

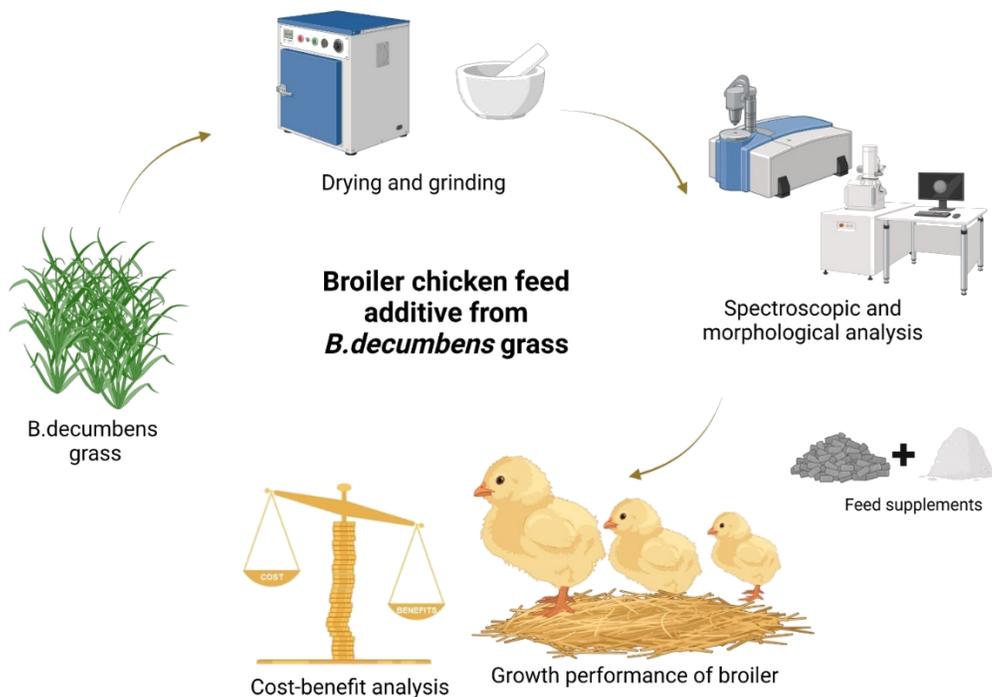
Physicochemical Properties and Cost-Benefit of Supplementing Signal Grass (*Brachiaria decumbens*) in Sasso Broilers Production

Kelly Wong Kai Seng ^a, Alvin Lim Teik Zheng ^b, Yee Lyn Ong ^c,
Jacqueline Lease ^d, Yoshito Andou ^d, Faez Firdaus Abdullah Jesse ^e,
Frank R. Dunshea ^{f,g} and Eric Lim Teik Chung ^{c,*}

*Corresponding author: ericlim@upm.edu.my

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GRAPHICAL ABSTRACT



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There has been a growing interest in using natural alternatives to synthetic additives in animal feed. This study aimed to examine the physicochemical properties of signal grass (*Brachiaria decumbens*) and its cost-benefit application in broiler production. The characterization was performed using Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), thermogravimetric/derivative thermogravimetry (TG/DTG), and scanning electron microscopy (SEM). A feeding trial involving 216 Sasso broiler chicks was conducted to assess the economic value of including *B. decumbens* grass meal in their diets. The chicks were divided into six groups, with Treatments 1 and 2 serving as controls (without antibiotics and with oxytetracycline, respectively). Treatments 3 to 6 received diets supplemented with 1.25, 2.50, 3.75, and 5.00 g/kg of *B. decumbens* grass meal without antibiotics. Body weight and feed intake were monitored over eight weeks to determine growth performance and feed conversion ratio. Broilers in Treatment 6, which received 5.00 g/kg of the grass meal, showed significantly improved growth ($p < 0.05$). A cost-benefit analysis revealed that T6 was the most profitable, suggesting *B. decumbens*' potential as an effective feed additive for broilers.

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Keywords: *Brachiaria decumbens*; Feed supplement; Physicochemical analysis; Growth performance; Cost and benefit analysis; Sasso broilers

Contact information: a: Department of Agribusiness and Bioresource Economics, Faculty of Agriculture, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia; b: Department of Science and Technology, Faculty of Humanities, Management, and Science, Universiti Putra Malaysia Bintulu Campus, Bintulu 97008, Sarawak, Malaysia; c: Department of Animal Science, Faculty of Agriculture, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia; d: Department of Life Science and Systems Engineering, Graduate School of Life Science and Systems Engineering, Kyushu Institute of Technology, Fukuoka 808-0196, Japan; e: Department of Veterinary Clinical Studies, Faculty of Veterinary Medicine, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia; f: School of Agriculture, Food, and Ecosystem, Faculty of Science, The University of Melbourne, Parkville VIC 3010, Australia; g: Faculty of Biological Science, The University of Leeds, Leeds LS2 9JT, United Kingdom;

* Corresponding author: ericlim@upm.edu.my

INTRODUCTION

Chickens are omnivorous birds that naturally forage for a diverse diet consisting of seeds, insects, worms, fruits, and leafy greens, allowing them to obtain essential nutrients from both plant and animal sources (Vlaicu *et al.* 2024). In contrast, modern farm-raised broilers are typically fed formulated diets based on corn, soybean meal, and supplementary

vitamins and minerals to optimize growth, feed efficiency, and meat quality (Leyva-Jimenez *et al.* 2024). In livestock production, antibiotics are frequently used for a variety of purposes, such as treating sick animals (therapeutic use), administering to a group when at least one animal shows signs of infection (metaphylaxis), and preventing disease (prophylaxis). In the poultry industry, antibiotics are also used as growth promoters, typically at lower doses than those used for therapeutic purposes. However, this practice can contribute to the emergence of antibiotic-resistant bacteria (Ong *et al.* 2024). Despite extensive research on phytobiotics as alternatives to antibiotics in feed additives, there is still limited information on the use of phytochemicals in grass and leaf meals for poultry (Alghirani *et al.* 2021, 2022). Consequently, it is crucial to investigate local alternatives, such as grass meals, that can be incorporated into poultry diets to effectively address antibiotic resistance.

Grass is typically associated with the diet of ruminants, which possess specialized microbial fermentation systems in their rumen that allow them to break down fibrous plant materials efficiently. While poultry lacks this fermentation capability, there is growing interest in the potential benefits of grass inclusion in their diets (Ong *et al.* 2024a). Broilers rely on enzymatic digestion in their gastrointestinal tract, and while they cannot fully digest high-fiber grasses, moderate levels of roughage may still offer important functional benefits. For example, *Brachiaria decumbens*, also known as signal grass, is extensively used in the ruminant sector across Latin America, Australia, and Southeast Asia (Low 2015; Pedreira *et al.* 2017). Its high nutritional value, along with resistance to pests and drought, makes *B. decumbens* a crucial forage source for cattle in the tropics. However, steroidal saponins, a harmful compound associated with secondary hepatogenous photosensitization in ruminants, can be extracted from the leaf and stem fractions of *B. decumbens* (Muniandy *et al.* 2020). Due to the high prevalence of these saponins, intoxication is commonly observed in grazing ruminants, such as goats and sheep, particularly during the wet season when the grass undergoes rapid new growth (Chung *et al.* 2018). This may be attributed to the fact that saponin concentrations in *B. decumbens* are highest when the plant is young and immature, with levels reaching 3.15% at 60 days and 1.11% at 360 days (Low 2015).

Despite the adverse effects of saponins on ruminants, optimal inclusion levels in poultry diets have been reported to offer benefits, such as increased growth rates, improved feed efficiency, reduced excreta odor, and enhanced overall bird health (Chaudhary *et al.* 2018; Ong *et al.* 2024b). Therefore, the inclusion of *B. decumbens* in poultry feed offers the potential for multiple functional benefits, including improved gut health through bioactive phytochemicals such as saponins, flavonoids, tannins, and phenolics, which support digestion, reduce inflammation, and enhance gut microbiota balance. While not a primary energy source, its fiber content aids gut motility, enzyme secretion, and digestion while promoting satiety and reducing stress-related behaviors. Additionally, its antioxidant properties help mitigate oxidative stress, potentially enhancing feed conversion efficiency and overall broiler performance (Alghirani *et al.* 2021).

Although *B. decumbens* has been extensively studied in ruminant diets, its potential application in poultry feed remains underexplored. *B. decumbens* is already widely available as a forage crop for cattle, and understanding its nutritional profile, phytochemical composition, and growth-promoting effects in ruminants provides a foundational basis for investigating its suitability for poultry. Since it is known to contain bioactive compounds with antimicrobial and antioxidant properties, these same properties may offer similar functional benefits in non-ruminant species, such as broiler chickens.

Therefore, this paper aims to provide a comprehensive characterization of untreated *B. decumbens* grass as a sustainable livestock feed option. Notably, no previous studies have conducted an in-depth analysis of raw *B. decumbens*. Furthermore, establishing the optimal inclusion levels of *B. decumbens* grass meal in broiler diets is crucial for maximizing its benefits while ensuring farm productivity and cost efficiency. This study could serve as a foundation for further research into its potential applications in animal health and feed innovation to replace antibiotics.

EXPERIMENTAL

Materials

Unless otherwise stated, all reagents and materials were used without further purification.

Planting and Harvesting of *B. decumbens* Grass

Brachiaria decumbens grass was cultivated at Farm 15, Department of Animal Science, Universiti Putra Malaysia, and harvested at four weeks of age. After harvesting, the grass was weighed and oven-dried at 60 °C for three days, or until it reached a constant weight. Once dried, it was ground into a fine powder for further analysis.

Nutritional Composition, Phytochemical, and Antioxidant Activity Analyses

Table 1 shows the nutrient composition, phytochemical content, and antioxidant activity of *B. decumbens* grass. The levels of dry matter (DM), crude fiber (CF), crude protein (CP), ether extract (EE), and ash were determined according to AOAC (1995). The concentrations of saponins, tannins, flavonoids, and alkaloids in *B. decumbens* were quantified using a modified version of the method described by Osuntokun and Olajubu (2014). Furthermore, the DPPH radical scavenging activity of *B. decumbens* grass was evaluated following the protocol of Jack *et al.* (2020) with some modifications.

Table 1. Nutritional Composition, Phytochemical, and Antioxidant Activity of *B. decumbens* Grass Meal

Parameters	Values
Nutrient Composition	
Metabolizable energy (MJ/kg)	17.23 ± 0.35
Dry matter (%)	28.57 ± 0.67
Crude protein (%)	11.31 ± 0.22
Crude fiber (%)	28.00 ± 0.45
Ether extract (%)	1.28 ± 0.07
Ash (%)	5.84 ± 0.12
Phytochemical	
Saponins (%)	2.40 ± 0.34
Tannin (%)	1.09 ± 0.04
Alkaloid (%)	1.81 ± 0.13
Flavonoid (%)	0.95 ± 0.03
Antioxidant Activity	
DPPH radical scavenging activity (%)	38.24 ± 0.00

All values were expressed as mean ± standard error

Physicochemical Characterizations

The morphology of ground *B. decumbens* was examined using a JEOL 6000 scanning electron microscope (JEOL Ltd., Tokyo, Japan) operating at an accelerating voltage of 15 kV. To improve conductivity and image quality, the samples were coated with carbon using a vacuum carbon coater (JOEL Ltd., Tokyo, Japan) before analysis. The crystalline structure of the sample was analyzed with a Rigaku Miniflex 600 diffractometer (Rigaku Analytical Devices, Inc., Waltham, MA, USA), equipped with Cu K- α radiation, operating at 40 kV and 15 mA, with a scanning rate of 10° per minute. Fourier transform infrared (FTIR) spectroscopy was performed using a Nicolet iS5 spectrometer (Thermo Fisher Scientific, Madison, WI, United States). Thermogravimetric analysis (TGA) was conducted with an EXSTAR TG/DTA7000 instrument (Hitachi High-Tech, Tokyo, Japan) under a continuous nitrogen (N₂) flow.

Poultry Feeding Trial

The study was conducted in accordance with international, national, and institutional guidelines for the care and use of animals. All procedures for animal care, handling, and sampling were conducted in accordance with the guidelines and regulations approved by the Institutional Animal Care and Use Committee (IACUC) of Universiti Putra Malaysia. Approval was obtained prior to the commencement of the research under the protocol number UPM/IACUC/AUP-R047/2022, ensuring compliance with ethical standards for animal research.

A total of 216-day-old Sasso broiler chicks were obtained from a local hatchery. The chicks were weighed and randomly assigned to six treatment groups, each with six replicates of six broilers per replicate. The broilers were housed in stainless-steel tiered cages (113 cm x 82 cm x 45 cm) in an open-sided house for 56 days, with a stocking density of six birds per cage. The average temperature and relative humidity during the study were 30.9 °C and 71.2%, respectively. On day 7, all chicks were vaccinated intraocularly against infectious bronchitis (IB) and Newcastle disease (ND). On day 14, they received eye-drop vaccinations for infectious bursal disease (IBD). Feed and fresh water were provided ad libitum throughout the study (Chung *et al.* 2019).

The starter diet was provided from day 0 to day 28, followed by the finisher diet from day 29 to day 56. In Treatment 1 (negative control), broilers were fed commercial diets without antibiotics. In Treatment 2 (positive control), broilers received commercial feeds containing 100 mg/kg of oxytetracycline. Treatments 3, 4, 5, and 6 consisted of the same commercial diets supplemented with 1.25, 2.50, 3.75, and 5.00 g/kg of *B. decumbens* grass meal, respectively, without any antibiotics. The inclusion levels of both *B. decumbens* (1.25 to 5.00 g/kg) and antibiotics were selected based on prior studies on phytobiotic-rich feed additives in poultry diets, considering potential growth benefits, toxicity thresholds, and a stepwise dose-response approach to determine the optimal supplementation level (Nkukwana *et al.* 2014; Basit *et al.* 2020; Ong *et al.* 2024a,b). Correspondingly, Tables 2 and 3 detail the ingredients and nutritional composition of the treatment groups for both the starter and finisher phases. The measured metabolizable energy, dry matter, crude fiber, crude protein, ether extract, and ash content were analyzed using the Official Methods of Analysis of AOAC International (Horwitz 2010).

During the eight-week study, body weight (BW) and feed intake (FI) were recorded for each replicate using a digital weighing scale with a precision of two decimal places (Mettler Toledo Industrial Scale, BBA211 series, Greifensee, Switzerland). These data

were used to calculate body weight gain (BWG) and total feed intake (TFI). The feed conversion ratio (FCR) was then calculated using the formula: $FCR = TFI / BWG$.

Table 2. Composition of Basal Diets for Starter and Finisher Diets

Ingredients (%)	Starter	Finisher
Corn	46.00	52.1
Wheat bran	4.50	6.0
Soybean meal	40.00	32.0
L-Lysine	1.32	1.05
DL-Methionine	0.55	0.45
Choline chloride	0.18	0.20
Calcium carbonate	0.80	0.80
Palm oil	3.35	5.10
Dicalcium phosphate	2.60	1.60
Salt	0.30	0.30
Mineral premix ¹	0.15	0.15
Vitamin premix ²	0.15	0.15
Toxin binder	0.10	0.10
Total	100	100

¹ Mineral mix (provided per kg of the product): Selenium 0.30 g; iron 80.0 g; manganese 100.0 mg; zinc 80.0 g; copper 16.0 g; potassium 6.0 g; sodium 1.80 g; iodine 1.25 g, and cobalt 0.25 g; ² Vitamin premix (provided per kg of the product): Vitamin D3 9.0 MIU; vitamin A 35.0 MIU; vitamin K3 6.0 g; vitamin E 90.0 g; vitamin B1 (thiamine) 7.0 g; vitamin B2 (riboflavin) 22.0 g; vitamin B6 (pyridoxine) 12.0 g; vitamin B12 (cobalamin) 0.070 g; nicotinic acid (niacin) 120.0 g; pantothenic acid 35.0 g; folic acid 3.0 g; biotin 300.000 mg; phytase 25,000.0 FTU

Statistical Analysis

All collected data were analyzed using RStudio version 4.1.3 (Posit, PBC, Boston, MA, USA). A one-way analysis of variance (ANOVA) was conducted based on a completely randomized design model. Tukey's HSD *post-hoc* test was used to determine significant differences among treatment groups, with significance set at $p < 0.05$. For mortality data, the Chi-square test was applied as a non-parametric statistical method.

Cost and Benefit Analysis

Average cost is defined as the cost of production per unit of output. A firm is considered cost-efficient if it can produce output at a lower cost than other producers. Therefore, a rational producer aims to minimize the cost per unit of output, accounting for both variable and fixed costs. Lower average cost, average variable cost, and average fixed cost indicate that the firm is achieving production efficiency and demonstrates effective cost management. The formulas below were used for average cost, average variable cost, and average fixed cost,

$$\text{Average Cost} = (\text{Total Cost}) / (\text{Total Number of Chickens Sold})$$

$$\text{Average Variable Cost} = (\text{Total Variable Cost}) / (\text{Total Number of Chickens Sold})$$

$$\text{Average Fixed Cost} = (\text{Total Fixed Cost}) / (\text{Total Number of Chickens Sold})$$

where Total Cost = Variable cost + Fixed Cost; Total Revenue = Number of chickens sold × Weight of one chicken × Price; Total Profit = Total Revenue – Total Cost. ** The weight of one chicken is measured in kg per bird and the price is measured in RM per kg.

Table 3. Nutrient Composition of Broiler Diets Added with Different Levels of *B. decumbens* Grass Meal

Parameters	Treatments					
	T1	T2	T3	T4	T5	T6
Starter Diet (1 to 28 days)						
Metabolizable energy (MJ/kg)	12.88 ± 0.15	12.55 ± 0.14	12.88 ± 0.28	12.50 ± 0.27	12.66 ± 0.14	12.57 ± 0.24
Dry matter (%)	90.67 ± 0.33	91.33 ± 0.71	90.50 ± 0.22	91.50 ± 0.22	91.17 ± 0.65	90.00 ± 0.45
Crude protein (%)	23.92 ± 0.44	23.13 ± 0.16	23.85 ± 0.34	23.99 ± 0.38	24.20 ± 0.13	24.34 ± 0.16
Crude fiber (%)	3.23 ± 0.08	3.27 ± 0.10	3.37 ± 0.09	3.28 ± 0.10	3.20 ± 0.10	3.17 ± 0.06
Ether extract (%)	4.10 ± 0.12	4.03 ± 0.08	4.23 ± 0.14	4.32 ± 0.07	4.15 ± 0.16	4.02 ± 0.09
Ash (%)	5.70 ± 0.34	5.94 ± 0.24	5.52 ± 0.01	5.67 ± 0.21	6.31 ± 0.23	5.96 ± 0.08
Finisher Diet (29 to 56 days)						
Metabolizable energy (MJ/kg)	13.04 ± 0.09	13.00 ± 0.11	13.39 ± 0.04	13.28 ± 0.05	13.40 ± 0.07	13.17 ± 0.04
Dry matter (%)	89.25 ± 0.32	88.23 ± 0.35	88.80 ± 0.26	88.18 ± 0.09	89.14 ± 0.14	88.86 ± 0.10
Crude protein (%)	19.78 ± 0.23	19.86 ± 0.20	19.98 ± 0.31	19.97 ± 0.42	19.94 ± 0.34	19.94 ± 0.14
Crude fiber (%)	3.29 ± 0.11	3.42 ± 0.08	3.46 ± 0.09	3.33 ± 0.09	3.06 ± 0.22	3.38 ± 0.23
Ether extract (%)	6.85 ± 0.02	6.97 ± 0.02	6.95 ± 0.03	6.89 ± 0.02	6.85 ± 0.05	6.92 ± 0.03
Ash (%)	5.17 ± 0.07	5.59 ± 0.06	4.92 ± 0.21	5.42 ± 0.09	5.00 ± 0.11	5.01 ± 0.29

All values expressed as mean ± standard error; T1: Negative control (Basal diet only); T2: Positive control (Basal diet + 100 mg/kg of oxytetracycline); T3: Basal diet + 1.25 g/kg of grass meal; T4: Basal diet + 2.50 g/kg of grass meal; T5: Basal diet + 3.75 g/kg of grass meal; T6: Basal diet + 5.00 g/kg of grass meal

A rational producer seeks to minimize production costs while simultaneously maximizing profits. Both average revenue and average profit measure the average monetary gain derived from productivity. Higher average revenue and average profit indicate greater profitability for the firm at a specific output level.

$$\text{Average Revenue} = (\text{Total Revenue}) / (\text{Total Number of Chickens Sold})$$

$$\text{Average Profit} = (\text{Total Profit}) / (\text{Total Number of Chickens Sold})$$

The net profit margin reflects a producer's ability to generate profits, with a high net profit margin indicating effective cost control and/or the capacity to sell goods or services at a price significantly above the production cost. Conversely, a low net profit margin suggests an inefficient cost structure and/or ineffective pricing strategy.

$$\text{Net Profit Margin} = (\text{Total Profit}) / (\text{Total Revenue}) \times 100\%$$

The break-even point is a crucial financial concept that signifies the point at which total revenue equals total costs, resulting in zero profit. It represents the level of sales revenue necessary to fully cover the total cost of production, including both variable and fixed costs. Additionally, break-even analysis can identify the minimum sales or production level required to cover all expenses and avoid financial losses. A lower break-even point indicates that the producer has a lower cost of production, making it easier to cover expenses (the lower, the better). In contrast, a higher break-even point means the producer must generate a larger volume of output to cover all expenses.

$$\text{Break-even} = (\text{Total Fixed Cost}) / ((\text{Average Revenue} - \text{Average Variable Cost}))$$

The margin of safety helps businesses assess their capacity to handle market fluctuations and unforeseen challenges. It is a vital tool for financial planning and decision-making, offering a safety net that enables businesses to navigate uncertainties while maintaining financial stability. A larger margin of safety signifies a greater buffer against unexpected financial difficulties, thereby reducing risk.

$$\text{Margin of Safety (in unit)} = \text{Number of chickens sold} - \text{Number of Break-even}$$

$$\text{Margin of Safety (in \%)} = (\text{Margin of Safety (in unit)}) / (\text{Number of Chickens Sold}) \times 100\%$$

RESULTS AND DISCUSSION

Physicochemical Characterizations

Figure 1(a) shows the morphology of raw *B. decumbens* under 100x magnification, revealing its complex microstructure. The varied morphological features indicate a heterogeneous composition of the grass material. The predominant elements are long, thin, fibrous structures, likely representing plant cells or cell fragments, as shown in Fig. 1(a). These fibers exhibit a range of lengths and diameters, with average lengths between 30 and 80 μm , and their surfaces appear rough and uneven. The surface composition of the grass is likely composed of cellulose, hemicellulose, and lignin, which together form bundles of interconnected cells (Al-Awa *et al.* 2023). At higher magnification (Fig. 1(b)), smaller, amorphous particles can be seen scattered among the fibrous structures. These particles may be associated with mineral deposits or other organic components and appear to be either embedded within the fibrous matrix or loosely attached to the fiber surfaces. This

observation confirms that the grinding method was adequate to obtain small-sized particles without the need for additional treatment. The adequacy of the grinding method can be seen from the preservation of these fibrous structures, as it ensures uniform particle size distribution. This uniformity is critical in enhancing the digestibility and bioavailability of the phytochemical constituents when incorporated into broiler diets. The small particle size increases the surface area available for interaction with digestive enzymes, thereby optimizing nutrient release and absorption in the gastrointestinal tract. By confirming the suitability of the grinding method, the study eliminates the need for additional costly or complex size-reduction treatments. This streamlines the production process, making the incorporation of *B. decumbens* more practical and cost-effective for poultry farmers. Furthermore, the presence of both fibrous and amorphous particles suggests that the feed supplement may provide a dual benefit: promoting gut motility due to its fiber content and delivering bioactive compounds efficiently.

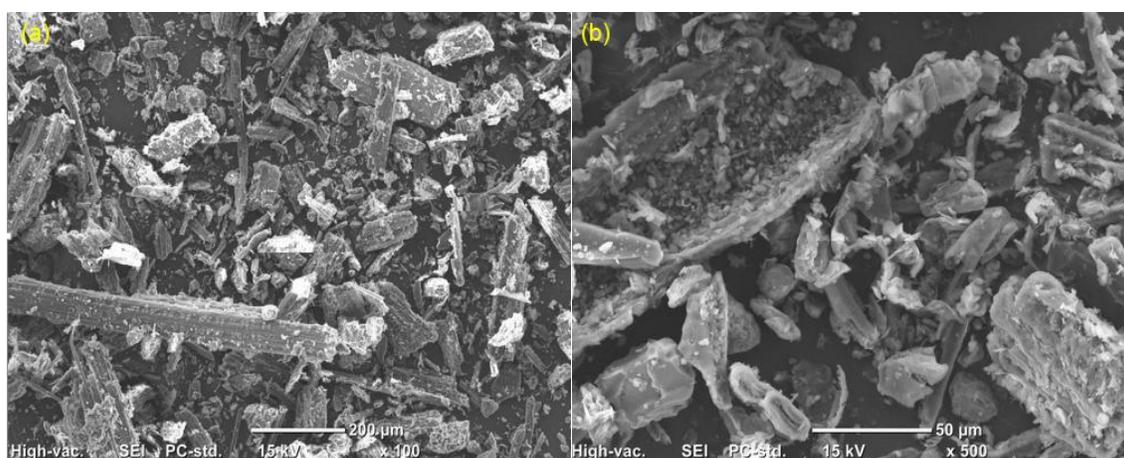


Fig. 1. Scanning electron (SEM) micrographs of the *B. decumbens* grass under (a) 100x magnification and (b) 500x magnification

The FTIR spectrum presented in Fig. 2 provides crucial insights into the chemical composition of *B. decumbens* grass. The presence of functional groups, such as O-H, C-H, C=O, and C-C, indicates a complex mixture of organic compounds, including carbohydrates, proteins, lipids, and lignin (Scoble *et al.* 2024). Moreover, the obtained spectrum is comparable to those reported for other biomass materials (He *et al.* 2022). The broad band centered around 3319 cm^{-1} corresponds to the $\nu(\text{O-H})$ region, where sorbed water and surface $\nu(\text{O-H})$ groups absorb (Soliman *et al.* 2016). This peak may also arise from hydroxyl groups present in lignin, hemicellulose, cellulose, and other impurities (Khalid *et al.* 2023). The distinct $\nu(\text{C-H})$ symmetric and $\nu(\text{C-H})$ asymmetric bands at 2919 cm^{-1} indicate the presence of well-organized aliphatic compounds. The bands observed around 1050 cm^{-1} and 1374 cm^{-1} can be attributed to C-O stretching and C-H bending, respectively, in cellulose, as previously documented (Rana *et al.* 2018). The region between 1400 and 1600 cm^{-1} is associated with C-C stretching vibrations, suggesting the presence of aromatic rings or aliphatic chains. The shoulder peak at 1739 cm^{-1} is due to C=O stretching vibrations, possibly originating from alkyl esters in lipid membranes and pectin within cell walls (Wu *et al.* 2020). The peak near 1648 cm^{-1} corresponds to the absorption of C=C backbone stretching vibrations in the aromatic ring.

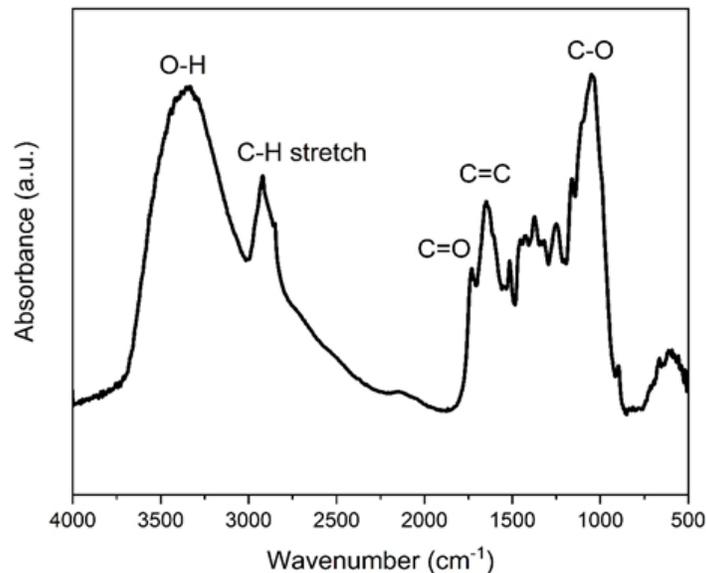


Fig. 2. FTIR spectra of *B. decumbens* grass

The TG/DTG curves in Fig. 3 illustrate the thermal decomposition behavior of raw *B. decumbens* under a nitrogen atmosphere. The multiple decomposition stages observed in the DTG profile suggest a complex mixture of organic components with varying thermal properties. The residual weight loss indicates the presence of inorganic matter, such as minerals or ash. A small, broad peak around 100 °C in the DTG curve suggests the removal of moisture and other low-boiling-point substances. A sharp, intense peak between 230 and 340 °C corresponds to the rapid decomposition of organic components, likely including cellulose, hemicellulose, and lignin.

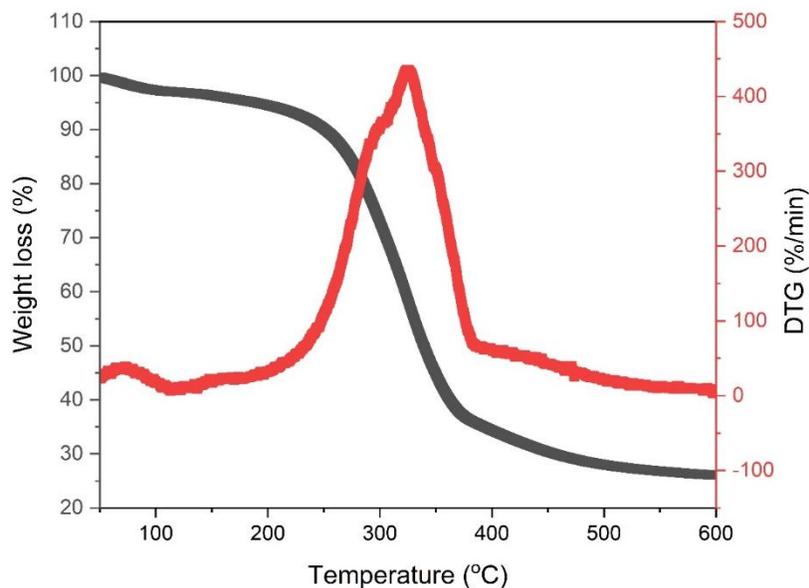


Fig. 3. TG/DTG thermogram of *B. decumbens*

After this stage, the gradual decrease in the weight loss rate suggests the decomposition of the remaining organic matter and the formation of inorganic residues (Cheng *et al.* 2020). The TG profiles revealed an initial slight weight loss around 100 °C,

primarily attributed to the evaporation of moisture and low-boiling-point substances. This stage reflects the release of water and other physically adsorbed compounds, while thermal degradation of the material has not yet begun, as pyrolysis occurs at higher temperatures (Reza *et al.* 2020). The primary degradation, accounting for nearly 50% of weight loss, occurred in the second stage between 230 and 330 °C, resulting from the breakdown of cellulose and hemicellulose. During the final stage, a steady weight loss was observed from 340 to 600 °C, attributed to the decomposition of the more complex compound lignin. These findings indicate that the grass contains close to 80% volatile matter.

The XRD spectrum of *B. decumbens* indicates a predominantly amorphous nature of the material (Lee *et al.* 2021). This amorphous characteristic is typical of organic matter, such as cellulose, hemicellulose, and lignin, which generally lack a well-defined crystalline structure. Three crystallographic planes, (101), (002), and (040), were observed, which are distinctive features of microcrystalline cellulose (Bezerra *et al.* 2014). This amorphous nature may affect the physical and mechanical properties of *B. decumbens*, including its flexibility, strength, and biodegradability. The prominent cellulosic peaks around 16° and 22° at 2θ angles suggest the presence of cellulose. Sharp peaks of varying intensities between 28° and 60° indicate the presence of oxides and metal composites in the samples (Alves *et al.* 2022). These characteristic peaks in the diffractogram are consistent with previous findings (Luengnaruemitchai and Anupapwisetkul 2020). The remaining components, mainly hemicellulose, lignin, and extractives, are likely to belong to the amorphous phase because these constituents do not form larger crystals (Al-Awa *et al.* 2023).

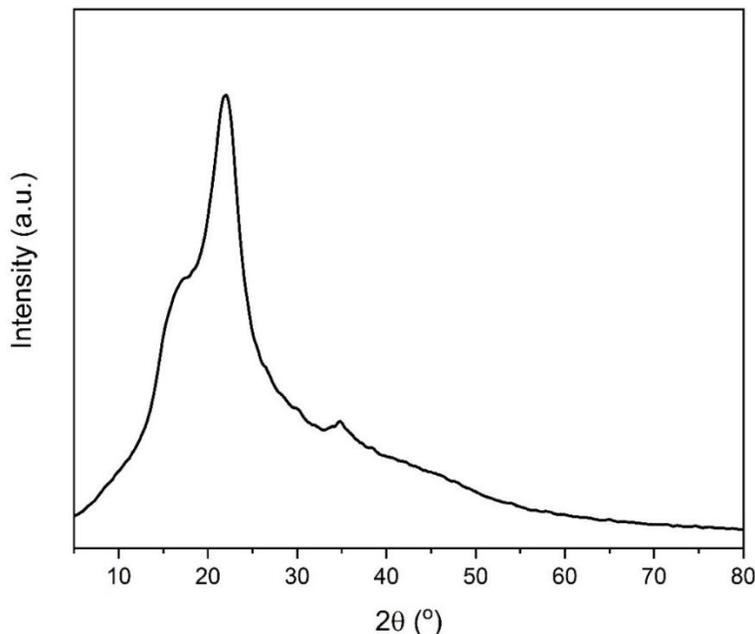


Fig. 4. XRD spectra of *B. decumbens* grass

Growth Performance

The effect of *B. decumbens* leaf meal supplementation on the growth performance of Sasso broilers by day 56 is presented in Table 4. Significant differences were observed only in feed intake and cumulative feed conversion ratio (FCR) ($p < 0.05$). The feed consumption of broilers supplemented with *B. decumbens* leaf meal, regardless of the inclusion level, was comparable ($p > 0.05$) to that of the T2 (antibiotic group). Furthermore, during the finisher phase, the FCR for T6 was similar ($p > 0.05$) to that of T2. Although

body weight gain (BWG) did not differ significantly ($p > 0.05$) between T6 and T1, the feed intake of T6 decreased 9.94%, leading to a 6.8% improvement in cumulative FCR by day 56 compared to T1.

The results indicated that the supplementation of 5.00 g/kg of *B. decumbens* led to the best growth performance, comparable to that of the antibiotic-treated group. The inclusion of saponin-rich supplements in broiler diets at appropriate levels has been shown to enhance growth performance and feed efficiency, aligning with the findings of this study (Chaudhary *et al.* 2018). This effect can be attributed to the presence of steroidal saponins, which positively influence the digestive system by increasing nutrient absorption through enhanced villi height (Alghirani *et al.* 2022). Additionally, other phytochemicals, such as tannins, flavonoids, and alkaloids, contribute to improved growth performance by boosting immunity, maintaining microbial balance, and exhibiting antimicrobial properties, thereby reducing pathogenic load and promoting intestinal health (Tonda *et al.* 2018; Redondo *et al.* 2022). The present study suggests that indigenous broiler chickens may tolerate phytochemicals and fiber better than commercial chickens, which could explain why T6 achieved enhanced growth performance despite a higher inclusion level, contrary to previous findings (Alghirani *et al.* 2022; Manyelo *et al.* 2022). The improvement in FCR observed in broilers supplemented with *B. decumbens* may also be linked to its antioxidant properties. Oxidative stress is known to impair cellular function, damage gut integrity, and negatively affect feed utilization efficiency (Redondo *et al.* 2022). Phytochemicals such as flavonoids and condensed tannins present in *B. decumbens* may contribute to the stabilization of gut microbiota and the reduction of inflammation, thereby enhancing overall digestive efficiency and ultimately improving the growth performance of broiler chickens (Chaudhary *et al.* 2018; Alghirani *et al.* 2021).

Cost and Benefit

Table 5 provides a summary of the production costs across the six treatments. The fixed cost remained constant at RM 558.97 across all treatments, comprising labor (RM 500.00) and electricity (RM 58.97). The variable costs, however, ranged from RM 599.48 to RM 657.00. Treatment 2 (T2) with antibiotics had the lowest variable cost of RM 599.48, while T1 had the highest variable cost of RM 657.00. Despite the slight variations in costs, T2 (basal diet with antibiotics) had the lowest total cost of production at RM 1158.44, followed by T6 at RM 1178.28. T1 (negative control) had the highest total cost at RM 1215.96, indicating inefficiency when no supplementation was used.

According to Wongnaa *et al.* (2023), cost efficiency measures how effectively a producer can minimize costs while maximizing poultry output. In broiler production, variable and fixed costs directly affect profitability. T6 has the lowest average cost per bird at RM 32.73 compared to the highest (RM 34.74) in T1 (control).

Table 4. Effect of *B. decumbens* Grass Meal Supplementation on the Growth Performance of Sasso Broilers

Parameters	Treatments						p-value
	T1	T2	T3	T4	T5	T6	
Initial body weight (kg)	0.04 ± 0.00	0.04 ± 0.00	0.04 ± 0.00	0.04 ± 0.00	0.04 ± 0.00	0.04 ± 0.00	0.835
Final body weight (kg)	1.80 ± 0.06	1.72 ± 0.03	1.78 ± 0.04	1.75 ± 0.01	1.70 ± 0.03	1.74 ± 0.06	0.550
Body weight gain (kg)	1.76 ± 0.06	1.68 ± 0.03	1.73 ± 0.04	1.71 ± 0.01	1.66 ± 0.03	1.70 ± 0.06	0.550
Feed intake (kg)	3.62 ± 0.12 ^a	3.21 ± 0.07 ^b	3.54 ± 0.08 ^{ab}	3.45 ± 0.02 ^{ab}	3.30 ± 0.06 ^{ab}	3.26 ± 0.10 ^b	0.006
Cumulative FCR	2.06 ± 0.02 ^a	1.91 ± 0.02 ^d	2.04 ± 0.01 ^{ab}	2.01 ± 0.02 ^{ab}	1.99 ± 0.01 ^{bc}	1.92 ± 0.00 ^{cd}	< 0.000

All values expressed as mean ± SE; superscripts ^a, ^b, ^c, and ^d values within the row are significantly different at $p < 0.05$. T1: Negative control (Basal diet only); T2: Positive control (Basal diet + 100 mg/kg of oxytetracycline); T3: Basal diet + 1.25 g/kg of grass meal; T4: Basal diet + 2.50 g/kg of grass meal; T5: Basal diet + 3.75 g/kg of grass meal; T6: Basal diet + 5.00 g/kg of grass meal; FCR: feed conversion ratio

Despite a higher initial variable cost for T6 compared to T2 (which uses antibiotics), T6 delivers a more efficient use of inputs, such as grass meal, which leads to better cost-per-bird outcomes. This reflects the economies of scale derived from substituting a portion of conventional feed with a lower-cost feed supplement like *B. decumbens* grass. Producers using T6 can therefore save on feed costs while still achieving optimal broiler growth rates, making it a cost-efficient choice in both the short and long term.

The revenue per treatment ranged from RM 1190.00 to RM 1281.60. T6, which utilized 5.0g/kg of *B. decumbens* grass meal, generated the highest revenue (RM 1281.60) and was the most profitable, with a net profit of RM 74.52 (RM 2.07 per bird) and a profit margin of 5.95%. In contrast, T3 showed a lower profit of RM 63.76 and a profit margin of 4.97%. The treatments without *B. decumbens* grass supplementation (T1 and T2) showed lower profit margins, with T1 at 3.49% and T2 at 3.78%. The inclusion of *B. decumbens* grass meal, particularly in T6, resulted in higher revenues and profits than the control treatments, indicating its potential as an alternative feed supplement that promotes growth while reducing costs. T6's profitability was supported by a higher final weight of 1.75 kg per bird, compared to T2's 1.69 kg per bird.

Table 6 further breaks down the average costs and revenues per bird across the treatments. The average variable cost per bird was lowest for T2 (RM 17.13), closely followed by T6 (RM 17.20). However, T6's cost advantage came through its higher average revenue per bird (RM 34.80) and higher profit per bird (RM 2.07). This makes T6 the most cost-efficient treatment overall, with the lowest average cost per bird (RM 32.73) compared to T1, which had the highest at RM 34.74 per bird. The net profit margins ranged from a low of 1.23% for T5 to a high of 5.95% for T6. The superior performance of T6 indicates that supplementing the basal diet with 5.0 g/kg of *B. decumbens* grass meal can effectively reduce costs and increase profitability without the need for antibiotics, aligning with sustainable farming practices.

According to Ball *et al.* (2000), Al-Sehali and Spear (2004), and Dahan and Srinivasan (2011), the main goal of any agricultural enterprise is to maximize profitability. T6 generates the highest revenue (RM 1252.80) and net profit (RM 74.52) among all treatments. More importantly, the profit per bird for T6 is RM 2.07, significantly higher than T2's RM 1.30, and T1's RM 1.26. This makes T6 the most profitable choice, with the highest net profit margin of 5.95% compared to other treatments, indicating better financial returns on the resources invested. From an economic perspective, profit margins are critical in assessing how well a production system can generate returns over time. A higher margin of 5.95% suggests that T6 not only covers its costs but also provides a small return on investment, making it a preferable choice for producers aiming for profitability.

Furthermore, risk management is essential in any business, and in broiler production, managing fluctuations in revenue and costs is key to ensuring sustainability (Ishag 2019). Break-even analysis is crucial in determining the number of broilers needed to cover costs. This indicates that fewer sales are needed to avoid losses compared to other treatments, which have higher break-even points. T6 has the lowest break-even point, requiring only 31.8 birds to cover its costs, followed by T3 with 32.3 birds. A lower break-even point indicates that fewer broilers need to be sold to recover production costs, making T6 the most efficient.

Greater resilience to market fluctuations and a larger safety net against losses are indicated by higher positive margins of safety (Fatmawatie 2021). T6 had the biggest margin of safety, a critical sign of financial resilience, at 11.8%, implying that it could

sustain a greater reduction in sales before becoming unprofitable. Even if output or sales fall by roughly 12%, the business will remain profitable. This provides some buffer against market uncertainties, such as fluctuating feed prices, disease outbreaks, or changes in market demand. In comparison, treatments like T5 and T1 have much lower margins of safety (2.55% and 7.30%, respectively), which increases their vulnerability to financial loss in adverse conditions (higher risk).

Table 5. Summary of Production Cost, Revenue, and Profit of Sasso Broilers Supplemented with Different Levels of *B. decumbens* Grass Meal

Treatments	T1	T2	T3	T4	T5	T6
VARIABLE COST (RM)						
Grass	0.00	0.00	4.02	8.04	12.07	16.09
Antibiotic	0.00	0.72	0.00	0.00	0.00	0.00
Chick	129.05	129.05	132.74	129.05	129.05	125.36
Starter feed	116.48	94.46	108.29	99.07	100.22	96.77
Finisher feed	410.51	374.41	412.91	391.23	374.22	380.25
Water	0.96	0.83	0.92	0.89	0.86	0.84
Total Variable Cost (RM)	657.00	599.48	658.87	628.28	616.42	619.31
FIXED COST (RM)						
Electricity	58.97	58.97	58.97	58.97	58.97	58.97
Labour	500.00	500.00	500.00	500.00	500.00	500.00
Total Fixed Cost (RM)	558.97	558.97	558.97	558.97	558.97	558.97
TOTAL COST (RM)	1,215.96	1,158.44	1,217.84	1,187.25	1,175.39	1,178.28
REVENUE						
No. of live birds sold	35	35	36	35	35	36
Final weight (kg)	1.80	1.72	1.78	1.75	1.70	1.74
TOTAL REVENUE (RM)*	1,260.00	1,204.00	1,281.60	1,225.00	1,190.00	1,252.80
TOTAL PROFIT (RM)	44.04	45.56	63.76	37.75	14.61	74.52
Note: * the total revenue is calculated based on the farm price of RM 20 per kg. T1: Negative control (Basal diet only); T2: Positive control (Basal diet + 100 mg/kg of oxytetracycline); T3: Basal diet + 1.25 g/kg of grass meal; T4: Basal diet + 2.50 g/kg of grass meal; T5: Basal diet + 3.75 g/kg of grass meal; T6: Basal diet + 5.00 g/kg of grass meal						

One of the most compelling reasons why T6 is the best choice lies in its long-term sustainability. The rising global push towards reducing antibiotics in animal production due to public health concerns and regulatory pressures makes T6 an attractive, forward-thinking option. While T2 (the antibiotic treatment) may reduce production costs in the short run, relying on antibiotics is becoming increasingly unsustainable. T6 provides a non-antibiotic solution that not only matches T2 in terms of economic performance but surpasses it. The use of *B. decumbens* grass meal aligns with sustainable agriculture practices by reducing dependency on synthetic additives. In the long run, broiler producers who adopt T6 will likely face fewer regulatory hurdles and experience continued market

access, particularly in regions that impose stricter regulations on antibiotic use in livestock production. From an economic perspective, the efficiency of resource use is critical in maximizing returns. T6 shows the highest final weight per bird (1.75 kg), which suggests that the supplementation of *B. decumbens* grass at 5.00 g/kg enhances growth performance more effectively than the control treatments. This further boosts the economic efficiency of T6, as producers achieve higher yields for the same or lower input costs, improving the overall resource use efficiency.

Table 6. Summary of the Cost and Benefit Analysis Indicators of Sasso Broilers Supplemented with Different Levels of *B. decumbens* Grass Meal

Treatments	T1	T2	T3	T4	T5	T6
Average Variable Cost (RM per bird)	18.77	17.13	18.30	17.95	17.61	17.20
Average Fixed Cost (RM per bird)	15.97	15.97	15.53	15.97	15.97	15.53
Average Cost (RM per bird)	34.74	33.10	33.83	33.92	33.58	32.73
Average Revenue (RM per bird)	36.00	34.40	35.60	35.00	34.00	34.80
Average Profit (RM per bird)	1.26	1.30	1.77	1.08	0.42	2.07
Net Profit Margin (%)	3.49%	3.78%	4.97%	3.08%	1.23%	5.95%
Break-even (birds)	32.44	32.36	32.31	32.79	34.11	31.76
Margin of safety (birds)	2.56	2.64	3.69	2.21	0.89	4.24
Margin of safety (%)	7.30%	7.54%	10.24%	6.33%	2.55%	11.76%
T1: Negative control (Basal diet only); T2: Positive control (Basal diet + 100 mg/kg of oxytetracycline); T3: Basal diet + 1.25 g/kg of grass meal; T4: Basal diet + 2.50 g/kg of grass meal; T5: Basal diet + 3.75 g/kg of grass meal; T6: Basal diet + 5.00 g/kg of grass meal						

CONCLUSIONS

1. The structural, morphological, and chemical characteristics of *B. decumbens* were analyzed. The SEM images revealed irregularly-shaped aggregates and fibrous particles, with an average particle size ranging from 30 to 80 μm . Chemical analysis identified functional groups commonly found in biomass, such as O-H, C=O, C=C, C-H, and C-O. Thermal analysis indicated significant degradation of the grass between 230 and 340 $^{\circ}\text{C}$, corresponding to the breakdown of extractives, hemicellulose, cellulose, and lignin. The XRD analysis showed prominent cellulosic peaks, suggesting an amorphous structure.
2. Moreover, a poultry feeding trial demonstrated that supplementing 5.00 g/kg of *B. decumbens* grass meal in T6 colored broilers resulted in superior growth performance, as evidenced by the lowest cumulative feed conversion ratio (FCR) observed during the study period.
3. Incorporating *B. decumbens* grass meal in the T6 diet allows producers to effectively balance costs and revenues, providing some return on investment while reducing reliance on antibiotics, making it an optimal choice in the evolving poultry farming industry.

- The findings from this study enhance our understanding of the physicochemical properties of *B. decumbens* and highlight its potential as a feed additive for broiler chickens. Furthermore, these results pave the way for future research and development in animal health and feed innovations.

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