Research Article

Dietary Replacement with Fermented Duckweed-Banana Pseudostem-Rice Bran Blend Improves Growth Uniformity, Nutrient Digestibility and Fecal Bacterial Profile in Local Grey Meat Geese

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Abstract | Locally available fermented feed resources are of practical interest for goose production, but evidence for their use in local grey meat geese under Mekong Delta smallholder conditions remains limited. This study evaluated the effects of a fermented duckweed–banana pseudostem–rice bran blend (FFB) on growth performance, flock uniformity, nutrient digestibility, fecal quality, fecal bacterial counts, and oxidative–immune status. A total of 320 clinically healthy 15-day-old geese were randomly allotted to four dietary treatments with eight replicate pens per treatment and 10 geese per pen. Treatments were Control (0% FFB), FFB8 (8% FFB), FFB16 (16% FFB), and FFB24 (24% FFB), where the percentages represented dietary dry matter replaced by FFB. The feeding trial lasted from 15 to 70 days of age. Fermentation reduced pH and yeast and mold counts and increased lactic acid concentration and lactic acid bacteria (LAB) counts (all $P < 0.001$). FFB16 produced the highest final body weight and average daily gain (ADG) and the lowest feed conversion ratio (FCR) and feed cost per kilogram of gain (all $P < 0.001$). FFB16 also produced the lowest body weight variation and the highest flock uniformity, improved apparent digestibility of dry matter, crude protein, crude fiber, and organic matter, and reduced fecal score, moisture, and pH (all $P < 0.001$). Moreover, FFB16 was associated with increased fecal LAB counts, reduced fecal coliform and *E. coli* counts and serum malondialdehyde (MDA), and increased serum superoxide dismutase (SOD) activity and immunoglobulin A (IgA) concentration (all $P < 0.001$). Responses at 24% replacement were generally weaker than those at 16%. Among the tested levels, replacing 16% of dietary dry matter with FFB produced the most favorable overall response in local grey meat geese.

Keywords | Fermented feed blend, Duckweed, Banana pseudostem, Local grey goose, Growth uniformity, Apparent digestibility, Fecal bacteria

Received | July 09, 2026; **Accepted** | September 09, 2026; **Published** | November 14, 2026
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Citation | Nhan P, Chuc NT, Tri NM (2027). Dietary replacement with fermented duckweed-banana pseudostem-rice bran blend improves growth uniformity, nutrient digestibility and fecal bacterial profile in local grey meat geese. J. Anim. Health Prod. 15(1): 85-96.
DOI | https://dx.doi.org/10.17582/journal.jahp/2027/15.1.85.96
ISSN (Online) | 2308-2801

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INTRODUCTION

Feed cost remains one of the major constraints in smallholder poultry production, particularly in systems where farmers depend heavily on commercial feed while local feed resources are not fully utilized. Chen *et al*. (2019) stated that feed accounts for about 70% of poultry production costs. This is particularly the case in the Mekong Delta where aquatic plants, banana by-products and rice bran are locally available but not always effectively converted into balanced feed resources for smallholder poultry production. Therefore, upgrading agricultural by-products into livestock feed ingredients is a promising strategy to improve production sustainability and generate

economic benefits in smallholder systems (Zaini and Pindi, 2024). Moreover, Ye *et al.* (2017) characterized geese as herbivorous and feed-efficient poultry, implying that improving the use of fibrous feed resources is particularly relevant in goose nutrition. Improving feed efficiency, especially in local grey meat geese, is important because body weight gain, flock uniformity and market readiness are strongly affected by the ability of geese to use dietary nutrients efficiently. Previous studies also indicated that pasture-based feeding systems can reduce feed input per unit of weight gain and decrease body-cavity fat deposition in geese, although growth rate may be lower than in intensive systems (Snyder *et al.*, 1955; Kivimae, 1976; Omar *et al.*, 2024; Stevenson, 1989). These findings support the practical value of exploiting fibrous and green feed resources in goose production. Developing locally available feed ingredients that can be partly substituted for conventional feed without impairing growth performance is a practical direction for goose production under smallholder conditions.

Duckweed is a promising local feed resource, as it can supply protein, minerals, pigments, and other nutrients. Duckweeds, belonging to the family Lemnaceae, have received increasing attention as a potential resource for both human nutrition and animal feeding because of their rapid growth and nutrient value (Petersen *et al.*, 2021). Several studies have shown that selected duckweed species have considerable nutritional potential, particularly due to their protein content, amino acid profile, fatty acid composition, and biomass production capacity (Appenroth *et al.*, 2017, 2018; Chakrabarti *et al.*, 2018). However, their feeding value may vary according to duckweed species, biomass quality, growing conditions, and harvesting stage. Demann *et al.* (2023) reported that duckweed differed in crude protein content, amino acid digestibility, and phosphorus digestibility when evaluated as a protein feed for broiler chickens, indicating that its practical use needs attention to nutrient quality and consistency. Banana pseudostem is also widely available in tropical farming areas and can provide structural fiber, whereas rice bran is a practical agricultural by-product for goose diets. Sun *et al.* (2016) reported that full-fat rice bran inclusion at 0–18% did not impair growth performance in Sichuan geese and improved average daily gain during the later growing period at the 18% inclusion level. Nevertheless, these local materials may present limitations when used directly, including high moisture content, high fiber content, variable nutrient composition, and reduced storage stability.

Fermentation is a practical approach to improve the feeding value and microbial quality of local feed materials. Banana-derived residues have been shown to serve as suitable substrates for microbial enzyme production under solid-state fermentation, and the effectiveness of solid-state fermentation is influenced by substrate characteristics, moisture availability, microbial growth, and fermentation conditions (Krishna and Chandrasekaran, 1996; Raghavarao *et al.*, 2003). In fermented feed, acidification and the proliferation of beneficial bacteria are important indicators of fermentation quality. In geese, Yan *et al.* (2019) showed that fermented feed modulated growth performance and the cecal microbiota community, indicating that fermentation-based feeding strategies may influence production traits and gut-related responses.

Despite these findings, information remains limited on the use of a fermented local feed blend based on duckweed, banana pseudostem, and rice bran in local grey meat geese raised under smallholder conditions in the Mekong Delta. Most feeding studies focus mainly on average growth performance and feed conversion, whereas less attention has been given to flock uniformity, apparent nutrient digestibility, fecal quality, fecal bacterial counts, and oxidative–immune biomarkers. These indicators are important because a dietary treatment may influence not only mean body weight, but also growth consistency within the flock and physiological conditions associated with nutrient utilization and gut stability.

Therefore, this study was conducted to evaluate the effects of replacing 0, 8, 16, and 24% of dietary dry matter with a fermented duckweed–banana pseudostem–rice bran blend on growth performance, feed utilization, flock uniformity, apparent nutrient digestibility, fecal quality, fecal bacterial profile, and selected oxidative–immune biomarkers of local grey meat geese raised under smallholder conditions in the Mekong Delta. It was hypothesized that a moderate replacement level would improve feed efficiency, flock uniformity, nutrient utilization, and gut-related indicators, whereas excessive replacement could reduce the benefit because of the increased dietary fiber load.

MATERIALS AND METHODS

Study animals

The study was conducted from May to August 2024 at a livestock farm located in Dong Phuoc commune, Can Tho City, Vietnam. A total of 320 clinically healthy local grey meat geese were used in the feeding trial. Before the experiment, all geese were brooded under similar farm management conditions. At 15 days of age, geese with normal appearance, active behavior, no visible clinical abnormality, and relatively uniform body weight were selected for the experiment. The geese were not sexed, but they were randomly distributed among replicate pens and dietary treatments to minimize the potential effect of sex on growth performance. All geese were housed in floor pens under the same management conditions throughout the trial. Bedding material, ventilation, lighting, drinking water

supply, feeding schedule, and routine health management were kept similar among treatments to reduce non-dietary variation. The health status, abnormal behavior, feed refusal and mortality of the geese were checked daily.

Feed and feeding

Fresh duckweed, identified as *Lemna minor* L. based on morphological characteristics, and banana pseudostem were obtained from local sources in Dong Phuoc commune, Can Tho City, Vietnam. Fresh full-fat rice bran obtained from a local rice mill was used as the rice bran component of the fermented feed blend. The duckweed was thoroughly washed with clean water and drained to remove excess surface moisture, whereas the banana pseudostem was chopped into small pieces before mixing. The fermented feed blend was prepared by mixing fresh duckweed, banana pseudostem, and fresh full-fat rice bran at a ratio of 50:25:25 on a fresh-weight basis, respectively. The mixture was inoculated with a commercial bacterial preparation containing *Lactobacillus acidophilus* (LACTOTARUM 20B, Bio-Floc, Vietnam; declared viable count ≥2.0 × 10^{10} CFU/g) at 0.05 g/kg fresh material, corresponding to a minimum theoretical inoculation level of approximately 1 × 10^{6} CFU/g fresh material. A strain-level designation was not provided by the manufacturer. After inoculation, the mixture was packed tightly into plastic containers, sealed to maintain anaerobic conditions, and fermented for 5 days at ambient temperature.

The samples of the blend were taken after fermentation and before air-drying for fermentation quality and chemical composition assessment. The pH of the fermented blend was determined on an aqueous extract using a digital pH meter. Lactic acid concentration was determined by titration and expressed as percentage of the fermented material. Lactic acid bacteria were enumerated on de Man, Rogosa and Sharpe agar after serial dilution, whereas yeasts and molds were counted on potato dextrose agar. Microbial counts were expressed as log CFU/g. The remaining fermented blend was air-dried until it reached a moisture level suitable for mixing with the basal diet. The fermentation quality reported for the blend was determined before air-drying, whereas the air-dried product was used for diet formulation and replacement calculations.

The chemical composition of the fermented blend and experimental diets was analyzed using standard laboratory procedures. Dry matter, crude protein, ether extract, crude fiber, and ash were determined according to AOAC (1990). Neutral detergent fiber and acid detergent fiber were also determined to characterize the fiber fractions of the fermented blend and experimental diets. Organic matter was calculated as the difference between dry matter and ash. The analyzed composition of the fermented blend was used to formulate the experimental diets.

The basal diet was formulated to meet the nutrient requirements of growing local grey meat geese. Four experimental diets were prepared by replacing 0, 8, 16, and 24% of dietary dry matter with the air-dried fermented duckweed-banana pseudostem-rice bran blend. The dietary treatments were Control, basal diet without fermented feed blend; FFB8, basal diet with 8% of dietary dry matter replaced by the fermented blend; FFB16, basal diet with 16% of dietary dry matter replaced by the fermented blend; and FFB24, basal diet with 24% of dietary dry matter replaced by the fermented blend. The diets were formulated to be as similar as possible in crude protein and metabolizable energy, while crude fiber, neutral detergent fiber, and acid detergent fiber increased gradually with increasing fermented feed blend replacement. Feed was offered twice daily, in the morning and afternoon, and clean drinking water was provided ad libitum throughout the experimental period. Feed offered and feed refusals were recorded daily by replicate pen to calculate feed intake and feed conversion ratio.

Experimental design

A completely randomized design was used in this study. At 15 days of age, 320 clinically healthy local grey meat geese with relatively uniform body weight were randomly assigned to four dietary treatments: Control, FFB8, FFB16, and FFB24. Each treatment included eight replicate pens, with 10 geese per pen. The experimental period lasted from 15 to 70 days of age. The pen was considered the experimental unit for growth performance, feed intake, feed conversion ratio, flock uniformity, apparent nutrient digestibility, fecal quality, fecal bacterial counts, and feed cost efficiency. For serum oxidative–immune biomarkers and total protein, one representative goose from each replicate pen was sampled at 70 days of age.

Measurements

Growth performance and feed utilization

Body weight was recorded individually at 15, 28, 42, 56, and 70 days of age using an electronic scale. Average daily gain was calculated for each replicate pen based on body weight change during the experimental period. Feed offered and feed refusals were recorded daily by pen, and average daily feed intake was calculated on a pen basis. Feed conversion ratio was calculated as the ratio of feed intake to body weight gain. Mortality was recorded daily and the survival rate was calculated for each replicate pen.

Flock uniformity

Flock uniformity was evaluated based on the individual body weight data at 15, 42 and 70 days of age. The coefficient of variation of body weight was calculated for each pen. The proportion of geese within ±10% of the pen mean body weight was used as the uniformity rate. Geese with body weight below 85% of the pen mean were

classified as underweight geese.

Apparent nutrient digestibility

Apparent nutrient digestibility was determined from 63 to 67 days of age using total excreta collection at the pen level. Excreta were collected from each pen during the collection period, weighed, and pooled by pen. Feathers, bedding material and spilled feed were removed prior to sample processing. Feed and excreta samples were dried, ground and analysed for dry matter, crude protein, crude fibre, ash and organic matter. Dry matter, crude protein and ash were determined by the AOAC (1990) method and organic matter was calculated as the difference between dry matter and ash. Apparent digestibility of each nutrient was calculated from nutrient intake and nutrient excretion. The pen was used as the experimental unit for digestibility measurements.

Apparent digestibility (%) was calculated as [(nutrient intake − nutrient excretion) / nutrient intake] × 100

Fecal quality

Fecal quality was assessed during the experimental period using fresh fecal observations from each replicate pen. Fecal score was determined using a 0–3 scale where 0 was normal and well-formed feces, 1 was slightly soft feces, 2 was watery feces and 3 was severe watery feces. Fresh fecal samples were collected at 70 days of age to determine fecal pH and moisture content.

Fecal bacterial counts

Fecal bacterial counts were determined from fresh fecal samples collected at 70 days of age from each replicate pen. Samples were transported to the laboratory under cooled conditions and processed immediately for culture-based enumeration. Serial dilutions of fecal samples were prepared using sterile physiological saline before plating. Lactic acid bacteria were counted on de Man, Rogosa and Sharpe agar. Coliforms were counted on violet red bile agar, whereas *E. coli* was counted on eosin methylene blue agar. Plates were incubated under appropriate temperature and time conditions for each bacterial group, and bacterial counts were expressed as log CFU/g fresh feces.

Serum oxidative–immune biomarkers and total protein

Blood samples were collected at 70 days of age from one representative goose per replicate pen. The sampled goose was selected as the individual closest to the mean body weight of the corresponding pen. Serum was separated and used for biochemical and immunological analyses. Serum malondialdehyde concentration was determined using a Lipid Peroxidation (MDA) Assay Kit (colorimetric/fluorometric TBARS assay; Abcam, Cambridge, UK; Cat. No. ab118970), and superoxide dismutase activity was measured using a Superoxide Dismutase Activity Assay Kit (Abcam, Cambridge, UK; Cat. No. ab65354). Serum immunoglobulin A was quantified using a goose-specific Immunoglobulin A ELISA Kit (MyBioSource, San Diego, CA, USA; Cat. No. MBS029455). Total protein was determined using a Total Protein Assay Kit based on the biuret method (Nanjing Jiancheng Bioengineering Institute, Nanjing, China; Cat. No. A045-1-1). All assays were performed according to the manufacturers' instructions.

Feed cost efficiency

Feed cost efficiency was calculated using the total feed intake, diet cost and body weight gain of each replicate pen. The cost of each experimental diet was calculated from the actual ingredient prices and the ingredient composition of the diet. Feed cost per kilogram of weight gain was calculated as total feed cost per pen divided by total body weight gain per pen.

Statistical analysis

Data were analyzed using Minitab 16. For fermentation characteristics, values obtained before and after fermentation from the same independent fermentation batches were compared using a paired t-test, with fermentation batch considered the experimental unit. For the feeding trial, the replicate pen was considered the experimental unit for growth performance, feed intake, feed conversion ratio, flock uniformity, apparent total tract digestibility, fecal quality, fecal bacterial counts, and feed cost efficiency. For serum oxidative–immune biomarkers and total protein, one representative goose sampled from each replicate pen was used for analysis. Data were checked for normality and homogeneity of variance before analysis. Bacterial counts were expressed as log CFU/g before statistical analysis. Dietary treatment effects were analyzed using one-way analysis of variance under a completely randomized design. When a significant treatment effect was detected, means were compared using Tukey's test. Survival rate and the proportions of uniform and underweight geese were subjected to arcsine square-root transformation before statistical analysis, whereas untransformed treatment means are presented in the tables for ease of interpretation. Results are presented as treatment means with pooled standard error of the mean. Differences were considered statistically significant at $P < 0.05$.

RESULTS

Fermentation characteristics and nutrient composition of the fermented feed blend and experimental diets

Table 1 shows that the chemical composition of the duckweed–banana pseudostem–rice bran blend changed only slightly after 5 days of fermentation. Dry matter decreased from 30.24 to 29.58%, whereas crude protein

increased numerically from 15.72 to 16.38% DM; neither change was significant (P= 0.286 and P = 0.102, respectively). Ether extract remained nearly unchanged, decreasing from 4.82 to 4.76% DM (P= 0.641). Crude fiber, NDF, and ADF decreased from 18.64 to 17.86% DM, 42.18 to 40.74% DM, and 25.36 to 24.08% DM, respectively, but these differences were not significant. Ash content was also similar before and after fermentation, with values of 10.42 and 10.68% DM (P= 0.342).

Table 1: Chemical composition and fermentation quality of the duckweed–banana pseudostem–rice bran blend before and after fermentation.

Parameter	Before fermentation	After 5 days of fermentation	SEM	P value
Dry matter (%)	30.24	29.58	0.37	0.286
Crude protein (% DM)	15.72	16.38	0.28	0.102
Ether extract (% DM)	4.82	4.76	0.09	0.641
Crude fiber (% DM)	18.64	17.86	0.33	0.118
NDF (% DM)	42.18	40.74	0.56	0.081
ADF (% DM)	25.36	24.08	0.42	0.054
Ash (% DM)	10.42	10.68	0.18	0.342
pH	6.18	4.12	0.06	<0.001
Lactic acid (%)	0.34	2.26	0.09	<0.001
LAB (log CFU/g)	5.24	8.38	0.11	<0.001
Yeasts and molds (log CFU/g)	3.68	2.42	0.10	<0.001

Values are means from three independent fermentation batches. DM = dry matter; NDF = neutral detergent fiber; ADF = acid detergent fiber; LAB = lactic acid bacteria; CFU = colony-forming units; SEM = pooled standard error of the mean. P-values indicate the effect of fermentation stage.

In contrast, the fermentation-quality characteristics changed markedly. As shown in Table 1, pH decreased from 6.18 to 4.12, while lactic acid concentration increased from 0.34 to 2.26% (P < 0.001). LAB counts increased from 5.24 to 8.38 log CFU/g, whereas yeast and mold counts decreased from 3.68 to 2.42 log CFU/g (P < 0.001). Thus, the main changes during fermentation were acidification, increased LAB counts, and reduced yeast and mold counts rather than major alterations in the basic chemical composition of the blend.

Table 2 presents the nutrient composition of the four experimental diets containing increasing levels of FFB. Dry matter decreased slightly from 89.42% in Control to 88.08% in FFB24. Metabolizable energy also declined gradually from 2852 to 2815 kcal/kg DM, whereas crude protein remained relatively stable, ranging from 17.74 to 17.86%. Ether extract decreased slightly from 4.86 to 4.65%. In contrast, crude fiber increased from 5.86 to 7.86%, NDF from 15.42 to 20.12%, and ADF from 7.68 to 10.18% as FFB replacement increased. Calcium, available phosphorus, lysine, and methionine remained within narrow ranges among the four diets.

Table 2: Calculated and analyzed nutrient composition of the experimental diets.

Parameter	Control	FFB8	FFB16	FFB24
FFB inclusion (% dietary DM)	0.00	8.00	16.00	24.00
Dry matter (%)	89.42	88.96	88.51	88.08
Metabolizable energy (kcal/kg DM)	2852.00	2840.00	2828.00	2815.00
Crude protein (%)	17.82	17.86	17.80	17.74
Ether extract (%)	4.86	4.78	4.71	4.65
Crude fiber (%)	5.86	6.48	7.12	7.86
NDF (%)	15.42	16.84	18.36	20.12
ADF (%)	7.68	8.46	9.25	10.18
Calcium (%)	0.82	0.81	0.82	0.80
Available phosphorus (%)	0.39	0.39	0.38	0.38
Lysine (%)	0.91	0.90	0.89	0.88
Methionine (%)	0.38	0.38	0.37	0.37

Control= basal diet without fermented feed blend; FFB8, FFB16 and FFB24= diets in which 8, 16 and 24% of dietary dry matter was replaced by the fermented feed blend, respectively. FFB= fermented duckweed–banana pseudostem–rice bran blend; DM= dry matter; NDF= neutral detergent fiber; ADF= acid detergent fiber. Dry matter is expressed on an as-fed basis; other nutrient concentrations are expressed on a dry matter basis unless otherwise stated.

Growth performance, feed utilization and feed cost efficiency

Table 3 shows that body weight at 15 days of age was similar among treatments, ranging from 0.68 to 0.69 kg, with no significant treatment effect (P= 0.861). By 70 days of age, body weight differed significantly among treatments (P < 0.001). FFB16 produced the highest final body weight at 4.59 kg, followed by FFB8 and FFB24 at 4.36 and 4.34 kg, respectively, while Control had the lowest value at 4.17 kg. FFB8 and FFB24 did not differ significantly from each other.

Average daily gain showed a similar treatment response, as presented in Table 3. FFB16 had the highest ADG at 70.91 g/goose/day, followed by FFB8 and FFB24 at 66.91 and 66.55 g/goose/day, respectively, while Control had the lowest ADG at 63.45 g/goose/day (P < 0.001). In contrast, ADFI remained similar among treatments and ranged from 181.84 to 184.05 g/goose/day (P = 0.734).

Feed conversion ratio differed significantly among treatments (P < 0.001). FFB16 had the lowest FCR at 2.60 and differed significantly from all other treatments. FFB8 had an FCR of 2.74 and was lower than control at 2.87.

Table 3: Growth performance, feed utilization, survival rate and feed cost efficiency of local grey meat geese from 15 to 70 days of age.

Parameter	Control	FFB8	FFB16	FFB24	SEM	P value
Body weight at day 15 (kg)	0.68	0.68	0.69	0.68	0.01	0.861
Body weight at day 70 (kg)	4.17^{c}	4.36^{b}	4.59^{a}	4.34^{b}	0.04	<0.001
ADG (g/goose/day)	63.45^{c}	66.91^{b}	70.91^{a}	66.55^{b}	0.76	<0.001
ADFI (g/goose/day)	181.84	183.22	184.05	183.41	1.42	0.734
FCR	2.87^{a}	2.74^{b}	2.60^{c}	2.76^{ab}	0.03	<0.001
Survival rate (%)	96.25	97.50	98.75	97.50	1.08	0.462
Feed cost/kg weight gain (VND)	38200^{a}	34700^{b}	31400^{c}	34200^{b}	520	<0.001

Values are treatment means based on eight replicate pens per treatment, with 10 geese per pen. ADG = average daily gain; ADFI = average daily feed intake; FCR = feed conversion ratio; SEM = pooled standard error of the mean. Feed cost/kg weight gain was calculated from feed intake, diet cost and body weight gain during the experimental period. Means within a row with different superscripts differ significantly at $P < 0.05$.

Table 4: Flock uniformity of local grey meat geese fed diets containing different levels of fermented feed blend

Parameter	Control	FFB8	FFB16	FFB24	SEM	P-value
CV of body weight at day 15 (%)	8.92	8.86	8.78	8.91	0.28	0.984
CV of body weight at day 42 (%)	12.36^{a}	10.78^{b}	9.12^{c}	10.94^{b}	0.36	<0.001
CV of body weight at day 70 (%)	14.08^{a}	11.22^{b}	8.68^{c}	11.76^{b}	0.41	<0.001
Uniform geese within ±10% of pen mean at day 70 (%)	68.75^{c}	78.75^{b}	90.00^{a}	76.25^{b}	2.64	<0.001
Underweight geese below 85% of pen mean at day 70 (%)	11.25^{a}	7.50^{b}	3.75^{c}	8.75^{ab}	1.18	0.002

Values are treatment means based on eight replicate pens per treatment. CV = coefficient of variation. Uniform geese were defined as geese with individual body weight within ±10% of the pen mean body weight. Underweight geese were defined as geese with individual body weight below 85% of the pen mean body weight. Means within a row with different superscripts differ significantly at $P < 0.05$.

FFB24 had an intermediate FCR of 2.76 and did not differ significantly from either Control or FFB8. Survival rate ranged from 96.25 to 98.75% and was not significantly affected by dietary treatment (P= 0.462).

Feed cost per kilogram of weight gain also differed significantly among treatments, as shown in Table 3. The lowest value was observed in FFB16 at 31,400 VND/kg gain, followed by FFB24 and FFB8 at 34,200 and 34,700 VND/kg gain, respectively. These latter two treatments did not differ significantly from each other, whereas Control had the highest feed cost at 38,200 VND/kg gain. Overall, FFB16 combined the highest final body weight and ADG with the lowest FCR and feed cost per kilogram of gain.

Flock uniformity

Table 4 indicates that flock uniformity was similar among treatments at the beginning of the experiment. The CV of body weight at day 15 ranged from 8.78 to 8.92% and did not differ significantly among treatments (P= 0.984).

Clear treatment differences developed later in the feeding period. At day 42, the CV of body weight was highest in Control at 12.36%, intermediate in FFB8 and FFB24 at 10.78 and 10.94%, respectively, and lowest in FFB16 at 9.12% ($P < 0.001$). The same pattern was observed at day 70. Control had the highest CV at 14.08%, followed by FFB24 and FFB8 at 11.76 and 11.22%, respectively, whereas FFB16 had the lowest value at 8.68% ($P < 0.001$).

The proportion of geese within ±10% of the pen mean body weight also differed significantly among treatments, as shown in Table 4. FFB16 had the highest proportion of uniform geese at 90.00%, followed by FFB8 and FFB24 at 78.75 and 76.25%, respectively, while Control had the lowest proportion at 68.75% ($P < 0.001$).

The proportion of underweight geese also differed among treatments (P= 0.002). FFB16 had the lowest proportion at 3.75%, whereas Control had the highest at 11.25%. FFB8 had an intermediate value of 7.50%. FFB24 had a value of 8.75% and did not differ significantly from either Control or FFB8. Taken together, the lowest body weight variation and the highest proportion of uniform geese were observed in FFB16.

Apparent nutrient digestibility and fecal quality

Table 5 shows significant differences among treatments in apparent nutrient digestibility. Dry matter digestibility was highest in FFB16 at 72.86% ($P < 0.001$). FFB24 had an intermediate value of 70.34%, whereas FFB8 at 70.15%

did not differ significantly from either Control at 68.42% or FFB24.

Crude protein digestibility was also highest in FFB16 at 71.44% (P < 0.001). FFB8 had an intermediate value of 68.92%, while FFB24 at 68.73% did not differ significantly from either FFB8 or Control at 66.81%. Crude fiber digestibility was highest in FFB16 at 35.26%, intermediate and statistically similar in FFB8 and FFB24 at 31.82 and 32.41%, respectively, and lowest in Control at 28.65% (P < 0.001). Organic matter digestibility was highest in FFB16 at 74.32%, whereas Control, FFB8, and FFB24 had statistically similar values of 70.14, 71.86, and 71.94%, respectively (P < 0.001).

Fecal quality also differed significantly among treatments, as presented in Table 5. Fecal score was highest in Control at 1.42 and lowest in FFB16 at 0.86 (P < 0.001). FFB8 had a value of 1.15, whereas FFB24 at 1.08 did not differ significantly from either FFB8 or FFB16.

Fecal moisture was highest in Control at 72.64% and lowest in FFB16 at 68.92% (P < 0.001). FFB8 had a value of 70.85%, while FFB24 at 70.48% was statistically intermediate and did not differ significantly from either FFB8 or FFB16. A similar pattern was observed for fecal pH. Control had the highest pH at 6.82 and FFB16 had the lowest at 6.21 (P < 0.001). FFB8 had a pH of 6.54, whereas FFB24 at 6.39 did not differ significantly from either FFB8 or FFB16. Overall, FFB16 showed the most favorable combination of apparent nutrient digestibility and fecal quality.

Fecal bacterial profile and oxidative–immune status

Table 6 suggests that dietary treatment significantly affected fecal bacterial counts. LAB counts were lowest in Control at 6.48 log CFU/g and increased in all FFB treatments (P < 0.001). FFB16 had the highest numerical value at 7.36 log CFU/g and was significantly higher than FFB8 at 6.92 log CFU/g. FFB24 had an intermediate LAB count of 7.08 log CFU/g and did not differ significantly from either FFB8 or FFB16.

Table 5: Apparent nutrient digestibility and fecal quality of local grey meat geese fed diets containing different levels of fermented feed blend.

Parameter	Control	FFB8	FFB16	FFB24	SEM	P-value
Dry matter digestibility (%)	68.42^{c}	70.15^{bc}	72.86^{a}	70.34^{b}	0.48	<0.001
Crude protein digestibility (%)	66.81^{c}	68.92^{b}	71.44^{a}	68.73^{bc}	0.53	<0.001
Crude fiber digestibility (%)	28.65^{c}	31.82^{b}	35.26^{a}	32.41^{b}	0.72	<0.001
Organic matter digestibility (%)	70.14^{b}	71.86^{b}	74.32^{a}	71.94^{b}	0.50	<0.001
Fecal score, 0–3	1.42^{a}	1.15^{b}	0.86^{c}	1.08^{bc}	0.06	<0.001
Fecal moisture (%)	72.64^{a}	70.85^{b}	68.92^{c}	70.48^{bc}	0.44	<0.001
Fecal pH	6.82^{a}	6.54^{b}	6.21^{c}	6.39^{bc}	0.07	<0.001

Values are treatment means based on eight replicate pens per treatment. Apparent nutrient digestibility was determined during days 63–67 of age using total excreta collection at the pen level. Fecal score was assessed using a 0–3 scale, where 0 = normal and well-formed feces, 1 = slightly soft feces, 2 = watery feces and 3 = severe watery feces. Means within a row with different superscripts differ significantly at P < 0.05.

Table 6: Fecal bacterial counts, serum oxidative–immune biomarkers and total protein of local grey meat geese fed diets containing different levels of fermented feed blend.

Parameter	Control	FFB8	FFB16	FFB24	SEM	P-value
Fecal LAB (log CFU/g)	6.48^{c}	6.92^{b}	7.36^{a}	7.08^{ab}	0.08	<0.001
Fecal Coliforms (log CFU/g)	5.82^{a}	5.41^{b}	5.03^{c}	5.28^{bc}	0.07	<0.001
Fecal *E. coli* (log CFU/g)	5.36^{a}	5.02^{b}	4.68^{c}	4.89^{bc}	0.06	<0.001
Serum MDA (nmol/mL)	5.42^{a}	4.86^{b}	4.21^{c}	4.58^{bc}	0.11	<0.001
Serum SOD (U/mL)	96.50^{c}	104.28^{b}	116.35^{a}	107.82^{b}	1.86	<0.001
Serum IgA (mg/mL)	0.86^{c}	0.94^{b}	1.08^{a}	0.97^{b}	0.02	<0.001
Serum total protein (g/L)	41.25^{b}	42.86^{b}	45.32^{a}	43.18^{ab}	0.62	<0.001

Values are treatment means based on eight replicate pens per treatment. Fecal samples were collected at day 70 from each replicate pen. Blood samples were collected at day 70 from one representative goose per pen. LAB = lactic acid bacteria; CFU = colony-forming units; MDA = malondialdehyde; SOD = superoxide dismutase; IgA = immunoglobulin A; SEM = pooled standard error of the mean. Means within a row with different superscripts differ significantly at P < 0.05.

Fecal coliform counts were highest in Control at 5.82 log CFU/g and lower in all FFB treatments (P < 0.001).

FFB16 had the lowest numerical count at 5.03 log CFU/g and differed significantly from FFB8 at 5.41 log CFU/g. FFB24 had an intermediate count of 5.28 log CFU/g and did not differ significantly from either FFB8 or FFB16. Fecal *E. coli* showed the same statistical pattern. Counts decreased from 5.36 log CFU/g in Control to 4.68 log CFU/g in FFB16 ($P < 0.001$). FFB8 had a value of 5.02 log CFU/g, while FFB24 at 4.89 log CFU/g did not differ significantly from either FFB8 or FFB16. Serum oxidative and immune-related biomarkers also differed among treatments, as shown in Table 6. Serum MDA was highest in Control at 5.42 nmol/mL and lowest in FFB16 at 4.21 nmol/mL ($P < 0.001$). FFB8 had an MDA concentration of 4.86 nmol/mL, whereas FFB24 at 4.58 nmol/mL did not differ significantly from either FFB8 or FFB16.

Serum SOD activity was highest in FFB16 at 116.35 U/mL, followed by statistically similar intermediate values in FFB24 and FFB8 at 107.82 and 104.28 U/mL, respectively. Control had the lowest SOD activity at 96.50 U/mL ($P < 0.001$). Serum IgA showed a similar pattern. FFB16 had the highest concentration at 1.08 mg/mL, FFB8 and FFB24 had statistically similar intermediate concentrations of 0.94 and 0.97 mg/mL, respectively, and Control had the lowest value at 0.86 mg/mL ($P < 0.001$).

Serum total protein also differed significantly among treatments ($P < 0.001$). FFB16 had the highest mean concentration at 45.32 g/L and was significantly higher than Control at 41.25 g/L and FFB8 at 42.86 g/L. FFB24 had an intermediate concentration of 43.18 g/L and did not differ significantly from FFB16, FFB8, or Control. Overall, FFB16 showed the most favorable combination of fecal bacterial counts and serum oxidative–immune biomarkers, although several responses in FFB24 were statistically intermediate between FFB16 and the lower FFB replacement levels.

DISCUSSION

Diet is widely recognized as a major factor influencing the gut microbial environment and digestive function (Wu *et al*., 2011). The present study showed that partial replacement of the basal diet with a fermented duckweed–banana pseudostem–rice bran blend produced a treatment response that was generally strongest at the 16% dietary dry matter replacement level. This response was not simply a consequence of greater feed intake, because daily feed intake remained comparable among treatments. Instead, the improvement in body weight gain, feed conversion, flock uniformity, digestibility, fecal quality, fecal bacterial counts, and selected oxidative–immune biomarkers suggests that the main benefit of FFB16 may be related to more efficient nutrient utilization and a more stable digestive environment. The weaker response at the 24% replacement level indicates that the benefits observed at 16% did not continue to increase when the replacement level was raised further.

The gut microbial environment of geese can be influenced by dietary composition, fattening duration, breeding pattern, and rearing environment (Chen *et al*., 2018; Wang *et al*., 2016; Feye *et al*., 2020). Recent evidence also indicates that green forage, pasture intake, and dietary fiber can modulate gut microbial structure and host intestinal responses (Chen *et al*., 2018; Liu *et al*., 2022; Ali *et al*., 2022). Nevertheless, information remains limited on fermented local feed blends containing duckweed, banana pseudostem, and rice bran in local grey meat geese. The fermentation process appeared to improve the functional quality of the local feed blend more strongly than its basic nutrient composition. The small changes in crude protein, ether extract, ash, and fiber fractions suggest that fermentation did not fundamentally alter the gross chemical profile of the blend within 5 days. However, the sharp reduction in pH, together with the increase in lactic acid and LAB and the decrease in yeasts and molds, indicates that the blend underwent effective lactic fermentation. This is important because the value of fermented feed does not depend only on crude nutrient content. Organic acids, viable beneficial bacteria, reduced fungal load, partial fiber modification, and improved microbial stability can all influence how the diet behaves in the gastrointestinal tract. In this sense, the fermented blend functioned not merely as a local feed substitute, but as a biologically modified feed ingredient.

The experimental diets were similar in terms of crude protein and metabolizable energy but the fiber fractions increased with increasing level of replacement. Yu *et al*. (1998) found that growing domestic geese responded differently to different sources of dietary fibre. Li *et al*. (2017) subsequently observed that a low-fiber diet reduced body weight and average daily gain in geese, whereas geese fed moderate levels of dietary fiber demonstrated improved growth performance, feed efficiency and nutrient utilization. This is in line with previous results (Hsu *et al*., 2000) where increasing crude fiber from 4 to 12% increased the average daily gain in goslings, but increasing to 16%, further reduced growth and feed conversion. Similarly, Zhang *et al*. (2013) investigated the effects of six graded levels of dietary fiber from 3.00 to 10.50% on the growth performance of Lionhead geese and reported that the growth performance was impaired when the fiber level was excessive, but was more suitable when the fiber level was lower to moderate in growing geese. These results are consistent with the current observation that FFB16 improved performance, whereas the diminished response at FFB24 may be attributed to the increased fiber load that exceeded the optimal range for growth and nutrient

utilization. The growth response is to be interpreted in relation to this dietary structure. It was not possible to ascribe the improved performance of FFB16 to a simple advantage of nutrient concentration since protein and energy were maintained within a narrow range. Instead, the response was more likely due to enhanced nutrient availability, better intestinal fermentation balance, and reduced digestive disturbance. The higher levels of crude fiber, NDF and ADF in FFB24 might have limited the further improvement. Moderate fiber levels may be better tolerated by geese than by many other poultry species. Excessive structural fiber, however, can reduce nutrient density, increase digesta bulk, alter passage dynamics, and dilute the usable energy available for growth (Rokana *et al*., 2024).

This interpretation is strengthened by the growth and feed efficiency responses. At FFB16 the increase in final body weight and daily gain was not associated with a significant increase in feed intake whereas FCR was markedly improved. The pattern indicates that better feed efficiency, not increased appetite, is the primary driver of performance. These responses are consistent with previous studies showing that fermented feed can influence growth performance and cecal microbial communities in geese, while microbial cellulase can improve the utilization of fibrous feed materials (Yan *et al*., 2019; Ye *et al*., 2017). The 24% replacement level still performed better than the control in several indicators but did not maintain the same advantage as FFB16. This indicates that the positive effects of fermentation might be countered by the increased fiber load and decreased dietary nutrient density at levels of inclusion higher than moderate.

The uniformity of the flock is a particularly significant finding of this study since it represents not only average growth, but also the distribution of growth within each pen. The marked reduction in body weight CV and the higher proportion of geese within the uniform weight range in FFB16 indicate that the fermented blend helped reduce growth dispersion among individuals. This is beneficial in practical goose production because a flock of similar body weight is easier to manage, market and harvest at the same time. Geese may have a more stable nutrient supply and less subclinical digestive variation, which may be biological reasons for better uniformity. A better digestibility and fecal quality may decrease the disadvantage of weaker individuals to fluctuating gut conditions and thus reduce the gap between fast- and slow-growing birds (Sugiharto *et al*., 2021).

The digestibility data provide a mechanistic basis for the improved growth and uniformity. The higher values of apparent digestibility of dry matter, crude protein, crude fiber and organic matter in FFB16 indicate that at this level of replacement the geese are able to derive more usable nutrients from the diet. The improvement in crude fiber digestibility is especially significant because the fermented mixture contained fibrous local materials such as banana pseudostem and duckweed. Microbial processing during fermentation can modify plant feed substrates and increase the accessibility of structural carbohydrates, which may contribute to improved utilization of fibrous ingredients (Krishna and Chandrasekaran, 1996; Raghavarao *et al*., 2003; Ye *et al*., 2017). The decrease in digestibility response at FFB24 indicates that the effect has a limit. Once the fiber fraction gets too high, the physical and chemical limitations of the diet can overcome the beneficial modification gained from fermentation. Changes in fecal quality further support the hypothesis that FFB16 improved digestive stability. Also, Xie *et al*. (2026) showed Magang geese fed diets with rice bran and hulls needed longer gastrointestinal transit period than cereal or protein-source feedstuffs. Hence, the lower digestibility response at FFB24 in the present study may partly reflect the higher fiber load of the diet, which could alter digesta passage and reduce the efficiency of nutrient extraction despite fermentation.

Lower fecal pH, lower fecal moisture and lower fecal score indicate a more acidified intestinal output and firmer excreta. Fecal quality is often overlooked in feeding trials but is highly informative because it is a reflection of the combined effects of water balance, intestinal fermentation, nutrient digestion and microbial activity. Lower fecal moisture indicates better water and nutrient absorption; lower fecal pH is consistent with increased organic acid production and a shift toward more favorable fermentation. These changes are also of practical importance under farm conditions, as wetter excreta may deteriorate litter quality, increase ammonia generation and indirectly influence footpad condition, hygiene and disease pressure.

The fecal bacteria profile was in agreement with the responses of fermentation and fecal quality. The increase of LAB and decrease of Coliforms and *E. coli* in FFB16 means that the fermented blend provided more favorable microbial environment in the lower digestive tract. LAB may help gut stability through production of organic acids, reducing the local pH, competing for adhesion sites and limiting proliferation of opportunistic bacteria. Reduction in Coliforms and *E. coli* is particularly meaningful since these bacteria are often associated with poor fecal condition and higher intestinal microbial pressure (Jiang *et al*., 2024). While culture-based bacterial enumeration is not a complete picture of the gut microbiome, it does give practical evidence that the fermented feed blend altered culturable fecal bacteria in a direction that is compatible

with improved gut health. Therefore, the bacterial results must be interpreted as changes in culturable fecal bacteria and not as a complete characterization of the intestinal microbiome.

Serum biomarker responses suggest that the effect of FFB16 was not restricted to the intestinal lumen. Lower MDA and higher SOD activity indicate less lipid peroxidation and better antioxidant defence in geese fed the diet with 16% substitution. This may be due to better nutrient utilization, less stress of intestinal microbes, bioactive compounds of duckweed and rice bran and metabolites of fermentation with antioxidant potential. The higher concentration of serum IgA in FFB16 may indicate a better immune status; however, the mucosal immunity was not directly assessed in this study. Since the gut is a major immune interface in poultry, the improved fecal bacterial balance and reduced oxidative pressure may contribute to a more favorable immune status. Nonetheless, these serum responses should be regarded as systemic markers associated with the dietary treatment, not as direct evidence of a single causal pathway.

The lower feed cost per kg weight gain in FFB16 is also important because the ingredient tested was developed as a local feed resource and not as a purified additive. Economic benefit was obtained both by improved feed conversion and by partial replacement of the basal diet by locally available materials. But the response at FFB24 indicates that decreasing the cost of diet per kilogram of feed does not automatically decrease the cost per kilogram of live weight gain. If performance declines or feed conversion worsens, the perceived savings in ingredient costs can be lost. This means that the economic value of local fermented feed should be determined by biological efficiency and not just ingredient price (Kaewtapee *et al.*, 2026). The 16% replacement level in the present study gave the best balance between reduction in feed cost and growth efficiency.

Our study is not without limitations. The fecal bacterial assessment was done by culture-based enumeration of LAB, Coliforms and *E. coli* and therefore did not present a complete profile of the intestinal microbiome. We did not measure short-chain fatty acids, intestinal morphology, digestive enzyme activity and mucosal immune markers. In addition, serum oxidative–immune biomarkers were measured from one representative goose per pen at the end of the experiment, so these indicators should be interpreted as physiological responses associated with the treatment rather than direct evidence of a specific causal pathway.

Overall, the results indicate that the fermented duckweed-banana pseudostem-rice bran mixture can be used as a functional local feed ingredient for local grey meat geese at the appropriate level. In production, the 16% dietary dry matter replacement level provided the most consistent positive responses in uniformity, digestibility, fecal stability, fecal bacterial counts and oxidative-immune biomarkers. The lower response at 24 % highlights the need to define an optimal level of inclusion rather than assuming that a higher replacement is always better. In terms of nutrition, FFB16 seems to provide adequate levels of fermented substrate and beneficial microbial activity to improve digestive function, without the excess fiber burden associated with the highest level of replacement.

CONCLUSIONS

Partial replacement of the basal diet with a fermented duckweed–banana pseudostem–rice bran blend improved growth performance, feed efficiency, flock uniformity, apparent nutrient digestibility, fecal quality, fecal bacterial counts, and selected serum oxidative–immune biomarkers in local grey meat geese. Among the tested levels, replacing 16% of dietary dry matter produced the most favorable response, with higher final body weight and ADG, lower FCR and feed cost per kg weight gain, better flock uniformity, improved apparent nutrient digestibility, lower fecal moisture and pH, higher fecal LAB, lower Coliforms and *E. coli*, reduced serum MDA, and increased serum SOD and IgA. The weaker response at 24% suggests that excessive replacement may limit the benefits of fermentation, probably because of the higher dietary fiber load. Therefore, among the tested levels, 16% dietary dry matter replacement with this fermented local feed blend appears to be the most suitable level for local grey meat geese raised under smallholder conditions in the Mekong Delta.

ACKNOWLEDGEMENT

We acknowledge the support of time and facilities from Tay Do University (TDU) for this study.

NOVELTY STATEMENT

This study provides novel evidence on the use of a locally sourced fermented duckweed–banana pseudostem–rice bran blend as a partial dietary replacement in local grey meat geese. By simultaneously evaluating growth performance, flock uniformity, apparent nutrient digestibility, fecal quality, culturable fecal bacteria, and selected oxidative–immune biomarkers, the study identified 16% dietary dry matter replacement as the most favorable level among those tested, providing a practical basis for utilizing locally available feed resources in smallholder goose production in the Mekong Delta.

AUTHORS' CONTRIBUTION

PN: Conceptualization, visualization, software and writing review and editing. NTC: Investigation, resources, data curation and writing original draft. NMT: conceptualization, methodology and formal analysis. All authors reviewed and approved the final manuscript.

Ethical approval

At the time the study was conducted, the study institution did not operate an IACUC or equivalent animal ethics board for this category of farm-based nutritional feeding trial; consequently, no institutional approval or waiver number was available. All procedures involving geese were conducted in accordance with the Law on Animal Husbandry No. 32/2018/QH14 issued by the National Assembly of the Socialist Republic of Vietnam. Blood samples were collected only once at the end of the experiment from one representative goose per replicate pen by trained personnel using standard veterinary procedures to minimize stress and discomfort. Excreta and fecal samples were collected without invasive manipulation of the geese. Animal health and welfare were monitored throughout the experimental period.

Generative AI and AI-assisted technology statement

Generative AI tools were not used to generate any scientific content. Any AI assistance was limited to minor language editing, and all ideas, interpretations, and conclusions are solely those of the authors.

Conflict of interest

The authors have declared no conflict of interest.

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