

Article

Biotransforming of Poultry and Swine Slaughterhouse Waste as an Alternative Protein Source for Ruminant Feeding

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Abstract: The biotransformation of poultry (PSW) and swine (SSW) slaughterhouse waste might provide protein feedstuffs, ensuring efficient ruminant systems while safeguarding the environment. The present study aimed to evaluate the potential of PSW and SSW as alternative protein feed for ruminant animals. A total of 24 lambs [25.4 ± 3.13 kg of body weight (BW), mean $\pm$ SD] were randomly allocated to one of three groups ($n = 8$): a control diet formulated with typical protein ingredients (CTRL) and two diets formulated with PSW or SSW meal as a protein source. Dietary inclusion of PSW or SSW did not alter ($p = 0.05$) dry matter intake or final BW. However, animals fed SSW showed the highest average daily gain (ADG, $p = 0.04$). In addition, substituting PSW and SSW improved the feed conversion ratio (FCR, $p = 0.05$). There were no diet effects ($p = 0.05$) on N intake, while fecal N excretion increased ($p = 0.03$) with SSW feeding. Compared to CTRL and PSW, ingestion of SSW decreased ($p = 0.001$) and retained N. The digestibility of crude protein and organic matter remained unchanged ($p = 0.05$). Additionally, there were no differences ($p = 0.05$) in potential microbial protein synthesis based on either protein content (SPMp) or energy content (SPMe). Similarly, potential metabolizable protein by protein (PMp) and potential metabolizable energy by protein (PMe) were not affected ($p = 0.05$). Overall, both PSW and SSW positively influenced the growth performance of ewe lambs. However, further studies are warranted to explore the impact of PWS or SSW feeding on rumen function, nitrogen pollution, and protein escaping the rumen into the intestine in ruminants.

Keywords: lamb; protein feedstuff; ruminant nutrition; slaughterhouse waste



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1. Introduction

An upward trend in the global demand for food obtained from ruminant livestock production, rooted mainly in the ever-growing human population, will be challenged by food–feed–fuel competition, excessive use of natural resources, climate change, and economic volatility, particularly in less developed countries [1–3]. This increase in feed demand from ruminant livestock production might be met by alternative, efficient, high-quality feed sources with a lower environmental footprint for use in ruminant feed [3,4]. Like the efficiency, the circular economy is a fluid concept still evolving in the livestock

industry [5]. The circular economy model aims to reduce slaughterhouse waste (SW) by reusing and recycling products for as long as possible, thus extending their lifecycle and keeping materials within the economy [6]. The efficient use of animal by-products can directly impact circular economy and minimize environmental pollution [7]. Conversely, failure to utilize these by-products will lead to additional expenses for waste disposal, potential revenue loss, and ecological and human health effects [8,9]. In this context, the scientific management of waste from the slaughterhouse industry in Mexico is becoming increasingly important [10]. Furthermore, the growing impact of climate change requires efficient practices and the enactment of public policies [11]. The UN has proclaimed efficient development goals: 17 agendas and 169 goals to achieve by 2030, the key features of which are environmental impact and economic security. Most of these agendas have been proposed to increase the regulations provided for in the legislation of the European Union, China, and the United States of America [12].

Therefore, interest in converting SW into usable protein has increased. This approach aims to introduce new cost-effective environmentally friendly food options while addressing the health and environmental concerns associated with SW disposal. The poultry (PSW) and swine (SSW) industries generate significant organic by-products worldwide. Over 70 billion chickens and 1.5 billion pigs were slaughtered for food production in 2023 alone [6]. Nevertheless, the biotransformation of PSW and SSW into valuable feed ingredients is very complex, primarily due to the pathogenic nature, higher water content, a tendency towards rapid auto-oxidation, and high levels of enzymatic activity [1,2]. Furthermore, as alternative energy sources emerge, several questions will be asked concerning the safety of the end products generated. In the case of using slaughterhouse waste in biogas production, the microbial quality of the product is of major concern as SW can be contaminated with high number of microorganisms, including bacteria, viruses, prions, fungi, yeasts, and associated microbial toxins [13]. These wastes can put human and animal health at risk unless they are handled and treated correctly [13,14]. Recent advancements in the utilization of SW have unveiled various applications, including its use as biofuel for renewable energy generation, feedstock for anaerobic digestion, and biomaterial of processed foods for human consumption, besides its application as protein feed ingredients in animal diets [2]. Jayathilakan et al. [8] reviewed some feeding trials concerning the inclusion of SW in animal diets. Despite being a rich source of protein, the functional applications of SW are limited due to its non-homogeneous composition, presence of non-proteinaceous materials, and poor solubility [1].

Additionally, the few scientific reports that have described the reliability of SW for ruminant feeding have evaluated the effectiveness of bone and hydrolyzed feather meal in cattle diets [8], meat and bone meal in steers [15], poultry litter in Friesian steers [16], and slaughterhouse blood in steers [17]. Also, the authors have concluded that the PSW and SSW are significant rendering by-products with high protein content for use as protein feed ingredients for ruminants [2,18]. The content of crude protein (CP), ether extracts (EE), and ash of PSW ranged from 50 to 63%, 18 to 27%, and 9.0 to 15.5% of dry matter (DM) [19]. Also, in an *in vivo* trial, the protein efficiency of PSW for growing steers was superior to that of meat and bone meal [16]. Moreover, the dietary inclusion of PSW as a protein substitute for soybean meal (SBM) decreased feed costs in growing hair lambs [20]. However, we identify at least two challenges regarding incorporating PSW and SSW into ruminant diet formulations, whose investigation is required to increase the data on the viability of SW as a source of protein. First, feeding a ruminant with a source of CP increases the excretion of nitrogen (N) into the environment, negatively impacting health and reproductive performance [21]. Ruminant livestock exhibit relatively low efficiency in utilizing feed nitrogen (N). Studies involving dairy cows have shown varying milk N efficiency, ranging from 14% to 45% (with an average of 25% and 28% and standard deviations of 4.1% and 3.6% for North American and North European data, respectively), as outlined in a meta-analysis by Huhtanen and Hristov [22]. Nitrogen mass balance assessments on dairy farms and beef feedlots have demonstrated feed N conversion

efficiencies into milk or body weight gain of 27% and 14%, respectively [23]. While it is essential to improve the efficiency of converting feed protein into milk protein, it is equally crucial to meet the nitrogen requirements of rumen microbes [24] to prevent adverse impacts on microbial growth and activity, ruminal fermentation, synthesis of microbial crude protein (MCP), and, consequently, nutrient digestibility, feed intake, and milk yield (MY) and quality, including nutrient concentrations and fatty acid (FA) profile [22,23]. Neglecting this aspect could lead to significant consequences.

Secondly, nitrogen not utilized for animal tissue retention or milk production is excreted via urine and feces, contributing to environmental issues such as water pollution, gaseous nitrogen emissions, and the formation of small particulate matter in the atmosphere [23,25,26]. Urinary nitrogen is particularly susceptible to rapid leaching and volatilization losses compared to fecal nitrogen. The substantial variability in urinary nitrogen excretion offers opportunities to reduce it through dietary manipulation [27]. Consequently, comprehending nitrogen metabolism and investigating processes and strategies to enhance nitrogen utilization efficiency for productive purposes have been central themes in ruminant nutrition research for over a century [28,29]. Recent research has shifted towards mitigating nitrogen emissions (such as ammonia, nitrate, and nitrous oxide) into the environment. It is essential to have an accurate and precise model of the utilization of feed with high protein levels for SW in ruminants. This will help to obtain reliable experimental results on nitrogen utilization by ruminant species in different periods [29]. As a result, this topic can be introduced into the ruminant nutrition industry as a protein feed source that will be widely accepted and used [5].

Looking ahead, challenges in food security will drive significant changes in the ruminant production sector. This adoption will require management practices such as identifying and utilizing alternative protein-rich feeds. In this context, research endeavors [5,19] have targeted PSW and SSW as environment-friendly feedstuff for ruminant feeding; however, inadequate feeding trials constrain their use in ruminant feeds. With this background information, the present study aimed to investigate the effects of PSW and SSW inclusion on growth performance, nutrient digestibility, and N balance in lamb diets. We hypothesized that substituting either PSW or SSW with typical dietary protein sources does not adversely affect the performance and digestibility of lambs. To our knowledge, this is the first study evaluating the biotransformation of PSW or SSW as alternative protein feed for lambs.

2. Materials and Methods

2.1. Study Site

The study was conducted at the Sheep Unit of the School of Agronomy and Veterinary Medicine at the Autonomous University of San Luis in Ejido Palma de la Cruz, Soledad de Graciano Sanchez, San Luis Potosi, Mexico. The slaughterhouse waste meal and the animal data were prepared during the end of winter and spring, 2024. The average temperature was 27 °C/7 °C during the fattening phase.

2.2. Slaughterhouse Waste Meal Preparation

The method to prepare the slaughterhouse waste meal followed the Mexican normative standard Mexican Official Standard NOM-060-ZOO-1999, Animal health specifications for the processing of animal offal and its use in animal feed. This trial follows the disposition of tissues and raw offal of animal origin in ruminant rations. Although ruminant-origin meal was to be included in the ruminant feed, meal from non-ruminant animal species in ruminant feed was used in compliance with the provisions NOM-060-ZOO-1999. When processing swine and poultry tissues, they must be processed at a minimum temperature of 80 °C for 30 min. This reduces the potential risk to animal and human health from microbial abundance and contamination by diverse bacteria, viruses, prions, fungi, yeasts, and associated microbial toxins.

2.3. Animal Feeding and Management

The process (Figure 1) starts with sterilizing the viscera at 120 °C for 80 min with a pressure of 20 psi and grinding to 2 mm diameter particles. The ground viscera were first mixed with molasses and bacterial inoculum (natural yogurt) and left at room temperature (approximately 25 °C) for 24 h for a little fermentation process. After 24 h, it was mixed with calcium propionate as a food preservative. The mix was prepared and dried in a solar dryer for 48 h or the time necessary to obtain a product with a minimum of 90% dry matter. The procedures for the growth experiment were subjected to a thorough ethical review, and approval was obtained from the Committee for the Ethical Use of Animals in Experiments at the Universidad Autónoma de San Luis Potosi (DCA-2018-034).

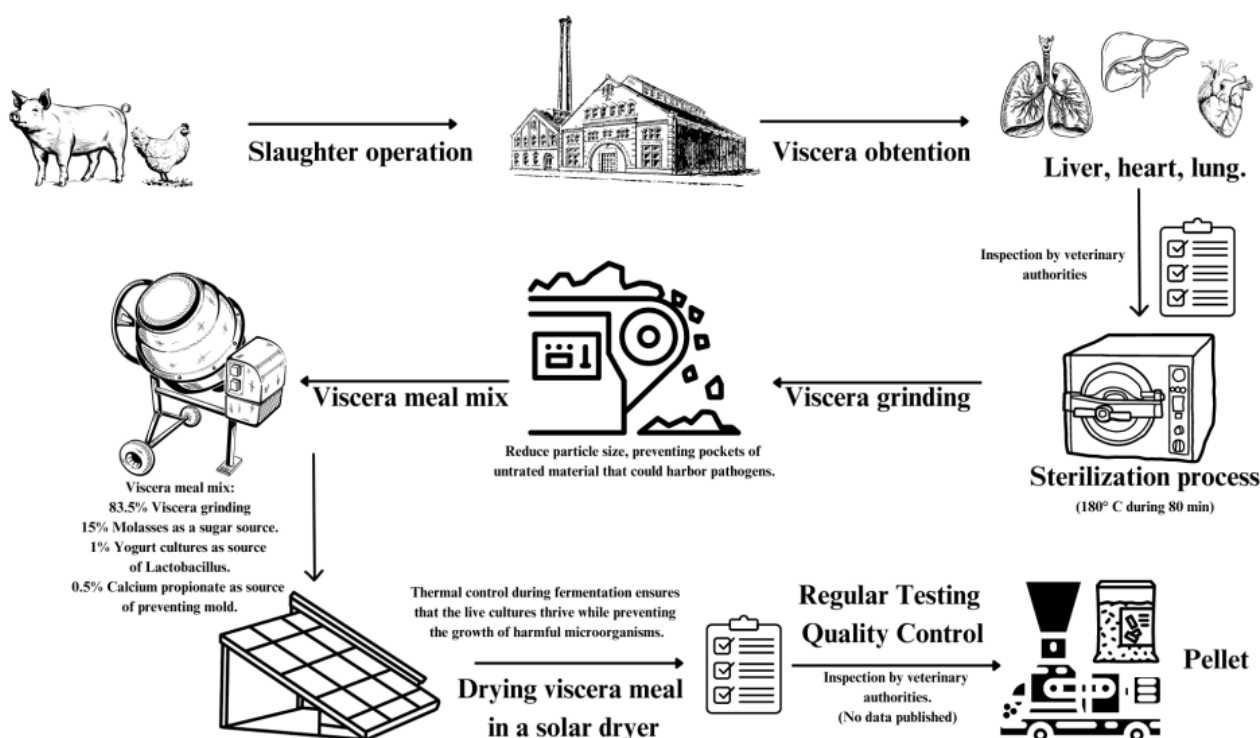


Figure 1. Production scheme for biotransformation of PSW and SSW into an alternative source of protein.

Twenty-four young Rambouillet ewes with body weight (BW) of 25.45 ± 3.13 kg (mean $\pm$ SD) were utilized for the growth experiment. These lambs were individually identified, weighed, and housed in metabolic cages (0.80×1.2 m) equipped with a feeder and waterer. Before starting the study, the ewes were treated with vitamins A–D–E (Bayer, Mexico city, México; 1 mL = 500,000 IU of vitamin A; 75,000 IU of vitamin D; 50 mg of vitamin E), and 0.5 mL per ewe of deworming Ivermectin (Sanfer Lab, Mexico city, México) was also applied. Additionally, the housing arrangement followed the specifications outlined in Mexican Official Standards NOM-051-ZOO-1993, NOM-051-ZOO-1995, and NOM-062-ZOO-1999. The ewes were assigned to one of three treatments: (a) Control: Diet formulated with typical ingredients (CTRL); (b) Diet formulated with poultry slaughterhouse waste meal as a protein source (PSW); and (c) Diet formulated with swine slaughterhouse waste meal as a protein source (SSW). Table 1 details the chemical composition of the experimental diets.

Table 1. Ingredients and nutrient composition (DM basis) of experimental diets.

Ingredients	Diets ¹		
	CTRL	SSW	PSW
Sorghum stubble, %	29.0	25.0	24.0
Ground corn, %	12.0	10.7	11.0
Rolled corn, %	12.0	10.7	11.0
Ground sorghum, %	20.0	22.0	22.0
Soybean paste, %	12.0	0.00	0.00
PSW ¹ , %	0.00	0.00	15.0
SSW ² , %	0.00	15.5	0.00
Ground peanut, %	7.00	6.00	8.00
Molasses, %	8.00	8.00	8.00
Mineral salt, %	1.00	1.00	1.00
Chemical composition (% DM)			
Dry material (%)	69.8	69.5	73.3
Crude protein (%)	12.6	12.6	13.3
Neutral detergent fiber (%)	52.2	61.9	53.8
Ethereal extract (%)	7.81	9.80	11.9
Ash (%)	10.2	10.8	8.55

^{1,2} CTRL, PSW, and SSW were formulated with typical protein feed ingredients, poultry slaughterhouse waste meal, and swine slaughterhouse waste meal, respectively, as a protein source.

Feedings were conducted at 08:00 and 15:00 h, and all ewes had free access to feed to ensure 100 g of orts per kg of the daily amount fed. This protocol was implemented to maintain ethical standards and ensure the well-being of the animals throughout the experiment.

Samples of 1 kg of experimental diets were collected and combined to create composite samples for each period. These composite samples were then utilized for analysis. The feed samples were dried in a forced air oven at 60 °C for 48 h and were ground using a 10-micron mesh. Dry matter (DM) content was determined, and ash content was calculated by measuring weight loss after desiccation at 75 °C for 24 h, followed by incineration in a muffle at 500 °C for five hours. The analyses were conducted following the AOAC methods [30] for dry matter (DM), crude protein (CP), and ethereal extract (EE). Neutral detergent fiber (NDF) was determined according to Van Soest et al. [31] by adding 1 mL of amylase to the procedure.

For the growth performance analysis, lambs were fed experimental diets for 35 days. The DM intake (DMI) was calculated daily by the difference between the amount of feed offered and the feed refused. Lambs were weighed at the beginning (day 1) and at the end (day 35) of the experiment to evaluate body weight (BW) and estimate average daily gain (ADG). The feed conversion ratio (FCR) was expressed as the ratio of DMI to ADG. After the growth test, feces and urine were collected over five days for N balance. The collected 20 mL of urine was preserved by adding 1 mL of sulfuric acid (30%) to prevent N loss by volatilization following the methodology by Hristov et al. [32]. At the same time, the feces (15 g) were directly obtained from the rectum, dried in an oven at 60 °C, and stored until further analysis. Based on the collected data, calculations were performed to predict protein flux using the metabolizable protein system [33]. This system estimates the potential amount of microbial protein (g/kg MS) that can be generated by fermenting a substrate in the rumen, considering its energy and rumen-degradable protein content.

2.4. Statistical Analysis

All statistical analyses were performed in SAS software version 9.2 (SAS/STAT, SAS Institute Inc., Cary, NC, USA) using a general linear model (GLM) procedure. The model included dietary treatment (CTRL, PSW, and SSW) as fixed effects and the residual error, while ewes were included as a random factor. Three covariance structures were tested (autoregressive-1, spatial power, and unstructured), and the one resulting in the lowest

Akaike information criterion was chosen. Differences in least-square means (LS means) were compared using Tukey's multiple comparison test, and the results are expressed as LS means with the standard error of the mean (LS means $\pm$ SEM). The significance level was set at $p \leq 0.05$, and trends were declared at $p \leq 0.10$ and $p > 0.05$.

3. Results and Discussion

By 2050, ruminant production will need to expand by 70% to fulfill the enormous demand of approximately 9.5 billion people for ruminant-based food products [3,6]. However, global ruminant production will require more feed due to water shortages, land degradation, and industrialization [3,4]. Additionally, there is an increase in the costs of conventional feed sources, with protein sources being undoubtedly the most expensive ingredients, posing yet another challenge for the ruminant sector [6,14]. All these factors have driven the inevitable search for alternative, cost-effective, and protein-feed ingredients to support efficient production [1–3]. In this context, we assessed the usefulness of biotransforming PSW or SSW as efficient alternatives for protein feedstuffs. To our knowledge, no investigation has addressed PSW and SSW in ewe lamb feed. Our results indicate that PSW and SSW could successfully substitute typical protein ingredients in ewe diets without negatively impacting digestibility and microbial protein synthesis while enhancing growth rate and improving FCR. Dietary inclusion of neither PSW nor SSW altered ($p \leq 0.05$) the dry matter intake (DMI) of ewe lambs compared with the CTRL group (Table 2). This result proves that lambs can intake feed that includes slaughterhouse waste as a source of protein.

Table 2. Growth performance of ewes fed slaughterhouse waste of poultry (PSW) and swine (SSW) as an alternative source of protein ¹.

Variables ²	Diets ³			SEM ⁴
	CTRL	PSW	SSW	
IBW, kg	25.33	25.45	25.43	1.22
FBW, kg	30.66	32.14	32.13	1.84
DMI, kg animal ^{−1} day ^{−1}	1.66	1.71	1.64	0.87
ADG, g animal ^{−1} day ^{−1}	191.14 ^b	238.4 ^a	240.3 ^a	15.97
FCR	8.6 ^a	7.17 ^b	6.82 ^b	0.23

^{ab} Within a row, means without a common uppercase superscript letter differ ($p \leq 0.05$). ¹ Values are least-square means (LSMs). ² IBW = initial body weight; FBW = final body weight; DMI = dry matter intake; ADG = average daily gain; FCR = feed conversion ratio. ³ CTRL, PSW, and SSW were formulated with typical protein feed ingredients, poultry slaughterhouse waste meal, and swine slaughterhouse waste meal, respectively, as a protein source. ⁴ SEM = pooled standard error of the mean.

Also, no differences ($p \leq 0.05$) were observed between diets in initial BW (IBW) and final BW (FBW); however, animals fed SSW showed the highest ($p \leq 0.05$) average daily gain (ADG), followed by PSW (Table 2). In confirmation, previous reports have shown that poultry and pork by-products are feasible ruminant feedstuffs [4,5,34]. It has been reported [4] that replacing SBM with PSW in the diets of fattening lambs did not affect DMI and ADG. Likewise, feeding dairy cows with feather meal substituting SBM did not change DMI [35]. Andrighetto and Bailoni [36] showed similar DMI following the inclusion of a feather and blood meal mixture in lactating doe diets. Also, the dietary inclusion of PSW powder for fattening lambs did not significantly affect DMI [37]. In the present study, ewe lambs fed PSW or SSW had 24.7% and 25.8% higher ADG than those fed CTRL. The substitution of both PSW and SSW as alternative sources of protein improved ($p \leq 0.05$) feed conversation ratio (FCR), with SSW having the lowest value. Our results show that using poultry by-product meal as a ruminant protein source positively affected ADG. Lallo and Garcia [20] observed improved ADG and FCR with poultry by-product meal replacing SBM in growing lambs. These authors indicated that young growing lambs utilized the poultry by-product meal more efficiently than SBM. However, it has been reported that the ADG of finishing lambs remained unchanged following ingestion of either poultry by-product meal [31] or PSW [4] as a replacement for SBM. These conflicts could be mainly related to

the type of poultry by-products used [38], their processing, the experimental conditions, and the animals used in research [4,24]. Studies with steers reported that feeding poultry by-product meal [39] and meat and bone meal [16] as sources of supplemental nitrogen led to higher ADG compared to those fed SBM.

The N intake and excreted N in feces and urine are presented in Table 3. There were no dietary effects on N intake ($p \leq 0.05$), while fecal N excretion ($p \leq 0.05$) increased with SSW feeding. Also, the highest ($p \leq 0.05$) urinary N excretion was for ewes fed SSW, followed by PSW. However, the dietary inclusion of SSW was accompanied by lower ($p \leq 0.05$) retained N compared to both CTRL and PSW.

Table 3. Nitrogen balance of ewes fed slaughterhouse waste of poultry (PSW) and swine (SSW) as an alternative source of protein ¹.

Variables ²	Diets ³			SEM ⁴
	CTRL	PSW	SSW	
N intake, g/d	33.35	34.19	33.44	7.41
N Fecal, g/d	5.40 ^b	5.75 ^b	6.04 ^a	0.86
N Urine, g/d	1.63 ^c	1.91 ^b	2.22 ^a	0.04
N Retained, g/d	26.32 ^a	26.53 ^a	25.18 ^b	1.58
N Excreted, g/d	7.03 ^b	7.66 ^{ab}	8.26 ^a	0.9

^{abc} Within a row, means without a joint uppercase superscript letter differ ($p \leq 0.05$). ¹ Values are least-square means (LSM). ² N = Nitrogen. ³ CTRL, PSW, and SSW were formulated with typical protein feed ingredients, poultry slaughterhouse waste meal, and swine slaughterhouse waste meal, respectively, as a protein source. ⁴ SEM = pooled standard error of the mean.

The N intake in ruminants is mainly dictated by the diet's DMI and CP content [40]. Our results showed that the N intake was similar between ewes fed either CTRL or PSW and SSW; this is reflected in the results obtained in the final weight. However, N excretion in PSW and SSW were 8.9% and 17.5% higher than CTRL, respectively. Also, the lowest N retention occurred with SSW (4.3% lower than CTRL). N excretion was also reported to increase in goats fed feather meal [35,36] and blood meal [18]. However, the lack of significant differences between PSW and CTRL diets regarding retained N and excreted N suggests that the part of PSW protein that is not degraded in the rumen can be digested in the small intestine to support production functions and indicates that the amino acids in the diets were being utilized with similar efficiencies [24,41]. In line with this, Kazemi-Bonchenari et al. [5] showed that supplementing diets with PSW can increase the amount and alter the pattern of amino acids entering the small intestine and increase nitrogen retention. Research has demonstrated [8] that feather and bone meals can be un-degraded protein sources, increasing nitrogen utilization in finishing cattle. Moreover, as a confirmation, Shirazi et al. [4] showed that replacing PSW with SBM does not change blood urea nitrogen (BUN) of fattening lambs as an indicator of nitrogen efficiency. These authors also suggest that the rumen undegradable protein in PSW was digested and absorbed in the small intestine, making it bioavailable. Overall, the current results indicate that although PSW presented no advantage or disadvantage for N utilization, SSW can increase nitrogen excretion, and potential N pollution of the environment should be considered.

Feed digestibility is an essential factor when it comes to including by-products and wastes as alternative feedstuffs [3]. The digestibility of CP is more critical than that of other nutrients since it influences NH₃-N accessibility, microbial protein synthesis, and undegraded protein supply to the post-rumen [41]. Thus, rumen CP degradation and escaped CP reaching the small intestines are critical factors in determining the nutritional value of feedstuffs [42]. The digestibility of crude protein (CP) and organic matter (OM) remained unchanged ($p \leq 0.05$) with ingestion of PSW and SSW in ewes (Table 3). Additionally, there were no differences ($p \leq 0.05$) for potential microbial protein synthesis based on either protein content (SPMp) or energy content (SPMe). Similarly, potential metabolizable

protein by protein (PMp) and potential metabolizable energy by protein (PMe) were not affected ($p \leq 0.05$) by diets (Table 4).

Table 4. Protein of ewes fed slaughterhouse waste of poultry (PSW) and swine (SSW) as an alternative source of protein ¹.

Variables ²	Diets ³			SEM ⁴
	CTRL	PSW	SSW	
CP, %	12.6	13.3	12.6	1.28
OM digestibility, %	76.4	75.6	75.9	3.86
CP digestibility, %	82.2	81.4	79.6	1.85
SPMe, g/kg	79.8	78.9	79.3	0.67
SPMp, g/kg	103.6	108.3	100.2	2.70
PMp, g/kg	91.1	96.9	91.4	4.53
PMe, g/kg	71.9	73.4	74.6	0.99
PMp g/d	151.1	165.6	149.8	4.81
PMe g/d	119.5	125.5	122.3	3.72

¹ Values are least-square means (LSM). ² CP = crude protein; OM = organic matter; OMD = degradable organic matter; DEG = CP degradability; SPMp = potential microbial protein synthesis of a food based on protein content; SPMc = potential microbial protein synthesis of a food based on energy content; PMp = potential metabolizable protein by protein; PMc = potential metabolizable energy by protein. ³ CTRL, PSW, and SSW were formulated with typical protein feed ingredients, poultry slaughterhouse waste meal, and swine slaughterhouse waste meal, respectively, as a protein source. ⁴ SEM = pooled standard error of the mean.

In our study, the dietary inclusion of PSW and SSW did not alter CP or OM digestibility. Previously published data [33,43] revealed that poultry waste meal did not affect digestibility coefficients for DM and CP in sheep and steers. In line with our results, Shirazi et al. [4] showed that feeding PSW did not affect the digestibility of DM and CP in lambs. Likewise, the dietary inclusion of poultry waste did not affect the apparent digestibility of DM, OM, NDF, or ADF [44]. It has also been reported [16] that true protein digestibility in the gastrointestinal tract of lambs was not affected by the inclusion of poultry by-product meal.

These enhanced growth rates may be attributed to increased digestible CP and, consequently, the quantity of protein reaching the small intestine [23]. It has been well documented that animal-derived protein sources increase the total flow of digestible protein to the small intestine or provide digestible ruminal undegraded protein complementary to any limiting amino acid in microbial CP [41]. In addition, Kamalak et al. [41] reported that PSW could be considered for increased bypass protein. Altogether, our results indicated a favorable effect of both PSW and SSW on the growth performance of ewe lambs, an effect probably associated with a higher supply of rumen undegradable protein and protein flow to the small intestine. However, future studies should clarify the effects of PSW or SSW application on protein and amino acid supply for ewes. Finally, this study could be used as a circular economic model regarding “closing loops” [45], requiring minimal changes in livestock production and slaughterhouse procedures and reducing the destruction of biological materials [13]. This model also improves the virtuous circle where industry benefits from potential waste reintroduced to the same financial infrastructure as the livestock sector does [12,46]. Thus, public policies could adopt the principle of this type of study, postulating compensatory laws to benefit the environment [46].

4. Conclusions

PSW and SSW are protein feed ingredients for environment-friendly and efficient ruminant production. In this study, we assessed the impact of including both PSW and SSW meals in the diets of lambs. Our results indicate that both PSW and SSW could successfully substitute typical protein ingredients in ewe diets without negatively impacting digestibility and microbial protein synthesis while improving growth rate and FCR. However, SSW feeding was associated with higher N excretion. These results reinforce our conclusions

that rendered wastes are feasible feedstuffs for ewe lambs. Further research is needed to explore the impact of these waste materials on rumen function and nitrogen pollution.

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