broiler chickens.

Parameter	Perlakuan						
	R0	R1	R2	R3	R4	R5	R6
Feed intake (g/bird)	3458.41^{c}	3489.24^{d}	3562.99^{e}	3412.64^{bc}	3391.88^{abc}	3349.58^{ab}	3330.95^{a}
Body weight gain (g/bird)	1877.49^{cde}	1831.11^{de}	1904.17^{de}	1818.82^{bcd}	1793.54^{bc}	1724.98^{ab}	1712.83^{a}
Feed conversion ratio	1.95^{c}	1.92^{bc}	1.79^{a}	1.84^{ab}	1.88^{bc}	1.94^{c}	1.94^{c}
Carcass yield (%)	70.16^{ab}	71.13^{bc}	72.07^{c}	70.83bc	69.96^{ab}	68.93^{a}	68.75^{a}
Abdominal fat (%)	2.35^{bc}	2.26^{b}	2.09^{a}	2.21^{b}	2.26^{bc}	2.32^{bc}	2.36^{c}
Organic matter digestibility (%)	82.83^{ab}	83.35^{bc}	84.45^{e}	84.02^{d}	83.60^{cd}	83.02^{abc}	82.71^{a}
Apparent nitrogen digestibility (%)	59.63^{b}	63.87^{c}	66.33^{e}	64.95^{d}	63.94^{c}	61.33^{b}	58.16^{a}
Economic efficiency (IDR/bird)	5693.01	6008.00	6915.83	7063.69	6833.79	6486.45	6782.97

Values within the same row bearing different superscripts differ significantly ($P < 0.05$).

The reduction in feed intake at higher STIO inclusion levels may be associated with changes in the physical characteristics and nutrient composition of the diet. Fishmeal sludge and cassava pulp are finely ground ingredients that may increase the bulk density and fiber fraction of the ration, thereby limiting feed consumption because of the restricted capacity of the gastrointestinal tract. In addition, increasing dietary energy concentration may reduce voluntary feed intake because broilers regulate feed consumption primarily to satisfy their metabolizable energy requirements, as previously described by Wahju (1992). Similar observations have been reported by Ogbuewu and Mbajiorgu (2023), who concluded that cassava-derived feed ingredients can partially replace conventional energy sources without impairing broiler performance when incorporated at appropriate inclusion levels and formulated to meet nutrient requirements.

The relatively high feed intake observed at the 10% substitution level suggests that the combination of fishmeal sludge and cassava pulp provided a favorable balance between dietary energy, protein, and palatability. Fishmeal sludge supplies highly digestible protein and essential amino acids, whereas cassava pulp contributes readily digestible carbohydrates that complement the dietary energy supply. Such nutritional complementarity likely enhanced feed utilization without reducing feed acceptance by the birds. dos Reis et al. (2025) also reported that fish-processing by-products represent promising alternative protein sources because of their high digestibility and balanced amino acid profile, enabling partial replacement of conventional protein ingredients in poultry diets.

From the perspective of sustainable poultry nutrition, the present findings demonstrate that fishmeal sludge and cassava pulp can be utilized as alternative feed ingredients without adversely affecting feed intake when included at moderate levels. The utilization of these agro-industrial by-products not only reduces dependence on conventional feed ingredients but also supports waste valorization and circular bioeconomy strategies, which are increasingly promoted in sustainable livestock production systems (Simmons et al., 2023).

Body Weight Gain

Analysis of variance demonstrated that partial replacement of commercial feed with a mixture of fishmeal sludge and cassava pulp (STIO) significantly affected ($P < 0.05$) body weight gain (BWG) of broiler chickens (Table 1). The highest BWG was obtained in broilers receiving the diet containing 10% STIO (R2), whereas further increases in the substitution level resulted in a gradual decline in growth performance. These findings indicate that moderate inclusion of STIO provided a more favorable nutritional balance to support optimal growth compared with either the control diet or higher substitution levels.

The improvement in BWG observed at the 10% substitution level may be attributed to the complementary nutritional characteristics of fishmeal sludge and cassava pulp. Fishmeal sludge serves as a source of highly digestible animal protein containing essential amino acids, whereas cassava pulp contributes readily digestible carbohydrates that provide energy for tissue growth. The balanced availability of protein and energy likely enhanced nutrient utilization, thereby promoting protein deposition and muscle development. In addition to amino acids, nutrients such as lipids, minerals, and vitamins supplied by the diet may have further supported metabolic processes associated with growth.

The present findings are consistent with the classical concept proposed by Wahju (1992), who stated that animal-derived protein generally possesses superior biological quality compared with plant protein because of its more balanced essential amino acid profile. Furthermore, animal protein provides greater concentrations of bioavailable calcium, phosphorus, and vitamin B12, all of which are important for supporting optimal growth and skeletal development in broiler chickens.

Recent studies have also demonstrated that fish-processing by-products are valuable alternative protein sources because they contain highly digestible protein and balanced amino acid

profiles capable of maintaining growth performance when incorporated into properly formulated poultry diets dos Reis et al. (2025). Likewise, Ogbuewu and Mbajiorgu (2023) reported that cassava-derived feed ingredients can successfully replace a proportion of conventional feed ingredients without compromising body weight gain, provided that dietary protein and essential amino acid requirements are adequately fulfilled. These findings support the present study, in which moderate STIO inclusion improved growth performance, whereas higher substitution levels tended to reduce BWG, possibly because the nutritional balance of the diet became less optimal.

From a practical perspective, the results indicate that incorporating 10% STIO into commercial broiler diets can improve growth performance while simultaneously utilizing locally available agro-industrial by-products. This strategy not only contributes to reducing feed costs but also supports more sustainable poultry production through the valorization of industrial residues, in line with the principles of circular bioeconomy (Simmons et al., 2023).

Feed Conversion Ratio

Analysis of variance revealed that dietary substitution of commercial feed with a mixture of fishmeal sludge and cassava pulp (STIO) significantly affected ($P < 0.05$) the feed conversion ratio (FCR) of broiler chickens (Table 1). The lowest FCR (1.79) was obtained in broilers receiving the diet containing 10% STIO (R2), indicating the highest feed utilization efficiency among all treatments. Conversely, increasing the substitution level beyond 15% resulted in a gradual increase in FCR, suggesting a reduction in feed utilization efficiency.

The improved FCR observed at the 10% substitution level may be attributed to the complementary nutritional characteristics of fishmeal sludge and cassava pulp. Fishmeal sludge provides highly digestible protein with a balanced profile of essential amino acids, whereas cassava pulp supplies readily digestible carbohydrates that serve as an energy source. The combination of these ingredients likely improved the dietary protein-to-energy balance, thereby enhancing nutrient utilization for growth rather than maintenance. Consequently, broilers were able to convert feed into body weight gain more efficiently.

The present findings are consistent with the classical concept proposed by North (1978), who stated that feed conversion ratio is closely associated with feed intake, body weight gain, health status, and the overall nutritional quality of the diet. Likewise, Wahju (1992) emphasized that balanced nutrient composition, particularly adequate dietary protein and energy, is essential for achieving efficient feed utilization in broiler chickens. Recent nutritional studies have further demonstrated that improving amino acid balance and protein digestibility is one of the most effective strategies for reducing FCR and enhancing broiler productivity (Aviagen, 2022). In addition, dos Reis et al. (2025) reported that fish-processing by-products can serve as highly digestible alternative protein sources capable of maintaining feed efficiency when incorporated into properly formulated poultry diets.

The gradual increase in FCR observed at substitution levels above 15% suggests that excessive replacement of commercial feed may have reduced dietary nutrient balance or digestibility, thereby decreasing the efficiency with which nutrients were converted into body tissue. Similar observations have been reported by Ogbuewu and Mbajiorgu (2023), who concluded that cassava-derived feed ingredients can effectively replace conventional feed ingredients only within appropriate inclusion levels that maintain adequate nutrient balance.

Overall, the present results indicate that incorporating 10% STIO into commercial broiler diets optimizes feed conversion efficiency while simultaneously reducing dependence on conventional feed ingredients. This finding supports the potential utilization of fishmeal sludge and cassava pulp as sustainable alternative feed resources for economically and environmentally responsible broiler production (Simmons et al., 2023).

Carcass Yield

Analysis of variance indicated that partial replacement of commercial feed with a mixture of fishmeal sludge and cassava pulp (STIO) significantly affected ($P < 0.05$) carcass yield of broiler chickens (Table 1). The highest carcass percentage (72.07%) was obtained in broilers receiving the diet containing 10% STIO (R2), whereas carcass yield gradually declined as the substitution level increased above 15%.

The improvement in carcass yield observed at the 10% substitution level may be associated with the complementary nutritional characteristics of fishmeal sludge and cassava pulp. Fishmeal sludge provides highly digestible animal protein with a balanced profile of essential amino acids, particularly lysine and methionine, which are recognized as the first limiting amino acids for muscle protein synthesis in broiler chickens. Meanwhile, cassava pulp supplies digestible carbohydrates that provide sufficient energy to support efficient protein deposition. The balanced availability of dietary protein and energy likely enhanced lean tissue accretion, resulting in a higher carcass percentage.

The present findings agree with the classical concept proposed, who stated that animal-derived protein possesses a more balanced essential amino acid composition than plant protein, thereby supporting more efficient protein synthesis and tissue development. Essential amino acids cannot be synthesized in sufficient quantities by poultry and therefore must be supplied through the diet to maximize growth performance and carcass development.

Recent nutritional studies have further demonstrated that balanced amino acid nutrition, particularly adequate lysine and methionine, plays a central role in improving carcass yield and breast muscle development in modern broiler strains (Aviagen, 2022). In addition, dos Reis et al. (2025) reported that fish-processing by-products represent highly digestible protein sources capable of partially replacing conventional protein ingredients without compromising carcass performance when dietary formulations are properly balanced. Therefore, the present findings suggest that moderate dietary inclusion of STIO provides sufficient nutrients to support efficient muscle

deposition while simultaneously promoting the utilization of agro-industrial by-products in sustainable poultry production.

Abdominal Fat Percentage

Dietary substitution with STIO significantly affected ($P < 0.05$) abdominal fat percentage in broiler chickens (Table 1). The lowest abdominal fat deposition (2.09%) was observed at the 10% substitution level (R2), whereas higher substitution levels resulted in a gradual increase in abdominal fat percentage.

The reduction in abdominal fat at moderate STIO inclusion may be associated with improved dietary protein quality and more efficient nutrient partitioning toward lean tissue growth rather than fat deposition. Fishmeal sludge provides high-quality animal protein containing essential amino acids that support protein synthesis, while cassava pulp supplies dietary energy required for growth. A balanced protein-to-energy ratio likely enhanced protein deposition and reduced the conversion of excess dietary energy into body fat.

Wahju (1992) reported that dietary nutrient balance, particularly protein and energy, strongly influences carcass composition and fat deposition in broiler chickens. Likewise, Parakkasi (1983) explained that excessive dietary fiber may reduce nutrient digestibility and consequently impair growth performance. In the present study, moderate inclusion of STIO appeared to maintain nutrient utilization efficiency, whereas higher substitution levels may have altered dietary composition sufficiently to reduce nutrient utilization and increase fat accumulation.

Recent studies have confirmed that improving dietary amino acid balance not only enhances growth performance but also reduces abdominal fat deposition by directing nutrients toward muscle protein accretion rather than lipid synthesis (Zhang et al., 2022). Adeola and Cowieson (2011) reported that improved nutrient digestibility contributes to more efficient utilization of dietary protein and energy, thereby minimizing unnecessary fat deposition in broiler chickens.

Overall, the present findings demonstrate that incorporation of STIO at a 10% substitution level improves carcass quality by increasing carcass yield while simultaneously reducing abdominal fat accumulation. These results highlight the potential of fishmeal sludge and cassava pulp as sustainable alternative feed ingredients capable of improving carcass characteristics and production efficiency in broiler chickens.

Apparent Nitrogen Digestibility

Analysis of variance showed that partial replacement of commercial feed with a mixture of fishmeal sludge and cassava pulp (STIO) significantly affected ($P < 0.05$) apparent nitrogen digestibility in broiler chickens (Table 1). The highest nitrogen digestibility (66.33%) was obtained in broilers receiving the diet containing 10% STIO (R2), whereas digestibility gradually declined as the substitution level increased beyond 15%.

The improvement in nitrogen digestibility observed at the 10% substitution level may be associated with differences in dietary protein quality among the experimental diets. Fishmeal sludge provides highly digestible animal protein with a balanced profile of essential amino acids, thereby improving protein utilization efficiency. In contrast, excessive substitution may reduce dietary nutrient balance, consequently decreasing the efficiency of protein digestion and amino acid absorption.

The present findings support the classical concept proposed by Koentjoko and Surisdiarto (1990), who reported that differences in protein quality result in differences in amino acid availability and digestibility. Protein utilization is influenced not only by amino acid composition but also by the physicochemical characteristics of protein and its interaction with other dietary components. Likewise, Tillman et al. (1991) explained that increasing dietary fiber levels may reduce nutrient digestibility by limiting nutrient accessibility during digestion.

Recent studies have confirmed that improving dietary amino acid balance and protein digestibility enhances nitrogen utilization and reduces nitrogen excretion in broiler chickens, thereby improving both production efficiency and environmental sustainability (Adeola & Cowieson, 2011). Similarly, dos Reis et al. (2025) reported that fish-processing by-products provide highly digestible protein capable of maintaining nitrogen utilization efficiency when included at appropriate dietary levels. Therefore, the superior nitrogen digestibility observed at the 10% STIO inclusion level indicates that this dietary formulation provided a more favorable balance of digestible protein and energy for broiler growth.

Organic Matter Digestibility

Dietary substitution with STIO significantly influenced ($P < 0.05$) organic matter digestibility in broiler chickens (Table 1). The highest organic matter digestibility (84.45%) was observed at the 10% substitution level (R2), whereas higher inclusion levels tended to decrease digestibility. Differences in organic matter digestibility among dietary treatments were likely associated with variations in nutrient composition and digestibility of the experimental diets. Fishmeal sludge supplied highly digestible protein, whereas cassava pulp contributed readily digestible carbohydrates (nitrogen-free extract, NFE), providing complementary nutrient sources that enhanced digestive efficiency. At moderate inclusion levels, this nutritional complementarity likely improved nutrient availability and absorption.

The present findings are consistent with Tillman et al. (1991), who reported that increasing dietary fiber content may reduce the digestibility of carbohydrates, proteins, lipids, and vitamins. Likewise, Koentjoko and Surisdiarto (1990) emphasized that differences in nutrient composition and protein quality directly influence nutrient digestibility. More recently, Adeola and Cowieson (2011) demonstrated that improving nutrient digestibility is one of the principal strategies for enhancing feed efficiency and nutrient utilization in modern poultry production. Therefore, the higher digestibility observed at the 10% STIO inclusion level suggests that moderate dietary substitution optimized nutrient availability without adversely affecting digestive processes.

Economic Efficiency

Economic efficiency was calculated based on the difference between income generated from broiler production and feed

costs incurred during the feeding trial. Dietary substitution with STIO improved the economic efficiency of broiler production, with the highest economic return recorded at the 15% substitution level (R3), reaching IDR 7,063.69 per bird. In contrast, the control diet (R0) produced the lowest economic return.

The superior economic performance observed at the 15% substitution level indicates that partial replacement of commercial feed with STIO effectively reduced feed costs while maintaining satisfactory production performance. Although the highest biological performance was achieved at the 10% substitution level, the slightly greater inclusion of STIO in R3 provided additional savings in feed cost that compensated for the minor reduction in productive performance. Consequently, R3 generated the highest overall economic return.

These findings are in agreement with Kartadisastra (1997), who stated that economic efficiency in poultry production is strongly influenced by the relationship between production output and feed expenditure. More recent studies have also demonstrated that replacing conventional feed ingredients with nutritionally balanced agro-industrial by-products can substantially improve farm profitability while simultaneously reducing environmental impacts associated with feed production (Simmons et al., 2023). Consequently, the present study indicates that incorporating STIO at moderate inclusion levels not only enhances biological performance but also improves the economic sustainability of broiler production through more efficient utilization of locally available agro-industrial by-products.

IV. CONCLUSION

The present study demonstrated that partial replacement of commercial broiler feed with a mixture of fishmeal sludge and cassava pulp (STIO) significantly influenced feed intake, body weight gain, feed conversion ratio, carcass yield, abdominal fat percentage, organic matter digestibility, apparent nitrogen digestibility, and economic efficiency. Dietary inclusion of STIO up to 30% maintained acceptable productive performance, indicating that these agro-industrial by-products have considerable potential as sustainable alternative feed ingredients for broiler production. Among the evaluated treatments, a 10% substitution level produced the most favorable biological performance, as reflected by superior body weight gain, feed conversion ratio, carcass yield, and nutrient digestibility, whereas the highest economic efficiency was achieved at the 15% substitution level. These findings suggest that moderate inclusion of fishmeal sludge and cassava pulp provides an optimal balance between production performance and feed cost, while simultaneously supporting the valorization of agro-industrial by-products and reducing dependence on conventional feed ingredients. Further studies are recommended to evaluate the long-term effects of STIO inclusion on meat quality, gut health, nutrient metabolism, and environmental sustainability under commercial production conditions.

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