Universidad Técnica de Manabí
Fundada en 1952

BASES DE LA CIENCIA
REVISTA CIENTÍFICA
FACULTAD DE CIENCIAS BÁSICAS
Portoviejo - Manabí - Ecuador

Ciencias Biológicas

NUTRITIONAL AND MICROBIOLOGICAL CHARACTERIZATION OF BREWER'S SPENT GRAIN IN PIG FEEDING AND ESTIMATION OF METABOLIZABLE ENERGY

CARACTERIZACIÓN NUTRICIONAL Y MICROBIOLÓGICA DE BAGAZO CERVECERO EN ALIMENTACIÓN PORCINA Y ESTIMACIÓN DE LA ENERGÍA METABOLIZABLE

CARACTERIZAÇÃO NUTRICIONAL E MICROBIOLÓGICA DO BAGAÇO CERVEJEIRO NA ALIMENTAÇÃO DE SUÍNOS E ESTIMATIVA DA ENERGIA METABOLIZÁVEL

Autores:

Danny José Altamirano Rodríguez*

dannyaltamirano@espam.edu.ec

Wilmer Joel Garay Cevallos

wilmer.garay@espam.edu.ec

Jean Pierre Zambrano Rodríguez

jean.zambranor.41@espam.edu.ec

Grupo de Investigación, Calidad e Inocuidad de los alimentos CIA, Carrera de Agroindustria, Escuela Superior Politécnica Agropecuaria de Manabí Manuel Félix López (ESPAM MFL), Campus Politécnico El Limón, 130101 Calceta, Manabí, Ecuador

* Autor para correspondencia.

Editor Académico

Nancy Hernández de Guerrero

Citación sugerida: Altamirano Rodríguez, D.J., Garay Cevallos, W. J., Zambrano Rodríguez, J.P. (2026). Nutritional and microbiological characterization of brewer's spent grain in pig feeding and estimation of metabolizable energy. *Revista Bases de la Ciencia, 11(1),* 50-60. DOI: 10.33936/revbasdelaciencia.v11i1.8308

Recibido: 24/2/2026
Aceptado: 28/04/2026
Publicado: 30/04/2026

Abstract

Brewer's spent grain (BSG), the main by-product of the brewing industry, represents a lignocellulosic residue with potential application in animal nutrition within circular bioeconomy strategies. In this study, the physicochemical composition, microbiological quality, and digestible and metabolizable energy estimated through predictive models of pig diets formulated with different levels of BSG inclusion (0, 20, 30, and 40 % substitution of corn meal) were evaluated, without conducting in vivo trials. Significant differences ($p < 0{,}05$) were observed among treatments in crude protein, fiber, ether extract, and ash content. The 30 % inclusion level presented the most balanced nutritional profile, with an adequate crude protein content (16.75 %) and moderate fiber levels. Microbiological analysis confirmed the absence of Salmonella spp. in all treatments, while total Enterobacteriaceae counts, expressed as CFU/g, remained within regulatory limits for most formulations. Under a medium fiber scenario (NDF = 60,9 %; ADF = 20,59 %), theoretical estimation indicated that the 30 % inclusion treatment reached a metabolizable energy (ME) of 16.04 MJ kg^{-1} DM, whereas a higher inclusion level (40 %) led to a reduction in available energy attributed to dilution by structural fiber. Moderate incorporation of BSG constitutes a viable strategy for partial replacement of conventional cereals in pig diets; however, in vivo studies are required to validate the estimated energy values.

Keywords: Brewers' spent grain, Pig nutrition, Metabolizable energy, Co-products valorization

Resumen

El bagazo de la industria cervecera (BSG), principal subproducto del proceso de elaboración de cerveza, representa un residuo lignocelulósico con potencial aplicación en la nutrición animal dentro de estrategias de bioeconomía circular. En este estudio se evaluó la composición físico-química, la calidad microbiológica y la energía digestible y metabolizable estimada mediante modelos predictivos de dietas para cerdos formuladas con diferentes niveles de inclusión de BSG (0, 20, 30 y 40 % de sustitución de harina de maíz), sin la realización de ensayos in vivo. Se observaron diferencias significativas ($p < 0{,}05$) entre los tratamientos en el contenido de proteína bruta, fibra, extracto etéreo y cenizas. El nivel de inclusión del 30 % presentó el perfil nutricional más equilibrado, con un contenido adecuado de proteína bruta (16,75 %) y niveles moderados de fibra. El análisis microbiológico confirmó la ausencia de Salmonella spp. en todos los tratamientos, mientras que el recuento de enterobacterias totales (UFC/g) se mantuvo dentro de los límites regulatorios establecidos para la mayoría de las formulaciones. En un escenario de contenido medio de fibra (NDF = 60, 9 %; ADF = 20, 59 %), la estimación teórica indicó que el tratamiento con 30 % de inclusión alcanzó una energía metabolizable (EM) de 16,04 MJ/kg de MS, mientras que un nivel de inclusión elevado (40 %) condujo a una reducción de la energía disponible atribuida a la dilución por fibra estructural. La integración moderada de BSG constituye una estrategia viable para la sustitución parcial de cereales convencionales en dietas porcinas; no obstante, se requieren estudios in vivo para validar las estimaciones energéticas obtenidas.

Palabras clave: Bagazo cervecero, Nutrición porcina, Energía metabolizable, Valorización de coproductos.

Resumo

O bagaço de cervejaria (BSG), principal subproduto da indústria cervejeira, representa um resíduo lignocelulósico com potencial aplicação na nutrição animal dentro de estratégias de bioeconomia circular. Neste estudo, foram avaliadas a composição físico-química, a qualidade microbiológica e a energia digestível e metabolizável estimadas por meio de modelos preditivos de dietas para suínos formuladas com diferentes níveis de inclusão de BSG (0, 20, 30 e 40 % de substituição do milho), sem a realização de ensaios in vivo. Foram observadas diferenças significativas ($p < 0{,}05$) entre os tratamentos quanto ao teor de proteína bruta, fibra, extrato etéreo e cinzas. O nível de inclusão de 30 % apresentou o perfil nutricional mais equilibrado, com teor adequado de proteína bruta (16,75 %) e níveis moderados de fibra. A análise microbiológica confirmou a ausência de Salmonella spp. em todos os tratamentos, enquanto a contagem de enterobactérias totais, expressa em UFC/g, manteve-se dentro dos limites regulatórios para a maioria das formulações. Em um cenário de teor médio de fibra (FDN = 60, 9 %; FDA = 20, 59 %), a estimativa teórica indicou que o tratamento com 30 % de inclusão atingiu uma energia metabolizável (EM) de 16,04 MJ/kg de MS, enquanto um nível elevado de inclusão (40 %) resultou em redução da energia disponível atribuída à diluição pela fibra estrutural. A incorporação moderada de BSG constitui uma estratégia viável para a substituição parcial de cereais convencionais em dietas suínas; no entanto, são necessários estudos in vivo para validar os valores energéticos estimados.

Palavras chave: Bagaço de cervejaria, Nutrição suína, Energia metabolizável, Valorização de coprodutos.

CC BY NC ND

UNIVERSIDAD TÉCNICA DE MANABÍ
Fundada en 1952

BASES DE LA CIENCIA
REVISTA CIENTÍFICA
FACULTAD DE CIENCIAS BÁSICAS
Portoviejo - Manabí - Ecuador

1. Introduction

The agri-food sector is undergoing a structural transformation driven by the need to reconcile productivity with environmental sustainability. Industrial food processing generates large amounts of organic by-products, whose inadequate management contributes to greenhouse gas emissions and inefficient resource use (Salcedo et al., 2020). Within this context, the brewing industry produces significant quantities of brewer's spent grain (BSG), which accounts for approximately 85 % of total residues and is generated at a rate of about 20 kg per hectoliter of beer (Fernandes & Silva, 2025). Despite its availability and nutritional potential, BSG remains underutilized in animal feeding systems (Pasquet et al., 2024).

BSG is a lignocellulosic by-product with potential application in animal nutrition due to its content of proteins, fiber, and residual lipids (Mitri et al., 2022). Nevertheless, factors related to digestibility, storage stability, and energy availability may restrict its direct utilization in swine feeding systems (Adams et al., 2022; Stahn et al., 2023). These characteristics constrain its direct inclusion in animal diets, particularly in swine production systems where energy density and digestibility are critical.

Modern pig production faces increasing pressure to improve resource efficiency while reducing environmental impact. Feed composition plays a central role in this process, as dietary energy directly influences growth performance, feed conversion efficiency, and nitrogen excretion (Geicsnek-Koltay et al., 2022). Although agro-industrial by-products such as BSG represent a promising alternative to conventional feed ingredients, their high fiber content and variable composition complicate the accurate estimation of metabolizable energy (ME), which is essential for diet formulation.

Current research on BSG utilization in pig diets remains fragmented, with most studies focusing either on processing technologies or isolated feeding trials, while integrated evaluations combining compositional characterization and energy prediction are still limited. In particular, the lack of standardized approaches for estimating metabolizable energy in high-fiber by-products represents a relevant gap that restricts their efficient incorporation into swine diets.

Therefore, this study aimed to evaluate the nutritional composition, microbiological quality, and theoretically estimated metabolizable energy of grower–finisher pig diets formulated with increasing levels of brewer's spent grain inclusion.

2. Materials and Methods

2.1. Study Location and Raw Material Collection

The experimental work was conducted at the Bromatology, Microbiology, cereal and oilseed industrialization Laboratories of the Agroindustry Program, Escuela Superior Politécnica Agropecuaria de Manabí (ESPAM MFL), located in Bolívar canton, Manabí province, Ecuador.

Brewer's spent grain (BSG) was obtained from a single production batch from an artisanal brewery (Cervecería MADERO, Tosagua, Ecuador). The material was collected immediately after the mashing stage and exhibited an initial moisture content of 80,3 $\pm$ 0,7 % prior to drying.

2.2. Stabilization and Production of BSG Flour

Fresh BSG was manually pressed with a linen cloth to remove excess free water. The material was transported in polypropylene bags (50 cm $\times$ 70 cm; 50 kg capacity; 80 μm thickness) to the laboratory and dried in a forced-air oven (Memmert C405.1786) at 70 °C for 14 h until the moisture content was reduced below 13 %. Moisture content was determined using a thermobalance (PCE-MA 110), following standardized procedures aligned with ISO 6496 for moisture determination in feed materials. This threshold was selected in accordance with the Ecuadorian technical regulation for balanced feed (NTE INEN 1829:2014), which establishes a maximum moisture content of 13 % to ensure microbiological stability and safe storage conditions. From a broader technological perspective, moisture levels below approximately 14–14.5 % are widely recognized as suitable for the preservation of dry cereal-based matrices, as they limit microbial growth and extend shelf life, supporting the selection of a more conservative threshold in this study (Bodor et al., 2024). Drying was therefore performed to ensure product stabilization under both regulatory and physicochemical criteria applicable to agro-industrial by-products (Aguilera et al., 2023; Mitri et al., 2022; Stahn et al., 2023).

After drying, the material was ground using a stainless-steel hammer mill. Particle size was controlled by a 0.05 mm

CC BY NC ND

revista.bdlaciencia@utm.edu.ec | Vol. 11. Núm. 1 (50-60): Enero-Abril, 2026 | DOI: 10.33936/revbasdelaciencia.v11i1.8308

sieve installed in the hammer mill (model mmar40) to obtain BSG flour. The flour was packaged in polypropylene bags and stored at 23–25 °C in a dry environment for 5 days until analysis.

2.3. Experimental Design and Diet Formulation

A completely randomized design with four treatments and four replicates was used, resulting in 16 experimental units. The experimental treatments consisted of a partial substitution of corn flour (initially 51 percent of the total formulation) with BSG flour, with inclusion levels of: T0: 0 percent (control), T1: 20 percent, T2: 30 percent, and T3: 40 percent. Each experimental unit consisted of 5 kg of formulated feed. The ingredients included corn flour, soybean meal, wheat bran, fine bran, salt, molasses, vegetable oil, vitamin premix, carbonate, and phosphate. All dry ingredients were mixed manually for 10 minutes until a homogeneous mixture was achieved, resulting in a yellowish color, then liquid ingredients were added. The feed was vacuum-packed in 200 g portions for laboratory analysis and stored at 25–30 °C under dry conditions. Table 1 shows the composition of the ingredients in the experimental diets.

Table 1. Ingredient composition of experimental diets with increasing levels of brewers' spent grain (BSG) inclusion (%).

Ingredients	**Treatments** (%)			
	Control (T0)	**T1 (20 % BSG)**	**T2 (30 % BSG)**	**T3 (40 % BSG)**
Corn flour	51.0	31.0	21.0	11.0
Brewers' spent grain flour	0.0	20.0	30.0	40.0
Soybean meal	19.0	19.0	19.0	19.0
Wheat bran	11.0	11.0	11.0	11.0
Fine bran (Polvillo)	9.50	9.50	9.50	9.50
Salt	1.40	1.40	1.40	1.40
Molasses	2.00	2.00	2.00	2.00
Vegetable oil	1.70	1.70	1.70	1.70
Vitamin premix	0.50	0.50	0.50	0.50
Carbonates (Ca source)	3.00	3.00	3.00	3.00
Phosphate	0.90	0.90	0.90	0.90
Total	100	100	100	100

2.4. Physicochemical and Microbiological Analysis

Brewers' spent grain (BSG) flour and experimental diets were subjected to proximate and microbiological analyses to evaluate compositional quality and safety. The moisture content, crude protein, ether extraction (crude fat), crude fiber and ash were determined in the Bromatology Laboratory in accordance with standard complementary analysis procedures. Moisture levels were controlled to remain below 13 % in accordance with Ecuador's technical regulation for balanced feed (NTE INEN 1829:2014). Although there is no specific Ecuadorian standard for BSG flour, the Ecuadorian technical standard for cereal corn (NTE INEN 2051:1995) was used as a comparative reference framework for compositional interpretation. The microbiological quality was assessed by enumeration of Enterobacteriaceae (CFU/g) and detection of Salmonella spp., according to the microbiological standards established by Colombian Technical Standard 1839 animal feed, complete feed for pigs. A summary of the official analysis methods and standards applied to each determination is presented in Table 2.

UNIVERSIDAD TÉCNICA DE MANABÍ
Fundada en 1952

BASES DE LA CIENCIA
REVISTA CIENTÍFICA
FACULTAD DE CIENCIAS BÁSICAS
Portoviejo - Manabí - Ecuador

Table 2. Official analytical methods used for physicochemical and microbiological determinations.

Parameter	Method	Standard	Incubation/Condition
Moisture	Oven drying	ISO 6496	105 °C
Crude protein	Kjeldahl	ISO 5983-1	N×6.25
Crude fat	Soxhlet	ISO 6492	Petroleum ether
Crude fiber	Weende	ISO 6865	–
Ash	Muffle furnace	ISO 5984	550 °C
Enterobacteriaceae	Plate count	ISO 21528-1	37 °C, 24 h
Salmonella spp.	Detection	ISO 6579	Absence in 25 g

2.5. Theoretical Prediction of Digestible and Metabolizable Energy

The digestible energy (DE) and metabolizable energy (ME) of BSG and experimental diets were theoretically estimated using regression equations developed for cereal processing by-products in pig nutrition (Zhao, Zhu et al., 2024). These equations were derived from a dataset of 15 by-products and validated in pigs, showing high predictive accuracy (R^2 up to 0.99). Given that brewer's spent grain is a lignocellulosic cereal by-product, these models were considered suitable for predictive purposes.

Digestible energy (DE, MJ kg^{-1} DM) was calculated as:

$$DE = -0{,}1451 \times NDF + 0{,}3025 \times CP + 13{,}8595 \quad \text{(Equation 2.1)}$$

Metabolizable energy (ME, MJ kg^{-1} DM) was estimated as:

$$ME = 1{,}1155 \times DE + 0{,}0363 \times ADF - 2{,}3412 \quad \text{(Equation 2.2)}$$

where NDF, ADF, and CP are expressed as percentages of dry matter (Adams et al., 2022; Zhao, Zhu et al., 2024).

Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were not experimentally determined due to analytical limitations. Instead, these fractions were estimated proportionally using reference values for BSG (NDF = 60,9 % DM; ADF = 20,59 % DM) reported in the literature. The fiber content of each diet was calculated according to the level of BSG inclusion (0, 20, 30, and 40 %), assuming that the contribution of detergent fiber from the remaining ingredients remained constant across treatments. Energy values were expressed on a dry matter basis and converted from MJ kg^{-1} to kcal kg^{-1} using a factor of 239. Since no direct fiber determination (Van Soest method) or in vivo digestibility assays were performed, the resulting DE and ME values should be interpreted as comparative theoretical estimates.

2.6. Statistical Analysis

All statistical analyses were performed using R statistical software (R Foundation for Statistical Computing, Vienna, Austria) in the RStudio environment (version 4.5.2). Data normality was evaluated using the Shapiro–Wilk test, and homogeneity of variances was assessed using Levene's test.

Since four independent batches were prepared for each treatment ($n = 4$), a one-way analysis of variance (ANOVA) was applied to determine differences among treatments when parametric assumptions were met. When significant effects were detected ($p < 0{,}05$), Dunnett's multiple comparison test was used to compare each treatment with the control (T0).

For variables that did not meet normality assumptions, the Kruskal–Wallis non-parametric test was applied. When appropriate, post-hoc pairwise comparisons were conducted using Dunn's test with Bonferroni adjustment to control Type I error.

The general sequence of experimental procedures is summarized in Figure 1.

CC BY NC ND

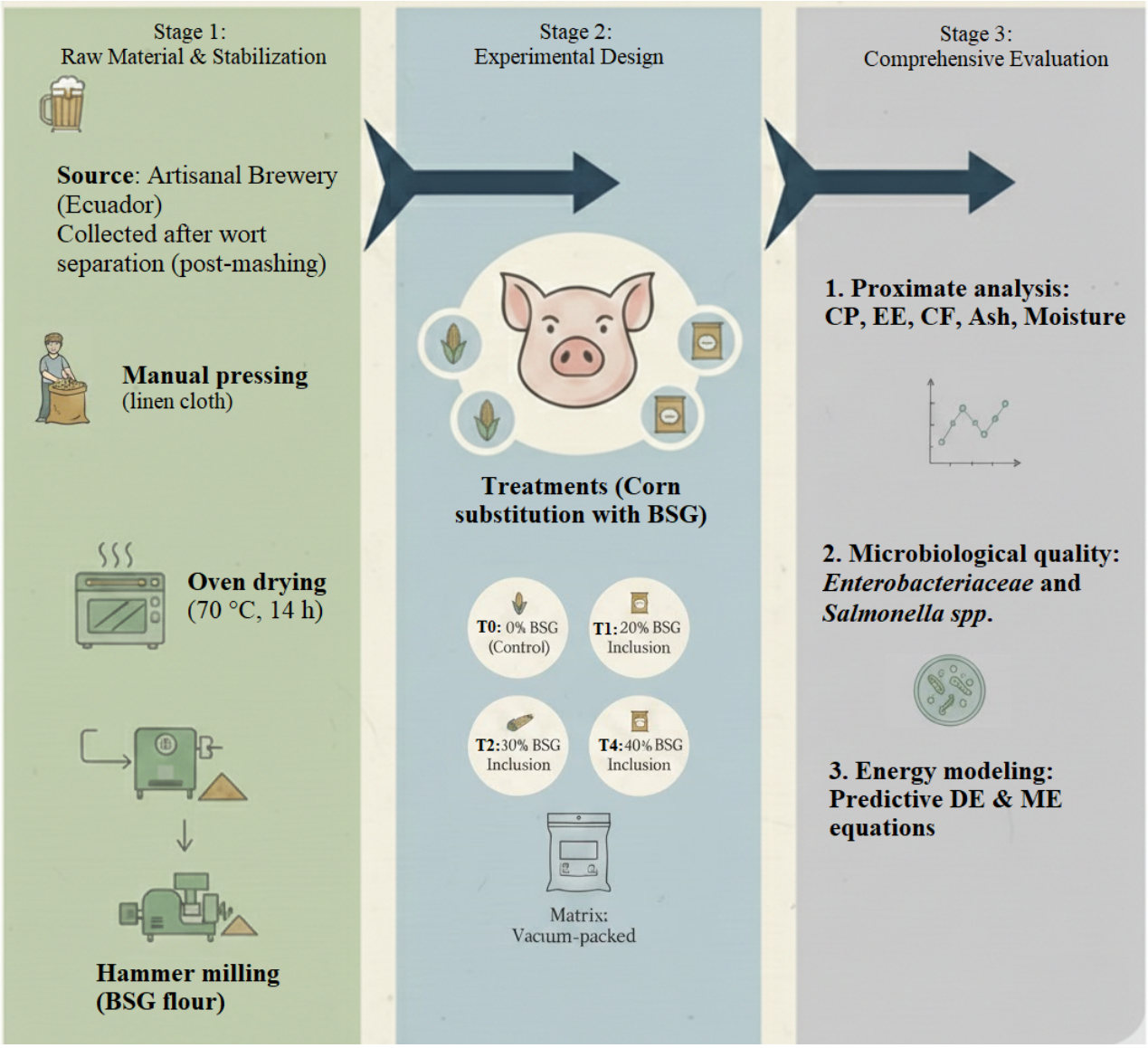


Figure 1. Methodological framework for brewer's spent grain (BSG) valorization in swine diets. This figure summarizes the three-stage approach: (1) raw material stabilization and milling of BSG, (2) formulation of diets under a completely randomized design with 0–40 % corn substitution, and (3) proximate analysis, microbiological evaluation, and regression-based modeling of digestible and metabolizable energy (DE/ME).

3. Results and Discussion

3.1. Proximate Composition of Brewers' Spent Grain (BSG) Flour

3.1.1. Effect of BSG Inclusion on Moisture Content

The inclusion of BSG by brewers significantly influenced the moisture content of experimental diets (ANOVA, $p <$ 0,001). Although statistical differences between treatments and commercial control were discovered, all formulations remain below the maximum 13 % threshold established by NTE INEN 1829:2014 for balanced pig feed. The control diet (T0) had a moisture content of 10.32 %, while treatments containing BSG had moisture content levels of 11.73 % (T1), 11.27 % (T2), and 10.75 % (T3). Despite the statistical significance, the magnitude of the variation was nutritionally moderate and remained within the technical limits acceptable.

Moisture is a critical determinant of feed stability. Fresh BSG usually contains up to 80 % water, severely restricting

UNIVERSIDAD TÉCNICA DE MANABÍ
Fundada en 1952

BASES DE LA CIENCIA
REVISTA CIENTÍFICA
FACULTAD DE CIENCIAS BÁSICAS
Portoviejo - Manabí - Ecuador

storage due to microbial proliferation and enzyme degradation (Bianco et al., 2020). The stabilisation process used in this study reduced BSG moisture to 5.77 %, ensuring safe incorporation into composite foods. Although molasses (2 %) and oil (1.7 %) were included in the treatment, the moisture content remained controlled. Ruiz (2022) reports that the incorporation of liquid ingredients can increase final moisture content if the first dry matter is not properly standardized. The present results show effective drying and mixing practices. From a nutritional point of view, moisture does not directly alter the concentration of metabolizable energy (ME) when expressed on a dry matter basis. However, excessive water content reduces the nutrient density per kilogram of feed and can influence the intake behaviour of grower–finisher pigs (Zhao, Zhu et al., 2024). Therefore, the observed moisture range does not compromise food safety or nutrient supply. Interestingly, the slight decrease in moisture at higher inclusion levels (T3) can reflect the lower intrinsic moisture of the stabilized BSG compared to corn flour, suggesting that BSG inclusion does not inherently increase water retention in the final matrix.

3.1.2. Effect of BSG Inclusion on Ash Content

The content of ashes differed significantly among treatments (Kruskal–Wallis, $p < 0{,}05$), indicating a progressive increase with higher levels of BSG inclusion. Commercial control (T0) showed 6.18 % ash, while experimental diet showed 6.50 % (T1), 12.25 % (T2) and 12.75 % (T3). The increase in the ash content is consistent with the compositional characteristics of BSG, which retain mineral fractions derived from barley kernel components and treatment residues. BSG typically contains significant levels of phosphorus, magnesium and trace minerals in its lignocellulosic matrix (Sampath et al., 2023). As corn flour was gradually replaced, the mineral contribution of BSG increased proportionally. From a nutritional point of view, mineral fractions do not directly contribute to metabolizable energy (ME). On the contrary, an increased amount of ash can dilute the organic nutritional fraction of the diet. In opposition, an increased ash content can dilute the organic nutritional fraction of the diet, thereby reducing its effective energy density. In this sense, Feng et al. (2023) demonstrated that ash is commonly incorporated as a negative predictor in regression models used to estimate digestible energy (DE) and metabolizable energy (ME) in cereal-based ingredients, reflecting its dilution effect on available energy. Consistently, Zhao et al. (2024) reported that higher mineral proportions are associated with a reduction in the energy available in feed ingredients for pigs. From a physiological perspective, excessive mineral inclusion may alter the energy-to-protein ratio of the diet, ultimately affecting feed efficiency in grower–finisher pigs. In line with this, Taipe Cando (2023) suggested that ash levels above approximately 9 % in swine diets can compromise weight gain efficiency by displacing energy-yielding nutrients. Within this framework, the results obtained in the present study indicate that treatments T2 and T3 exceeded this threshold, whereas T1 (6.50 %) and T0 (6.18 %) remained within a physiologically acceptable range.

It is important to distinguish between mineral adequacy and mineral excess. While adequate mineral supply is essential for skeletal development and metabolic regulation, excessive ash without energy compensation may reduce dietary energy density. Wang et al. (2023) emphasized that energy concentration, rather than crude protein alone, is the primary driver of growth performance in finishing pigs.

3.1.3. Effect of BSG Inclusion on Crude Fiber Content

The content of crude fibers differed significantly between treatments (Kruskal–Wallis, $p < 0{,}05$). The control diet (T0) showed a fiber level of 8.19 %, while experimental treatments showed 2.50 % (T1), 6.50 % (T2) and 10.50 % (T3). Although a linear increase in relation to control was not observed, the fiber content increased progressively between T1, T2 and T3 depending on the higher levels of brewers' spent grain (BSG), reflecting its lignocellulosic composition. The increase in crude fiber observed from T1 to T3 is consistent with previous reports describing greater fiber contributions in diets formulated with increasing levels of BSG (Zhao, Song et al., 2024). In grower–finisher pigs, crude fiber levels between 3 and 6.5 % are generally considered adequate to support digestive function without markedly reducing dietary energy density (Ruiz Rivera & Satama Tene, 2022). In this study, T2 (6.50 %) was within the recommended range, T1 (2.50 %) was below the suggested minimum, and T3 (10.50 %) exceeded the optimal level. The control diet (8.19 %) was above the recommended range but remained below the maximum 10 % set by NTE INEN 1829. Since structural fibers are a negative predictor of digestible energy (DE) and metabolizable energy (ME), high fiber levels can reduce anticipated energy availability due to reduced enzyme digestibility and nutrient encapsulation (Falconez et al., 2021; Feng et al., 2023; Wang et al., 2023).

Interestingly, the control diet showed a relatively high level of crude fiber (8.19 %), suggesting that commercial formulations can rely on fibrous co-products. High fiber levels in commercial feed are sometimes used to reduce

CC BY NC ND

revista.bdlaciencia@utm.edu.ec | Vol. 11. Núm. 1 (50-60): Enero-Abril, 2026 | DOI: 10.33936/revbasdelaciencia.v11i1.8308

formulation costs, but can have a negative impact on feed conversion efficiency if they are not compensated by higher energy ingredients (Wang et al., 2023). From the energy modeling point of view, fiber content is one of the strongest determinants of DE and ME reduction. Feng et al. (2023) showed that increasing structural fiber significantly reduces metabolizable energy concentration due to reduced enzyme digestibility and increased endogenous losses.

3.1.4. Effect of BSG Inclusion on Ether Extract (Crude Fat)

The content of ether extracts differed significantly from treatment to treatment (Kruskal–Wallis, $p < 0{,}05$). The control diet (T0) showed the highest level of fat (10.09 %), while the experimental treatment showed 3.75 % (T1), 7.12 % (T2) and 8.62 % (T3). Although the control showed the greatest ether extraction value, the fat content progressively increased between T1, T2, and T3 according to the higher levels of inclusion of brewing grains (BSG), indicating that increasing BSG inclusion contributed to higher ether extract levels in the formulated diets. Lipids are the most energy-intensive macronutrients in pig diets and provide approximately 2.25 times more gross energy than carbohydrates. In grower–finisher pigs, food fat increases energy density and can improve feed conversion efficiency if balanced with adequate protein supply (Wang et al., 2023). However, excessive fat content may have a negative impact on body composition and dietary balance. The recommended fat levels for grower-finisher pigs generally range from 3 % to 9 % in order to optimize energy use without compromising the quality of the body (Godoy Valdiviezo, 2023). In this study, T1 (3.75 %) reaches the minimum recommended level, T2 (7.12 %) is within the optimal range and T3 (8.62 %) approaches the upper limit. The control diet (10.09 %) exceeded typical recommendations, suggesting a potential formula imbalance or excessive energy density.

3.1.5. Effect of BSG Inclusion on Crude Protein

The content of crude proteins (CPs) differed significantly between treatments (Kruskal–Wallis, $p < 0{,}05$). Control diet (T0) showed 8.00 % CP, while experimental treatments showed 16.40 % (T1), 16.75 % (T2), and 16.70 % (T3). The protein concentration increased considerably with increasing levels of BSG inclusion, resulting in crude protein values that were substantially higher than those observed in the control diet. In agricultural and agricultural pigs, the recommended raw protein levels generally range from 8 % to 14 %, depending on the growth stage and the balance of amino acids (Ulcuango Granizo, 2022). In this framework, T1 (16.40 %), T2 (16.75 %), and T3 (16.70 %) exceed the recommended range. Control diet (8.00 %) falls within the lower limit of the recommended interval for productive performance. However, the concentration of crude proteins alone does not determine nutritional adequacy. Digestibility and amino acid availability are equally important. High structural fiber levels can reduce the obvious ideal digestibility of amino acids and overall protein use (Feng et al., 2023). Although T1, T2, and T3 present elevated protein levels, the higher fiber content observed in T3 (10.50 %) may partially limit protein digestibility. T2 therefore represents a more balanced formulation, combining high protein supply with moderate fiber levels and improved projected energy efficiency. The overall proximate composition of BSG flour and experimental diets is summarized in Table 3, facilitating direct comparison among treatments.

Table 3. Proximate composition of brewers' spent grain (BSG) flour and experimental grower–finisher pig diets.

Parameter / (%)	BSG Flour	T0 (0 % BSG)	T1 (20 % BSG)	T2 (30 % BSG)	T3 (40 % BSG)
Moisture	5.77 ± 0.13	10.32 ± 0.13	11.73 ± 0.14	11.27 ± 0.13	10.75 ± 0.15
Ash	2.39 ± 0.16	6.18 ± 0.18	6.50 ± 0.12	12.25 ± 0.21	12.75 ± 0.22
Crude Fiber	9.58 ± 0.09	8.19 ± 0.15	2.50 ± 0.12	6.50 ± 0.18	10.50 ± 0.07
Ether Extract (Fat)	5.37 ± 0.21	10.09 ± 0.20	3.75 ± 0.20	7.12 ± 0.18	8.62 ± 0.20
Crude Protein	12.90 ± 0.32	8.00 ± 0.56	16.40 ± 0.14	16.75 ± 0.29	16.70 ± 0.42

3.1.6. Microbiological Quality

Enterobacteriaceae counts inoculated into petrifilm samples at 10^{-1}, 10^{-2}, and 10^{-3} dilutions were $1{,}10 \times 10^2$ (T0), $9{,}51 \times 10^2$ (T1), $1{,}12 \times 10^2$ (T2), and $8{,}05 \times 10^2$ CFU/g (T3), respectively. All treatments complied with the NTE INEN 1829:2013 standard. Since the stabilized BSG showed a low moisture content (5.77 %), the observed microbial

ISNN 2588-0764 | Vol. 11. Núm. 1 (50-60): Enero-Abril, 2026 | DOI: 10.33936/revbasdelaciencia.v11i1.8308

UNIVERSIDAD TÉCNICA DE MANABÍ
Fundada en 1952

BASES DE LA CIENCIA
REVISTA CIENTÍFICA
FACULTAD DE CIENCIAS BÁSICAS
Portoviejo - Manabí - Ecuador

variations are more likely associated with handling conditions than with intrinsic contamination of the raw material. Salmonella spp. was not detected in any treatment, confirming the hygienic adequacy of the drying and formulation processes. From a sanitary perspective, the absence of Salmonella spp. and the controlled levels of enterobacteria indicate a low microbiological risk, reducing the probability of enteric infections and subclinical inflammatory responses in pigs. This is particularly relevant, as subclinical microbial contamination can impair feed efficiency by activating the immune system and diverting nutrients away from growth (Wang et al., 2023). In terms of feed quality, the results suggest that the diets are microbiologically stable and suitable for storage and consumption under controlled conditions, without compromising safety or nutritional performance. Nevertheless, the variability observed among treatments highlights the need to reinforce good manufacturing practices during feed handling and processing to ensure consistent microbiological quality.

Table 4. Microbiological results for Enterobacteriaceae and compliance with NTE INEN 1829:2013.

Treatment Identification	Results (CFU/g)	Acceptable Limit (CFU/g)	Regulatory Compliance
Control (T0)	$1{,}10 \times 10^2$	$10^2 \leq x \leq 10^3$	Acceptable
Treatment (T1)	$9{,}51 \times 10^2$	$10^2 \leq x \leq 10^3$	Acceptable
Treatment (T2)	$1{,}12 \times 10^2$	$10^2 \leq x \leq 10^3$	Acceptable
Treatment (T3)	$8{,}05 \times 10^2$	$10^2 \leq x \leq 10^3$	Acceptable

3.2. Integrated Evaluation of Experimental Diets

The selection of the most suitable formulation was based on proximate composition, regulatory compliance, and predicted effects on digestible and metabolizable energy (DE and ME). Although all treatments complied with the maximum moisture limit established by NTE INEN 1829:2014, significant differences were observed in ash, fiber, fat, and crude protein content.

Among the evaluated diets, T2 (30 % BSG inclusion) showed the most balanced nutritional profile. Crude fiber (6.50 %) was within the recommended range for grower–finisher pigs (3–6.5 %), crude protein (16.75 %) was above the suggested requirement (8–14 %), and ether extract (7.12 %) remained within the optimal interval (3–9 %) for efficient energy utilization. In contrast, T1 presented high protein (16.40 %) and low fiber (2.50 %), while T3 exhibited excessive fiber (10.50 %) and elevated ash content (12.75 %), which may dilute dietary energy density and reduce nutrient digestibility.

Although T2 exceeded recommended ash levels (> 9 %), its overall nutrient balance and predicted energy profile were superior to other treatments. Microbiological evaluation indicated that improvements in handling practices are required to ensure full regulatory compliance.

Overall, T2 was identified as the most nutritionally appropriate inclusion level of BSG for grower–finisher pig diets.

3.3. Predicted Digestible and Metabolizable Energy of Experimental Diets (Medium Scenario)

As shown in Table 5, the theoretical prediction of digestible energy (DE) and metabolizable energy (ME) in medium fiber scenarios (NDF = 60,9 %; ADF = 20,59 %) reveals clear differences between treatments. Treatment T1 (20 % BSG inclusion) presented the highest forecast values (DE = 17,05 MJ/kg DM; ME = 16,83 MJ/kg DM), followed by T2 (DE = 16,28 MJ/kg DM; ME = 16,04 MJ/kg DM), while T3 showed a reduction in both parameters (DE = 15,38 MJ/kg DM; ME = 15,11 MJ/kg DM). The highest ME observed in T1 is associated with its high crude protein content (16.40 %) and lower fiber ratio (NDF 12.18 %). Energy prediction models for cereal by-products consistently indicate that crude protein contributes positively to DE estimates, while increasing NDF and ADF reduces predicted energy due to the limited digestibility of structural carbohydrates in pigs. In contrast, the higher fiber levels for T3 (NDF 24.36 %; ADF 8.24 %) explain the predicted decrease in ME, confirming that excessive inclusion of lignocellulosic fractions negatively affects metabolizable energy availability. The ME range obtained through treatments (15.11–16.83 MJ/kg DM) falls within the typical energy density reported for commercial grower–finisher diets, supporting the nutritional feasibility of moderate BSG inclusion. Overall, the values presented in Table 5 indicate that the diet containing 20 % BSG inclusion contains the highest predicted energy profile among the evaluated formulations.

CC BY NC ND

revista.bdlaciencia@utm.edu.ec | Vol. 11. Núm. 1 (50-60): Enero-Abril, 2026 | DOI: 10.33936/revbasdelaciencia.v11i1.8308

Table 5. Predicted DE and ME of grower–finisher pig diets containing increasing levels of brewers' spent grain.

Treatment	CP (%)	NDF est. (%)	ADF est. (%)	DE (MJ/kg DM)	ME (MJ/kg DM)	DE (kcal/kg DM)	ME (kcal/kg DM)
T1 (20 %)	16.40	12.18	4.12	17.05	16.83	4075.0	4022.4
T2 (30 %)	16.75	18.27	6.18	16.28	16.04	3891.0	3834.0
T3 (40 %)	16.70	24.36	8.24	15.38	15.11	3675.8	3611.3

CP = crude protein; NDF est. and ADF est. = proportionally estimated detergent fiber fractions based on BSG inclusion using reference values (NDF = 60,9 % DM; ADF = 20,59 % DM); DE = digestible energy; ME = metabolizable energy; DM = dry matter.

4. Conclusions

This study demonstrates that brewer's spent grain can be incorporated into grower–finisher pig diets following appropriate stabilization, while maintaining acceptable nutritional characteristics and microbiological quality. Among the evaluated formulations, moderate inclusion levels showed the most favorable balance between nutrient composition and predicted energy availability. The results support the potential use of BSG as an alternative feed ingredient and highlight its relevance within circular bioeconomy strategies aimed at valorizing agro-industrial by-products. However, because energy values were estimated through predictive models and no biological performance trials were conducted, in vivo studies are required to confirm digestibility, growth performance, and practical applicability under production conditions.

5. Conflict of Interest

The authors report no conflicts of interest related to this research.

6. References

Adams, C. B., Souza, O., Agilar, J. C., Muller, G., Rodrigues, B., & Stefanello, C. (2022). Energy values of brewer's grains and olive pomace waste for broiler chickens determined using the regression method. *Agriculture*, *12*(4), 444. https://doi.org/10.3390/agriculture12040444

Aguilera, D. D. S., Terán, S. G. S., Pino, D. R. A., Escobar, K. Y. R., Pisco, M. L. C., & Morejón, J. P. A. (2023). Caracterización fisicoquímica de fréjol canario (Vigna unguiculata) y chocho guaranguito (Lupinus mutabilis) y su incidencia en la funcionalidad de harinas. *Revista Bases de la Ciencia*, *8*(1), 1-12. https://doi.org/10.33936/revbasdelaciencia.v8i1.5452

Bianco, A., Budroni, M., Zara, S., Mannazzu, I., Fancello, F., & Zara, G. (2020). The role of microorganisms on biotransformation of brewers' spent grain. *Applied Microbiology and Biotechnology*, *104*, 8661-8678. https://doi.org/10.1007/s00253-020-10843-1

Bodor, K., Szilágyi, J., Salamon, B., Szakács, O., & Bodor, Z. (2024). Physical–chemical analysis of different types of flours available in the Romanian market. *Scientific Reports*, *14*, 881. https://doi.org/10.1038/s41598-023-49535-x

Falconez, M. C. S., Alcívar, D. C. C., & Macías, L. A. V. (2021). Harina de cefalotórax de camarón en dietas de pollos broiler cobb-500 en etapa inicial. *Revista Espamciencia*, *12*(2), 116-123. https://doi.org/10.51260/revista_espamciencia.v12i2.245

Feng, G., Li, R., Jiang, X., Yang, G., Tian, M., Xiang, Q., et al. (2023). Prediction of available energy and amino acid digestibility of Chinese sorghum fed to growing–finishing pigs. *Journal of Animal Science*, *101*, skad262. https://doi.org/10.1093/jas/skad262

UNIVERSIDAD TÉCNICA DE MANABÍ
Fundada en 1952

BASES DE LA CIENCIA
REVISTA CIENTÍFICA
FACULTAD DE CIENCIAS BÁSICAS
Portoviejo - Manabí - Ecuador

Fernandes, P. C., & Silva, J. (2025). Brewing by-products: Source, nature, and handling in the dawn of a circular economy age. *Biomass*, *5*(3), 49. https://doi.org/10.3390/biomass5030049

Geicsnek-Koltay, I. A., Benedek, Z., Baranyai, N. H., Such, N., Pál, L., Wágner, L., et al. (2022). Impacts of age, genotype and feeding low-protein diets on the N-Balance parameters of fattening pigs. *Agriculture*, *12*(1), 94. https://doi.org/10.3390/agriculture12010094

Godoy Valdiviezo, M. J. (2023). *Elaboración de balanceado peletizado más la adición de probióticos para cerdos en la etapa de crecimiento y engorde* [Trabajo experimental de Ingeniería Zootecnista]. Escuela Superior Politécnica de Chimborazo. http://dspace.espoch.edu.ec/bitstream/123456789/19168/1/17T01863.pdf

Mitri, S., Salameh, S. J., Khelfa, A., Leonard, E., Maroun, R. G., Louka, N., & Koubaa, M. (2022). Valorization of brewers' spent grains: Pretreatments and fermentation, a review. *Fermentation*, *8*(2), 50. https://doi.org/10.3390/fermentation8020050

Pasquet, P. L., Villain-Gambier, M., & Trébouet, D. (2024). By-product valorization as a means for the brewing industry to move toward a circular bioeconomy. *Sustainability*, *16*(8), 3472. https://doi.org/10.3390/su16083472

Ruiz Rivera, F. A., & Satama Tene, Á. E. (2022). *Incidencia de los residuos de papa Capira Solanum tuberosum y plátano barraganete Musa paradisiaca en el proceso y calidad del balanceado peletizado para cerdos en la etapa de engorde* [Trabajo de grado]. Universidad Técnica del Norte. http://repositorio.utn.edu.ec/handle/123456789/13018

Salcedo, Y. G., Alcívar, A. V., Menéndez, F. A. M., Rodríguez, J. P., & Delgado, E. A. R. (2020). Evaluación del proceso de hidrólisis de residuales sólidos del beneficio de café para la producción de enzimas lipasas. *Revista Bases de la Ciencia*, *5*(3), 55-72. https://doi.org/10.33936/revbasdelaciencia.v5i3.2431

Sampath, V., Sureshkumar, S., Seok, W. J., & Kim, I. H. (2023). Role and functions of micro and macro-minerals in swine nutrition: a short review. *Journal of Animal Science and Technology*, *65*(3), 479. https://doi.org/10.5187/jast.2023.e9

Stahn, T., Storandt, R., Grebenteuch, S., Rohn, S., May, D., Dolsdorf, C., & Pleissner, D. (2023). Utilization of brewer's spent grains and agricultural residues in pig feed formulation. *Sustainability*, *15*(18), 13774. https://doi.org/10.3390/su151813774

Taipe Cando, E. M. (2023). *Estudio comparativo de la alimentación en el rendimiento productivo de cerdos de engorde alimentados con balanceado de la línea EXIBAL y balanceado comercial en la etapa inicial, crecimiento y engorde, en el cantón Chambo – Chimborazo* [Proyecto de investigación para optar al título de Ingeniera Agroindustrial]. Universidad Técnica de Cotopaxi. https://repositorio.utc.edu.ec/server/api/core/bitstreams/88e21ad6-0103-4835-914a-eb88de523927/content

Ulcuango Granizo, V. H. (2022). *Elaboración de balanceados a partir de productos infrautilizados con Colocasia esculenta y Manihot esculenta para cerdos en la etapa de engorde* [Tesis de Licenciatura]. Universidad Nacional de Chimborazo, Riobamba, Ecuador. http://dspace.unach.edu.ec/bitstream/51000/10140/1/%5B...%5D.pdf

Wang, L., Zeng, Z., Hu, Q., Wang, L., Shi, H., Lai, C., & Zhang, S. (2023). Determination and prediction of the available energy and amino acids digestibility of full-fat soybean fed to growing pigs. *Journal of Animal Science*, *101*, skac395. https://doi.org/10.1093/jas/skac395

Zhao, J., Song, X., Yang, M., Zhang, G., & Liu, L. (2024). Determination and prediction of available energy in 13 cereal feed ingredients for growing pigs. *Veterinary Sciences*, *11*(12), 648. https://doi.org/10.3390/vetsci11120648

Zhao, J., Zhu, Q., Song, X., Yang, M., & Liu, L. (2024). Development of Prediction Equations for Digestible and Metabolizable Energy in 15 Cereal Processing By-Products Fed to Growing Pigs. *Animals*, *14*(21), 3101. https://doi.org/10.3390/ani14213101

CC BY NC ND

7. Contributions from authors

Author	Contribution
Wilmer Garay-Cevallos	Experimental design and execution, data collection and analysis, and manuscript writing.
Jean Zambrano-Rodríguez	Experimental design and execution, data collection and analysis, and manuscript writing.
Danny Altamirano-Rodríguez	Critical review of the manuscript and contribution to the final writing of the article.