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Phytochemical-Mediated Nutrient Effects of Ensiled Cassava and Sweet Potato Leaves on Transient Growth Responses in Broiler Chickens with Low Protein Diets

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ABSTRACT

Improving the efficacy of low-protein feeding strategies is important for reducing feed costs and nitrogen emissions in broiler production. The present study aimed to evaluate whether a standard-protein broiler diet can be replaced by a low-protein diet containing 18% crude protein (CP) supplemented with ensiled cassava or sweet potato leaf meal. Ensiled cassava leaf (ECL) at 100 g kg^{-1}, ensiled sweet potato leaf (ESPL) at 100 g kg^{-1}, and ECL-ESPL blends (50 g kg^{-1}) were incorporated into both low-protein (18% CP in starter and grower) and standard-protein diets (22.5% CP in starter and 20% CP in grower). The present study used a 2 × 3 factorial design with 108 broiler chickens from day 1 to day 42. The treatment groups included ECL, ESPL, and a 50:50 blend of both protein levels, with 36 chickens in each group. Chemical analysis indicated that ECL exhibited stronger 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical-scavenging activity (IC_{50}: 33.35 versus 88.08 µg mL^{-1}) and higher total phenolics (21.43 versus 12.34 mg Gallic acid equivalent g^{-1}) compared to the ESPL group, whereas ESPL contained higher flavonoids (12.00 versus 2.86 mg Quercetin equivalent g^{-1}) compared to the ECL group. During the dietary transition phase (days 14-21), broiler chickens subjected to the low-protein diet demonstrated superior average daily gain (51.57 versus 44.91 g) and feed conversion ratio (1.78 versus 2.11) in comparison to those fed the standard-protein diet. However, from day 22 onward, broiler chickens fed the standard-protein diet grew faster than those fed the low-protein diet, resulting in higher final body weight (1,887.89 g versus 1,751.67 g, respectively). Carcass yield, dressing percentage, meat cuts, income over feed and chick cost, and return on investment did not differ among protein levels or silage sources. Overall, an 18% CP diet supplemented with either ECL, ESPL, or the ECL plus ESPL blend can replace a standard-protein diet without adverse impact on carcass yield, dressing percentage, commercial meat cuts, or economic returns, despite a moderate reduction in final body weight. These findings supported the feasibility of using low-protein diets for broiler chickens, incorporating locally available ensiled leaf meals as a cost-effective strategy for smallholder producers.

Keywords: Broiler chicken, Ensiled cassava leaf, Ensiled sweet potato leaf, Low-protein diet, Phase-dependent growth, Phytochemical compound

INTRODUCTION

Broiler chicken production faces economic challenges due to fluctuations in feed protein costs. Soybean meal (SBM), which accounts for 30-40% of standard broiler chicken diets, makes up 46% of worldwide SBM consumption and significantly influences fluctuations in feed costs (Ravindran, 2012). Soybean price differed with international commodity markets, climatic conditions, and policy trends (Pardhi et al., 2025). Since feed represents approximately 70% of total production expenses and protein nearly one-third, SBM price instability has direct implications for profitability (Pope et al., 2023). In tropical developing countries, reliance on imported SBM increased producers' vulnerability to global market fluctuations, supply chain disruptions, and trade interruptions (Pexas et al., 2023). Relying on the imported food sources elevates the cost of animal feed, limits consumer access, and affects nutrition and rural livelihoods (FAO, 2018). Identifying locally available, cost-effective protein alternatives that can sustain performance is essential.

Ensiled cassava (*Manihot esculenta*) and sweet potato (*Ipomoea batatas*) leaves are promising alternatives to traditional feed ingredients. Cassava and sweet potato are abundant in Southeast Asia, Africa, and Latin America and contain 18-28% crude protein (CP; dry basis), with amino acid profiles comparable to those of conventional forages (Morgan and Choct, 2016; Laya and Koubala, 2020). In the Philippines, cassava production reached 1.8 million tons annually (Department of Agriculture, 2020), supporting industrial applications in Mindanao (PRDP, 2015), while sweet

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potato processing centers continue to expand in the Visayas (PNA, 2024; VSU, 2025). Despite this expansion, most leaf biomass is discarded (ASEAN Cassava Centre, 2023) rather than being used as a feed resource (Sun et al., 2014; Miranda et al., 2024). Converting this agricultural waste into animal feed improves resource efficiency and supports rural development strategies (Krungsri Research, 2025). Ensiling stabilizes the biomass and reduces antinutritional compounds, thereby enhancing the suitability of the leaves for monogastric animals (Dong et al., 2019; Pereira et al., 2020).

Cassava and sweet potato leaves contain phytochemical compounds, including polyphenols, flavonoids, carotenoids, and alkaloids (Laya and Koubala, 2020). These compounds can modulate metabolism and gut function in poultry (Obianwuna et al., 2024). These bioactive compounds enhance intestinal integrity, mitigate oxidative stress, influence nutrient transporters, and promote beneficial microbiota (Diarra and Anand, 2020). These phytochemicals activate transcription factors such as *Nuclear factor erythroid 2–related factor 2* (*Nrf2*; Huang and Lee, 2017) and Peroxisome proliferator-activated receptors (PPAR; Asiamah et al., 2025), which regulate antioxidant capacity and lipid metabolism (Wang et al., 2023). However, the potential role of phytochemical compounds in supporting broiler chickens under protein restriction remains insufficiently explored.

Reduced protein diets can lower feed costs and nitrogen emissions while maintaining amino acid balance through targeted supplementation (Hristov, 2013). Conventional broiler chicken diets contain 21-23% CP (Costa et al., 2001; Kamely et al., 2020); however, lowering CP to 17-19% can still maintain the broiler chickens' performance if essential amino acid requirements are met (Hilliar et al., 2020; Hofmann et al., 2020). Nonetheless, low-protein feeding induces metabolic adaptations, altering hormone profiles, upregulating hepatic lipogenic genes, and changing feed efficiency and energy use (Pezeshki et al., 2016; Asiamah et al., 2025). Additionally, these diets may trigger hyperphagia and heighten susceptibility to environmental stressors (Aletor et al., 2000).

Interest in phytochemical-rich feed ingredients has increased; however, there is still limited evidence on how growth responses vary across different phases during protein intake restriction. Many feeding trials focused on overall performance but did not observe short-term metabolic changes throughout growth phases. Bioactive-rich silages can reduce oxidative and metabolic stress during adaptation to nutrient limitation, potentially providing temporary performance benefits at specific growth stages. The present study aimed to determine whether a standard-protein broiler chicken diet can be replaced with a low-protein diet (18% CP) supplemented with ensiled cassava or sweet potato leaf meal by evaluating growth performance, carcass traits, and economic returns over 42 days.

MATERIALS AND METHODS

Ethical approval

All animal procedures received approval from the Institutional Animal Care and Use Committee of Agusan del Sur State College of Agriculture and Technology (ASSCAT), Bunawan, Agusan del Sur, Philippines, in accordance with the Philippines Republic Act No. 8485, known as the "Animal Welfare Act of 1998."

Experimental location

The present study was conducted from August 1 to September 20, 2025, at Agusan del Sur State College of Agriculture and Technology (ASSCAT) in Bunawan, Agusan del Sur, Caraga Region XIII, Philippines (8°30′N, 125°44′E; 80 meters above sea level). The site experiences a Type II climate (no dry season with very pronounced maximum rainfall from November to January), with a mean annual precipitation of 3,500 mm and a mean annual temperature of 27.5°C (Philippine Atmospheric, Geophysical and Astronomical Services Administration, 2024).

Ensiled leaf meal preparation

Sweet potato leaves (*Ipomoea batatas*, cultivar TMS 96/1414) and cassava leaves (*Manihot esculenta*, cultivar Golden Yellow) were harvested 60 days after planting from ASSCAT root crops gardens, Philippines. Fresh leaves were stripped from stems, washed with potable water, and chopped into 2-3 cm pieces, then wilted and pre-dried (An and Lindberg, 2004). Two cylindrical silos (200 L plastic barrels) were cleaned with detergent, disinfected with 70% ethanol, air-dried, and prepared with a 5-cm sand layer at the bottom for leachate drainage. Pre-welted chopped leaves were loaded in 10-cm layers and manually compacted to exclude air (Kung Jr, 2009). Silos were sealed with plastic sheeting secured with elastic bands and stored at ambient temperature (28-32°C) for 60 days (Zheng et al., 2022). After fermentation, representative samples (1 kg per silo) were collected from the top, middle, and bottom layers, pooled, oven-dried at 60°C for 48 hours, ground through a 1-mm hammer mill screen, and stored in airtight containers until diet formulation.

Chemical analyses

The 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical-scavenging activity was determined using the DPPH decolorization assay (Blois, 1958) following the approach described by Brand-Williams et al. (1994), with minor modifications for the extraction and reaction conditions. Silage extracts (0.5 g) were prepared in 80% methanol, sonicated for 30 minutes, centrifuged at 3000 × g for 10 minutes, and serially diluted prior to reaction with 0.1 mM DPPH for 30 minutes in the dark (Siroha and Sandhu, 2017). Absorbance was measured at 517 nm, and IC_{50} values were calculated from dose-response curves, consistent with common reporting practice for DPPH assays.

Total phenolic content was quantified using the Folin-Ciocalteu method (Martins et al., 2021). The extract (20 µL) was mixed with Folin-Ciocalteu reagent (100 µL) and 7.5% Na_2CO_3 (80 µL), incubated for 30 minutes at 25°C, and the absorbance was read at 765 nm. Results of the phenolic content were expressed as mg gallic acid equivalents (mg Gallic acid equivalent g^{-1} dry weight) using a 0-500 µg mL^{-1} standard curve.

Total flavonoid content was determined using the aluminum-chloride colorimetric method (Ribarova et al., 2005). The extract (50 µL) was mixed with 10% $AlCl_3$ (10 µL), 1 M potassium acetate (10 µL), and distilled water (130 µL), incubated for 30 minutes at 25°C, and the absorbance was read at 415 nm. Values were expressed as mg quercetin equivalents (mg QE g^{-1} dry weight) using a 0-100 µg mL^{-1} standard curve.

Qualitative phytochemical screening of the methanolic extracts was conducted using standard colorimetric assays. These phytochemical screening included tests for alkaloids (Dragendorff's and Mayer's reagents; Okpo et al., 2001), phenols (ferric chloride test; Runbanza et al., 2003), tannins (gelatin test; Obreque-Slier et al., 2010), terpenoids (Salkowski test; Malik, 2017), steroids (Liebermann-Burchard test; Noormazlinah et al., 2019), saponins (foam test; Yousif et al., 2021), and flavonoids (Shinoda test; Qasim and Al-Salman, 2022).

Experimental diets

Six experimental diets were formulated utilizing a corn-soybean meal basal diet at two levels of CP. The standard-protein diet contained 22.5% CP for the starter phase (days 14-21) and 20% CP for the grower phase (days 22-42). Additionally, a low-protein diet (LP) comprising 18% CP was implemented across both phases (Table 1). At each protein level, diets included one of three silage treatments, including 100 g kg^{-1} ensiled sweet potato leaf (ESPL), 100 g kg^{-1} ensiled cassava leaf (ECL), or a 50:50 blend of ESPL and ECL. All diets were isocaloric (Metabolizable energy at 3000 kcal kg^{-1}) and supplemented with crystalline amino acids (L-lysine HCl, DL-methionine, L-threonine) to meet the digestible amino acid requirements outlined by NRC (1994). Additionally, a vitamin-mineral premix (0.25%) was provided. Ensilaged materials were incorporated after 60 days of fermentation. All diets were mixed in a horizontal paddle mixer for 15 minutes, pelleted through a 3-mm die, and stored in sealed polyethylene bags. The inclusion rate of 100 g kg^{-1} (10%) was selected based on previous studies that demonstrated leaf meal at 5-15% of the diet sustains acceptable palatability and nutrient balance without adversely affecting feed intake in broiler chickens (Iheukwumere et al., 2008).

Table 1. Standard chicken starter, grower, and low-protein diets based on corn and soy for broiler chickens

Nutrients	Standard		Low protein
	Starter (Day 14-21)	Grower (Day 22-42)	(Day 14-42)
Crude protein	Min. 22.50%	Min. 20.00%	Min. 18.00%
Crude fat	Min. 4.00%	Min. 3.00%	Min. 6.00%
Crude fiber	Max. 3.50%	Max. 5.00%	Max. 5.50%
Moisture	Max. 12.00%	Max. 12.00%	Max. 12.00%
Calcium	0.85 – 1.15%	0.90 – 1.10%	0.80 – 1.10%
Phosphorus	Min. 0.70%	Min. 0.70%	Min. 0.70%

Each diet contained 0.25 kg of vitamin premix: Vitamin A, 10,000 IU; Vitamin D_3, 2,000 IU; Vitamin E, 10 mg; Vitamin K_3, 2 mg; Vitamin B_1, 1 mg; Vitamin B_2, 4 mg; Vitamin B_{12}, 0.01 mg; Niacin, 20 mg; Biotin, 0.05 mg; Folic acid, 0.5 mg; Pantothenic acid, 10 mg; Choline chloride, 300 mg; Manganese, 60 mg; Copper, 5 mg; Magnesium, 300 mg; Iron, 40 mg; Zinc, 50 mg; Iodine, 0.3 mg; Selenium, 0.15 mg. Min: Minimum; Max: Maximum

Experimental design and animals

The trial utilized a 2×3 factorial arrangement in a randomized complete block design (RCBD), featuring six treatment groups across three blocks. Each experimental unit contained six broiler chickens. A total of 108-day-old Ross 308 broiler chickens of mixed sex, each with an initial body weight (BW) of 40 ± 2 g, were obtained from a commercial source hatchery. Broiler chickens were kept for 14 days in a climate-controlled environment at 32-34°C and 60-70% relative humidity, with *ad libitum* access to commercial booster feed and water. At day 14, chickens were randomly assigned to treatment groups with balanced initial BW. To evaluate growth performance, the experimental period was divided into four weekly intervals, including the starter phase (day 14-21), early grower phase (day 22-28), mid-grower phase (day 29-35), and late grower phase (day 36-42).

Broiler chickens were kept in raised wire-floor cages measuring 50 × 50 × 30 cm within an open-sided house equipped with adjustable tarpaulin curtains. Each cage contained six chickens, a hanging feeder with a 2 kg capacity, and a nipple drinker. The photoperiod was 24 hours of light from day 14 to day 21, then changed to 23 hours of light and 1 hour of darkness from day 22 onwards. Average ambient conditions were 28.5 ± 2.1°C and 75 ± 5% relative humidity. Broiler chickens were vaccinated in accordance with the farm's health program. Newcastle disease vaccination was administered once during the experimental period, on day 7, using a live LaSota strain vaccine (VAKSINDO, Indonesia) via the ocular route, and no booster dose was administered during the 42-day trial. Infectious bronchitis vaccination was administered on day 7 via the intranasal route using Bronchivac (Lloyd Laboratories, Philippines). Infectious bursal disease (Gumboro) vaccination was administered on day 14 via intramuscular injection using Gumboro vaccine (Biovac, Philippines).

Growth performance measurements

Individual BW was recorded on days 14, 21, 28, 35, and 42 using a digital scale (0.1 g precision; Ohaus Scout Pro SP6001, China). Average daily gain (ADG, $g\ d^{-1}$) for each interval was calculated by using Formula 1.

$$\text{ADG} = \frac{\text{BW}^2 - \text{BW}^1}{d^2 - d^1} \qquad \text{(Formula 1)}$$

where BW2 and BW1 indicate the body weights on days 1 (D1) and 2 (D2).

Feed intake (FI) was calculated according to Formula 2.

FI = feed offered - residue – spillage (Formula 2)

The feed conversion ratio (FCR) was calculated using Formula 3.

$$\text{FCR} = \frac{\text{FI}}{(\text{BW}^2 - \text{BW}^1)} \qquad \text{(Formula 3)}$$

Carcass characteristics and meat cuts

On day 42, two broiler chickens from each cage were selected to represent the average BW of the cage. Chickens were fasted for 12 hours, but water was provided. Chickens were then weighed, manually stunned, and euthanized via jugular vein severance. After bleeding for three minutes, carcasses were scalded at 60°C for two minutes, mechanically defeathered, and manually eviscerated. Warm carcass weight was measured immediately after slaughter, and carcass yield was determined by dividing warm carcass weight by live BW (Faria et al., 2011). Dressing percentage was calculated as the eviscerated carcass weight divided by the live BW. Chilled carcasses were then dissected into breasts, thighs, drumsticks, and wings, each weighed and expressed as a percentage of the chilled carcass weight.

Economic analysis

For the economic analysis, a 2 × 3 factorial arrangements generated six diet–silage combinations, including LP plus ECL, LP plus ESPL, LP plus ECL (ESPL [50:50]), SD plus ECM, SD plus ESP, and SD plus ECL (ESPL [50:50]). These combinations were evaluated to identify the treatment that yielded the highest income over feed and chick cost (IOFCC) and return on investment (ROI). Economic performance was evaluated using IOFCC and ROI. Costs covered day-old chicks and feed ingredients priced in August to September 2025 (Butuan City, Philippines). Revenue was determined based on the market price of live broiler chickens. The IOFCC was calculated according to Formula 4 (Zulfan and Zulfikar, 2020).

Income over feed and chick cost = Gross sales - (Feed cost + broiler chickens cost) (Formula 4)

Statistical analysis

Data were analyzed using IBM SPSS Statistics 25. The experimental unit for growth performance was the cage (n = 6 broiler chickens), and the experimental unit for carcass traits was the individual broiler chicken (n = 12 broiler chickens per treatment). Normality and homogeneity of variance were verified using Shapiro-Wilk and Levene’s tests, respectively. A two-way ANOVA assessed the main effects of diet (SP diet versus LP diet) and silage type (ESPL, ECL, ESPL with ECL), as well as their interaction. When a significant main effect or interaction was detected, Tukey's HSD test was applied to compare all treatment means and identify differences between specific groups. Results were presented as means ± standard deviation (SD), with significance declared at $p < 0.05$.

RESULTS

Antioxidant capacity and phytochemical composition

The ECL group had significantly higher DPPH radical scavenging activity (IC_{50} = 33.35) than the ESPL group (IC_{50} = 88.08; Table 2). The ECL group contained greater total phenolic content (21.43 versus 12.34 mg Gallic acid equivalent g^{-1}) compared to the ESPL group, whereas ESPL had higher flavonoid content (12.00 versus 2.86 mg Quercitin equivalent g^{-1}) compared to the ECL group. Qualitative phytochemical screening indicated the presence of alkaloids, flavonoids, phenols, steroids, and saponins in both silages, with differences in band intensity and relative abundance (Table 3).

Table 2. Antioxidant property, phenolic and flavonoid content of leaf silages

Sample	IC 50 (ppm)	Gallic acid equivalent (mg G^{-1})	Quercetin equivalent (mg G^{-1})
Ensiled cassava leaf meal	33.35 ± 4.91^a	21.43 ± 0.40^b	2.86 ± 1.10^a
Ensiled sweet potato leaf meal	88.08 ± 4.37^b	12.34 ± 0.04^a	12.00 ± 0.01^b
P-value	0.001	0.001	0.001

[a,b] Means within a column with different superscript letters differ significantly ($p < 0.05$). Data are presented as mean ± standard deviations.

Table 3. Qualitative phytochemical composition of ensiled leaves

Sample	Alkaloids	Flavonoids	Phenols	Saponins	Tannins	Steroids	Terpenoids
Ensiled cassava leaf meal	+++	+++	+++	++	+	+++	++
Ensiled sweet potato leaf meal	++	+++	+++	++	++	+++	+

+++: Strong presence, ++: Moderate presence, +: Weak presence

Growth performance

Growth responses exhibited a clear phase-dependent pattern (Table 4). Diet type significantly affected BW. During the transition feeding period (days 14-21), broiler chickens that were fed the LP diet gained higher BW (720.78 g) than those fed the SP diet (662.76 g; $p < 0.05$). However, from day 28 onward, broiler chickens that were fed the SP diet exhibited superior performance compared to those fed the LP diet, with significantly higher BW observed at days 28, 35, and 42 ($p < 0.05$). Final BW at day 42 was higher in broiler chickens fed the SP diet (1887.89 g) compared to those fed the LP diet (1751.67 g). The type of silage and the interaction between diet and silage exhibited no significant effect on BW at any measured time point or sampling time ($p > 0.05$).

The boiler chickens fed the LP diet demonstrated significantly higher ADG versus the SP diet on days 14 to 21 (51.57 versus 44.91 g d^{-1}; $p < 0.05$). From day 22 onward, broiler chickens fed the SP diet demonstrated superior compensatory growth, with significantly higher ADG during days 29-35 compared to the LP diet ($p < 0.05$). While ADG during days 36-42 did not differ significantly between diets ($p > 0.05$), it was notable that from days 14 to 42 of the study period, ADG was significantly higher in the SP diet than in the LP diet ($p < 0.05$). Furthermore, silage type had no significant effect on ADG at any growth phase. Weight gain demonstrated no significant differences across silage types or in the interaction between diet and silage type ($p > 0.05$).

There was no statistically significant difference in feed intake among the diets ($p > 0.05$), except during days 36-42 when broiler chickens fed the LP diet exhibited higher feed consumption (1,188.88 g) compared to those fed the SP diet (1,129.80 g). Overall feed intake from days 14-42 exhibited no significant differences across the dietary groups ($p > 0.05$). Additionally, there were no significant effects of silage type or the interaction between diet and silage type on BW at any sampling time ($p > 0.05$). The broiler chickens fed the LP diet exhibited a significantly improved FCR over the SP diet during days 14-21 (1.78 versus 2.11; $p < 0.05$). The chickens fed the SP diet demonstrated a more efficient FCR than LP diet during days 22-28 (1.92 versus 2.91; $p < 0.05$). No statistically significant differences were observed across any growth phases ($p > 0.05$). Additionally, silage type did not significantly influence FCR in any phase ($p > 0.05$).

Table 4. Phase-specific growth performance of broiler chickens fed low-protein and standard-protein diets supplemented with ensiled cassava and sweet potato leaves

Data source	Protein level		Ensiled leaf source			P value		
	LP Diet	SP Diet	100g ESPL	100g ECL	50g + 50g ESPL and ECL	Diet	Silage	Diet $^{\times}$ Silage
Body weight at day 14 (g)	359.76 ± 25.42^{a}	348.36 ± 35.08^{a}	339.73 ± 31.61^{a}	357.21 ± 21.60^{a}	365.23 ± 35.29^{a}	0.452^{ns}	0.379^{ns}	0.516^{ns}
Day 14-21								
Body weight (g)	720.78 ± 44.58^{b}	662.76 ± 43.73^{a}	681.09 ± 48.78^{a}	699.73 ± 29.42^{a}	694.47 ± 76.11^{a}	0.010*	0.717^{ns}	0.073^{ns}
ADG (g)	51.57 ± 3.61^{b}	44.91 ± 5.17^{a}	48.76 ± 3.29^{a}	48.93 ± 3.52^{a}	47.03 ± 8.81^{a}	0.005*	0.681^{ns}	0.081^{ns}
Feed intake (g)	642.85 ± 25.75^{a}	655.55 ± 20.75^{a}	647.61 ± 21.50^{a}	647.61 ± 29.50^{a}	652.38 ± 23.32^{a}	0.266^{ns}	0.919^{ns}	0.162^{ns}
FCR (g feed: g gain)	1.78 ± 0.14^{a}	2.11 ± 0.29^{b}	1.90 ± 0.16^{a}	1.90 ± 0.18^{a}	2.04 ± 0.24^{a}	0.012*	0.489^{ns}	0.319^{ns}
Day 22-28								
Body weight (g)	1,049.95 ± 75.27^{a}	1,144.25 ± 70.49^{b}	1,056.78 ± 58.84^{a}	1,139.85 ± 102.51^{a}	1,094.66 ± 83.05^{a}	0.014*	0.162^{ns}	0.563^{ns}
ADG (g)	47.02 ± 13.36^{a}	68.78 ± 11.32^{b}	53.66 ± 14.54^{a}	62.87 ± 16.53^{a}	57.17 ± 19.50^{a}	0.005*	0.499^{ns}	0.790^{ns}
Feed intake (g)	912.69 ± 103.12^{a}	900.00 ± 52.48^{a}	864.28 ± 119.09^{a}	933.33 ± 23.32^{a}	921.42 ± 79.64^{a}	0.746^{ns}	0.324^{ns}	0.441^{ns}
FCR (g feed: g gain)	2.91 ± 0.64^{b}	1.92 ± 0.40^{a}	2.41 ± .054^{a}	2.28 ± 0.74^{a}	2.56 ± 0.95^{a}	0.003*	0.705^{ns}	0.485^{ns}
Day 29-35								
Body weight (g)	1,369.56 ± 90.25^{a}	1,521.33 ± 83.75^{b}	1,413.17 ± 69.83^{a}	1,463.17 ± 115.19^{a}	1,460.00 ± 158.00^{a}	0.005*	0.603^{ns}	0.758^{ns}
ADG (g)	45.65 ± 7.37^{a}	53.86 ± 7.79^{b}	50.91 ± 8.26^{a}	46.18 ± 5.52^{a}	52.19 ± 11.04^{a}	0.050*	0.416^{ns}	0.746^{ns}
Feed intake (g)	1,028.57 ± 94.76^{a}	1,050.79 ± 60.23^{a}	990.47 ± 71.52^{a}	1,059.52 ± 62.86^{a}	1069.04 ± 87.47^{a}	0.567^{ns}	0.221^{ns}	0.880^{ns}
FCR (g feed: g gain)	3.31 ± 0.74^{a}	2.84 ± 0.47^{a}	2.84 ± 0.53^{a}	3.32 ± 0.51^{a}	3.07 ±0. 87^{a}	0.156^{ns}	0.480^{ns}	0.737^{ns}
Day 36-42								
Body weight (g)	1,751.67 ± 72.72^{a}	1,887.89 ± 98.71^{b}	1,793.50 ± 56.73^{a}	1,864.17 ± 140.87^{a}	1,801.67 ± 118.75^{a}	0.005*	0.310^{ns}	0.290^{ns}
ADG (g)	54.58 ± 6.56^{a}	52.36 ± 8.97^{a}	54.33 ± 9.29^{a}	57.28 ± 4.67^{a}	48.80 ± 7.04^{a}	0.535^{ns}	0.173^{ns}	0.388^{ns}
Feed intake (g)	1,188.88 ± 16.66^{b}	1,164.81± 24.21^{a}	1,166.66 ± 27.88^{a}	1,177.77 ± 13.60^{a}	1,186.11 ± 26.70^{a}	0.033*	0.314^{ns}	0.649^{ns}
FCR (g feed: g gain)	3.04 ± 0.27^{a}	3.26 ± 0.61^{a}	3.15 ± 0.64^{a}	2.95 ± 0.25^{a}	3.36 ± 0.42^{a}	0.312^{ns}	0.329^{ns}	0.236^{ns}
Day 14-42								
ADG (g)	49.71 ± 2.43^{a}	54.98 ± 3.28^{b}	51.92 ± 2.50^{a}	53.81 ± 4.71^{a}	51.30 ± 4.37^{a}	0.002*	0.318^{ns}	0.434^{ns}
Feed intake (g)	3,773.01 ± 208.12^{a}	3,771.16 ± 83.94^{a}	3,669.04 ± 183.41^{a}	3,818.25 ± 105.09^{a}	3,828.96 ± 129.06^{a}	0.980^{ns}	0.163^{ns}	0.481^{ns}
FCR (g feed: g gain)	2.76 ± 0.27^{a}	2.53 ± 0.14^{a}	2.58 ± 0.14^{a}	2.61 ± 0.23^{a}	2.76 ± 0.32^{a}	0.053^{ns}	0.370^{ns}	0.498^{ns}

^{a,b} Means within a row with different superscript letters differ significantly ($p < 0.05$), *Significant at 0.05 level, ^{ns}Not significant at 0.05 level, LP: Low protein; SP: Standard diet; ESPL: Ensiled sweet potato leaves; ECL: Ensiled cassava leaves; Diet $^{\times}$ Silage: Diet and silage interaction. Data are presented as mean ± standard deviations.

Table 5. Effect of protein level and ensiled leaf source (mean ± SD) on carcasses and commercial cuts of broiler chickens

Data source	Protein level		Ensiled leaf source			P value		
	LP Diet	**SP Diet**	**100g ESPL**	**100g ECL**	**50g + 50g ESPL and ECL**	**Diet**	**Silage**	**Diet $^{\times}$ Silage**
Warm carcass (g)	1,616.67 ± 166.82^{a}	1,684.33 ± 153.04^{a}	1,633.83 ± 110.09^{a}	1,712.00 ± 187.33^{a}	1,605.67 ± 177.92^{a}	0.395^{ns}	0.522^{ns}	0.379^{ns}
Carcass yield (%)	81.51 ± 2.98^{a}	81.85 ± 2.54^{a}	80.72 ± 2.39^{a}	82.66 ± 3.09^{a}	81.66 ± 2.47^{a}	0.808^{ns}	0.539^{ns}	0.890^{ns}
Drumstick (g)	13.25 ± 1.41^{a}	13.57 ± 1.16^{a}	13.70 ± 0.66^{a}	12.85 ± 1.44^{a}	13.69 ± 1.24^{a}	0.597^{ns}	0.422^{ns}	0.669^{ns}
Thighs (g)	14.94 ± 1.98^{a}	14.21 ± 1.19^{a}	14.41 ± 1.43^{a}	14.56 ± 2.03^{a}	14.75 ± 1.47^{a}	0.412^{ns}	0.946^{ns}	0.966^{ns}
Breast (g)	26.72 ± 3.22^{a}	29.04 ± 3.76^{a}	26.86 ± 3.78^{a}	29.03 ± 3.03^{a}	27.76 ± 5.12^{a}	0.183^{ns}	0.570^{ns}	0.073^{ns}
Back (g)	18.09 ± 3.23^{a}	17.74 ± 1.60^{a}	17.48 ± 2.41^{a}	19.02 ± 3.24^{a}	17.25 ± 1.54^{a}	0.795^{ns}	0.501^{ns}	0.874^{ns}
Neck (g)	6.99 ± 1.01^{a}	7.06 ± 0.74^{a}	7.71 ± 0.74^{a}	6.51 ± 0.46^{a}	6.86 ± 0.95^{a}	0.862^{ns}	0.070^{ns}	0.822^{ns}
Wings (g)	13.42 ± 2.33^{a}	12.38 ± 2.27^{a}	14.01 ± 2.71^{a}	11.51 ± 1.64^{a}	13.19 ± 3.28^{a}	0.330^{ns}	0.171^{ns}	0.035*
Feet (g)	6.35 ± 0.82^{a}	5.70 ± 0.77^{a}	6.22 ± 0.87^{a}	5.81 ± 0.86^{a}	6.05 ± 0.89^{a}	0.147^{ns}	0.739^{ns}	0.919^{ns}

^{a} Means ± standard deviations within a row with different superscript letter differ significantly ($p < 0.05$), ^{ns}Not significant at 0.05 levels, LP: Low protein; SP: Standard diet; ESPL: Ensiled sweet potato leaves; ECL: Ensiled cassava leaves; Diet ^{x} Silage: Diet and silage interaction

Carcass characteristics and meat cut yields

Carcass traits did not differ significantly among diet types or silage types ($p > 0.05$; Table 5). Warm carcass weight did not differ significantly among broiler chickens fed the LP diet (1,616.67 g) and those fed the SP diet (1,684.33 g; $p > 0.05$). Dressing percentage was similar between LP and SP diets (81.51% versus 81.85%) and did not differ among silage treatment groups (range: 80.72%-82.66%; $p > 0.05$). There was no significant interaction between the diet and silage for warm carcass weight or dressing percentage ($p > 0.05$). Similarly, the relative yields of the breast, thighs, and drumsticks exhibited no statistically significant differences in response to diet type, silage type, or the interaction between diet and silage type ($p > 0.05$). The interaction between diet and silage significantly affected wing weight ($p < 0.05$), even though neither diet type nor silage type had significant effects on wing weight ($p > 0.05$).

Economic viability

Economic analysis indicated no significant differences among treatments ($p > 0.05$; Table 6). Production cost per broiler chicken ranged from 956.89 to 1043.03 PHP (16.00 to 18.00 USD), while broiler chicken carcass sales revenue ranged from 1,796.34 to 2091.96 PHP (29.00 to 34.00 USD). The IOFCC ranged from 766.54 to 1,048.92 PHP (13.00 to 18 USD), and the ROI ranged from 74.75 to 106.19%. None of the economic parameters exhibited significant differences concerning diet type, silage type, or the interaction between diet and silage ($p > 0.05$). Although (SP plus ECL) treatment produced the highest numerical IOFCC at 1,048.92 PHP (18.00 USD), the LP plus ECL and ESPL produced the lowest IOFCC at 766.54 PHP (13.00 USD), these differences were not statistically significant ($p > 0.05$).

Table 6. Economic viability of ensiled leaf supplementation diets for broiler chickens

Source of variations	Production cost (PHP)	Broiler carcass sales (PHP)	Income over feed and chick cost (PHP)	ROI
LP + ECL	1005.80 ± 43.95^{a}	1914.12 ± 306.03^{a}	908.31 ± 307.63^{a}	90.49 ± 30.82^{a}
LP + ESPL	956.89 ± 72.13^{a}	1964.03 ± 178.74^{a}	1007.14 ± 200.88^{a}	106.19 ± 26.04^{a}
LP + ECL and ESPL	1029.79 ± 44.19^{a}	1796.34 ± 68.12^{a}	766.54 ± 101.17^{a}	74.75 ± 12.39^{a}
SP + ECL	1043.03 ± 12.47^{a}	2091.96 ± 52.23^{a}	1048.92 ± 57.82^{a}	100.59 ± 6.23^{a}
SP + ESPL	1008.44 ± 29.33^{a}	1859.13 ± 35.69^{a}	850.68 ± 55.15^{a}	84.48 ± 7.47^{a}
SP + ECL and ESPL	1023.75 ± 18.05^{a}	1960.92 ± 288.76^{a}	937.16 ± 304.10^{a}	91.86 ± 31.15^{a}
P value (Diet type)	0.186^{ns}	0.395^{ns}	0.597^{ns}	0.861^{ns}
P value (Silage type)	0.162 ^{ns}	0.522^{ns}	0.564^{ns}	0.554^{ns}
P value (Diet type × Silage type)	0.482^{ns}	0.379^{ns}	0.333^{ns}	0.295^{ns}

^{a} Means ± standard deviations within a column with different superscript letter differ significantly ($p < 0.05$), ^{ns}Not significant at 0.05 levels, LP: Low protein, SP: Standard diet, ESPL: Ensiled sweet potato leaves, ECL: Ensiled cassava leaves, IOFCC: Income over feed and chick cost, ROI: Return on investment

DISCUSSION

Antioxidant and phytochemicals

The ECL group exhibited a 2.6-fold increase in DPPH radical-scavenging activity and higher total phenolic content than the ESPL group. This pattern was consistent with the findings of Boukhers et al. (2024), who reported increased polyphenol content and strong nitric oxide-scavenging activity in cassava leaf-enriched cassava flour. The positive association between phenolic level and antioxidant activity supports the role of phenolic compounds as major radical scavengers by forming resonance-stabilized phenoxyl radicals (Dudonné et al., 2009). Cassava leaves contain gallic acid, gallocatechin, catechin, chlorogenic acid, and epigallocatechin, with catechin identified as the main compound, potentially explaining the increased antioxidant activity observed in the ECL group (Fachriyah et al., 2023).

In contrast, the ESPL group had a 4.2-fold higher flavonoid content (12.00 versus 2.86 mg quercetin equivalent g^{-1}). Sweet potato leaves contain 0.65-2.76% flavonoids on a dry-weight basis, with quercetin accounting for more than 79% of total flavonoids (Ojong et al., 2008). Further analysis revealed the presence of caffeoylquinic acid derivatives and different flavonoids in sweet potato leaves (Zhang et al., 2019). Differences among different varieties can lead to phenolic contents up to 5.35 g gallic acid equivalent 100 g^{-1} DW and DPPH IC_{50} values that exceed those of ascorbic acid (Hue et al., 2012). The compositional contrast highlighted differences in antioxidant potential. Cassava leaves primarily focused on phenolic hydrogen donation, while sweet potato leaves indicated flavonoid-driven electron transfer and metal chelation activities.

Ensiling preserved the antioxidant capacity associated with phytochemicals after 60 days of fermentation, while also reducing the phytochemical losses often observed in sun-dried plant material. Evidence from *Moringa oleifera* indicated

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that silage had a higher antioxidant capacity, ranging from 200 to 250 counts per minute (CPM), compared to fresh or dried material, which measured 50 to 75 CPM, respectively. This increase may be due to the fermentation-related accumulation of low-molecular-weight metabolites (Cohen-Zinder et al., 2017; Zhang et al., 2019). Additionally, studies on plant drying have reported declines in phenolics and related bioactive compounds during drying processes, including sun drying, leading to decreased antioxidant activity (Hossain et al., 2021; Nowak et al., 2025). Fermentation can stabilize phytochemicals by limiting enzymatic oxidation and reducing anti-nutritional factors (Shiferaw and Augustin, 2020). He et al. (2019) indicated that ensiling mulberry leaves maintained total flavonoid levels between 57 and 76 mg rutin equivalents per g of DM and indicated DPPH scavenging activity exceeding 116 mg trolox equivalents per gram of DM. Meanwhile, Angthong et al. (2007) observed that leucaena leaf silage increased β-carotene from 88.50 to 99.92-120.28 mg per kg DM, a 13-36% increase, and decreased mimosine content by over 91%. The low pH levels during ensiling (4.4-4.5) suppress polyphenol oxidase activity (Yoruk and Marshall, 2003; Pellicer et al., 2021). Lactic acid bacteria inhibit spoilage microorganisms (Mokoena et al., 2020), while limited oxygen exposure further reduces oxidative losses (Oladosu et al., 2016).

The antioxidant capacity of the ECL and ESPL groups underscored their role as effective functional feed additives that enhance gut health and physiological functions in broiler chickens. Polyphenol compounds enhance the integrity of the intestinal barrier by inhibiting nuclear factor kappa-light-chain-enhancer of activated B cells (NF-κB)-mediated inflammation, reducing pro-inflammatory cytokine activity, and upregulating tight junction proteins such as occludin, claudin-1, and ZO-1 (Kikusato, 2021; Oni and Oke, 2025). Activation of *Nrf2* pathway enhances endogenous antioxidant defense mechanisms by upregulating the expression of superoxide dismutase, catalase, and glutathione peroxidase (Obianwuna et al., 2024). The prebiotic components found in tropical leaves support healthy gut microbes and boost the production of short-chain fatty acids (Nogal et al., 2021; Asghar et al., 2025). Modulation of anti-inflammatory signaling (NF-κB), activation of Nrf2-mediated antioxidant enzymes, and the production of short-chain fatty acids by the microbiota provide mechanistic evidence for enhanced resilience during dietary changes or environmental stress.

Growth response

The phase-specific growth pattern in chickens receiving the LP diet from days 14 to 21 indicated a shift from metabolic efficiency to substrate availability as the primary factor influencing growth. This reduction in protein levels in broiler chickens fed the LP diet indicated that short-term performance was limited more by metabolic load during adaptation than by the total amount of CP reduction.

Reducing dietary CP to 18% lowers the metabolic load by decreasing heat generated from amino acid breakdown and reducing the energy needed for nitrogen excretion (Swennen et al., 2007; Chrystal et al., 2019). Protein oxidation requires remarkable energy (Lopez and Leeson, 2005; Sutton et al., 2023), and diets high in protein increase the workload on the liver and kidneys for uric acid production (Such et al., 2021) and exacerbate oxidative stress linked to nitrogen metabolism (Naseem and King, 2018). Disposing of nitrogen in poultry requires energy due to deamination and uric acid production, which increases heat increment and reduces the net energy available for growth van Milgen (2021). As indicated by van Milgen (2021), the energetic cost was enough to affect feed efficiency when CP supply exceeded amino acid requirements. During the adaptation period (days 14-21), these energy savings allowed broiler chickens fed the LP diet to use nutrients more for protein growth than for maintenance.

The early growth benefit observed in broiler chickens fed the LP diet likely resulted from a reduced metabolic load associated with reduced dietary protein, rather than from a specific phytochemical effect. It is important to note that the present study did not include a silage-free control treatment; consequently, it is not possible to attribute observed performance outcomes directly to leaf phytochemicals. The current results confirmed that all three silage sources performed similarly at 100 g kg^{-1}, and broiler chickens fed the LP diet with leaf silage achieved market-acceptable results similar to those fed the SP diet. Polyphenols and flavonoids present in ensiled leaves are known to upregulate amino acid transporters, such as *PepT-1*, *CAT1*, and *y+LAT1*, improving absorption efficiency of limiting amino acids under marginal supply conditions (Désert et al., 2018; Wang et al., 2023; Obianwuna et al., 2024). Nevertheless, it cannot be confirmed whether these mechanisms were active in the current study without a comparison to a control diet.

Broiler chickens fed the LP diet exhibited endocrine changes characteristic of reduced dietary protein intake. Protein restriction increases growth hormone (GH) secretion, suppresses circulating thyroid hormones (T_3, T_4), and lowers Insulin-like growth factor 1 (IGF-I) concentrations, reflecting shifts in metabolic regulation during amino acid limitation (Tesseraud et al., 2008). These changes occurred rapidly, within 3-7 days after reducing protein intake. Broiler chickens fed LP diets demonstrated altered hepatic expression of lipogenic genes (*ACSL6*, *PNPLA3*, *ME1*), which affect energy distribution (Désert et al., 2018; Asiamah et al., 2025). Overall, the combination of a lower metabolic load, phytochemicals, and endocrine regulation created a synergistic advantage for broiler chickens fed the LP diet during days 14-21. Polyphenol compounds tended to mitigate oxidative stress associated with dietary transition. The transition from communal brooding to experimental diets induces physiological stress, leading to intestinal remodeling and fluctuations in digestive enzyme activity (Uni et al., 2003; Gous, 2018). Polyphenol compounds reduce lipid peroxidation and oxidative markers under stress conditions (Khodayari and Shahria, 2014; Sierżant et al., 2021). Broiler chickens on the LP diet exhibited reduced baseline metabolic stress, and the antioxidant activity of the ensiled leaves was sufficient to maintain redox balance (Yang et al., 2009; De Cesare et al., 2019). It was hypothesized that broiler chickens fed the SP diet (22.5% CP) experienced greater oxidative stress due to the higher protein load, thereby limiting the net benefit from the same polyphenol intake.

From day 22 onward, broiler chickens entered a rapid-growth phase characterized by increased muscle protein accumulation. While broiler chickens fed the LP diet maintained efficiency benefits, including reduced metabolic load, endocrine adaptations, and phytochemical support, these advantages were insufficient to overcome the 18% CP constraint. During the grower phase of this period, feed intake increased in line with the Cobb 500 performance objectives (Cobb-Vantress, 2022). Daily intake increased from 125-131 g/day at day 21 to 194-204 g/day at day 35. With a starter diet containing 22.5% CP (days 14-21) and a grower diet with 20% CP (days 22-42), the estimated daily CP intake increased from 28-29.5 g/day to about 38.8-40.8 g/day. Benahmed et al. (2023) and Son et al. (2023) reported similar increases in feed intake with age during the grower phase, with the most pronounced increase occurring between weeks three and five. This period is characterized by rapid lean tissue growth and higher amino acid needs. The steady feed intake pattern indicated that the slower growth during the LP diet was due to an insufficient amino acid density in the feed. The LP diet, therefore, failed to meet essential amino acid requirements during peak anabolic demand. Similar findings were commonly reported, indicating that even with crystalline amino acids supplementation, reduced-protein diets cannot sustain optimal growth during protein deposition periods (Chrystal et al., 2019; Hilliar et al., 2020). Consequently, broiler chickens fed the LP diet demonstrated compensatory growth beginning on day 22. Following adaptation, these chickens benefited from greater substrate availability (20% CP) and enhanced capacity to utilize higher levels of amino acids. The compensatory earlier reduction in growth during days 14-21 indicated that early growth suppression in broiler chickens fed the SP diet (days 14-21) was relatively more than absolute, influenced by temporary metabolic adjustments. Once adapted, broiler chickens fed the SP diet exhibited higher ADG and BW during days 29-35. Adequate amino acid supply and complete metabolic adaptation served as the primary factors driving this improvement.

Overall, the current results indicated that the effectiveness of phytochemicals depends on the context. Ensilaged cassava and sweet potato leaves offered notable benefits during stress, transitional, or low-nutrition periods. However, these treatments could not replace the need for adequate amino acid supply during the peak anabolic phase periods.

Feed intake and feed conversion efficiency

The similarity in overall feed intake across treatments indicated that broiler chickens regulate intake to meet essential amino acid requirements rather than energy needs. These findings aligned with the principle that intake reaches a stable level when the supply of essential amino acids meets metabolic demands (Zeng et al., 2015). The phytochemical compounds in ensiled leaves may enhance amino acid absorption and support gut health, enabling adequate nutrient intake without excessive hunger. Stable feed intake has been observed at lower dietary protein levels when essential amino acid requirements are met (Waldroup et al., 2005; Laudadio et al., 2011).

Superior early-phase FCR indicated improved metabolic efficiency rather than a decrease in feed intake. Reduced-protein diets can induce upregulation of hepatic genes such as *ACSL6*, *PNPLA3*, and *ME1*, which are associated with enhanced lipid oxidation and energy generation (Asiamah et al., 2025). Additionally, phytochemical compounds may have supported efficient nutrient utilization during adaptation. Reduced-protein diets resulted in greater nitrogen retention and lower plasma urea concentrations, which are indicators of improved amino acid use and reduced catabolism (Yang et al., 2009; Naseem and King, 2018).

Lower dietary CP levels have been linked to increased GH and reduced levels of triiodothyronine (T_3) and thyroxine (T_4), which supported short-term protein synthesis and nutrient mobilization (Rahimi and Hassanzadeh, 2023). The antioxidant effects of the ensiled leaves may have stabilized the endocrine adjustments observed, which included fluctuations in adaptation-related corticosterone (Scanes and Pierzchala-Koziec, 2014); and heightened lipogenic activity under LP feeding (Yang et al., 2009). The hyperphagia observed in broiler chickens fed the LP diet during the later phase (days 36-42) reflected compensatory feeding to overcome cumulative nutrient deficiency. Swennen et al. (2007) stated that this increase in intake is a compensatory mechanism caused by hypothalamic detection of amino acid deficiency, leading to the growth of digestive organs to support higher intake.

The FCR results in the later stages, along with the absence of significant overall differences, suggested near-complete compensatory adaptation growth. Compensatory growth following protein restriction is well documented in broiler chickens. Upon refeeding, these chickens exhibit accelerated lean tissue deposition, driven by increased GH secretion, enhanced IGF-I sensitivity, and higher rates of muscle protein synthesis (Lippens et al., 2002; Azis et al., 2011). These findings indicated that while early LP feeding offered short-term efficiency benefits, broiler chickens adjusted effectively once substrate availability increased, leading to metabolic adaptation.

Carcass and meat-cut

Carcass yield, dressing percentage, and the relative weights of major commercial cuts (breast, thigh, drumstick, and wing) did not differ between broiler chickens fed the LP and the SP diets. These findings indicated that moderate reductions in dietary protein intake, when supplemented with ensiled cassava and sweet potato leaves, preserved tissue growth efficiency. Phytochemical-rich or amino-acid-balanced LP diets preserve carcass yield and muscle deposition even under reduced CP formulations (Bregendahl et al., 2002; Attia et al., 2020). The similar weights of edible portions further indicated that the balance between lean and fat remained stable, despite differences in early growth patterns.

The similarity of carcass traits across different protein levels and all three silage sources indicated that neither the protein reduction nor the type of leaf silage affected tissue growth during the present study. Additionally, polyphenol compounds may enhance antioxidant defenses and reduce muscle breakdown (Shakeri et al., 2020; Eid et al., 2023). However, confirming whether these mechanisms were active in the present study or not required a control group without silage and specific biomarker analysis. The enhanced nitrogen balance and endocrine changes in chickens fed the LP diet likely helped sustain protein deposition and carcass yield, regardless of the silage source (Rahimi and Hassanzadeh, 2023).

Wing weight was particularly remarkable, showing a notable interaction between diet and silage, even though the primary effects of diet type and silage source were not significant. Wing contains less lean muscle than skin and bone, making relative wing yield (wing weight as a percentage of carcass weight) or sensitive to changes in peripheral nutrient distribution (Das et al., 2008). The protein level and silage source on wing weight interaction indicated that the impact of silage source on peripheral tissue growth differed with dietary protein levels. However, without tissue biomarker data, a detailed mechanism cannot be confirmed. Since wing yield accounted for only a small portion of the total carcass value, this interaction had limited commercial relevance.

Ensiled cassava and sweet potato leaves

Similar results across the ECL, ESPL, and 50:50 ECL plus ESPL blend groups indicated that broiler chickens' performance and carcass traits were not influenced by the source of leaf silage. Cassava leaves contained higher levels of phenolic compounds, whereas sweet potato leaves were richer in flavonoids; however, the distinct phytochemical profiles did not lead to different production outcomes. This might be related to the fact that at a 10% dietary inclusion level, the phytochemical load was not the main factor affecting performance differences; rather, the protein level appeared to be the key variable. The lack of a silage effect could be due to several reasons, including a sub-therapeutic phytochemical dose, reduced bioavailability caused by ensiling and pelleting, or similar roles among phytochemicals that prevent clear differentiation in effects. Producers can easily use either type of foliage interchangeably, allowing them to select any locally available crop residue without affecting outcomes, regardless of the mechanism.

Diarra and Anand (2020) found no differences in growth or carcass traits when using cassava- or copra-based meals as partial replacements for commercial rations in broiler chickens. Similarly, Nurrofingah et al. (2020) observed no significant interaction between cassava and sweet potato leaf meals in laying ducks, although some combinations enhanced lipid metabolism. Sun et al. (2014) indicated that sweet potato leaves, containing about 27% CP, are similar to other local forages and can be used interchangeably when dietary amino acid and energy balances are met. These findings were consistent with the current study, which noted similar growth responses from different leaf sources at the same inclusion levels.

Both ECL and ESPL groups provided phenolics, flavonoids, carotenoids, and other bioactive compounds that activate Nrf2 antioxidant pathways (Kikusato, 2021; Oni and Oke, 2025) and PPAR metabolic pathways (Park et al., 2020). Although cassava leaves contained 2.86% quercetin flavonoids and sweet potato leaves had 12.00%, both triggered similar responses related to cellular protection and nutrient metabolism. The current results indicate that different phytochemical profiles can produce similar physiological effects by activating overlapping signaling networks.

Cassava leaf meal can replace up to 15% of coconut oil meal without affecting growth and performance, and at 20% inclusion level, performance can be maintained with proper methionine and energy adjustments (Morgan and Choct, 2016). Cassava peel leaf blends have been reported to reduce ileal *E. coli* counts (Williams et al., 2023) and suppress lipid peroxidation in meat (Animashahun et al., 2024). Daniel et al. (2025) demonstrated that cassava-based feeds can maintain conventional growth performance while reducing mortality. Similarly, incorporating up to 10% sweet potato leaf meal has been demonstrated to support normal growth, carcass yield, and nutrient retention (Melesse et al., 2015). These findings indicated that both types of foliage have similar antioxidant and gut-protective effects, aligning with the current results.

The lack of a synergistic effect in the combined ECL and ESPL group indicated that the phytochemical response had reached near-saturation at 100 g kg^{-1}. However, Nurrofingah et al. (2020) noted that alternative ratios (5% sweet ptato leaf meal, 10% cassava leaf meal) enhanced lipid metabolism. For smallholder systems, the equivalence of cassava and sweet potato silages represented a key advantage. Both crops generated abundant underused foliage during ensiling, providing a stable, nutrient- and antioxidant-rich feed ingredient (Pereira et al., 2020). Fermentation reduces antinutritional factors, preserves polyphenols and flavonoids, and ensures consistent bioavailability across silage types. The substantial phenolic, flavonoid, and DPPH antioxidant values observed in the present study confirmed that ensiling maintained phytochemical integrity in both leaf sources. This flexibility allowed producers to include local foliage in feed formulations, lowering feed costs and enhancing resource efficiency without affecting broiler chicken performance.

Economic viability and sustainability

The IOFCC and ROI among treatments indicated that incorporating local bioresources into broiler chickens' diets can sustain economic viability without reducing profitability. Although the standard diet combined with ensiled cassava leaves yielded the highest income (1,048.92 PHP, or ~ 18.00 USD) and ROI (106.19%), these values were not notably different from those of the other dietary treatments. The current results confirmed that all tested formulations, including low-protein diets and those supplemented with ensiled foliage, were economically feasible during the present study.

The low- and standard-protein diets (18-22% CP) yielded similar economic returns, despite notable differences in the final BW. This finding indicated that lower ingredient costs could offset slightly lower performance. Karaarslan et al. (2024) reported similar findings, showing that early protein-energy restriction decreased growth but resulted in similar cost per kilogram of gain (€0.75 versus €0.76). This neutrality results from the ongoing balance of nutrient density, feeding behavior, and ingredient costs. Additionally, Omosebi et al. (2014) found that limited feeding practices enhanced feed efficiency and carcass quality, while also improving cost-benefit ratios. In the present study, broiler chickens consumed nearly the same total feed amount across protein levels (3773.01 versus 3771.16 g), thereby reducing the cost per unit gain with a more economical diet formulation.

CONCLUSION

The present study demonstrated that the standard broiler chicken diet can be replaced with a low-protein diet containing 18% CP, supplemented with ensiled cassava or sweet potato leaf meal, without significantly affecting carcass yield, dressing percentage, meat cut proportions, or economic returns profitability. Although the final body weight was lower in broiler chickens fed the low-protein diet, the practical impact was balanced by similar carcass and economic results, showing that a moderate protein reduction was a cost-effective alternative strategy. All three leaf silage sources, cassava, sweet potato, and a blend of both, provided producers with the flexibility to utilize locally available foliage without any loss of quality. Future investigations should include control diets and biomarker measurements to clarify the physiological mechanisms involved. Additionally, validation at a commercial scale and comprehensive assessments of long-term economic and environmental impacts are advised.

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Competing interests

The authors declared no competing interests or personal relationships in the present study.

Availability of data and materials

Data and materials are available from the corresponding author upon reasonable request.

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Authors' contributions

Gilmore Minerva Ramoso Jr. and Imelda Ulep Hebron conceptualized and developed the methodology for this study. Renante Decenella Taylaran and Charly Guillermo Alcantara were responsible for data validation and creating visualizations. Nelda Ruba Gonzaga and Eric Randy Reyes Politud drafted the original manuscript, while Rudy Mirabueno Camay contributed to writing it. All authors approved the final edition of the manuscript before publication in the present journal.

Ethical considerations

Ethical issues, including plagiarism, consent to publish, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, have been reviewed by all authors. No AI tool was used to conduct and prepare the present study.

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