Published August 6, 2015

# The effect of the inclusion of recycled poultry bedding and the physical form of diet on the performance, ruminal fermentation, and plasma metabolites of fattening lambs[1]

**D. Mirmohammadi,* Y. Rouzbehan,*[2] H. Fazaeli†**

*Department of Animal Science, Faculty of Agriculture, Tarbiat Modares University, P.O. Box 14115-336, Tehran, Iran; and †Animal Science Research Institute, P.O. Box 1483, Karaj 315, Iran

**ABSTRACT:** During a 125-d experimental period, 24 Afshari × Kurdish male lambs initially weighing 25.2 ± 1.2 kg were grouped by BW and randomly assigned to treatments under a completely randomized design with a 2 × 2 factorial arrangement of treatments to evaluate the effects of feeding recycled poultry bedding (RPB; 0 and 200 g/kg DM) and the physical form of the diet (mash and block) on nutrient intake and digestibility, ruminal and plasma parameters, microbial N supply, N balance, feeding behavior, and growth performance of the lambs. Two diets with and without RPB in both mash and block form were prepared. Neither the inclusion of RPB nor the physical form of the diet affected the concentration of VFA or the total tract apparent digestibility of nutrients. Dietary RPB inclusion increased DMI ($P < 0.01$), tended ($P = 0.10$) to reduce ADG, and decreased G:F ($P = 0.05$). The physical form of the diet had no effect on DMI but decreased ADG ($P = 0.01$) and G:F ($P = 0.02$) in lambs fed on the block diet compared with those fed on the mash diet. Neither the inclusion of RPB nor the physical form of the diets had any effect on microbial N supply (g/d) and N retention. Rate of eating ($P = 0.07$), time spent eating ($P = 0.87$) and ruminating ($P = 0.28$), and total chewing activity ($P = 0.65$) were not affected by dietary RPB inclusion. Rate of eating decreased ($P < 0.01$) and time spent eating and total chewing activity increased ($P = 0.01$ and $P = 0.02$, respectively) in lambs fed on the block diet compared with those fed on the mash diet. Results of the current study showed that inclusion of RPB up to 200 g/kg DM in diets for fattening was possible without any effect on performance and animal health. Processing of feed into the mash form gave higher livestock productivity in comparison to the block form.

**Key words:** lamb, performance, physical form, recycled poultry bedding


J. Anim. Sci. 2015.93:3843–3853
doi:10.2527/jas2014-8789

## INTRODUCTION

Hot, dry weather and low precipitation in arid and semiarid regions has led to a shortage in the supply of common livestock feedstuffs (Abarghuei et al., 2010). The use of agricultural byproducts such as recycled poultry bedding (**RPB**) is often used as a strategy to overcome this problem (Azizi-Shotorkhoft et al., 2012). In the United States, China, and Brazil (leading countries in the poultry industry), production of dry RPB is more than 16.3, 14.6, and 12.1 million t/yr, respectively (Bolan et al., 2010). Feeding RPB to sheep has great economic potential, due to its low cost and high level of protein (183 to 238 g/kg DM), when used as a replacement for soybean meal in sheep diets (Obeidat et al., 2011, 2012).

When diets are processed and incorporated into a complete diet in block, mash, or pellet form, they can be successfully used to optimize growth and milk production from ruminant animals (Reddy et al., 2003). The advantage of processing feed into block

[1]The authors wish to thank Javad Rezaei, Karen Beauchemin, and Manjo Kumar Tripathi for excellent technical assistance. The authors, also, would like to thank Gary Easton for his English language correction of the manuscript and Ali Mokhtassi-Bidgoli for his assistance with statistical analysis of the data.
[2]Corresponding author: rozbeh_y@modares.ac.ir
Received December 6, 2014.
Accepted May 16, 2015.

form is to reduce transportation cost, storage space, and losses during storage (Samanta et al., 2003). These researchers also reported that slower consumption of the diet in block form compared with mash form led to an improved synchronous supply of energy and nitrogen in the rumen. However, processing feed into mash form, in comparison with block form, increases livestock productivity (Anandan et al., 2012).

Therefore, the present experiment was performed to assess the effect of the inclusion of RPB (at 200 g/kg DM) and physical form (**PF**; mash or block) in a complete diet on the performance, ruminal parameters, and plasma metabolites of growing lambs.

## MATERIALS AND METHODS

This experiment was conducted at Tarbiat Modares University (Tehran, Iran) from January until June of 2012, in accordance with the *Care and Use of Agricultural Animals in Research and Teaching* (Federation of Animal Science Societies, 2010).

### *Diet Preparation*

To produce RPB from fresh litter, the fresh litter was thermally processed by indirect steam pressure (indirect steam boiler, model ABR-H; Aralsan Heat Equipment Ltd., Istanbul, Turkey) at 70°C for 30 min (Table 1). Two feed formulations were formulated with and without RPB (0 vs. 200 g/kg of dietary DM; Table 2). Diets were formulated to be equal in ME and MP content and to meet requirements for growing lambs (NRC, 2007). Then, both types of formula were prepared in mash and block forms (Nazdaneh-Khorasan Co., Neyshabur, Iran). For the preparation of the experimental diet, all the dietary ingredients were mixed in a horizontal double-shaft paddle mixer (model SSHJ4; Xinxiang Hengfu Electronic Machinery Co., Ltd., Xinxiang, China) until uniform (mash form) and this feed mixture was transferred into an automatic feed block-making machine (model AFBMM; Perfect Hydro Machines India Pvt. Ltd., Gurgaon, India) with 421.8 kg/cm$^2$ (6,000 psi) pressure to produce the block form.

### *Animals Study*

Twenty-four growing local Afshari × Kurdish male ram lambs (25.2 ± 1.2 kg initial BW) were randomly divided into 1 of 4 treatment groups. The treatments consisted of the following: 1) without RPB in mash form, 2) without RPB but in block form, 3) with RPB (200 g/kg DM) in mash form, and 4) with RPB (200 g/kg DM) but in block form. Before starting the experiment, animals were housed in individual pens (1.5 by 0.9 m), treated for internal parasites (triclabendazole + levamisole, 12 mL per each lamb; Darou-Pakhsh Co., Iran), and vaccinated (Enterotoxaemia Vac, 3 mL per each lamb; Razi Vaccine and Serum Research Institute, Iran) against common diseases as well as having a 20-d adjustment period to allow the lambs to acclimatize to the experimental conditions and diets before beginning the 105-d growing period. Throughout the experimental period, animals were allowed ad libitum (15% in excess of the previous day's intake) access to feed and water. Lambs were fed twice daily at 0800 and 1600 h, respectively. Feed offered and refused was weighed and recorded every day before morning feeding. Samples of feed offered and refused were stored in the freezer at –20°C. The liveweight changes were measured at 2-wk intervals and the ADG was estimated by fitting a simple linear regression model of weight over time (Rattanaronchart et al., 1983). Gain efficiency was calculated by dividing the ADG by DMI.

To measure the digestibility of nutrients, at d 92 of the fattening period, 5 lambs from each treatment were selected on the basis of BW (51.1, 48.9, 52.0 and 51.6 kg) as representing the average BW in each experimental diet. Animals were individually placed

**Table 1.** Chemical composition and biological analysis of recycled poultry bedding (RPB; g/kg of DM unless otherwise noted)

| Item | RPB |
|---|---|
| DM, g/kg of fresh weight | 926 |
| Chemical composition[1] | |
| CP | 251 |
| aNDFom | 376 |
| ADFom | 179 |
| ADL | 64.6 |
| Ether extract | 22.3 |
| Ash | 156 |
| Cu, mg/kg of DM | 51.7 |
| Zn, mg/kg of DM | 383 |
| RDP,[2] g/kg of CP | 209 |
| RUP,[2] g/kg of CP | 41.6 |
| MP | 143 |
| ME,[3] MJ/kg of DM | 9.21 |
| Biological analysis,[1] $\log_{10}$ cfu/g | |
| Total count | 1.89 |
| *Escherichia coli* | 0.0 |
| *Salmonella* | 0.0 |

[1]Mean values were calculated from the analysis of 4 samples in triplicate.

[2]Estimated from CP content of RPB and N degradation parameters (measured in a digestion trial) according to the Agricultural and Food Research Council (1993).

[3]Estimated as 0.80 × digestible OM (DOM; g/g of DM) × 18.5 (MJ/kg of DOM; Deshck et al., 1998).

**Table 2.** Ingredient and chemical composition of the diets fed in the trial

| Item | Diet[1] | |
|---|---|---|
| | RPB0 | RPB200 |
| Total mixed ration ingredient, g/kg of DM | | |
| Alfalfa hay | 250 | 250 |
| Wheat straw | 50 | 50 |
| Recycled poultry bedding | 0 | 200 |
| Barley grain | 187 | 163 |
| Wheat grain | 113 | 140 |
| Wheat bran | 220 | 80 |
| Molasses | 120 | 80 |
| Meat meal | 30 | 10 |
| Urea | 5 | 2 |
| Sodium bicarbonate | 5 | 5 |
| Salt white | 5 | 5 |
| Minerals and vitamins premix[2] | 5 | 5 |
| Bentonite | 10 | 10 |
| DM, g/kg, as-fed basis | 876 | 889 |
| Chemical composition | | |
| OM | 910 | 896 |
| CP | 151 | 155 |
| aNDFom[3] | 391 | 369 |
| ADFom[4] | 202 | 192 |
| ADL | 51.7 | 51.4 |
| Ether extract | 39.8 | 39.5 |
| Ca | 9.47 | 10.5 |
| P | 4.89 | 5.33 |
| Mg | 3.28 | 3.69 |
| K | 19.1 | 18.8 |
| Na | 5.71 | 6.01 |
| Zn, mg/kg DM | 53.8 | 88.2 |
| Cu, mg/kg DM | 8.24 | 11.1 |
| Mn, mg/kg DM | 77.3 | 92.5 |
| RDP,[5] g/kg of CP | 98.1 | 109 |
| RUP,[5] g/kg of CP | 52.9 | 45.7 |
| MP[5] | 92.4 | 93.5 |
| ME,[6] MJ/kg of DM | 11.5 | 11.8 |

[1]RPB0 = diet containing 0 g/kg DM recycled poultry bedding (RPB); RPB200 = diet containing 200 g/kg DM RPB.

[2]Provided per kilogram of DM: 171 g Ca, 73.4 g P, 38.8 g Mg, 14.1 g K, 5.33 g S, 2.93 g Fe, 3.44 g Zn, 22.6 mg Se, 826 mg Cu, 21.7 mg/kg Se, 44.1 mg Co, 422,000 IU vitamin A, 37,000 IU vitamin D, and 2,424 IU vitamin E.

[3]aNDFom.

[4]ADFom.

[5]Calculated from coefficient of degradability for individual feed ingredients according to the Agricultural and Food Research Council (1993) guidelines.

[6]Calculated by the following equation (AFRC, 1993); ME = 0.0157 × DOMD.

in metabolism crates for a period of 14 d, allowing 7 d for adaptation to metabolism crates and 7 d for the collection period. Feed offered and refusals were weighed and recorded daily, and samples of these were then stored in a –20°C freezer until use. At the same time, total urine produced daily was collected in plastic vessels containing 100 mL of sulfuric acid solution (10%, vol/vol), to keep the final pH below 3 (to prevent bacterial growth and the loss of ammonia-N), placed below the urine outlet in the metabolism crates. The volume of urine collected every morning from an individual animal was measured. To prevent the precipitation (particularly of uric acid) of purine derivatives (**PD**) in urine during storage (Chen and Gomes, 1992), 10 mL of daily amount was sampled, diluted with 40 mL distilled water, and then stored at –20°C for the estimation of total N and PD.

Blood samples were collected via the jugular vein (in 10-mL vacutainer tubes; Vacutainer PST lithium heparin; Ava Pezeshk, Tehran, Iran) at 0800, 1100, and 1400 h on Days 24, 61, and 89. Samples were centrifuged (1,500 × *g* for 15 min at 25°C), and an aliquot of plasma was removed and stored at –20°C until analyzed. On Days 26, 63, and 91, ruminal fluid (approximately 100 mL) was sampled by stomach tube at 0800, 1100, and 1400 h and filtered through 4 layers of muslin cloth, and samples were collected for ammonia-N (5 mL being added to 1 mL of 0.2 *N* HCl) and VFA (1 mL was mixed with 0.25 mL of a solution containing 20 m*M* 2-ethylbutyric acid and 200 mL/L of orthophosphoric acid) analysis.

The same animals, facilities, experimental design, treatments (experimental diets), and feeding management used in the performance trial were adopted. Two observers were used to visually record the feeding behavior observations at 5 min intervals for 24 h on Days 44, 64, and 83 of the fattening period (Araujo et al., 2008). The time spent for each animal observation was not more than 5 s. Eating, ruminating, and total chewing times were determined and expressed as minutes per day. Time (expressed in minutes) expended in each activity was calculated by the number of observations recorded and multiplied by 5. Total chewing time was considered the sum of eating and ruminating times (Weidner and Grant, 1994). Eating, ruminating, and total chewing times were also expressed as minutes per gram of DM and NDF intakes.

### *Laboratory Analyses*

The pooled samples of feed offered, refusals, and feces were dried at 55°C in a forced-air oven (model FC-610, Advantec; Toyo Seisakusho Co. Ltd., Tokyo, Japan) to achieve a constant weight. Then, the dried samples were ground to pass through 1-mm sieve and were analyzed for DM, OM, CP, and ether extract (methods 967.03, 942.05, 976.06, and 920.29, respectively; AOAC, 1990). Dietary aNDFom and ADFom concentrations were analyzed following the method

described by Van Soest et al. (1991) with addition of heat stable α-amylase (A3306; Sigma) and sodium sulfite and were corrected for residual ash. The ADL was determined by solubilization of cellulose with 72% sulfuric acid, according to the method described by Robertson and Van Soest (1981). Diet and plasma samples were analyzed for determination of major and trace elements by an assay kit (Pars Azmun Diagnostics, Tehran, Iran). The concentrations of glucose, plasma urea N (**PUN**), triglycerides, creatinine, total protein, albumin, Zn, and Cu were measured using kits from Pars Azmun Diagnostics by a spectrophotometer (Jenway 6300; Jenway Ltd., Essex, UK).

Analysis of VFA in the ruminal fluid was performed by gas–liquid chromatography using ethylbutyric acid as the internal standard as described by Cottyn and Boucque (1968). Ammonia-N concentration was determined using a phenol-hypochlorite assay (Broderick and Kang, 1980).

Estimation of microbial N was performed based on urinary PD excretion (Chen and Gomes, 1992). Before the analysis, all samples were thawed and pooled for each lamb in proportion to daily urine output. Briefly, allantoin and xanthine plus hypoxanthine and uric acid were respectively measured using the colorimetric, xanthine oxidase (MAK078; Sigma), and uricase (02101203; MP Biomedicals) methods. The following nonlinear equation is used to describe the relationship between absorption of PD ($x$; mmol/d) and excretion of PD in urine ($y$; mmol/d; Chen and Gomes, 1992):

$$y = 0.84x + (0.150W^{0.75}\exp(-0.25x), \quad [1]$$

in which $W^{0.75}$ is metabolic BW (kg) of the animal and 0.84 is the recovery of absorbed PD in urine. Based on Eq. [1], the amount of exogenous PD absorbed can then be estimated from the daily excretion of PD. The calculation of $x$ from $y$ based on Eq. [1] can be performed by means of the Newton–Raphson iteration process, as given below (Chen and Gomes, 1992):

$$x(n+1) = xn - [f(xn)/f'(xn)], \quad [2]$$

in which

$$f(x) = 0.84x + 0.150W^{0.75}\exp(-0.25x) - y, \quad [3]$$

and the derivative of $f(x)$ is $f(x) = 0.84 - 0.038 W^{0.75}\exp(-0.25x)$.

Finally, produced microbial N was estimated on the following equation (Chen and Gomes, 1992):

$$\text{microbial N} = (x \times 70)/(0.116 \times 0.83 \times 1{,}000), \quad [4]$$

in which microbial N is expressed in grams N per day; $x$ is expressed in millimoles per day; 0.83, 70, and 0.116 are digestibility of microbial purines; N content of purines is 70 mg N/mmol; and ratio of purine N:total N in mixed rumen microbes is taken as 11.6:100, respectively.

Measuring of bulk density in each experimental diet with 10 replicates was performed based on the beginning and end of the experimental period. To measure bulk density in the mash diets, sampling from different parts of the completely mixed ration was performed. Then, the bulk density was calculated by filling and weighing a cubic box with known volume (Anandan et al., 2012). For block diets, bulk density was calculated in each block. Initial weight and volume (width × height × length) of each block was measured (Table 7). Then, bulk density was determined simply by dividing the weight by the volume for each block (Anandan et al., 2012). In blocked samples, hardness was expressed as peak force (N) needed for breaking of the samples. The hardness testing was performed using a computer-controlled servo-hydraulic Instron testing machine (model 8506; Instron Ltd., Buckinghamshire, England) with 2,500 kN capacity, as described by Thomas (1998).

### *Biological Analysis*

The counts of total bacteria, *Escherichia coli*, and *Salmonella* were determined according to the methods of Clesceri et al. (1998). One gram of each RPB sample was added to 9 mL of buffered peptone water (Fisher Scientific, Ottawa, ON, Canada), vortexed for 60 s, and then serially diluted 10-fold in buffered peptone water, resulting in dilutions ranging from $10^{-1}$ to $10^{-8}$ for enumeration. The counts of total bacteria, *E. coli*, and *Salmonella* in the serially diluted samples were quantified using plate count agar medium, MacConkey agar medium, and xylose lysine deoxycholate agar medium (numbers 1.05463, 1.05465, and 1.05287, respectively; Merck, Darmstadt, Germany). The media were transferred to sterile plates after sterilization (autoclaved at 120°C and 1.5 atm for 15 min). Then, 20 μL of each dilution was spread onto the me-

dium, with 3 replicates (plates) and 2 observations in each. All tubes and plates were incubated at 37°C for 24 h. The bacterial colonies were counted immediately after removal from the incubator. Bacteria were enumerated by a visual count of colonies by using the best replicate set from dilutions that resulted in 30 to 300 colonies per plate. The microbial enumerations of samples were expressed as $\log_{10}$ cfu per gram.

### *Statistical Analysis*

Obtained data were analyzed using PROC MIXED of SAS (SAS Inst. Inc., Cary, NC). All data were normally distributed (Shapiro–Wilk test from the UNIVARIATE procedure of SAS; $W \geq 0.95$). All data, except physical characteristics of diets, were analyzed as a 2 × 2 factorial arrangement under a completely randomized design, considering the fixed effects of factors RPB (0 and 200 g/kg DM), PF of diet (mash and block), and RPB × PF interaction. Ruminal fermentation (ammonia-N and VFA) and plasma parameters were analyzed as repeated measures assuming an ar(1) covariance structure. The effect of sampling days (discrete variable) and sampling hour (continuous variable) and their interaction were not significant ($P > 0.05$) for any of the variables and were, therefore, not included in the final model; data were averaged per lamb and the mean values were used in the statistical analysis. The statistical significance and tendency were declared at $P \leq 0.05$ and $P < 0.10$, respectively. Means are presented as least squares means. Data on physical properties were statistically analyzed using the GLM procedure to assess diet effect.

## RESULTS

### *Chemical Composition and Biological Analysis of Recycled Poultry Bedding and Diets*

Chemical and biological analyses of the RPB are presented in Table 1. The thermal processing method used in the present study completely eliminated *E. coli* and *Salmonella* from the raw RPB. A separate chemical analysis for the experimental diets (Table 2) illustrated a numerical difference in some components in the diets.

### *Rumen Fermentation and Plasma Parameters*

The effects of RPB inclusion and PF of diet on ruminal and plasma parameters are presented in Table 3. The average ruminal ammonia-N concentration was greater ($P < 0.01$) for lambs fed diets containing RPB but was not affected ($P = 0.19$) by the PF of the diet. The molar proportions of VFA and acetate to propionate ratio were not affected by the experimental diet.

Plasma concentrations of PUN increased ($P = 0.01$) with the inclusion of RPB into the diet. Plasma concentrations of glucose, triglycerides, total protein, albumin, creatinine, Zn, and Cu were unaffected by the experimental diet.

### *Nutrient Digestibility, Intake, and Growth Performance*

The effects of RPB inclusion and PF of diet on nutrient digestibility, intake, and growth performance of lambs are presented in Table 4. Because there were no interactions of RPB × PF, only the main effects are listed in the table. Total tract apparent digestibility of dietary DM, OM, CP, ether extract, NDF, and ADF were unaffected by the experimental diet. The inclusion of RPB in the diet increased intake of DM ($P < 0.01$), OM ($P = 0.01$), and CP ($P < 0.01$). However, nutrient intake was not affected by the PF of the diet. Average daily gain was not influenced in lambs fed RPB diet compared with those offered RPB-free diet, whereas G:F was decreased ($P = 0.05$) by the dietary inclusion of RPB. Lambs fed block diet had lower ADG ($P = 0.01$) and G:F ($P = 0.02$) when compared with those offered mash diet. Final BW was not affected by experimental diet.

### *Microbial N and N Balance*

The effects of RPB inclusion and the PF of the diet on microbial N supply and N balance are presented in Table 5. Because there were no interactions of RPB × PF ($P > 0.05$), only the main effects are listed in the table. Urinary allantoin, uric acid, xanthine, and hypoxanthine and the estimated microbial N were not different ($P > 0.05$) among the diets. Inclusion of RPB in the diet increased intake of N ($P = 0.03$), fecal N excretion ($P = 0.03$), and total N excretion ($P < 0.01$). However, N retention was not affected by the inclusion of RPB or the PF of the diet.

### *Feeding Behavior and Physical Characteristics of Diets*

The effects of RPB inclusion and PF of diet on feeding behavior data are presented in Table 6. Because there were no interactions of RPB × PF ($P > 0.05$) and diet × time ($P > 0.05$), only the main effects are listed in the table. Also, physical properties of experimental diets are listed in Table 7. The rate of eating tended to be affected ($P = 0.07$) by inclusion of RPB in the diet but was decreased ($P < 0.01$) by

**Table 3.** Effect of recycled poultry bedding (RPB) level and physical form (PF; mash vs. block) on rumen fermentation and plasma metabolites in growing lambs

| | Level of RPB in diet, g/kg DM | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0.0 | | 200 | | | *P*-value | |
| Item | Mash | Block | Mash | Block | SEM | RPB[1] | PF |
| Ruminal parameters | | | | | | | |
| Ammonia, mg/dL | 12.1 | 9.92 | 18.5 | 16.6 | 1.56 | <0.01 | 0.19 |
| VFA, mol/100 mol | | | | | | | |
| Acetate | 63.3 | 64.7 | 63.8 | 64.3 | 1.28 | 0.95 | 0.46 |
| Propionate | 22.2 | 20.1 | 20.1 | 19.8 | 1.02 | 0.25 | 0.25 |
| Butyrate | 12.0 | 12.8 | 13.4 | 13.5 | 0.55 | 0.08 | 0.44 |
| Isovalerate | 0.82 | 0.93 | 0.78 | 0.95 | 0.08 | 0.91 | 0.13 |
| Valerate | 1.54 | 1.35 | 1.79 | 1.35 | 0.15 | 0.45 | 0.06 |
| Acetate: propionate | 2.87 | 3.23 | 3.19 | 3.3 | 0.21 | 0.39 | 0.30 |
| Plasma parameters | | | | | | | |
| Metabolites, mg/dL | | | | | | | |
| Glucose | 53.5 | 53.6 | 50.1 | 51.2 | 1.66 | 0.10 | 0.71 |
| Plasma urea-N | 15.9 | 15.0 | 19.2 | 17.4 | 1.02 | 0.01 | 0.21 |
| Triglycerides | 34.9 | 26.8 | 33.4 | 24.6 | 4.05 | 0.65 | 0.04 |
| Creatinine | 1.45 | 1.22 | 1.42 | 1.44 | 0.18 | 0.60 | 0.57 |
| Proteins, g/dL | | | | | | | |
| Total protein | 6.61 | 6.32 | 6.81 | 5.89 | 0.98 | 0.84 | 0.45 |
| Albumin | 4.06 | 3.91 | 4.24 | 3.88 | 0.71 | 0.91 | 0.73 |
| Minerals, µg/mL | | | | | | | |
| Zn | 1.07 | 1.05 | 1.09 | 1.07 | 0.08 | 0.85 | 0.79 |
| Cu | 0.67 | 0.63 | 0.59 | 0.66 | 0.04 | 0.60 | 0.74 |

[1]RPB = diets containing 0 vs. 200 g/kg DM RPB.

**Table 4.** Effect of recycled poultry bedding (RPB) level and physical form (PF; mash vs. block) on intake, total tract apparent digestibility, and performance in growing lambs

| | Level of RPB in diet, g/kg DM | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0.0 | | 200 | | | *P*-value | |
| Item | Mash | Block | Mash | Block | SEM | RPB[1] | PF |
| Apparent digestibility, g/kg | | | | | | | |
| DM | 658 | 679 | 678 | 671 | 11.2 | 0.61 | 0.50 |
| OM | 693 | 705 | 708 | 699 | 10.2 | 0.68 | 0.89 |
| CP | 684 | 679 | 678 | 658 | 11.6 | 0.24 | 0.28 |
| aNDFom[2] | 509 | 522 | 511 | 512 | 18.5 | 0.81 | 0.71 |
| ADFom[3] | 516 | 547 | 531 | 504 | 15.5 | 0.37 | 0.90 |
| Ether extract | 634 | 640 | 646 | 629 | 15.2 | 0.94 | 0.74 |
| Intake | | | | | | | |
| DM, g/d | 1,663 | 1,654 | 1,852 | 1,886 | 59.3 | <0.01 | 0.84 |
| OM, g/d | 1,524 | 1,509 | 1,648 | 1,673 | 53.7 | 0.01 | 0.93 |
| CP, g/d | 253 | 248 | 294 | 305 | 9.01 | <0.01 | 0.74 |
| aNDFom, g/d | 693 | 794 | 695 | 693 | 24.0 | 0.05 | 0.06 |
| ADFom, g/d | 327 | 332 | 324 | 308 | 11.5 | 0.25 | 0.61 |
| Ether extract, g/d | 65.0 | 66.1 | 72.7 | 74.2 | 2.35 | 0.08 | 0.74 |
| Growth performance | | | | | | | |
| Initial BW, kg | 25.3 | 25.6 | 25.5 | 25.6 | 1.08 | 0.86 | 0.90 |
| ADG, g/d | 288 | 252 | 291 | 279 | 8.70 | 0.10 | 0.01 |
| G:F, g/g DM | 0.17 | 0.15 | 0.15 | 0.14 | 0.052 | 0.054 | 0.020 |
| Final BW, kg | 55.4 | 52.2 | 55.9 | 54.3 | 1.28 | 0.30 | 0.07 |

[1]RPB = diets containing 0 vs. 200 g/kg DM RPB.

[2]aNDFom.

[3]ADFom.

PF of diet. There was a tendency for an interaction between RPB and PF for rate of eating ($P < 0.08$). Total chewing activity was not affected by RPB inclusion ($P = 0.65$) but was increased ($P = 0.02$) by PF of diet. There was a tendency for an interaction between RPB and PF for total chewing activity ($P < 0.08$). Time spent for eating activity was not affected by RPB inclusion but was increased ($P = 0.01$) by PF of diet. Time spent for ruminating activity was unaffected by experimental diets. With respect to bulk density of experimental diets, there was an interaction ($P = 0.01$) between RPB and PF. Overall, processing of diet in block form led to increase of bulk density; on the other hand, inclusion of RPB in the diet decreased ($P < 0.01$) bulk density of experimental diets and hardness of complete feed block.

## DISCUSSION

### *Chemical Composition and Biological Analysis of Recycled Poultry Bedding and Diets*

Using RPB in a ruminant diet has always been controversial and has stimulated a great deal of study in defense of its safety (Capucille et al., 2004; Obeidat et al., 2011). The presence of pathogenic organisms in raw RPB (Jeffrey et al., 1998; Martin et al., 1998) and heavy metals, which might cause serious hazards to animal and human health, are cause for safety concern (Rankins et al., 2002). One method used to overcome the risk of feeding RPB to ruminant animals is heat processing (Azizi-Shotorkhoft et al., 2012). In the present study, Table 1 shows that heat processing eliminated the *E. coli* and *Salmonella* spp. and decreased total bacteria count to less than 20,000 cfu/g, which is within the safety ranges reported by Caswell et al. (1975).

The high DM content (926 g/kg fresh weight) of RPB could be related to the heat processing and was similar to the amount reported by Azizi-Shotorkhoft et al. (2012). The high CP content of RPB indicates

**Table 5.** Effect of recycled poultry bedding (RPB) level and physical form (PF; mash vs. block) on microbial N supply and N balance in growing lambs

| | Level of RPB in diet, g/kg DM | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0.0 | | 200 | | | *P*-value | |
| Item | Mash | Block | Mash | Block | SEM | RPB[1] | PF |
| Intake,[2] g/d | | | | | | | |
| DM | 1,654 | 1,736 | 1,957 | 1,809 | 120 | 0.14 | 0.78 |
| DOMI[3] | 1,077 | 1,116 | 1,205 | 1,166 | 65.4 | 0.19 | 0.97 |
| Urinary purine derivatives, mmol/d | | | | | | | |
| Allantoin | 13.4 | 11.5 | 13.7 | 13.1 | 0.55 | 0.10 | 0.03 |
| Uric acid | 2.99 | 3.17 | 3.26 | 3.20 | 0.11 | 0.20 | 0.60 |
| Xanthine + hypoxanthine | 1.84 | 1.64 | 1.88 | 1.81 | 0.07 | 0.19 | 0.10 |
| Microbial N supply | | | | | | | |
| Microbial N, g/d | 15.3 | 13.6 | 15.8 | 15.1 | 0.62 | 0.11 | 0.06 |
| N balance, g/d | | | | | | | |
| N intake[4] | 39.5 | 41.1 | 49.1 | 45.4 | 2.91 | 0.03 | 0.71 |
| Fecal N excretion | 12.6 | 13.2 | 15.8 | 15.4 | 1.01 | 0.03 | 0.92 |
| Urinary N excretion | 17.7 | 19.4 | 24.1 | 21.0 | 1.93 | 0.06 | 0.75 |
| Total N excretion | 30.2 | 32.5 | 39.8 | 36.4 | 2.10 | <0.01 | 0.73 |
| N retention | 9.33 | 8.38 | 9.19 | 8.97 | 1.38 | 0.76 | 0.80 |

[1]RPB = diets containing 0 vs. 200 g/kg DM RPB.

[2]Intake during sampling days.

[3]DOMI = digestible OM intake.

[4]Crude protein intake during sampling days/6.25.

that RPB could be used as a source of protein in ruminant diets. However, the quality of protein in the RPB is lower in comparison with many other plant protein sources. The RPB used in our study had an NDF and ADF content close to the amounts reported by Azizi-Shotorkhoft et al. (2012; 353 and 185 g/kg of DM, respectively) and Obeidat et al. (2011; 334 and 215 g/kg of DM, respectively), whereas the respective values in the current study were less than the amounts reported in the study of Capucille et al. (2004; 528 and 317 g/kg of DM, respectively). It seems that the NDF content of the RPB can vary substantially due to various factors such as the type of bedding material used (e.g., straw, wood shavings, rice hulls, corn cobs, and peanut hulls) and the extent of heat damage occurring during heat processing (Capucille et al., 2004), indicating the importance of determining the chemical composition of RPB before incorporating it into diets. Due to high negative correlation reported between ash and ME content of the RPB, the ash content is one of the most important measures of the quality of RPB ($R^2$ = –0.97; Deshck et al., 1998). In the present study, the ash content of RPB was within the acceptable range for ruminant feed (i.e., between 114 and 167 g/kg DM) as reported by Deshck et al. (1998). Consequently, this has led to high concentration of ME in RPB (Table 1).

**Table 6.** Effect of recycled poultry bedding (RPB) level and physical form (PF; mash vs. block) of diets on feeding behavior of lambs

| | Level of RPB in diet, g/kg DM | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0.0 | | 200 | | | *P*-value | |
| Item | Mash | Block | Mash | Block | SEM | RPB[1] | PF |
| Intake,[2] g/d | | | | | | | |
| DM | 1,925 | 1,968 | 2,162 | 2,230 | 127 | 0.06 | 0.66 |
| aNDFom[3] | 800 | 942 | 806 | 818 | 52.6 | 0.27 | 0.16 |
| Rate of eating, g DM/min | 9.00 | 6.66 | 8.83 | 8.40 | 0.41 | 0.07 | <0.01 |
| Chewing, min/d | 559 | 705 | 604 | 628 | 35.4 | 0.65 | 0.02 |
| Eating, min/d | 217 | 303 | 253 | 273 | 20.4 | 0.87 | 0.01 |
| Ruminating, min/d | 342 | 402 | 350 | 355 | 17.6 | 0.28 | 0.08 |
| Nonchewing, min/d | 880 | 734 | 835 | 811 | 35.4 | 0.65 | 0.02 |

[1]RPB = diets containing 0 vs. 200 g/kg DM RPB.

[2]Average of intake recorded on 3 days of feeding behavior trial (d44, 64, and 83).

[3]aNDFom.

### *Rumen Fermentation and Plasma Parameters*

Ruminal ammonia-N concentrations were within the optimal range (i.e., 8.5 to over 30 mg/dL) reported by McDonald et al. (2011). Inclusion of RPB in the diet increased the ruminal ammonia-N concentration, which is probably due to the higher CP intake of animals fed the RPB diet. This is consistent with Muia et al. (2001), Animut et al. (2002), and Capucille et al. (2004), who noted that dietary RPB increased ruminal ammonia-N concentration.

As VFA are the end products of ruminal fermentation and represent the adequacy of energy supply for the ruminants (Van Soest, 1994), a reduction in their concentration would be nutritionally unfavorable for the animal. Neither the inclusion of RPB nor the diet's PF influenced the individual VFA proportions (acetate, propionate, and butyrate) in the rumen. It seems, therefore, that the inclusion of RPB up to 200 g/kg DM did not cause any problem in the end products of ruminal fermentation. Similarly, Capucille et al. (2004) found

**Table 7.** Physical characteristics of experimental diets

| | Level of RPB[1] in diet, g/kg DM | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.0 | | 200 | | | *P*-value[2] | | |
| Item | Mash | Block | Mash | Block | SEM | RPB | PF | RPB × PF |
| Bulk density, kg/m$^3$ | 345 | 742 | 315 | 632 | 15.1 | <0.01 | <0.01 | 0.01 |
| Hardness, N/cm$^2$ | – | 72.1 | – | 59.1 | 3.17 | <0.01 | – | – |

[1]RPB = recycled poultry bedding.

[2]RPB = diets containing 0 vs. 200 g/kg DM RPB; PF = physical form (of diets; mash vs. block).

that the inclusion of RPB in steer diets up to 350 g/kg of DM did not affect the concentration of individual VFA in ruminal fluid. However, Muia et al. (2001) found that the inclusion of RPB in the diet of Friesian cows at 910, 3,650, and 6,500 g RPB/cow per day increased the concentration of acetate and propionate. Such discrepancies may be due to diet type, PF of diet, animal variety, level of RPB inclusion, and sampling methods (Muia et al., 2001; Capucille et al., 2004).

Plasma metabolite concentrations represent an integrated index of the adequacy of nutrient supply in relation to nutrient utilization that is independent of physiological state and gives an immediate indication of nutritional status at that point in time (Cronjé and Pambu-Gollah, 1996). In our study, the plasma concentrations of glucose (50–80 mg/dL), PUN (8–20 mg/dL), creatinine (1.2–1.9 mg/dL), total protein (6–7.9 g/dL), albumin (2.4–3.0 g/dL), Zn (0.8–1.2 μg/mL), and Cu (0.7–1.3 μg/mL) in all lambs were within the typical ranges previously reported for sheep (Radostitis et al., 2007). The concentration of triglycerides were in the typical range reported for fat-tailed Iranian sheep (18.03–50.93 mg/dL; Mojabi, 2011), whereas the respective value was greater than the typical range (0–14 mg/dL) reported by Radostitis et al. (2007). The higher concentration of PUN in animals fed RPB diets may be related to a greater concentration of ruminal ammonia-N. Similarly, Hennessy and Nolan (1988) reported that PUN is highly correlated with ruminal ammonia-N. Plasma albumin content reflects the dietary conditions and decreases in unhealthy animals (Radostitis et al., 2007). As expected, there was no sign of deficiency or toxicity in regards to the plasma levels of Cu and Zn (Radostitis et al., 2007). According to the results obtained from plasma metabolites, the dietary RPB or the PF of the diet had no influence on the concentration of these metabolites.

### *Nutrient Digestibility, Intake, and Growth Performance*

Apparent total-tract digestibility of nutrients was not affected by RPB inclusion or the PF of the diet, which can be explained by the ideal ruminal fermentation characteristics such as ammonia-N values (Table 3) in all experimental diets (Van Soest, 1994). The lack of effect on nutrient digestibility with the inclusion of RPB concurred with the previous research study (Animut et al., 2002). However, in opposition to the results obtained in the current study, another study feeding RPB at levels of 200 or 400 g/kg DM had decreased nutrient digestibility in Awassi sheep compared with those fed a diet free of RPB (Obeidat et al., 2011, 2012). They suggested that the decline in the digestibility in RPB diets is caused by the litter material containing wood shavings (about 25%), which are almost completely indigestible. The lack of effect of PF of diets on the nutrient digestibility was inconsistent with the results of Anandan et al. (2012), who reported that OM, ADFom digestibility were decreased in lambs fed mash diets compared with those offered blocked diets. Anandan et al. (2012) proposed that the decline in digestibility in animals that consumed mash diets was due to the higher DM intake compared with those fed blocked diets (Van Soest, 1994).

High rates of nitrogen ruminal degradation in RPB diets (as can be seen from high ruminal ammonia-N in Table 3) compared with those without RPB may be due to an increased ruminal rate of passage resulting in increased feed intake in animals on RPB diets vs. those fed diets free from RPB. Also, the increased feed intake in animals offered RPB diets may be due to the high mineral content in RPB, which accelerated the passage rate of digesta in the rumen as suggested by Muia et al. (2001). Consistent with our results, Capucille et al. (2004) reported that DM intake increased for steers fed 350 g/kg RPB compared with those fed a diet without RPB. However, a previous study with growing lambs found no effect on DM intake when including RPB at 100 and 200 g/kg DM as a replacement for soybean meal (Obeidat et al., 2011). Variations in the DM intake response to RPB feeding are probably related to factors such as the components of the control diet, the level of RPB, and the chemical composition of RPB.

Feed intake was not affected by PF of the diet. Inconsistent with our results, Anandan et al. (2012) reported that a diet in mash form led to increased intake compared with lambs fed block form. Anandan et al. (2012) assumed that the higher intake observed in mash fed animals might have been supported by a lesser retention time of the smaller feed particles of the mash diets. They also assumed that greater chewing activity in lambs fed the block diet could lead to an increase in heat production of animals and ultimately decreased intake.

Although lambs fed RPB diets had higher intake, their ADG was not affected in comparison to those offered RPB-free diets (Table 4). Based on digestible OM intake (Table 4), the absence of significant differences in ADG is because the absorbed energy from RPB diets was utilized less efficiently than that from RPB-free diets. Moreover, the higher CP intake, ruminal ammonia-N concentration, PUN concentration, and urinary N excretion and lower glucose concentrations in plasma support the less efficient use of energy in lambs fed RPB diets in comparison to those offered RPB-free diets. Consistent with our results, feeding RPB-containing diet to Awassi lambs at 200 g/kg DM (Obeidat et al., 2011) and inclusion of RPB in lamb

diets up to 300 g/kg (Elemam et al., 2009) did not affect ADG

In the current study, the dietary inclusion of RPB significantly decreased G:F, which is primarily related to the greater DMI, with no effect on ADG in animals fed RPB diets in comparison to those offered RPB-free diets (Table 4). Higher CP intake in animals fed RPB diets was not synchronized with efficient use of energy, which implies that more energy is needed when RPB is added to the diet. Similarly, including RPB at 0 or 150 g/kg in diets for lambs did not affect feed efficiency (Elemam et al., 2009), whereas when RPB was fed at levels of 300 or 450 g/kg, feed efficiency decreased; the authors suggested that the lower G:F could be related to the lower energy density when RPB was included in the diet.

Lower ADG in lambs fed block diets might be related to more energy spent in eating and chewing activity (as shown in Table 6). Lower ADG in lambs fed the block form agree with the findings of Anandan et al. (2012), who reported that the processing of diet in block form reduced ADG in lambs compared with the mash form. Anandan et al. (2012) suggested that the reduction in ADG may be due to a lower intake.

### *Microbial N and N Balance*

Although animals fed RPB diets consumed more N than those on RPB free diets, N balance was not affected due to higher total N excretion (Table 5). Caswell et al. (1978) reported that N excretion increased for sheep fed a 184 g RPB/kg diet compared with those fed a control diet; however, Caswell et al. (1978) reported no major difference between the experimental and control diets in term of N retention.

Urinary excretions of total PD, which are indicators of microbial protein arriving at the duodenum (Balcells et al., 1991), were not significantly affected by either RPB inclusion or the PF of the diet. Yield of microbial protein produced in the rumen is maximized when the ratio of available energy (fermentable OM) to protein (nitrogen) is optimized. Therefore, the absence of any difference in the microbial N between animals fed RPB diets compared with those fed diets without RPB is probably due to the lack of energy available for producing more microbial N with high ruminal ammonia-N concentration in animals fed the RPB diet.

### *Feeding Behavior and Physical Characteristics of Diets*

The lack of effects of RPB inclusion on time spent eating and ruminating are inconsistent with those reported by Rossi et al. (1998), who investigated the effect of 2 sources of RPB in small and large particle size fractions in the diets of steers at 0.5% BW. Results from this study reported decreased eating and ruminating time with RPB inclusion. The difference in results was likely related to factors such as NDF content and level of concentrate in the diet.

The slower rate of eating and, consequently, longer eating and chewing time of lambs fed the block diet compared with the mash diet may be due to different physical characteristics of the block diets such as hardness, resistance to fracture, and bulk density (Thomas, 1998; Anandan et al., 2012). Hardness is a physical property of pelleted and blocked diets that can be considerably changed by heating and pressing during processing. This parameter describes the resistance of a material to break under static force and directly related to the distribution of particles (Thomas, 1998). Differences in the hardness of diets with and without RPB in block form may be related to less temporal disassociation between feed ingredients in each feed formula. Bulk density is one of the most important feed characteristics that could be affecting the handling, storage, and transport costs of feeds (Anandan et al., 2012). In the present study, the process of block making from low bulk density roughage resources improved feeing management (i.e., reducing the storage space and allowing full mechanization for handling and transportation).

### *Conclusions*

Dietary inclusion of RPB up to 200 g/kg DM (mash form) reduced the cost of the ration with no negative effect on the growth performance and animal health of fattening lambs.

## LITERATURE CITED

Abarghuei, M. J., Y. Rouzbehan, and D. Alipour. 2010. The influence of the grape pomace on the ruminal parameters of sheep. Livest. Sci. 132:73–79. doi:10.1016/j.livsci.2010.05.002

Agricultural and Food Research Council (AFRC). 1993. Energy and protein requirements of ruminants. An advisory manual prepared by the AFRC Technical Committee on Responses to Nutrients. Compiled by G. Alderman, in collaboration with B. R. Cottrill. CAB International, Wallingford, UK.

Anandan, S., H. Zoltan, A. A. Khan, D. Ravi, and M. Blümmel. 2012. Feeding value of sweet sorghum bagasse and leaf residues after juice extraction for bio-ethanol production fed to sheep as complete rations in diverse physical forms. Anim. Feed Sci. Technol. 175:131–136. doi:10.1016/j.anifeedsci.2012.05.005

Animut, G., R. C. Merkel, G. Abebe, T. Sahlu, and A. L. Goetsch. 2002. Effects of level of broiler litter in diets containing wheat straw on performance of Alpine doelings. Small Rumin. Res. 44:125–133. doi:10.1016/S0921-4488(02)00041-X

Araujo, R. C., A. V. Pires, I. Susin, C. Q. Mendes, G. H. Rodrigues, I. U. Packer, and M. L. Eastridge. 2008. Milk yield, milk composition, eating behavior, and lamb performance of ewes fed diets containing soybean hulls replacing coastcross (*Cynodon* species) hay. J. Anim. Sci. 86:3511–3521. doi:10.2527/jas.2008-0940

Association of Official Analytical Chemists (AOAC). 1990. Official methods of analysis, 15th ed. AOAC, Arlington, VA.

Azizi-Shotorkhoft, A., Y. Rouzbehan, and H. Fazaeli. 2012. The influence of the different carbohydrate sources on utilization efficiency of processed broiler litter in sheep. Livest. Sci. 148:249–254. doi:10.1016/j.livsci.2012.06.014

Balcells, J. A., J. A. Guada, C. Castrillo, and J. Gasa. 1991. Urinary excretion of allantoin and allantoin precursors by sheep after different rates of purine infusion into the duodenum. J. Agric. Sci. 116:309–317. doi:10.1017/S002185960007773X

Bolan, N. S., A. A. Szogi, T. Chuasavathi, B. Seshadri, M. J. Rothrock Jr., and P. Panneerselvam. 2010. Uses and management of poultry litter. Worlds Poult. Sci. J. 66:673–698. doi:10.1017/S0043933910000656

Broderick, G. A., and J. H. Kang. 1980. Automated simultaneous determination of ammonia and total amino acids in ruminal fluid and in vitro media. J. Dairy Sci. 63:64–75. doi:10.3168/jds.S0022-0302(80)82888-8

Capucille, D. J., M. H. Poore, and G. M. Rogers. 2004. Growing and finishing performance of steers when fed recycled poultry bedding during the growing period. J. Anim. Sci. 82:3038–3048.

Caswell, L. F., J. P. Fontenot, and K. E. Webb Jr. 1975. Effect of processing method on pasteurization and nitrogen components of broiler litter and on nitrogen utilization by sheep. J. Anim. Sci. 40:750–759.

Caswell, L. F., J. P. Fontenot, and K. E. Webb Jr. 1978. Fermentation and utilization of broiler litter ensiled at different moisture levels. J. Anim. Sci. 46:547–561.

Chen, X. B., and J. M. Gomes. 1992. Estimation of microbial protein supply to sheep and cattle based on urinary excretion of purine derivatives: An overview of the technical details. Occasional publication of the International Feed Resources Unit, Rowett Res. Inst., Bucksburn, Aberdeen, UK.

Clesceri, L. S., A. E. Greenberg, and A. D. Eaton. 1998. Standard methods for the examination of water and wastewater. 20th ed. American Public Health Association, American Water.

Cottyn, B. G., and C. V. Boucque. 1968. Rapid method for the gas-chromatographic determination of volatile fatty acids in rumen fluid. J. Agric. Food Chem. 16:105–107. doi:10.1021/jf60155a002

Cronjé, P. B., and R. Pambu-Gollah. 1996. The use of blood profiles as animal response indicators. Bull. Grassl. Soc. South. Afr. 7(Suppl. 1):28–35.

Deshck, A., M. Abo-Shehada, E. Allonby, D. I. Givens, and R. Hill. 1998. Assessment of the nutritive value for ruminants of poultry litter. Anim. Feed Sci. Technol. 73:29–35. doi:10.1016/S0377-8401(98)00135-7

Elemam, M. B., A. M. Fadelelseed, and A. M. Salih. 2009. Growth performance, digestibility, N-balance and rumen fermentation of lambs fed different levels of deep-stack broiler litter. Res. J. Anim. Vet. Sci. 4:9–16.

Federation of Animal Science Societies. 2010. Guide for the care and use of agricultural animals in research and teaching, 1st rev. ed. Federation of Animal Science Societies, Champaign, IL.

Hennessy, D. W., and J. V. Nolan. 1988. Nitrogen kinetics in cattle fed a mature subtropical grass hay with and without protein meal supplementation. Aust. J. Agric. Res. 39:1135–1150. doi:10.1071/AR9881135

Jeffrey, J. S., J. H. Kirk, E. R. Atwill, and J. S. Cullor. 1998. Research notes: Prevalence of selected microbial pathogens in processed poultry waste used as dairy cattle feed. Poult. Sci. 77:808–811. doi:10.1093/ps/77.6.808

Martin, S. A., M. A. McCann, and W. D. Waltman. 1998. Microbiological survey of Georgia poultry litter. J. Appl. Poult. Res. 7:90–98. doi:10.1093/japr/7.1.90

McDonald, P., R. A. Edwards, J. F. D. Greenhalgh, C. A. Morgan, L. A. Sinclair, and R. G. Wilkinson. 2011. Animal nutrition. 7th ed. Ashford Colour Press, Gosport, UK.

Mojabi, A. 2011. Veterinary clinical biochemistry, 2nd ed. (In Farsi.) Noorbakhsh Publishing, Tehran, Iran.

Muia, J. M. K., S. Taminga, P. N. Mbugua, and J. N. Kariuki. 2001. Effect of supplementing napier grass (*Pennisetum purpureum*) with poultry litter and sunflower meal based concentrates on feed intake and rumen fermentation in Friesian steers. Anim. Feed Sci. Technol. 92:113–126. doi:10.1016/S0377-8401(01)00221-8

NRC. 2007. Nutrient requirements of small ruminants: Sheep, goats, cervids and new world camelids. Natl. Acad. Press, Washington, DC.

Obeidat, B. S., H. J. Al-Tamimi, T. M. Osaili, M. S. Awawdeh, and M. A. Abu Ishmais. 2012. Broiler litter as an alternative feedstuff for Awassi ewes: Effect on nursing performance and their lambs' performance. Anim. Feed Sci. Technol. 174:148–153. doi:10.1016/j.anifeedsci.2012.03.014

Obeidat, B. S., M. S. Awawdeh, A. Y. Abdullah, M. M. Muwalla, M. A. Abu Ishmais, B. T. Telfah, A. J. Ayrout, S. K. Matarneh, H. S. Subih, and T. O. Osaili. 2011. Effects of feeding broiler litter on performance of Awassi lambs fed finishing diets. Anim. Feed Sci. Technol. 165:15–22. doi:10.1016/j.anifeedsci.2011.02.007

Radostitis, O. M., C. C. Gay, D. C. Blood, and K. W. Hinchliff. 2007. Veterinary medicine. A text book of the diseases of cattle, sheep, goats and horses. 10th ed. W.B. Saunders Ltd., London, UK.

Rankins, D. L., Jr., M. H. Poore, D. J. Capucille, and G. M. Rogers. 2002. Recycled poultry bedding as cattle feed. Vet. Clin. North Am. Food Anim. Pract. 18:253–266. doi:10.1016/S0749-0720(02)00015-4

Rattanaronchart, S., M. Grossman, R. L. Femando, and R. D. Shanks. 1983. A Monte-Carlo comparison of estimators of average daily gain in body weight. J. Anim. Sci. 57:885–891.

Reddy, G. V. N., P. D. Wilhelmina, and M. S. Reddy. 2003. Effect of differently processed complete diet on performance of Murrah buffaloes. Indian J. Anim. Nutr. 20:131–135.

Robertson, J. B., and P. J. Van Soest. 1981. The detergent system of analyses and its application to human foods. In: W. P. T. James and O. Theander, editors, The analysis of dietary fiber. Marcel Dekker, New York, NY. p. 123–158.

Rossi, J. E., A. L. Goetsch, and D. L. Galloway Sr. 1998. Intake and digestion by Holstein steers consuming different particle size fractions of broiler litter. Anim. Feed Sci. Technol. 71:145–156. doi:10.1016/S0377-8401(97)00125-9

Samanta, A. K., K. K. Singh, M. M. Das, S. B. Maity, and S. S. Kundu. 2003. Effect of complete feed block on nutrient utilization and rumen fermentation in Barbari goats. Small Rumin. Res. 48:95–102. doi:10.1016/S0921-4488(02)00262-6

Thomas, M. 1998. Physical quality of pelleted feed. A feed model study. PhD Thesis, Wageningen Agricultural University, Wageningen, The Netherlands.

Van Soest, P. J. 1994. Nutritional ecology of the ruminant. Cornell Univ. Press, Ithaca, NY.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber and non-starch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583–3597. doi:10.3168/jds.S0022-0302(91)78551-2

Weidner, S. J., and R. J. Grant. 1994. Soyhulls as a replacement for forage fiber in diets for lactating dairy cows. J. Dairy Sci. 77:513–521. doi:10.3168/jds.S0022-0302(94)76979-4