Viability of the use of bovine milk whey at lamb finishing: performance, carcass, and meat parameters

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ABSTRACT
Bovine milk whey is a co-product of the dairy agroindustry that has potential for use in lamb feeding. The objective of this study was to evaluate the use of bovine milk whey on the performance, carcass characteristics, and meat quality of finishing lambs. Eighteen male lambs were distributed in three treatments (control diet – CD, diet with whey powder – DWP, and diet with liquid whey – DLW) with six replicates. The performance variables, loin-eye area measurements, cover and subcutaneous fat, marbling, yield, morphometry, conformation, and finishing of the carcasses were evaluated. There was a difference in the dry matter intake, with the CD (3.22%) and DWP (3.08%) treatments having higher levels than that of the DLW (2.46%) treatment. The averages for loin-eye area, subcutaneous fat, and marbling were 9.88 cm², 2.97 mm, and 1.39, respectively. There was a difference among the treatments for ethereal extract content of the meat; it was higher in CD (7.90%) and lower in DLW (5.19%). The inclusion of bovine milk whey did not alter the quantitative and qualitative parameters of the carcass; however, it altered the levels of ethereal extract content in the meat.

Introduction
Feeding is one of the most important and costly factors in animal production systems. In Brazil, due to the abundance of pastures, a large component of the sheep herd is pasture-raised, with the confinement system being mainly used for the category of finishing lambs.

In general, the intensive farming of ruminants in confinement depends on the availability and cost of feed used; thus, producers must increasingly use co-products from the agroindustry as alternative food sources. Several byproducts have already been tested for lamb finishing such as coffee husk (Souza et al. 2004), crude glycerin (Rego et al. 2015), and citrus pulp (Rodrigues et al. 2008).

Bovine milk whey is considered a byproduct of the cheese industry and is a potential environmental pollutant. Currently, this product is considered a co-product and contains numerous nutritional, functional, and bioactive compounds. It is estimated that the worldwide bovine milk whey production is 160 million tons per year, and only 30–50% are utilized (Kareb and Aider 2018).

Whey is recognized as an important product because of its high nutritional value with a high soluble protein content, and is rich in essential amino acids and B-complex vitamins. The intensive system uses a high proportion of dietary energy from sources such as cereal starch, which is partially ruminated. In addition to being a valuable dietary energy source, bovine milk whey is also a palatable product (Serafim et al. 2017) and can be used to replace a part of the maize in the diet, thereby decreasing costs. In addition, according to Moreno-Indias et al. (2009), the cheese whey presents differences in its composition according to its origin, be it of farms or cheese factories; which has repercussions on the application of whey in animal nutrition.

The objective of the present study was to evaluate the performance, carcass characteristics, and meat quality of lambs receiving bovine whey in liquid and powder forms in their diet.

Materials and methods
The experiment was conducted at Universidade Pitágoras Unopar (Campus Arapongas, Paraná). The present study was undertaken in accordance with the ethical principles of animal experimentation approved by the Ethics Committee for the Use of Animals at UNOPAR (ECA 002/15).

A total of 18 castrated male lambs from a crossbreed of male Santa Inês and undefined breed females were included in the study. The lambs, approximately 60 days old and with average weight of 21.3 kg, were divided into three treatments: control diet (CD), diet with whey powder (DWP), and diet with liquid whey (DLW). The design used was completely...
randomized with three treatments and six replicates. The animals were allocated to collective pens, with an area of 8.6 m².

The diets were formulated to be isonenergetic and isoprotein based on the nutritional requirements described by the National Research Council (NRC 2007), to obtain gains of 100 g per day, with requirements of 66% for total digestible nutrients (TDN) and 11% for crude protein (CP). The diets were composed of 30% bulky (elephant grass silage) and 70% concentrate in DM (Table 1). The elephant grass silage represented 20.0% DM, 7.2% MM, 7.93% CP, 0.9% ethereal extract (EE), 63.7% neutral detergent fibre (NDF), 41.8% acid detergent fibre (ADF), 0.175% neutral detergent insoluble nitrogen (NDIN), 0.155% acid detergent insoluble nitrogen (ADIN), and 44.73% TDN. The total diet of each treatment was analysed (Table 1) for DM, MM, CP, EE, NDF, ADF, lignin, NDIN, and ADIN following the methodologies described by Mizubuti et al. (2009).

Carbohydrate levels were estimated based on the methodology described by Sniffen et al. (1992), as well as the total carbohydrate (TC) = 100(%CP + %EE + %MM), which is a non-fibre carbohydrate, where (NFC) = 100–(%NFCp + %CP + %EE + %MM) – NDFcp equals the cell wall adjusted to MM and protein. To estimate TDN (Table 1), the following formula was used: NDT = NFCd + CPd + (FAd × 2.25) + NFCd – 7, where NFCd is the non-fibre digestive carbohydrate, CPd corresponds to the crude digestive protein, FAd is the digestive fatty acid, and NFCd corresponds to the NFC adjusted to digestible nitrogen.

The liquid whey and whey powder were analysed for moisture, MM, CP, and EE levels, as well as titratable acidity and pH. A portion of the liquid whey was stored and frozen for subsequent bromatological analyses. The composition of liquid whey and whey powder was as follows: DM – 8.00% and 96.40%, CP – 8.00% and 14.20%, MM – 3.75% and 6.84%, EE – 0.50% and 3.00%, respectively. Liquid whey presented 20.2°D and a pH of 5.88.

Diets were provided twice a day at 8 am and 4 pm. The whey powder was mixed in the feed at 5% of the total mixture. The whey powder and liquid whey were supplied in the amount of 5% of the total DM of the diet, which represented 2.14% of the body weight of the animal.

The diet supply was determined based on the food leftovers, with leftovers of 15% in the troughs maintained to reduce selection effects. Consumption of diets was registered daily, with the amount of food supplied and food leftovers from the previous day weighed. To monitor consumption and performance, the animals were weighed every 15 days. The performance variables evaluated were as follows: daily DM intake and daily weight gain.

Representative samples of the total diet offered were collected directly from the trough and from the samples of leftovers for the bromatological analyses. These samples (Table 1) were pre-dried in a forced air oven at 55°C for 72 h to determine dry-adsorbed matter and, then, processed in a Willey mill.

On the day prior to slaughter, in vivo carcase measurements were performed using a Sonoscope S6vet ultrasonography (Sonoscope, Shenzhen, China) in real time. Loin-eye area (LEA) was estimated with a convex multifrequency transducer at 5 MHZ frequency. Subcutaneous fat thickness (SFT) and marbling were estimated with a linear multifrequency transducer with a frequency of 10 MHZ. The marbling rate was estimated subjectively, using photographic patterns (AMSA 2001), where scores were given from 1 to 10 (1 = marbling traces and 10 = abundant marbling).

The animals remained confined for, on average, 70 days and were slaughtered at an average weight of 27.1 kg. Before slaughter, the animals were subjected to 16 h of fasting from solids and unrestricted water consumption, and were then weighed to obtain body weight at slaughter (BWS). Slaughter was performed following the standards for humane slaughter. The feet, head, and internal organs were removed before the carcass was weighed, resulting in measurement of the hot carcass weight (HCW). After removing the internal organs, the complete gastrointestinal tract was weighed. Thereafter, it was emptied and weighed again to obtain the empty gastrointestinal tract weight, thus enabling calculation of the weight of the gastrointestinal content and the empty body weight, which is the gastrointestinal content subtracted from the BWS.

After weighing the carcasses, they were transferred to a cold chamber at 4°C for 24 h. After the cooling period, the carcasses were weighed to obtain the cold carcass weight (CCW). The hot carcass yield (HCY) was determined by the ratio of HCW and BWS multiplied by 100. The cold carcass yield (CCY) was determined by the ratio of CCW and BWS multiplied by 100. For the determination of the biological yield (BY), the ratio of HCW and empty body weight multiplied by 100 was used. For the determination of the cooling loss (CL), the HCY minus CCY by the ratio of HCW multiplied by 100 was used.

Posteriorly, the morphometric measures of the carcasses were evaluated using a tape measure to measure the croup perimeter, leg perimeter, external length of the carcass, arm length, and arm perimeter. With the use of a pachymeter, the thorax width, back width, croup width, and arm depth were measured. Conformation evaluations were performed based on the European carcass classification (superior, excellent, very good, good, normal, and poor) and degree of finishing (ranging from 1 to 5, from absent to abundant) (Sañudo et al. 2000).

Table 1. Composition of nutrients and chemical-bromatological composition of experimental diets (%) of lambs finished with bovine milk whey in the diet.

| Ingredients (%) | CD | DWP | DLW |
|----------------|----|-----|-----|
| Ground corn    | 38.0 | 33.2 | 33.2 |
| Soybean meal   | 28.0 | 27.0 | 27.0 |
| Whey           | 0.0  | 5.0  | 5.0  |
| Silage         | 30.0 | 30.0 | 30.0 |
| Mineral salt   | 1.0  | 1.0  | 1.0  |
| Oil            | 3.0  | 3.0  | 3.0  |
| Chemical-bromatological composition (%) | 40.5 | 40.8 | 30.2 |
| Mineral matter | 6.04 | 5.83 | 5.75 |
| Crude protein  | 19.8 | 18.9 | 19.4 |
| Ethereal extract | 2.2 | 2.6  | 2.0  |
| Neutral detergent fibre | 26.4 | 23.2 | 22.7 |
| Acid detergent fibre | 14.9 | 15.4 | 16.3 |
| Lignin         | 4.8  | 4.9  | 5.1  |
| Neutral detergent insoluble protein | 0.77 | 0.70 | 0.91 |
| Acid detergent insoluble protein | 1.26 | 0.79 | 0.69 |
| *Non-fibrous carbohydrates | 49.23 | 51.73 | 55.98 |
| *Total digestible nutrients | 64.4 | 67.8 | 69.0 |

Note: CD: control diet; DWP: diet with whey powder; DLW: diet with liquid whey.
*Estimated according to the NRC (2001).
Samples of the *Longissimus dorsi* muscle were collected 24 h after slaughter, and sent to the Laboratory of Animal Bromatology at Universidade Pitágoras. The samples were divided into two portions, one of them, approximately 50 g, was used for the analysis of colour, pH, and water retention capacity (WRC) on the same day. The other portion, approximately 100 g, was frozen for subsequent analysis of moisture, EE, CP, and MM based on the methodologies described by Mizubuti et al. (2009) and to measure losses by thawing and cooking of the meat.

The WRC of the meat was evaluated by the pressure application method, i.e., weighing a meat sample before and after the superimposition of a 10 kg weight for 5 min, and then obtaining the value of the loss of water by pressure.

To estimate the loss by thawing, samples were thawed under refrigeration (5°C) for 24 h, calculating the thaw loss. For cooking, these samples were previously weighed and roasted in a pre-heated gas oven at 170°C until a temperature of 71°C was reached at the geometric centre; measurements were taken using a digital thermometer. After cooking, the samples were cooled at room temperature (25–30°C) and weighed again. The weight loss by thawing was calculated by the difference between the weight of the frozen meat before and after thawing, and the weight loss by cooking via the difference between the weight of the refrigerated and roasted meat, expressed as a percentage of the initial weight (IW) (AMSA 2015).

The pH of the meat was measured using a digital portable pH metre TESTO 205 (Testo AG, Lenzkirch, Germany) during the 24 h post-mortem period. The meat colour was measured using a portable colorimeter CR-10 (Konica Minolta, Tokyo, Japan) with illuminant D65, and 10° inclination angle for the evaluation of components L* (brightness), a* (red-green component), and b* (yellow-blue component). With these values, the tone angle (h*) was calculated using the equation $h^* = \tan^{-1} \left( \frac{b^*}{a^*} \right)$ and saturation index or chroma (*) using the equation $c^* = (a^2 + b^2)^{0.5}$ (Houben et al. 2000).

The variance homogeneity was tested by the Bartlett test ($P > 0.05$) and the residue normality was verified by the Shapiro-Wilk test. Data were submitted to analysis of variance and, when significant, were submitted to Tukey’s test, at the 5% level. All statistical evaluations were performed with the aid of the R software program.

**Results**

IW, final weight, daily weight gain averages, and confinement periods were 21.3 kg, 27.1 kg, 0.76 g, and 70 days, respectively, and did not differ ($P > 0.05$) among treatments.

In contrast, DM intake (in kg per group) and percentage of body weight values were statistically different from each other ($P < 0.0001$). The lambs that received the CD treatment consumed 763 g per day (4.6 kg/group), which represented 3.22% of their body weight. These values of consumption were higher than that in the DLW treatment (3.2 kg/day/group), whereas consumption in the DWP treatment (3.9 kg/day/group) did not differ from the CD treatment, demonstrating that the inclusion of this co-product in powder form did not affect consumption by the animals.

**Table 2.** Performance variables and carcass characteristics estimated in vivo by real-time ultrasonography of lambs finished with bovine milk whey in the diet.

| Treatments | CD | DWP | DLW | Average | $^2P$ | $^3CV$ (**) |
|------------|----|-----|-----|---------|------|------------|
| IW (kg)    | 21.0 | 23.7 | 20.1 | 21.30   | 0.51 | 24.58      |
| FW (kg)    | 25.8 | 30.1 | 26.1 | 27.10   | 0.07 | 13.14      |
| DWG (g/day)| 43.0 | 106.0 | 80.0 | 76.30   | 0.15 | 73.75      |
| DM* (kg/lot/day) | 4.6 | 3.9 | 3.2 | 3.90 | 0.0001 | 29.35 |
| CBW (%)    | 3.22 | 3.08 | 2.46 | 2.92 | 0.0001 | 25.08 |
| CP (%)     | 80.3 | 56.8 | 71.9 | 70.00 | 0.52 | 46.93      |
| LEA (cm²)  | 9.02 | 10.89 | 9.72 | 9.88 | 0.266 | 19.09      |
| SFT (mm)   | 2.80 | 3.09 | 3.02 | 2.97 | 0.907 | 36.88      |
| Marbling   | 2.16 | 2.00 | 2.21 | 2.12 | 0.921 | 43.12      |

Note: CD: control diet; DWP: diet with whey powder; DLW: diet with liquid whey.

In relation to the averages of LEA, SFT, and marbling (Table 2), these were not statistically different among the treatments ($P > 0.05$) and were 9.88 cm², 2.97 mm, and 2.12, respectively.

The inclusion of bovine milk whey in the diet did not interfere with BWS, HCW, and CCW, with mean values of 27.3, 13.9, and 13.5 kg, respectively. Carcass yields (CCY, HCY, and BY), CL, conformation, and finishing of carcasses (Table 3) were not altered by the diets ($P > 0.05$) used.

The mean BY was 57.4% and did not change among diets, which was expected considering that this variable is dependent on the amount of the animal gastrointestinal content and, consequently, is influenced by the voluminous and concentrated relationship of the diet offered (ARC 1980). In this scenario, the diets had the same proportions of bulky and concentrated products, and had similar energy contents (between 64.0% and 69.0% of TDN). Thus, there was no difference in the BY between treatments.

The mean values for conformation observed, between 2.8 and 3.2, meant that conformation carcasses were classified as normal to good (Table 3). The averages for finishing were between 3 and 3.6 (Table 3).

In relation to the physical-chemical analysis of lamb meat, mean values of WRC, loss by thawing, and loss by cooking did not differ among the treatments.

**Table 3.** Qualitative variables of the lambs carcass finished in confinement with bovine milk whey in the diet.

| Treatments | CD | DWP | DLW | Average | $^2P$ | $^3CV$ (**) |
|------------|----|-----|-----|---------|------|------------|
| BWS (kg)   | 35.8 | 30.1 | 26.1 | 27.3 | 0.074 | 13.14      |
| HCW (kg)   | 13.61 | 15.01 | 13.13 | 13.92 | 0.18 | 12.18      |
| CCW (kg)   | 13.22 | 14.57 | 12.71 | 13.50 | 0.16 | 11.93      |
| HCY (%)    | 52.8 | 49.90 | 50.5 | 51.06 | 0.137 | 5.05      |
| CCY (%)    | 51.3 | 48.40 | 48.9 | 49.53 | 0.116 | 5.11      |
| BY (%)     | 58.8 | 56.90 | 56.6 | 57.43 | 0.461 | 5.36      |
| CL (%)     | 2.82 | 3.01 | 3.16 | 2.99 | 0.678 | 21.95      |
| Conformation | 3.17 | 3.20 | 2.86 | 3.07 | 0.793 | 30.69      |
| Finishing  | 3.67 | 3.60 | 3.00 | 3.42 | 0.248 | 22.94      |

Note: CD: control diet; DWP: diet with whey powder; DLW: diet with liquid whey.

In BWS (body weight at slaughter), HCW (hot carcass weight), CCW (cold carcass weight), HCY (hot carcass yield), CCY (cold carcass yield), BY (biological yield), CL (cooling loss), Conformation and Finishing of the carcass.

$^2P =$ probability of significance.

$^3CV =$ coefficient of variation (%)
Table 4. Physical and chemical characteristics in meat of lambs finished in confinement with bovine milk whey in the diet.

| Variables | Treatments | CD | DWP | DLW | Average | \(2P\) | \(3CV\) (%) |
|-----------|------------|----|-----|-----|---------|-------|------------|
| WCR (%)   | 77.93      | 86.79 | 80.36 | 81.7 | 0.5285  | 15.98 |
| LBT (%)   | 31.93      | 34.15 | 34.96 | 33.68 | 0.7169  | 19.95 |
| LBC (%)   | 33.74      | 35.33 | 37.56 | 35.54 | 0.4643  | 15.27 |
| L* (%)    | 42.17      | 42.92 | 43.32 | 43.13 | 0.9872  | 9.78  |
| a* (%)    | 17.48      | 17.67 | 16.92 | 17.35 | 0.9024  | 17.44 |
| b* (%)    | 9.24       | 10.41 | 10.04 | 9.90  | 0.698   | 23.71 |
| c (%)     | 19.84      | 20.58 | 21.97 | 20.04 | 0.9048  | 17.20 |
| h (%)     | 27.49      | 30.43 | 30.19 | 29.37 | 0.5182  | 16.34 |
| pH        | 5.87       | 5.80  | 6.00  | 5.89  | 0.5556  | 5.42  |
| M (%)     | 67.86      | 67.57 | 68.91 | 68.11 | 0.7442  | 4.20  |
| EE (%)    | 7.90\*     | 6.79\* | 5.19\* | 6.62  | 0.0355  | 25.94 |
| CP (%)    | 23.22      | 24.28 | 24.95 | 24.15 | 0.4577  | 10.08 |
| MM (%)    | 1.27       | 1.29  | 1.36  | 1.31  | 0.4333  | 10.09 |

Note: CD: control diet; DWP: diet with whey powder; DLW: diet with liquid whey.
1WCR (water retention capacity). LBT (loss by thawing). LBC (loss by cooking). L (luminosity). \(a^*\) (green-red component). \(b^*\) (blue-yellow component). c (chroma). h (hue). M (moisture). EE (etheral extract). CP (crude protein). MM (mineral matter).
\(2P\): probability of significance.
\(3CV\): coefficient of variation (%).

Discussion

Lower consumption by animals fed rations containing liquid whey (DLW treatment) found in the present study could be lower than 10% of that in the CD treatment. Lower consumption by animals fed rations containing liquid whey changed the EE content of the meat. The higher EE content in the CD treatment than that in the DLW treatment can be attributed to the higher DM consumption within the limits that are considered a good quality meat.

The chemical composition of the meat in the present study was within the standards established by Prata (1999) with values of approximately 75.0% for moisture, 19.0% for CP, 4.0% for EE, and 1.0% for MM. The mean pH values were within the limits that are considered a good quality meat.

Regarding the chemical composition of meat (Table 4), a significant difference among treatments for EE content was observed (\(P < 0.05\)), with higher levels in the CD (7.9% fat) and DWP (6.79%) treatments than that in the DLW (5.19%) treatment. The averages for moisture, CP, and MM were 68.11%, 12.27%, and 1.31%, respectively.

Discrimination

The HCW and CCW of 13.92 and 13.50 kg, respectively, were close to the observations by Cartaxo et al. (2011), who verified the carcasses of lambs Bergamacia × Santa Inês and Ille de France × Santa Inês, fed with a CD for both genotypes, verified meat values of 30.58–38.00 for L*, 12.27–18.01 for \(a^*\), and 3.34–5.65 for \(b^*\). These differences in meat colour tones may be due not only to intrinsic factors, but also to factors related to pre- and post-slaughter management.

The chemical composition of the meat in the present study was within the standards established by Prata (1999) with values of approximately 75.0% for moisture, 19.0% for CP, 4.0% for EE, and 1.0% for MM. The mean pH values were within the limits that are considered a good quality meat.

Under the conditions of the present study, the inclusion of bovine milk whey, whether in liquid or powder form, in the diet of confined lambs was considered viable, without significant changes in lamb performance and without changing the quantitative and qualitative variables of the carcass. However, the use of liquid whey changed the EE content of the meat.

Disclosure statement

No potential conflict of interest was reported by the authors.

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