2025, Scienceline Publication
World's Veterinary Journal
World Vet J, 15(3): 549-557.
ISSN 2322-4568

DOI: https://dx.doi.org/10.54203/scil.2025.wvj55
PII: S232245682500055-15

Effects of Food Waste Fermented with *Rhizopus oligosporus* on the Performance and Carcass Quality of Alabio Ducks

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ORIGINAL ARTICLE
Received: June 19, 2025
Revised: July 21, 2025
Accepted: August 24, 2025
Published: September 30, 2025

ABSTRACT

The incorporation of food waste as an alternative feed ingredient has attracted considerable academic attention, owing to its potential to decrease feed costs and promote sustainable practices within livestock production systems. The present study aimed to evaluate the effects of food waste from Pesantren (FWP), Indonesia, fermented with *Rhizopus oligosporus* (*R. oligosporus*) as feed on the performance and carcass quality of Alabio ducks. A completely randomized design with four replications was used in the present study. A total of 200 one-day-old male Alabio ducks, with an average initial body weight of 39 ± 2 grams, were raised for eight weeks and randomly divided into five dietary groups, consisting of 40 ducks per group and five ducks per replicate with different FWP inclusion levels. The treatments varied based on the inclusion levels of FWP fermented with *R. oligosporus* in the diets of Alabio ducks which included FWP 0% (Treatment A, the control group), FWP 10% (Treatment B), FWP 20% (Treatment C), FWP 30% (Treatment D), and FWP 40% (Treatment E). Different parameters were observed at 56 days of age, including feed consumption, final body weight, feed conversion ratio (FCR), protein intake, carcass percentage, and abdominal fat percentage. The current results indicated that FWP significantly affected feed consumption, final body weight, FCR, and protein intake. Treatment D resulted in the highest body weight, protein intake, and the best FCR. However, there were no significant differences among treatments in carcass and abdominal fat percentages. In conclusion, incorporating up to 30% of FWP fermented with *R. oligosporus*, based on dry matter, into the diet of male Alabio ducks does not negatively impact their performance or carcass quality. Using FWP fermented with *R. oligosporus* as part of the duck feed offered a sustainable and cost-effective method for organic waste management in Pesantren poultry systems.

Keywords: Alabio duck, Carcass quality, Fermented feed, Growth performance, *Rhizopus oligosporus*

INTRODUCTION

Duck farming in Indonesia has significant potential, particularly with local breeds such as the Alabio duck (*Anas platyrhynchos Borneo*), which is native to South Kalimantan, Indonesia (Suryana et al., 2011). Alabio ducks are recognized for their exceptional environmental adaptability, high egg production, and superior meat quality (Sulaiman and Irawan, 2020). A significant challenge in duck farming is the high feed cost, making up over 60% of total expenses. Consequently, new strategies are essential to lower feed costs while maintaining production performance (Aji et al., 2022; Febrina et al., 2022). One promising approach is using organic waste as feed, which can lower feed expenses and enhance sustainability in poultry farming, especially in Pesantren-based duck production systems (Febrina et al., 2024).

Among different types of organic waste, food waste from Pesantren (FWP) offers unique advantages. Meanwhile, the nutrient content of hotel and restaurant food waste has been extensively studied, including crude protein at 21.41%, crude fiber at 5.90%, and 3,484.23 kcal/kg of metabolizable energy (Febrina et al., 2024). The use of organic waste as animal feed often relies on a centralized collection system, which smallholder farmers may not easily access. Furthermore, the supply of organic waste can be unpredictable, and transporting and processing the waste pose significant logistical challenges. In contrast, Pesantren Islamic boarding schools, where students live together, generate substantial amounts of food waste on-site, including rice leftovers, fish and meat scraps, and residues from fruit and

To cite this paper: Rusfidra, Maulana F, Prima HS, Susalam MK, Agasi SY, and Fajri F (2025). Effects of Food Waste Fermented with *Rhizopus oligosporus* on the Performance and Carcass Quality of Alabio Ducks. *World Vet. J.*, 15(3): 549-557. DOI: https://dx.doi.org/10.54203/scil.2025.wvj55

vegetables. This easily accessible and reliable waste stream offers a practical alternative feed source for duck farmers, especially in rural or Pesantren-focused communities (Rusfidra et al., 2025).

The nutritional content of FWP consists of 17.85% crude protein, 10.83% crude fat, 10.86% crude fiber, 92.89% dry matter, and 6.24% ash (Hidayat et al., 2024). To enhance FWP value, fermentation biotechnology can be utilized (Muslim et al., 2018). One of the most effective microorganisms for this purpose is *Rhizopus oligosporus (R. oligosporus)*, a fungus widely used in tempeh production (Rusfidra et al., 2025).

Rhizopus oligosporus produces protease, lipase, and amylase enzymes, which respectively break down proteins into amino acids, fats into fatty acids and glycerol, and starches into simple sugars, thereby enhancing the digestibility and bioavailability of nutrients for ducks (Djulardi et al., 2023). Fermentation with *R. oligosporus* has been shown to increase protein availability, reduce crude fiber, and diminish anti-nutritional factors (Ndego et al., 2023).

Previous studies have investigated the potential of organic waste as an ingredient in poultry feed (Muslim et al., 2018; Widjastuti et al., 2020; Febrina et al., 2024). However, studies on Pesantren-specific food waste, especially when combined with other local agro-industrial residues such as tofu dregs, remain limited. The present study expands on prior studies by employing a locally relevant feed mixture composed of 90% FWP and 10% tofu dregs, fermented with *R. oligosporus* (Rusfidra et al., 2025).

Therefore, the present study aimed to assess the potential of FWP fermented with *R. oligosporus* as an alternative feed for improving growth performance and carcass quality in Alabio ducks.

MATERIALS AND METHODS

Ethical approval

The collection of FWP in the present study was conducted with the consent of Pesantren administrators in Indonesia, who were informed about the study's objectives, procedures, and potential benefits. The current study was conducted after obtaining ethical approval under the Minister of Agriculture Decree No. 306/KPTS/TN.330/4/1994, which was approved by the Animal Research Ethics Committee of Andalas University, Padang, Indonesia, as required for the use of experimental animals in research and teaching.

Feed safety

Regarding feed safety, food waste can pose potential risks due to the presence of biological contaminants such as pathogenic bacteria or molds (Zhang et al., 2022). The waste materials used in the present study consisted of approximately 150 kg of food waste collected from the kitchen of an Indonesian Pesantren over 10 days. The waste included leftover cooked rice, vegetable peels, fruit residues, fish bones, and meat scraps. Before fermentation, all materials were manually sorted to remove non-organic contaminants such as plastic or packaging, then homogenized, mixed with 10% tofu dregs by weight. The waste materials underwent fermentation utilizing *R. oligosporus*, after which a thermal treatment was applied at 80°C for one hour to inactivate any potential undesirable microorganisms. Following fermentation, the material was sun-dried for two days under direct sunlight, with periodic turning to promote uniform drying, until it achieved a moisture content of approximately 10-12%. The dried product was subsequently subjected to proximate analysis to assess its nutritional adequacy before incorporation into feed formulations. These methodologies were meticulously employed to mitigate health risks and ensure the safe use of the fermented product in duck diets (Rusfidra et al., 2025).

Experimental design

A total of 200 one-day-old male Alabio ducks (*Anas platyrhynchos Borneo*), with an average initial body weight of approximately 39 ± 2 grams, were raised. The experiment was conducted over eight weeks, employing a completely randomized design that incorporated five distinct dietary treatments, each replicated four times, resulting in a total of 20 experimental units. The treatments varied based on the inclusion levels of FWP fermented with *R. oligosporus* in the diets of Alabio ducks which included 0% FWP (Treatment A, the control group), 10% FWP (Treatment B), 20% FWP (Treatment C), 30% FWP (Treatment D), and 40% FWP (Treatment E; Rusfidra et al., 2025). Each experimental unit consisted of 10 male Alabio ducks, resulting in a total of 200 ducks. The experimental cages were colony-type, each measuring 130 × 130 × 100 cm, with a total of 20 units used in the present study. Each cage was fitted with feeders, drinkers, a digital scale, and cleaning tools. The ducks were kept under controlled environmental conditions, with ambient temperatures ranging from 28 to 32°C and relative humidity maintained between 60% and 75%. Natural sunlight was supplemented to ensure a consistent 16-hour light and 8-hour dark cycle. Feed and water were provided *ad libitum*, allowing continuous access throughout the experimental period.

Experimental diets

The inclusion levels of FWP were determined based on previous studies that evaluated the optimal amount of food waste in poultry diet (Rusfidra et al., 2025). All experimental diets were formulated to be iso-nitrogenous (Containing the same amount of crude protein) and iso-caloric (Containing the same amount of metabolizable energy) with an average crude protein content of 17% and a metabolizable energy content of approximately 2,800 kcal/kg, based on the proximate analysis of each feed ingredient (Table 1). All diet formulations aimed to ensure equal protein and energy levels for male Alabio ducks according to established nutritional guidelines, according to NRC (1994), while utilizing modified ingredients such as corn, soybean meal, and rice bran. The feed composition for each treatment used for male Alabio ducks in the present study is listed in Table 2, and the nutritional content of the feed treatments for male Alabio ducks is displayed in Table 3.

The feed formulation was carried out to ensure all treatments met the nutritional requirements of Alabio ducks, in accordance with the guidelines provided by the Indonesian national standard (SNI 01-3931-2006) and NRC (1994), thereby eliminating any observed performance differences that could be attributed to the inclusion level of FWP rather than a nutrient imbalance.

Parameters

Feed consumption (g/head), final body weight (g/head), feed conversion ratio (FCR), and protein intake (g/head), along with carcass percentage and abdominal fat percentage, were evaluated during the present study.

Table 1. Feed ingredients and their nutritional contents used in the diets of male Alabio ducks (*Anas platyrhynchos Borneo*)

Ingredients	Crude protein (%)	Crude fat (%)	Crude fiber (%)	Calcium (%)	Phosphorus (%)	Lysine (%)	Methionine (%)	Metabolizable energy (Kkal)[a]
Ground corn[b]	8.55	2.66	3.00	0.38	0.19	0.26	0.18	3300.00
Fish meal[b]	54.83	3.01	2.29	3.92	2.03	6.43	2.43	2600.00
Soybean meal[b]	45.35	2.49	2.75	0.63	0.36	0.60	0.60	2240.00
Fermented food waste from Pesantren[b]	19.48	15.06	7.68	3.84	2.67	1.38	0.56	3100.00
Rice bran [b]	9.50	5.09	14.00	0.69	0.26	0.67	0.27	1640.00
Fish oil[b]	0	100.00	0	0	0	0	0	8600.00
Coconut oil[b]	0	100.00	0	0	0	0	0	8600.00
Bone meal[b]	0	0	0	24.00	12.00	0	0	0
CaCO3[b]	0	0	0	40.00	0	0	0	0
Top mix[c]	0	0	0	0.06	0	0.003	0	0

a: Scott et al. (1982), b: Laboratory analysis results during the study, c: Packaging label from PT Medion Indonesia

Table 2. Feed composition for each treatment used for male Alabio ducks (*Anas platyrhynchos Borneo*) in the present study

Ingredients	Treatment A (%)	Treatment B (%)	Treatment C (%)	Treatment D (%)	Treatment E (%)
Ground corn	57.00	49.00	42.00	35.00	27.00
Fish meal	10.00	10.00	10.00	10.00	10.00
Soybean meal	12.00	10.00	7.00	4.00	2.00
Fermented food waste from Pesantren	0.00	10.00	20.00	30.00	40.00
Rice bran	15.00	15.00	15.00	15.00	15.00
Fish oil	1.00	1.00	1.00	1.00	1.00
Coconut oil	1.00	1.00	1.00	1.00	1.00
Bone meal	1.00	1.00	1.00	1.00	1.00
CaCO3	2.00	2.00	2.00	2.00	2.00
Top mix	1.00	1.00	1.00	1.00	1.00
Total	100.00	100.00	100.00	100.00	100.00

Table 3. Nutritional content of the feed treatments used for male Alabio ducks (*Anas platyrhynchos Borneo*) in the present study

Nutrients	Treatment A (%)	Treatment B (%)	Treatment C (%)	Treatment D (%)	Treatment E (%)
Crude protein	17.22	17.58	17.57	17.56	17.92
Crude fat	4.88	6.12	7.37	8.61	9.86
Crude fiber	4.37	4.84	5.32	5.79	6.27
Calcium	1.83	2.17	2.51	2.85	3.19
Phosphorus available	0.88	0.76	1.00	1.24	1.49
Metabolizable energy	2827.80	2829.00	2840.80	2852.60	2853.80
Lysine	0.96	1.07	1.17	1.27	1.38
Methionine	0.46	0.49	0.51	0.54	0.57

Note: Compiled based on Table 1 and Table 2.

Fermentation of Pesantren food waste with *Rhizopus oligosporus*

A total of 500 grams of FWP was prepared and mixed with 50 grams of tofu dregs, obtained freshly from a local tofu producer in Padang, Indonesia, as an additional carbon source. The mixture was placed into heat-resistant polypropylene plastic bags (Cahayapack, Indonesia) and sterilized with an autoclave at 121°C and 15 psi for 20 minutes. After sterilization, the substrate was cooled at room temperature for approximately 45 minutes until it reached ambient temperature. The cooled substrate was then inoculated with *R. oligosporus* at a concentration of 3% of the total substrate weight (equivalent to 16.5 grams). The inoculum was prepared by suspending *R. oligosporus* spores in sterile distilled water to achieve a concentration of 10^6 spores per gram of substrate. The inoculation process was conducted under sterile conditions in a laminar airflow chamber. Following inoculation, the spores were evenly mixed into the substrate to ensure uniform distribution. This method was adapted from the established fermentation protocol described by Muslim et al. (2018) and Rusfidra et al. (2025).

The fermentation process was conducted aerobically in an incubator set at 32°C for five days. After incubation, the fermented material was heated at 80°C for one hour to inactivate the enzymatic and microbial activity of *R. oligosporus*. The final product was then dried at 60°C until the moisture content dropped below 14%, as confirmed by oven-drying (Eyela, Tokyo Rikakikai Co., Ltd., Japan) of a representative sample at 105°C for 24 hours following the standard method of proximate analysis (AOAC, 2005; Figure 1). A proximate analysis of the fermented product was performed to determine its nutritional composition, which served as the basis for designing the experimental diets in the present study (Rusfidra et al., 2025).

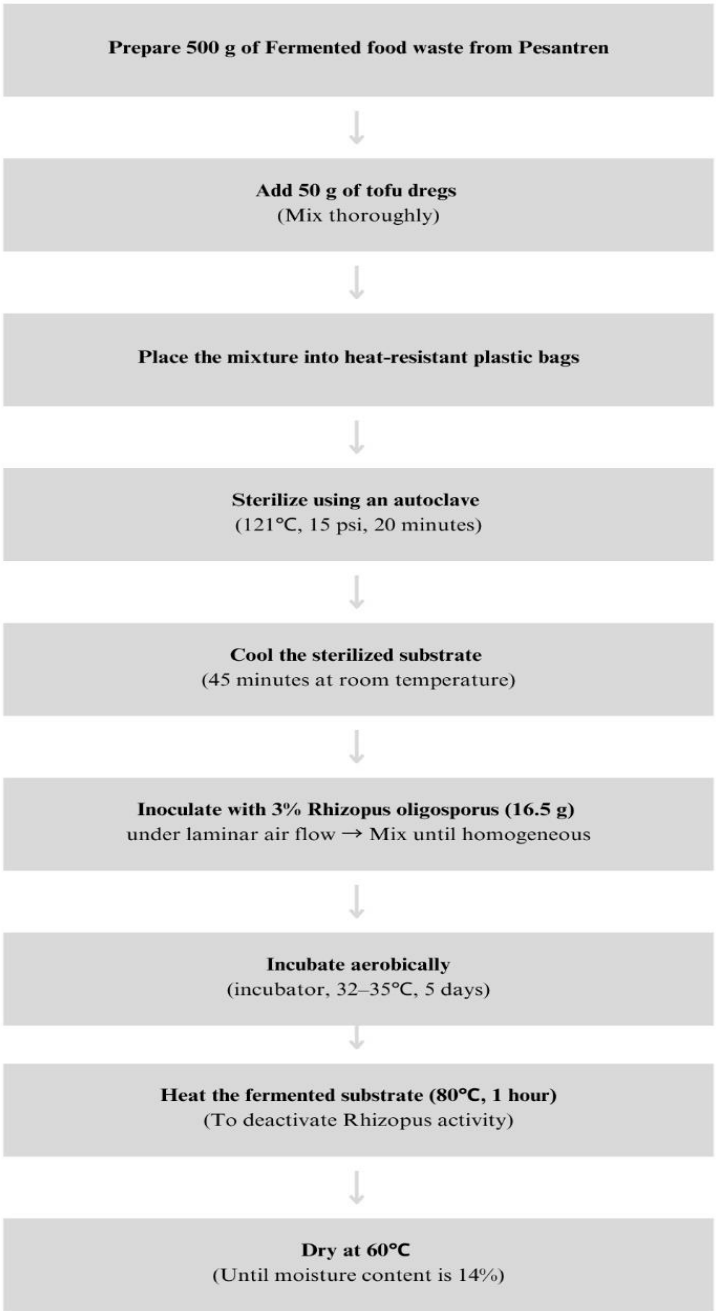

Figure 1. The preparation of Pesantren food waste fermented with *Rhizopus oligosporus*

The preparation of *Rhizopus oligosporus*

The preparation of *R. oligosporus* inoculant started with selecting high-quality soybeans, which were soaked for 6-12 hours, boiled, and manually dehulled to promote fungal growth. The soybeans were then coarsely ground to increase surface area, supporting optimal mycelial development. The substrate was sterilized in heat-resistant polypropylene bags using an autoclave at 121°C and 15 psi for 15 to 30 minutes, then cooled to 35°C, the ideal temperature for inoculation to prevent thermal damage to the spores and ensure successful fermentation (Rusfirda et al., 2025).

Inoculation was carried out under aseptic conditions inside a laminar airflow cabinet by applying a standardized spore suspension containing 10^7 to 10^8 colony-forming units (CFU) per gram to 100 g of sterile substrate. The *R. oligosporus* spores used in the present study were sourced from the Indonesian culture collection, Research Center for Biology, National Research and Innovation Agency, Indonesia (Rusfidra et al., 2023). Spore concentration was determined using a hemocytometer under a light microscope to ensure accurate and consistent inoculum levels.

The inoculated substrate was incubated at 32°C, an optimal temperature for *R. oligosporus* growth, for five days in shallow containers (1-2 cm thick) with adequate aeration to ensure proper fungal development. Following the incubation phase, the substrate that had been entirely colonized was dried at a low temperature (Not exceeding 40°C) to preserve the viability of the fungal spores. It was then finely ground and stored in sealed, light-protected containers at a temperature between 4°C and 10°C for later use in feed fermentation. The process of preparing the *R. oligosporus* inoculum is depicted in Figure 2.

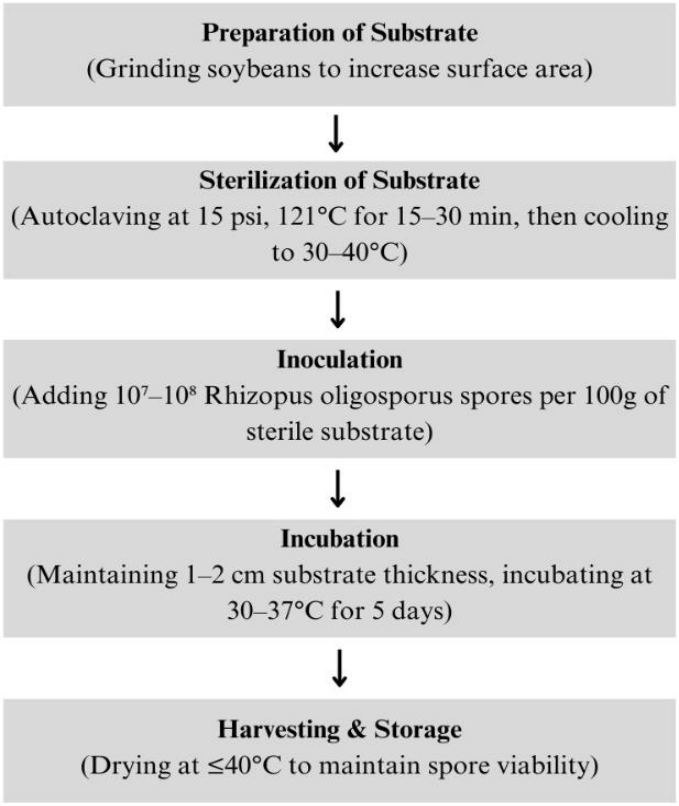

Figure 2. The preparation of *Rhizopus oligosporus*

Statistical analysis

The collected data were subjected to one-way analysis of variance (ANOVA) to assess the impact of different dietary treatments on the growth performance and carcass characteristics of Alabio ducks. Upon identifying a significant treatment effect ($p < 0.05$), Duncan's Multiple Range Test (DMRT) was used to assess mean differences among groups. The results were expressed as means ± standard error (SE), with SE representing the dispersion of the sample mean and reflecting the reliability of the reported mean estimates.

RESULTS AND DISCUSSION

The effects of fermented FPW on feed intake, final body weight, and FCR in male Alabio ducks at 8 weeks old are presented in Table 4. These performance metrics were assessed to understand how different levels of FPW in the diet influence growth and feed efficiency over the 8-week feeding period.

Table 4. Effects of fermented food waste from Pesantren on feed consumption, final body weight, and feed conversion in male Alabio Ducks (*Anas platyrhynchos Borneo*) at 8 weeks of age

Treatment	Feed consumption (g/head)*	Final body weight (g/head)*	Feed conversion ratio*
Treatment A (0% FWP)	4708.38 ± 42.93[a]	1532.42 ± 55,44[a]	3.07 ± 0.09[b]
Treatment B (10% FWP)	4650.38 ± 38.03[a]	1501.15 ± 62,68[a]	3.10 ± 0.15[b]
Treatment C (20% FWP)	4643.75 ± 45.37[a]	1495.21 ± 65,84[a]	3.11 ± 0.16[b]
Treatment D (30% FWP)	4632.94 ± 52.08[a]	1462.87 ± 68,60[a]	3.17 ± 0.17[b]
Treatment E (40% FWP)	4549.56 ± 55.90[b]	1329.94 ± 93,82[b]	3.43 ± 0.22[a]
SE	23.65	35.25	0.08
P-Value	0.005	0.009	0.042

FWP: Food waste from Pesantren fermented with *R. oligosporus*, SE: Standard error. [a,b] Different superscript letters in the same column indicate significant differences ($p < 0.05$).

Feed consumption of Alabio ducks fed FWP fermented with *R. oligosporus* ranged from 4549.56 ± 55.90 to 4708.38 ± 42.93 g per bird. Feed intake in treatments B, C, and D did not differ significantly from that of the control group ($p > 0.05$). The current results suggested that including FWP up to 30% did not decrease feed intake, indicating that the fermented feed was palatable. This may be due to the fermentation process of FWP, which improves flavor and aroma by producing glutamate compounds and B-complex vitamins (Trisna et al., 2019; Maulana et al., 2021; Wizna et al., 2025).

Moreover, all experimental diets were formulated to be iso-nitrogenous and iso-caloric, ensuring balanced nutrient profiles despite the reduced inclusion of conventional ingredients such as corn and soybean meal. This consistency across treatments A to D likely contributed to comparable feed intake and growth performance. Additionally, fermentation improved the palatability and digestibility of fermented FWP, enhancing nutrient availability and absorption in ducks.

Feed consumption was significantly decreased ($p < 0.05$) in Treatment E (4549.56 ± 55.90 g/head) compared to Treatments C (4643.75 ± 45.37 g/head) and D (4632.94 ± 52.08 g/head). This reduction may be attributed to the higher crude fiber content (6.27%), which likely increased gut fill and satiety, suppressing voluntary intake. Elevated fiber levels in poultry diets are known to slow digestion and prolong satiety (Svihus, 2011; Maulana et al., 2024).

The FWP fermented with *R. oligosporus* reduced the use of corn and soybean meal. In Treatment B, corn usage decreased by 14.04%, and soybean meal usage decreased by 16.67%. Treatment C lowered corn usage by 26.32% and soybean meal by 41.67%. Treatment D reduced the use of corn by 38.60% and soybean meal by 66.67% and Treatment E lowered corn usage by 52.63% and soybean meal by 83.33%. The final body weight among treatments A, B, C, and D showed no significant differences ($p > 0.05$), indicating that feed consumption and protein intake did not vary significantly across all treatments ($p > 0.05$). Notably, utilizing FWP up to 30% did not negatively impact feed intake or nutrient availability. Specifically, feed consumption and protein intake were recorded as Treatment A (4708.38 ± 42.93 g and 800.42 ± 7.30 g), Treatment B (4650.38 ± 38.03 g and 790.56 ± 6.47 g), Treatment C (4643.75 ± 45.37 g and 789.44 ± 7.71 g), and Treatment D (4632.94 ± 52.08 g and 792.24 ± 8.30 g).

Duck body weight gain depends on feed intake, as higher consumption boosts the chances of meeting nutritional requirements and promotes optimal growth (Zaqi et al., 2019). Additionally, weight gain is influenced by protein intake, as protein is essential for the development of new tissue (Obeidat et al., 2022). Protein intake is positively correlated with feed consumption, whereby an increase in feed intake leads to a corresponding increase in protein intake (Maulana et al., 2025).

The FCR is a crucial factor in assessing feed efficiency, especially when using waste or unconventional feed ingredients. A lower FCR signifies better efficiency, meaning less feed is needed to produce one kilogram of meat (Zhu et al., 2023). In the present study, the FCR values for each treatment were as follows: Treatment A (3.07 ± 0.09), Treatment B (3.12 ± 0.11), Treatment C (3.14 ± 0.08), Treatment D (3.17 ± 0.10), and Treatment E (3.43 ± 0.22). Treatments A to D indicated an improved feed efficiency (FCR 3.07-3.17), likely attributable to optimal feed-to-gain ratios, while Treatment E demonstrated a reduced efficiency (FCR 3.43). However, intergroup differences were not statistically significant ($p > 0.05$; Djulardi et al., 2023). The current FCR values (3.07-3.43) consistently exceeded commercial production standards (2.2-2.8), suggesting substantial scope for enhancing feed efficiency through targeted nutritional interventions (Pangeran et al., 2021). The effects of fermented FWP on protein intake, carcass percentage, and abdominal fat percentage in male Alabio ducks are presented in Table 5.

Table 5. Effect of food waste from Pesantren fermented with *Rhizopus oligosporus* on protein intake, carcass percentage, and abdominal fat percentage in male Alabio Ducks (*Anas platyrhynchos Borneo*) at 8 weeks of age.

Treatment	Protein intake (g/head)*	Carcass (%)^{NS}	Abdomen fat (%)^{NS}
Treatment A (0% FWP)	800.42 ± 7.30^{a}	63.50 ± 1.03	2.11 ± 0.07
Treatment B (10% FWP)	790.56 ± 6.47^{a}	63.17 ± 0.87	2.08 ± 0.05
Treatment C (20% FWP)	789.44 ± 7.71^{a}	62.64 ± 0.62	2.06 ± 0.03
Treatment D (30% FWP)	792.24 ± 8.30^{a}	62.21 ± 1.05	2.04 ± 0.09
Treatment E (40% FWP)	773.43 ± 9.50^{b}	61.83 ± 0.64	1.98 ± 0.04
SE	3.96	11.15	0.03
P-value	0.004	0.087	0.069

NS: Non-significant, FWP: Food waste from Pesantren fermented with *R. oligosporus*, SE: Standard error. $^{(*)a-b}$ Different superscript letters in the same column indicate significant differences ($p < 0.05$)

Adequate protein consumption is essential for optimal growth, tissue synthesis, and maintenance in poultry species (NRC, 1994). The current results indicated that Treatments A, B, C, and D did not differ significantly in protein intake values ($p > 0.05$). The current findings suggested that the feed formulations containing FWP in treatments A, B, C, and

D provided comparable protein intakes, with values of 800.42 ± 7.30 g/head (Treatment A), 790.56 ± 6.47 g/head (Treatment B), 789.44 ± 7.71 g/head (Treatment C), and 792.24 ± 8.30 g/head (Treatment D), respectively, which met the nutritional requirements of Alabio ducks as recommended by NRC (1994). Protein intake is influenced by feed consumption; higher feed consumption results in higher protein intake (Nova et al., 2022). Treatment E demonstrated a significantly lower protein intake (773.43 ± 9.50 g/head) compared to Treatment A (800.42 ± 7.30 g/head), Treatment B (790.56 ± 6.47 g/head), Treatment C (789.44 ± 7.71 g/head), and Treatment D (792.24 ± 8.30 g/head, $p < 0.05$).

The significantly lower protein intake in Treatment E (773.43 ± 9.50 g/head) likely resulted from reduced feed palatability due to the 40% inclusion of fermented Pesantren food waste. This suboptimal protein consumption may negatively impact growth performance, as feed palatability directly influences consumption and consequently protein intake in poultry (Wang et al., 2023).

Carcass percentages across all treatments; A (63.50 ± 1.03%), B (63.17 ± 0.87%), C (62.64 ± 0.62%), D (62.21 ± 1.05%), and E (61.83 ± 0.64%) showed no significant differences ($p > 0.05$) and remained within the established range (60-65%) for male Alabio ducks (NRC, 1994). The non-significant treatment differences ($p > 0.05$) demonstrated that fermented Pesantren waste can effectively replace conventional feed components while maintaining equivalent carcass yields in duck production systems. The current findings indicated that the inclusion of FWP as an alternative feed ingredient did not negatively affect key metabolic processes such as nutrient absorption and protein synthesis, nor did it impair muscle tissue development in Alabio ducks. Carcass percentage can be affected by suboptimal growth, which may be due to high crude fiber content in poultry feed (Nuraini et al., 2022).

Abdominal fat percentage is a parameter that reflects the efficiency of energy metabolism and fat accumulation in the animal's body (Ayuti et al., 2022). The present study indicated that the inclusion of FWP did not significantly ($p > 0.05$) affect the abdominal fat percentage across all treatments.

The average abdominal fat percentage was 2.11 ± 0.07 in Treatment A, 2.08 ± 0.05 in Treatment B, 2.06 ± 0.03 in Treatment C, 2.04 ± 0.09 in Treatment D, and 1.98 ± 0.04 in Treatment E. These results demonstrated that all dietary formulations maintained proper fat deposition patterns, indicating balanced nutritional conditions (Nova et al., 2022). The current findings suggest that the energy used from different feed treatments (A to D) was proportionally utilized by the ducks for both muscle growth, as shown by carcass percentages ranging from 61.83% to 63.50%, and fat deposition, with abdominal fat percentages between 2.11% and 2.03%.

The fermentation method using *R. oligosporus* on Pesantren food waste illustrated promising potential for use by small-scale duck farmers in Indonesia, especially those near Pesantren communities. Compared to other bioconversion methods, such as ensiling or enzymatic hydrolysis, the fermentation process in the present study was relatively simple, requiring only basic materials and equipment, including heat-resistant plastic containers, a household heat source (Stove or steamer), and a clean, well-ventilated space for incubation. Although the study employed an autoclave and a controlled incubator, in real-world settings, sterilization can be achieved through steaming for 30 to 60 minutes, and incubation can occur in a warm room with good airflow (Liu et al., 2022; Wang et al., 2023).

CONCLUSION

Fermenting Pesantren food waste with *Rhizopus oligosporus* was effective for Alabio duck diets at inclusion levels of up to 30%, preserving growth performance, feed efficiency, and carcass yield similar to those of conventional methods feeds. This approach provided a sustainable and cost-effective alternative that aligns with circular economy principles by valorizing local waste resources. Additionally, including up to 30% fermented Pesantren food waste could preserve nutritional quality and palatability, reduce reliance on traditional feed ingredients, and support eco-friendly poultry production in Pesantren communities. It is suggested that further refinement of processing methods or ingredient balancing may be needed to improve feed efficiency to meet commercial standards.

DECLARATIONS

Acknowledgments

The authors would like to thank the Department of Technology and Livestock Production, Universitas Andalas, the Department of Agricultural Industrial Technology, Politeknik Negeri Tanah Laut, the Department of Biology, Universitas Negeri Medan, and the Department of Agroindustry, Universitas Negeri Padang, Indonesia, for their support and collaboration in this study.

Authors' contributions

Rusfidra contributed to the conceptualization of the study and project administration. Fajri Maulana was responsible for formal analysis and writing the original draft of the manuscript. Heppy Setya Prima handled the investigation and validation of the research data. Malikil Kudus Susalam took charge of resources and visualization. Satri Yusasra Agasi provided supervision and methodology support. Finally, Fadhli Fajri was involved in data curation and funding acquisition. All authors read and approved the final edition of the manuscript for publication.

Funding

The present study did not receive any financial support.

Competing interests

The authors declared no conflict of interest.

Ethical considerations

This study was originally written by the authors and has not been published elsewhere. The authors checked the text of the article for plagiarism index and confirmed that the text of the article is written based on their original scientific results.

Availability of data and materials

The data to support the present study's findings are available upon reasonable request to the corresponding author.

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