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Utilization of biological silage from shrimp processing waste as a sustainable practice in productive performance of broiler chickens

Uso del ensilado biológico de residuos del procesamiento del camarón como práctica sustentable en el rendimiento productivo del pollo de engorde

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ABSTRACT

The use of aquaculture by-products transformed into biological silage represents a environmental sustainable alternative for improving the efficiency and performance of broiler production systems. However, scientific evidence regarding the efficacy of biological silage formulated from *Penaeus vannamei* waste in broiler nutrition remains scarce. Therefore, this study aimed to assess the effects of biological silage fermented with native bacteria on the production performance, conversion efficiency feed, and intestinal health of broiler chickens during the growth and finisher phases, conversion efficiency, and intestinal integrity of broiler chickens during the grower and finisher stages. A completely randomized design with a Tukey multiple comparison test was used with four treatments (0 %, 10 %, 15 %, and 20 % of biological silage). The variables evaluated included body weight gain, feed conversion ratio, apparent digestibility, carcass yield, economic merit, and gut morphology. In conclusion, the use of *P. vannamei* biological silage fermented with native bacteria represents a sustainable and cost-effective nutritional strategy that improves broiler performance, promotes sustainable production using aquaculture processing waste, and reduces production costs, offering a nutritious and functional feed.

Key words: Biological silage Penaeus vannamei; circular economy; broiler chickens; digestibility; sustainable production

RESUMEN

El uso de subproductos de la acuicultura transformados en ensilado biológico representa una alternativa ambiental sostenible para mejorar la eficiencia y el rendimiento de los sistemas de producción de pollos de engorde. Sin embargo, la evidencia científica sobre la eficacia del ensilado biológico formulado a partir de desechos de *Penaeus vannamei* en la nutrición de pollos de engorde sigue siendo escasa. Por lo tanto, este estudio tuvo como objetivo evaluar los efectos del ensilado biológico fermentado con bacterias nativas en el rendimiento productivo, la eficiencia de conversión alimenticia y la salud intestinal de pollos de engorde durante las fases de crecimiento y finalización. Se utilizó un diseño completamente aleatorizado con prueba de comparación múltiple de Tukey con cuatro tratamientos (0 %, 10 %, 15 % y 20 % de ensilado biológico). Las variables evaluadas incluyeron ganancia de peso corporal, índice de conversión alimenticia, digestibilidad aparente, rendimiento de la canal, valor económico y morfología intestinal. En conclusión, el uso de ensilado biológico de *P. vannamei* fermentado con bacterias nativas representa una estrategia nutricional sustentable y rentable que mejora el desempeño del pollo de engorde, promueve la producción sustentable utilizando desechos del procesamiento de la acuicultura y reduce los costos de producción, ofreciendo un alimento nutritivo y funcional.

Palabras claves: Ensilado biológico; Penaeus vannamei; economía circular; pollos de engorde; digestibilidad; producción sustentable

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INTRODUCTION

Conventional protein sources for poultry (fish meal and soybean meal) represent a significant economic challenge for the poultry industry, accounting for up to 70-80 % of total production costs [1 , 2]. Therefore, there is a need to identify and utilize cost-effective and sustainable alternative protein ingredients in broiler production systems [3 , 4].

Aquaculture and the fish and shellfish processing sectors generate organic waste, between 35 and 50 % of the total weight [5 , 6], In particular, shrimp (Penaeus vannamei) processing produces considerable volumes of waste material, including heads, shells and trimmings [7 , 8].

These wastes contain nutrients and are rich in proteins (41.1 %) [9 , 10], polysaccharides, proteins, carotenoids and fatty acids [11]. Considered many of them as functional foods, these wastes, by not having an adequate final disposal, contribute to environmental pollution and represent a lost opportunity for the recovery of resources within the framework of a circular economy [12 , 13 , 14].

In this context, a method of organic matter conservation known as biological silage (BS) was born [15], achieved through controlled fermentation with lactic bacteria considered as a strategy to valorize shellfish waste [16], this process improves nutritional quality, microbiological stability [17], and digestibility, while reducing its environmental impact [18 , 19].

The use of BS obtained from fish or shrimp waste processing waste has shown potential to partially replace fishmeal in diets for broiler chickens [3], and may even improve zootechnical characteristics such as production performance and feed conversion efficiency [3 , 20 , 21].

Furthermore, the production of eubiotic products present in BS from fermented shrimp heads uses native lactic acid bacteria that report improvements in chicken and hen production [22], Lactic acid bacteria such as Lactobacillus fermentum, BS fermenter, has been shown to be efficient and increase crude protein content, along with acceptable microbiological profiles [23].

Organic fermentation is a biotechnological method for the recovery of organic waste that offers additional improvements over chemical methods, including lower process costs, reduced labor costs, and increased safety [24], is an alternative to sustainable strategies that integrate poultry and aquaculture production systems [25].

The exact dosage for the utilization of waste-based BS, specifically produced with P. vannamei residues and native avian bacterial strains, used in broiler chicken diets is not known [23 , 26]. Knowing the usage levels can determine the expression of the productive potential of broiler chickens and the economic viability, especially in the context of the circular economy in sustainable poultry production [1].

Consequently, the present study aims to determine the optimal inclusion rate of shrimp waste-based BS, produced from P. vannamei heads and shells fermented with native avian lactic acid bacteria, and to be a protein source in broiler diets [25 , 27 , 28]. promoting a more sustainable and economically viable circular poultry industry [12].

MATERIALS AND METHODS

The present study was conducted at the Livestock Center of the Faculty of Agricultural Sciences, National University of Tumbes, located in the district of San Pedro de los Incas, Tumbes province and department, Peru (latitude: 3°35'21.1'' S, longitude: 80°30'04.6'' W, altitude: 5 m.a.s.l.). The trial was carried out between november 2022 and march 2023. A total of 40 broiler chickens (Gallus gallus domesticus, Cobb line), 2 weeks of age and selected based on initial live weight average 450 grams (g) (scale, Precisur brand, Model: SF-400), were used. Birds were randomly assigned to four treatments with five replicates each, following a completely randomized design (CRD) [5].

The treatments consisted of experimental diets containing increasing levels of BS made from P. vannamei waste, fermented with native bacteria isolated from the gastrointestinal tract of chickens. The proximate analysis of BS was: 86.1 % dry matter, 34.39 % protein, 4.69 % ether extract, 16.89 % ash, 5.98 % crude fiber and 24.01 % nitrogen-free extract. (Universidad Nacional Agraria La Molina, Lima, Peru)

The diets were as follows: T0 (0 % BS), T1 (10 %), T2 (15 %), and T3 (20 %). The BS was prepared through cooking, grinding, and anaerobic fermentation of shrimp heads [29].

Using a mother solution of native lactic acid bacteria (Lactobacillus fermentum) isolated from chicken, biochemically and genetically characterized following established methodologies [8 , 29].

In the process, organic acids are produced under anaerobic conditions, leading to a reduction in pH due to the growth of lactic acid bacteria (LAB) [3], reaching a final acidity of 2.3 % and pH of 4.5 (Portable pH/ORP Meter, model HI 8424) and maintaining a LAB count of 10×10^6 CFU [30].

The biological silage was incorporated into a basal isoproteic diet containing 18 % crude protein, formulated for the grower (21 days(d)) and finisher (14 d) phases.

A histological comparison of the size of intestinal villi was performed by histological section of chicken intestine, using the smear and comparison according to the Harris Hematoxylin and Eosin (HE) method or the one performed in pig by García et al. [29].

Each experimental unit consisted of a single bird, which were housed in individual cages within a chicken coop equipped with feeders and waterers. Temperature and ventilation were controlled with 3 meter (m) high burlap blankets.

Productive variables recorded included live weight, final weight kg (WF), fine weight gain kg (FWG), daily weight gain g/d (DWG), feed intake. (using platform scale, Patrick's TCS-K1), feed conversion ratio (FCR), apparent digestibility % (Dig) and economic merit % (ME)

The data obtained were analyzed using analysis of variance (ANOVA) with Minitab® software, followed by Tukey's multiple comparison test at a 95 % significance level.

The statistical model used was:

$Y_{ij} = \mu + T_i + \varepsilon_{ij}$

where Y_{ij} is the observed value,

μ is the overall mean,

T_i is the treatment effect, and

ε_{ij} is the random error.

RESULTS AND DISCUSSION

During the experimental period, a positive effect of BS from *P. vannamei* waste on weight gain in broiler chickens was observed (TABLE I).

TABLE I
Comparison of the main productive parameters of broiler chickens with the inclusion of different doses of biological silage in the diet.

TTO	Final weight (kg)	Fine weight gain (kg)	Daily weight gain (g/d)	Conversion rate (%)	Digestibility (%)	Economic merit (%)	Crack yield (%)
T1	3.01 A	1.53 A	79.27ª	1.58 B	75.34 A	91.76 A	76.1 A
T2	3.15 A	1.64 A	82.48 A	1.45 BC	76.52 A	118.45 A	75.7 A
T3	3.41 A	1.83 A	86.05 A	1.40 °C	75.41 A	137.79 A	75.8 A
T0	2.71 B	1.33 B	64.37 B	1.75 A	73.91 B	57.39 B	75.1 A

Media that do not share a letter are significantly different

According to TABLE I, the highest average weight gain was recorded in treatment T3 (20 % BS) with 1.83 kg, followed by T2 (15 %) with 1.64 kg and T1 (10 %) with 1.53 kg. The control treatment T0 (0 % BS) showed the lowest gain, 1.33 kg. Treatments with incorporated BS were statistically similar to each other, but significantly different from the control treatment ($P < 0.05$).

A similar behavior was observed for the final weight and daily weight gain values of treated broilers compared to the control, demonstrating that the inclusion of BS improves weight. The degradation and preservation process produces several bioactive metabolites, such as low molecular, weight peptides, readily absorbable amino acids, and Chito oligosaccharides with recognized prebiotic activity, these metabolic outcomes are consistent whit the finding of Shabani et al. [3] and Rossi et al. [11].

Along with bioactive compounds generated by lactic acid bacteria during fermentation that promote metabolic efficiency and intestinal microbial balance [3 , 5]. This physiological mechanism provides a justified explanation for the improvements in nutrient retention efficiency and consequent biomass accumulation [25]. The present finding are in agreement with the model proposed by Shabani et al. [3], who correlated improvement in growth performance in aquaculture species with the administration of hydrolyzed protein fractions derived from fish by-products in the form of silage.

According to Bezerra and Fonseca [31], mention that spotted surubim EB fermented with L. brevis represents a valuable protein source that produces organic acids essential for product preservation and nutritional enhancement [32].

The improved results can be attributed to the protein content of BS, the presence of prebiotic compounds generated during fermentation, which are beneficial for birds, The dose-dependent improvement in productive performance appears to result from a synergistic mechanism associated with enhanced nutrient bioavailability and the formation of functional metabolites during the fermentation [3 , 4].

Studies supported by Shabani et al. [3], Sun et al. [32] and Mebratu et al. [33], demonstrated that including 10 - 30 %, BS in broiler diets enhanced weight gain, nutrient digestibility, and gun health without compromising meat quality, indicate that shrimp waste BS fermented with native bacteria represents a sustainable and cost effective feed alternative for broiler during the grow and finish phase.

The FCR considered a critical zootechnical parameter for evaluating feed efficiency [3 , 34 , 35], the dose most efficient feed utilization was achieved in treatment T3 (FCR = 1.40), demonstrating a positive linear relationship between inclusion levels and productive performance. and improved the balance of intestinal health expressed in the size of intestinal villi [17].

Tanuja et al. [36] reported a less efficient FCR (3.26-3.27) for "Vanraja" broiler chickens fed acidified fish silage, highlighting the benefits of biological fermentation with native bacteria using BS (10 % BS) made with organic acids, formic acid (1.5 %) and HCl (1.5 %), on the other, hand more efficient FCR values between 1.60 and 1.68 by in poultry diets were reported by Sun et al. [32].

Rodríguez et al. [37] documented improvements in FCR in birds receiving diets supplemented with shrimp by-product silage. Comparable the value ratio is 1.7 to 1.9 when incorporating fish waste silage from red tilapia viscera treated with sulfuric (0.03 %) and formic (1.16 %) acids into poultry diets [5]. recover, fish or shrimp-based BS can effectively replace a portion of fishmeal in broiler diets [8].

Regarding apparent feed digestibility, significant differences were detected between the BS treatments (T3, T2 y T1) and control group (T0). The highest digestibility,and observation.

Similarly of Shabani et al. [3] showed that the inclusion of fish silage improves digestive enzyme activity and nutrient retention, which reported increases in the production of short-chain fatty acids in the cecum, which contributes to higher digestibility.

Cunha et al. [38] reported high metabolizability energy in diets with fish silage meal, attributed to protein solubility and macromolecule degradation during fermentation. These results highlight that partial hydrolysis of proteins during ensiling generates peptides and amino acids of low molecular weight that are easily assimilated, favors digestion and feed efficiency in broiler chickens, without affecting their health [5 , 6].

Abun et al. [20] document a dry matter digestibility of 75.53 % using fish silages fermented with bacterial consortia. The silage obtained is rich in proteins, lipids (up to 9.85 %) and minerals, with high digestibility (> 80 %), and amino acids of low molecular weight that are easily assimilated, favors digestion and feed efficiency in broiler chickens [18 , 33].

The ileal digestibility coefficient of crude protein was higher at 20 % (76.2 %), and crude fat at 20 % and 30 % in the groups receiving claw meal [33], along with bioactive compounds generated by LAB during fermentation that promote metabolic efficiency and intestinal microbial balance [3 , 5 , 6 , 33].

The economic merit analysis indicated that the inclusion of BS markedly enhanced profitability, with treatment T3 (20 % BS) achieving the highest return (137.79 %), values of treated broilers compared to the control, this suggests that the inclusion of BS not only improves production performance; but also reduces production costs per kilogram of meat, due to the low cost of the raw material (P. vannamei waste) and the quality protein contribution, these findings coincide with Shabani et al. [3], Zulfan et al. [4] and Safari et al. [35].

Confirming that the valorization of aquaculture waste through BS, who reported a lower cost-benefit ratio in birds supplemented with marlin waste meal without affecting performance, reducing feed costs and increasing income inclusion, enhancing the economic sustainability profitability of poultry systems [18 , 19 , 34].

Regarding carcass yield, although no significant differences were observed (P > 0.05), a positive trend was evident with increasing levels of BS inclusion. With respect to carcass yield, although no significant differences were observed (P > 0.05), a positive trend was evident with the inclusion of BS. The highest yield was observed in T3 (75.78 %), followed by T2 (75.51 %), T1 (75.33 %) and T0 (75.11 %).

These values exceed those reported by Boitai et al. [39], who with 10–15 % chemical fish silage obtained yields between 73.96 % and 74.9 %. Additionally, the yield of metabolic organs (gizzard, liver, heart and spleen) was higher in T3 (3.6 %) and T2 (3.7 %) compared to T0 (2.1 %).

Broilers fed 30 % fish meal were more efficient at converting feed to body weight and produced the highest carcass weight [33]. No relevant differences were observed in non-edible organs, although T0 and T1 showed slightly higher values, possibly due to greater moisture retention in birds not supplemented with BS [1 , 36].

These results suggest that the BS of P. vannamei allows to maintain or improve the performance of the carcass and metabolic organs without adverse effects, consolidating itself as a sustainable nutritional alternative, this improvement may be due to better nutrient digestibility and gut health.

Regarding intestinal health, the inclusion of BS favored the morphometry of intestinal villi in FIG. 1. The highest villus height was observed in T2 (1360 µm), followed by T1 (1168 µm), T3 (1004 µm), and T0 (946 µm). The significant morphological improvements in T2 and T3 are consistent with the findings reflect a larger absorptive surface area and a more developed intestinal mucosa, in line with those reported by Shabani et al. [3], and Mebratu et al. [33], The greatest villus width was observed in T3 (151 µm). This increase in absorptive surface area reflects more developed and functional intestinal mucosa.

Chile previous studies have evaluated fish or shrimp silage, the novelty of this research lies in the use of a bacterium native to the avian gastrointestinal tract for fermentation [33]. This strategy not only improves waste recovery but could also promote better adaptation and colonization of the ingredient in the avian intestinal environment, thus optimizing its functional benefits compared to the use of chemical acidifiers or exogenous bacterial strains, who attribute these effects to a healthier gut environment and balanced microflora, improvement in jejunum morphology, increased villus height and villus/crypt ratio, indicating better nutrient absorption [3].

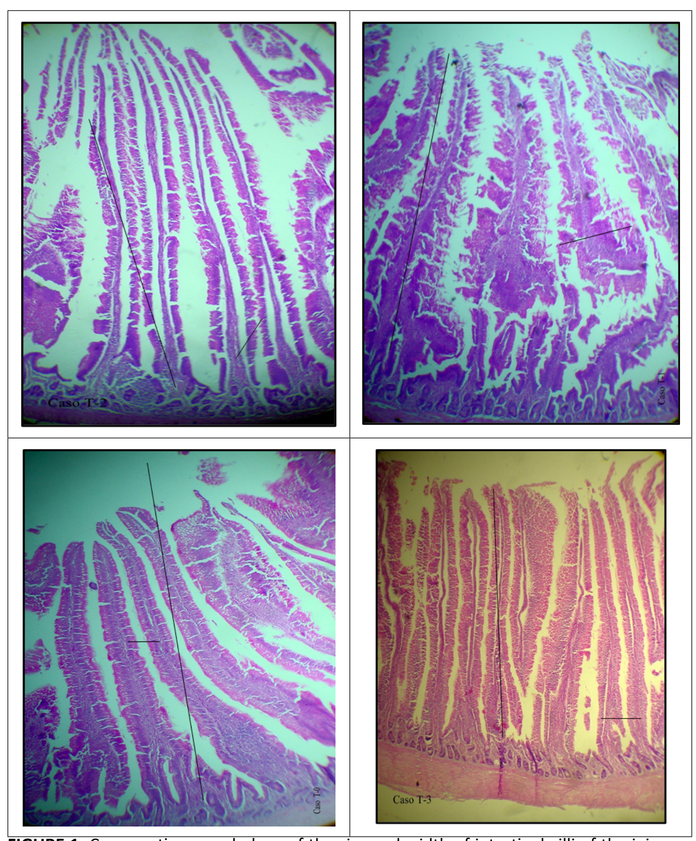

FIGURE 1. Comparative morphology of the size and width of intestinal villi of the jejunum (20 cm of the duodenal loop), of treatments a) T0, b) T1, c) T2 and d) T3 of chickens according to the treatment. Software used: Zeiss Labscope

It shows an increase in villus height and crypt depth with 20 % minnow meal, indicating improved nutrient absorption [33]. Together, these findings support the use of P. vannamei BS fermented with native bacteria as a functional ingredient that provides high-quality protein, optimizes nutritional efficiency, and promotes intestinal health in broiler chickens [31].

Consolidating its position as a strategic tool in sustainable poultry production systems, sactic acid bacteria used in silage modulate the intestinal flora by increasing beneficial populations and reducing pathogens, as highlighted by Bezerra and Fonseca [31]. This leads to a healthier environmental with less intestinal stress and increased mucosal integrity. who showed that fish waste ensilage improves villus height and crypt-to-villus ratio, as well as the findings of Ibrahim et al. [40] and Dowarah et al. [41].

Highlights that generating lower intestinal stress and greater mucosal integrity. These effects may be related to, the presence of short-chain fatty acids and other bioactive compounds generated during fermentation exert trophic effects on the intestinal epithelium [3].

Therefore, the use of BS (using P. vannamei residues as raw material) in broiler chicken feed supports the use of native bacteria as a viable fermentative organism to provide a quality protein-rich functional feed to improve broiler chicken production and gut health as a sustainable poultry production tool [33].

The result demonstrates how an aquaculture byproduct, demonstrate how an aquaculture byproduct, typically considered a polluting waste, can be reintegrated into the production chain as a valuable resource and integrated into the circular economy, closing the material loop between aquaculture and poultry farming, reducing dependence on conventional protein sources (fishmeal, soy) and decreasing the environmental footprint of both industries.

CONCLUSION

Diets in which *Penaeus vannamei* biological silage fermented with native bacteria was used for chicken feed significantly improved key production parameters (weight gain, feed efficiency, and digestibility), promoted intestinal health, as reflected in intestinal villi development, and maintained carcass yield. It also reduced feed costs, improved profitability, and promoted sustainability in aquaculture and poultry farming areas. *P. vannamei* BS is a protein and functional alternative.

The strategy demonstrates a clear economic benefit by reducing feed costs, positioning biosilage as a viable alternative to partially replace conventional proteins. Therefore, this work goes beyond the mere presentation of a feed supplement and validates a concrete circular economy model, transforming aquaculture waste into a valuable resource for poultry farming, contributing to the environmental and economic sustainability of both sectors.

Future research should evaluate the effect of biological silage on an industrial scale, analyze its impact on the sensory a nutritional quality of meat, and employ metagenomic techniques to accurately characterize its impact on the gun microbiome. This line of research has the potential to consolidate the use of biological silage as a fundamental tool in sustainable animal production.

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Conflict of interest

The authors declare that they have no conflict of interest.

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