Effects of Low-Fat Distillers Dried Grains with Solubles Supplementation on Growth Performance, Rumen Fermentation, Blood Metabolites, and Carcass Characteristics of Kiko Crossbred Wether Goats

Khim B. Ale, Jarvis Scott, Chukewueme Okere, Frank W. Abrahamsen, Reshma Gurung and Nar K. Gurung *

Department of Agricultural and Environmental Sciences, College of Agriculture, Environment and Nutrition Sciences, Tuskegee University, Tuskegee, AL 36088, USA
* Correspondence: ngurung@tuskegee.edu

Simple Summary: Distillers dried grains with solubles (DDGS) is a byproduct of the bioethanol industry, and it contains crude protein of 25% to 31% and ether extract of 9% to 13%. The DDGS produced from the bioethanol industry in the United States (US) are predominately low fat (3–5%). A nutritional profile of low-fat DDGS (LF-DDGS) showed that it is suitable feedstuff for livestock including goats and may reduce the production cost. However, there are limited studies on the effect of low-fat DDGS (LF-DDGS) in goats. Thus, this study aimed to evaluate the effect of feeding different amounts of LF-DDGS on the growth performance, growth efficiency, rumen fermentation, blood metabolites, and carcass characteristics of Kiko crossbred wether goats. The study was conducted for 84 days, feeding different amounts of LF-DDGS. The results suggest that up to 30% LF-DDGS can be included in the diets of castrated male goats without affecting the growth performance and carcass characteristics.

Abstract: Distillers dried grains with solubles (DDGS) produced in the US are predominately low fat, as the economics favor separating as much oil as possible for sale as renewable diesel feedstock and also for use in swine and poultry feed. This study aimed to evaluate the effect of feeding different amounts of low-fat DDGS (LF-DDGS) on the growth performance, growth efficiency, rumen fermentation, blood metabolites, and carcass characteristics of Kiko crossbred wether goats. Twenty-four goats, 5–6 months of age, were randomly assigned to one of the four experimental diets (n = 6/diet), 0%, 10%, 20%, and 30% LF-DDGS on an as-fed basis, and fed for 84 days. The data collected were analyzed using an orthogonal contrast test for equally spaced treatments. The average total gains, average daily gains, and gain-to-feed ratios were similar among the treatments (p > 0.05). The rumen acetate, propionate, and butyrate concentrations and the acetate:propionate ratios were similar (p > 0.05) among the treatments. There were no differences (p > 0.05) among the treatments for the dressing percentage, rib eye area, and backfat thickness. The findings suggest that at least up to 30% LF-DDGS can be included in the diets of castrated male goats without affecting the production performance and carcass characteristics.

Keywords: low fat; distillers dried grains with solubles; castrated goats; performance

1. Introduction

Ethanol is a renewable fuel that is widely used by blending in gasoline to reduce the emission from vehicles, and distillers dried grains with solubles (DDGS) is a coproduct produced alongside ethanol, with high nutritional value for animals. The United States (US) is the leader in bioethanol production, which alone produced 15 billion gallons of ethanol in 2021, approximately 55% of the world’s ethanol production [1]. Along with the increase in the production of ethanol over the last decade, the production of its coproduct, DDGS, is
also increasing; 22.2 million tons of DDGS were produced in 2021 in the US alone [2]. In the US, DDGS are predominately low fat, as the economics favor separating as much oil as possible for sale as renewable diesel feedstock and also as an ingredient in swine and poultry feed.

Low-fat distillers dried grain with solubles (LF-DDGS) is produced after distillers corn oil is extracted by heating and centrifuging thin stillage after it has been separated from whole stillage. In the US, 94% of the total ethanol production is from corn [3], where over 90% of the entire bioethanol plants in the US have been using various facilities for oil extraction [4]. In 2021, nearly 2 million tons of corn distillers oil (CDO) was produced in the US. Thus, the production of low-fat distillers dried grains with solubles is expected to increase.

DDGS is a nutritive feedstuff for livestock [5–7], along with poultry [8–10] and fish [11]. The nutrient content of DDGS varies according to the feedstocks, ethanol production process (dry or wet), and plants, and it also varies between each batch of production. Different researchers have observed different ranges of crude protein (25% to 31%), ether extract (9% to 13%), neutral detergent fiber (NDF) (25% to 53%), acid detergent fiber (ADF) (9% to 15%), and starch (0% to 8%) [7,12]. Some reports recommend DDGS up to only 20% of the total diet in lactating dairy cattle, and some suggest 40% to 50% of the total ration can also be included in the finishing cattle diet without any negative impact on the performance parameters [6,11]. Gurung et al. (2009) [13] observed no effect of the inclusion of DDGS up to 30% in growing meat goat diets. In another study, Gurung et al. (2012) [14] found no adverse effect on the digestibility and passage kinetics by including 38.1% DDGS in the diet of castrated male goats. Similarly, Sorensen et al. (2021) [15] reported that 100% of the soybean meal (SBM) could be replaced from finishing goat diets with corn DDGS without any effect on the growth performance and carcass characteristics [15]. Mjoun et al. (2010) [16] found a similar milk production and dry matter intake (DMI) of a lactating cattle-feeding soybean-based diet with up to 30% reduced fat DDGS (3.5% EE) [16]. Jacela et al. (2011) [17] reported that LF-DDGS contain higher CP but less energy content than DDGS, but when the reduced fat was overcome by adding dietary fat, the growth performance was not affected in nursing pig, whereas the growth performance was reduced in finishing pigs. Data regarding the usage of LF-DDGS for small ruminants, especially meat goats, are limited. Thus, this research objective was to determine the effect of LF-DDGS on the growth performance, rumen fermentation, blood metabolites, and carcass characteristics in growing meat goats.

2. Materials and Methods

2.1. Experimental Animals and Diets

This study was conducted at the Caprine Research and Education Unit at George Washington Carver Agricultural Experiment Station, Tuskegee University of Tuskegee, Alabama, USA. All experimental procedures, care, and handling of the animals were approved by the Institutional Animal Care and Use Committee of Tuskegee University. The goats were purchased from Spring Acres Farm, Quitman, Georgia, USA, and were quarantined for three weeks before starting the trial. After the quarantine period, the goats were individually housed in 1.1 m × 1.2 m pens with plastic slatted floors inside the indoor barn. Each pen was fitted with individual hayracks, concentrate troughs, and automated watering nipples. Twenty-four Kiko crossbreed castrated male goats (26.7 ± 1.21 kg initial bodyweight, 5–6 months of age) were randomly assigned to one of the four experimental diets: 0%, 10%, 20%, and 30% LF-DDGS supplementation diet on an as-fed basis.

The LF-DDGS used to formulate the experimental diet was Dakota Gold LF-DDGS purchased from Poet Nutrition, Inc., in Sioux Falls, South Dakota (Sioux Falls, SD, USA). A composite sample from both of the one-ton tote bags was collected and sent to Holmes Laboratory in Millersburg, OH, USA, for a nutrient analysis. Each treatment diet consisted of Bermudagrass hay (Cynodon dactylon), cracked corn, soybean meal, LF-DDGS, liquid molasses, and goat premix mixed at varying proportions, as shown in Table 1. The pro-
portion of soyabean meal and corn was reduced/replaced by increasing the inclusion of LF-DDGS in the experimental diets. The diets were formulated according to NRC (2007) to meet or exceed all nutritional requirements for growing meat goats and were mixed at a local feed mill (The Feed Mill, Eclectic, AL, USA).

Table 1. Composition of experimental diets containing varying levels of low-fat distillers dried grains with solubles (LF-DDGS) and hay used for 84 day feeding period (on an as-fed basis).

| Ingredient, % of Diet | Percentage of Low-Fat DDGS in the Diet, % |
|-----------------------|-------------------------------------------|
|                       | 0  | 10 | 20 | 30 |
| Bermudagrass Hay       | 50 | 50 | 50 | 50 |
| Cracked Corn           | 34 | 28.5 | 23 | 16.5 |
| Soybean Meal 48%       | 12.5 | 8 | 3.5 | 0 |
| Low-Fat DDGS           | 0  | 10 | 20 | 30 |
| Liquid Molasses        | 2.5 | 2.5 | 2.5 | 2.5 |
| Goat Premix †           | 1  | 1  | 1  | 1  |
| Total                  | 100 | 100 | 100 | 100 |

LF-DDGS = low-fat distillers dried grains with solubles. † Purina® Goat Mineral with a minimum of 15.3% calcium and 8% phosphorous; 50 ppm selenium; 4000 ppm zinc; 300,000 IU/lb vitamin A.

The animals were fed their respective diets for approximately three weeks for diet acclimatization before the first data collection and then continued for 84 days. Each goat was offered 50% hay and 50% grain mixes separately, calculated as 3 percent of the individual’s body weight (BW) and ad libitum water as well as access to free-choice salt blocks. The grain mixes contained 0, 20, 40, and 60% LF-DDGS so that the final diets contained 0, 10, 20, and 30% LF-DDGS on an as-fed basis. Each goat’s refused grain mixes and hay were collected, weighed, and recorded daily. The amount of feed offered was adjusted at three-day intervals; if the average weight of the grain mix or hay refusal for the previous three days was less than 10% of the feed offered, then the grain mix or hay offered was increased by 100 g for the next three days.

2.2. Sample Collection of Feed and Analysis

The composite samples of the grain mix for the respective treatments and Bermudagrass hay (BGH) were shipped to Holmes Laboratory (Millersburg, OH, USA) for analysis of the DM, CP, ADF, acid hydrolysis fat, ash, phosphorus, magnesium, potassium, sulfur, manganese, zinc, and iron. The nutritional analyses were completed according to the methods described by the American Organization of Analytical Chemists [18]. The NDF concentration was determined utilizing an ANKOM 2000 fiber analyzer (Ankom Technology, Macedonia, NY, USA) according to the manufacturer’s recommendations. The lignin concentration was determined according to the USDA’s (1970) Forage Fiber Analysis Handbook Procedure 397 [19].

2.3. Rumen Fermentation

The rumen fluid samples from goats were collected on day 84 of the trial. The samples were collected two hours after feeding to ensure adequate ingesta in the ruminal cavity at the sampling time. A speculum was placed over the tongue of the oral cavity to prevent animals from chewing and biting the tube during the process. The lubricated, beveled end of a 7 mm wide tube was slowly maneuvered through the esophagus and into the rumen. A 500 mL syringe was used as the vacuum pump to collect 30 mL of rumen fluid. The rumen fluid’s pH was determined using a pH meter. Three milliliters of 50% hydrochloric acid was added to each sample to prevent further fermentation and then stored at −20 °C for 24 h. The rumen samples were then thawed, and approximately 2 mL of the rumen fluid was transferred to microtubes. The microtubes were centrifuged at 4000 rfc for 20 min. The samples were then prepared according to the method described by Erwin et al. (1961) [20] using 25% metaphosphoric acid and ethyl butyrate as the internal
control; the concentrations of acetate, propionate, and butyrate were determined utilizing an Agilent 7890 GC (Santa Clara, CA, USA), equipped with a flame ionization detector (FID) and a DB-WAXxetr capillary column (30 m × 0.25 mm × 0.25 µm; Agilent, Santa Clara, CA, USA). The flow rate of helium was 1 mL/min. The injector temperature was set at 185 °C, with an injecting volume of 1 µL and a split inlet ratio of 4:1. The temperature of the FID detector was set at 250 °C. The oven temperature was programmed from 80 °C (held for 1 min) to 200 °C (held for 15 min) at a rate of 10 °C/min. The total VFAs were calculated according to the method described by Hall et al. (2015) [21].

2.4. Growth Performance and Blood Metabolites

The animals’ body weights were recorded before feeding on days 0 and day 84 using the Sheep and Goat Digital Scale (Lakeland Farm and Ranch Direct, Stonewall, MB, Canada), and the BW gain, average daily gain (ADG), and gain-to-feed ratio (G:F) were calculated. In addition, blood samples were collected on day 84 of the trial. From each animal, 10 mL of blood was collected via the jugular venipuncture technique in a blood collection tube with a serum separator and a tube with ethylenediaminetetraacetic acid (EDTA). The blood samples were then sent to the Tuskegee University Clinical Pathology Diagnostic Laboratory (Tuskegee, AL, USA) for hematological and serum biochemistry analysis. The serum chemical analysis was conducted using an IDEXX Catalyst DX system, which also provided reference ranges for each parameter (IDEXX Laboratories, Westbrook, ME, USA). Several serum chemical parameters were assessed to understand how the LF-DDGS supplementation affected organ function and overall animal health.

2.5. Carcass Quality

The animals were humanely slaughtered at the end of the trial according to USDA guidelines at the Fort Valley State University Meat Laboratory (Fort Valley, GA, USA). Twenty-four hours after arriving at the facility, the fasting weights of the goats were recorded before slaughtering. The hot carcass weights (HCWs, kg) were measured after the removal of offal. The chilled carcass weight (CCW, kg) was recorded 24 h after storing hot carcasses in a chilled room at 4 °C. The carcass evaluations, such as longissimus muscle area (LMA) and fat depth over the midpoint of the longissimus muscle at the 12th rib, were estimated by a certified USDA grader based on the USDA’s (2001) [22] series criteria, and the dressing percentage (DP) and carcass shrink were calculated.

2.6. Statistical Analysis

The data were analyzed using the general linear model procedures of SAS (SAS Institute Inc., Cary, NC, USA). The effects of varying the inclusion amounts of LF-DDGS on the DMI, VFA profiles, blood serum metabolites, and carcass characteristics were tested by orthogonal polynomial regression. In addition, an orthogonal contrast test for equal-spaced treatments was conducted to determine the linear and quadratic effects (SAS/STAT user guide, 2004) [23].

3. Results

3.1. Nutrient Composition of the Experimental Diets

The nutrient composition of the grain mixes, BGH, and LF-DDGS used in the trials are presented in Table 2. The average CP concentration of the grain mixes with different percentages of LF-DDGS were 20.14, 21.17, 19.75, and 24.68% for 0%, 20%, 40%, and 40% LF-DDGS, respectively. The crude fat content of the LF-DDGS used in this diet was 5.75%, and the fat percentage increased in the grain mixes with the increase in the inclusion rate of the LF-DDGS (3.77, 4.40, 4.63, and 4.78% for 0%, 20%, 40%, and 60% LF-DDGS, respectively). Similarly, the NDF and TDN concentrations were 8.57%, 12.48%, 14.25%, and 21.88% and 87.09%, 86.49, 85.22, and 83.71% for the 0%, 20%, 40%, and 460% LF-DDGS grain mixes, respectively. The two minerals of concern with LF-DDGS, phosphorous and sulfur, were
0.53, 0.59, 0.69, 0.84, and 0.95% and 0.27, 0.41, 0.57, and 0.74% for the 0%, 10%, 20%, and 30% LF-DDGS grain mixes, respectively.

Table 2. Analyzed chemical composition of the grain mixes, Bermudagrass hay (BGH), and low-fat distillers dried grains with solubles (LF-DDGS) used in the experimental diets fed over 84 days to growing castrated male goats.

| Nutrient Analysis † | Percentage of LF-DDGS in Grain Mixes, % | BGH | LF-DDGS |
|---------------------|----------------------------------------|-----|---------|
| Moisture, %         | 13.68 12.87 13.07 13.53               | 14.25 | 12.55 |
| Dry Matter (DM), %  | 86.32 87.13 86.93 86.47                | 85.75 | 87.45 |
| Crude Protein, %    | 20.14 21.17 19.75 24.68                | 9.28  | 29.95 |
| Available Protein, %| 19.88 20.77 19.36 24.08                | -    | -      |
| Adjusted Crude Protein, % | 20.14 21.17 19.75 24.68 | - | - |
| ADF Protein, %      | 0.26 0.4 0.39 0.6                    | -    | -      |
| NDF Protein, %      | 0.49 0.72 0.74 1.1                    | -    | -      |
| Lignin, %           | 0.21 0.21 0.21 0.21                   | -    | -      |
| Acid Detergent Fiber, % | 2.93 3.76 4.17 7.29                   | 26.80 | 9.71   |
| Neutral Detergent Fiber, % | 8.57 12.48 14.25 21.88             | 42.06 | 25.28 |
| Non-Fiber Carbohydrate (NFC), % | 62.42 56.77 55.11 43.01 | - | 33.80 |
| Crude Fat, %        | 3.77 4.4 4.63 4.78                    | -    | 5.75   |
| TDN, %              | 87.09 86.49 85.22 83.71                | 66.37 | 84.59 |
| NEf, Mcal/kg        | 2.01 2.00 1.97 1.93                   | 0.68  | 1.90   |
| NEm, Mcal/kg        | 2.15 2.13 2.10 2.05                   | 0.69  | 2.07   |
| NEg, Mcal/kg        | 1.48 1.46 1.43 1.39                   | 0.42  | 1.41   |
| Ash, %              | 4.32 4.74 5.88 5.87                   | -    | 5.24   |
| Lignin Insoluble Ash, % | 0.21 0.21 0.21 0.21             | -    | -      |
| Calcium (Ca), %     | 0.25 0.31 0.27 0.32                   | 0.46  | 0.05   |
| Phosphorus (P), %   | 0.53 0.59 0.69 0.84                   | 0.19  | 0.95   |
| Magnesium (Mg), %   | 0.23 0.19 0.21 0.27                   | 0.18  | 0.26   |
| Potassium(K), %     | 1.26 1.28 1.28 1.31                   | 1.56  | 0.92   |
| Sulfur (S), %       | 0.27 0.41 0.57 0.74                   | -    | 0.083  |
| Sodium (Na), %      | 0.314 0.376 0.477 0.45               | 0.07  | -      |
| Copper (Cu), ppm    | 26 32 34 31                           | 3    | 8      |
| Manganese (Mn), ppm | 52 57 62 54                           | 67   | -      |
| Zinc (Zn), ppm      | 106 161 165 156                       | 19   | 51     |
| Iron (Fe), ppm      | 143 190 182 172                       | 28   | -      |
| Nitrate (NO3)       | Negative Negative Negative Negative  | -    | -      |

† All values are on a dry matter basis except for moisture and DM. ADF = acid detergent fiber; NDF = neutral detergent fiber; TDN = total digestible nutrient; NEf = net energy for lactation; NEm = net energy for maintenance; NEg = net energy for growth; Mcal/kg = megacalorie per kilogram.

3.2. Dry Matter Intake, Growth Performance, and Efficiency

In this experiment, there were no differences for DMI (p > 0.05) among the experimental groups; however, DMI tended to follow the quadratic function (p = 0.05) (Table 3). The DMI intake was found to be 997, 1075, 1177, and 1052 g/day for goats with the 0%, 10%, 20%, and 30% LF-DDGS supplementation diets, respectively. The total live weight gains observed were 10.74, 12.35, 13.48, and 9.40 kg for 0%, 10%, 20%, and 30% LF-DDGS, which were statistically not different (p > 0.05) among the groups. The average daily gains followed a similar pattern as the total weight gain (111.77, 128.44, 140.30, and 97.89 g/day for the 0%, 10%, 20%, and 30% LF-DDGS included diets, respectively) at p > 0.05. The gain-to-feed ratios were observed to be similar among the experimental groups (p > 0.05) (0.10, 0.11, 0.11, and 0.08 for the goats fed with 0%, 10%, 20%, and 30% LF-DDGS, respectively).
Table 3. Dry matter intake and growth performance of the castrated male goats fed diets with different percentages of low-fat distillers dried grains with solubles (LF-DDGS) for 84 days.

| Parameters                  | Percentage of LF-DDGS in Diets, % | p-Value † |
|-----------------------------|-----------------------------------|-----------|
|                             | 0%  | 10% | 20% | 30% | SEM | Linear | Quadratic |
| DMI, g/day                  | 997 | 1075| 1177| 1052| 19.60| 0.21   | 0.05      |
| Initial BW, kg              | 28.46 | 27.24| 29.97| 27.61| 1.01 | 0.99   | 0.82      |
| Final BW, kg                | 39.21 | 39.58| 43.45| 37.02| 0.94 | 0.79   | 0.16      |
| Total live weight gain, kg  | 10.74 | 12.35| 13.48| 9.40 | 0.60 | 0.66   | 0.07      |
| Average daily gain, g/day   | 111.77 | 128.44| 140.30| 97.89| 6.26 | 0.66   | 0.49      |
| Gain:Feed Ratio             | 0.10 | 0.11| 0.11| 0.08| 0.004| 0.30   | 0.71      |

† Based on the orthogonal contrast for equally spaced treatments (n = 6 animals per experimental group). SEM = standard error of mean.

3.3. Rumen Fermentation and pH

The pH values of the rumen fluid samples were 6.31, 6.32, 6.35, and 6.43 for the 0%, 10%, 20%, and 30% LF-DDGS diets, respectively, and the observed pHs were similar (p > 0.05) among the experimental groups.

The observed concentrations of acetate, propionate, butyrate, and acetate:propionate ratios are presented in Figure 1. The acetate concentrations were 50.0, 49.1, 45.1, and 39.0 mmol/lit for the 0%, 10%, 20%, and 30% LF-DDGS inclusion diets, respectively. The propionate concentrations were 15.3, 14.4, 14.4, and 12.2 mmol/L while the values for the butyrate concentrations were 9.7, 8, 8, and 5 mmol/L, respectively. The acetate:propionate ratios (A:P) of 3.7, 3.6, 3.3, and 3.3 were observed for the 0%, 10%, 20%, and 30% LF-DDGS diets, respectively. The mean concentrations of acetate, propionate, butyrate, and the acetate-to-propionate ratio (A: P ratio) were similar (p > 0.05) among the experimental groups (Figure 1).

Figure 1. Acetate, propionate, and butyrate concentrations and the acetate:propionate ratio of the castrated male goats fed with different levels of low-fat distillers dried grains with solubles (LF-DDGS) for 84 days.
3.4. Blood Metabolites

The value of the different serum metabolites are presented in Table 4. The cholesterol concentrations increased linearly ($p = 0.004$) with an increasing amount of LF-DDGS included in the diet. The cholesterol concentrations were 51.75, 58.00, 63.92, and 67.17 mg/dl for the goats fed with 0%, 10%, 20%, and 30% LF-DDGS, respectively, which were within the normal cholesterol range in goats (80–130 mg/dL) [24]. The blood urea nitrogen (BUN) level tended to increase linearly ($p = 0.07$) with the increasing inclusion of LF-DDGS (14.75, 14.60, 16.75, and 17.17 mg/dL for 0%, 10%, 20%, and 30% LF-DDGS) diets, respectively.

| Serum Chemistry                  | Percentage of LF-DDGS in Diets, % | p-Values † |
|----------------------------------|-----------------------------------|------------|
|                                  | 0       | 10      | 20      | 30      | SEM     | Linear | Quadratic |
| Cholesterol, mg/dL               | 51.75   | 58.00   | 63.92   | 67.17   | 1.49    | 0.004 **| 0.69      |
| Creatine Kinase, U/L             | 221.58  | 275.60  | 287     | 294     | 8.35    | 0.02 *  | 0.27      |
| Alanine Aminotransferase, U/L    | 4.67    | 7.50    | 4.41    | 4.67    | 0.35    | 0.42    | 0.15      |
| Amylase, U/L                     | 78.08   | 43.20   | 29.92   | 39.75   | 8.14    | 0.16    | 0.28      |
| Alkaline Phosphatase, U/L        | 409.50  | 993.80  | 1127.50 | 1018.33 | 213.53  | 0.40    | 0.52      |
| Total Protein, g/dL              | 10.02   | 6.48    | 7.05    | 6.62    | 0.80    | 0.28    | 0.44      |
| Glucose, mg/dL                   | 65.75   | 67.20   | 65.00   | 55.76   | 1.27    | 0.03 *  | 0.10      |
| Phosphorus, mg/dL                | 12.67   | 9.42    | 9.13    | 10.35   | 1.01    | 0.51    | 0.38      |
| Bilirubin, Total, mg/dL          | 0.13    | 0.13    | 0.19    | 0.17    | 0.01    | 0.15    | 0.05      |
| Blood Urea Nitrogen, mg/dL       | 14.75   | 14.60   | 16.75   | 17.17   | 0.46    | 0.07    | 0.80      |
| Creatinine, mg/dL                | 0.64    | 0.61    | 0.58    | 0.63    | 0.01    | 0.57    | 0.24      |
| Carbon Dioxide, mmol/L           | 22.53   | 22.29   | 22.78   | 20.26   | 0.31    | 0.08    | 0.16      |
| Sodium, mmol/L                   | 142.71  | 142.82  | 143.05  | 143.70  | 0.17    | 0.10    | 0.53      |
| Potassium, mmol/L                | 4.75    | 4.87    | 4.99    | 4.99    | 0.04    | 0.07    | 0.56      |
| Chloride, mmol/L                 | 101.65  | 109.31  | 108.88  | 113.25  | 1.79    | 0.09    | 0.71      |
| Calcium, mg/dL                   | 9.65    | 9.48    | 9.78    | 9.07    | 0.08    | 0.10    | 0.17      |
| Albumin, g/dL                    | 2.24    | 2.50    | 2.60    | 2.41    | 0.03    | NS      | NS        |
| Triglycerides, mg/dL             | 22.42   | 22.70   | 24.33   | 26.50   | 0.93    | 0.18    | 0.68      |
| Gamma Glutamyl Transferase, U/L  | 37.58   | 36.00   | 28.42   | 32.67   | 0.94    | 0.04 *  | 0.21      |
| Aspartate Aminotransferase, U/L   | 51.00   | 87.60   | 64.83   | 99.08   | 3.01    | 0.001 **| 0.88      |
| Bilirubin, Direct                | 0.13    | 0.14    | 0.14    | 0.15    | 0.01    | 0.36    | 0.86      |

† Based on the orthogonal contrast for equally spaced treatments (n = 6 animals per experimental group). SEM = standard error of the mean. * Significant; ** highly significant. Serum chemistry analyzed by the IDEXX Catalyst DX system.

The blood glucose concentration decreased linearly ($p = 0.03$) with the increasing inclusion of LF-DDGS in the diet (65.75, 67.20, 65.0, and 55.76 mg/dL for 0%, 10%, 20%, and 30% LF-DDGS), but this was also within the normal range of 50–75 mg/dL (Merck Veterinary Manual). The concentration of creatine kinase (CK) and the aspartate aminotransferase (AST) concentration increased linearly ($p < 0.05$) with an increasing amount of the inclusion of LF-DDGS in the diet, and the concentration of gamma-glutamyl transferase (GGT) decreased linearly ($p < 0.05$) with an increasing amount of LF-DDGS inclusion in the diet. However, all values of CK, AST, and GGT, along with other serum biochemistry profiles (Table 4), were within the normal range as per reference values provided by the College of Veterinary Medicine, Cornell University [25].

3.5. Carcass Characteristics

The dressing percentage, longissimus muscle area (LMA), fat depth (at 12th rib), and carcass shrink percentage (Table 5) were found to not be affected ($p > 0.05$) by the inclusion of different levels of LF-DDGS in the castrated goat diet. Dressing percentages of 38.55%, 40.70%, 40.60%, and 39.86%; LM areas of 13.76, 13.87, 15.52, and 12.47 cm²; and back fat thicknesses of 2.17, 1.92, 1.93, and 1.77 mm were observed for the goats fed with the 0%, 10%, 20%, and 30% LF-DDGS diets, respectively.
Table 5. Carcass characteristics of the castrated male goats fed diets with different percentages of low-fat distillers dried grains with Solubles (LF-DDGS) for 84 days.

| Carcass Trait           | Percentage of LF-DDGS in Diets, % | p-Value †          |
|-------------------------|-----------------------------------|--------------------|
|                         | 0       | 10      | 20      | 30      | SEM   | Linear | Quadratic |
| Final wt., kg           | 39.21   | 39.58   | 43.45   | 37.02   | 0.94  | 0.79   | 0.16      |
| Fasting wt., kg         | 35.98   | 35.45   | 40.45   | 35.08   | 1.05  | 0.88   | 0.09      |
| Hot Carcass wt., kg     | 21.97   | 20.98   | 23.94   | 20.98   | 0.39  | 0.93   | 0.25      |
| Carcass Chilled wt., kg | 14.92   | 14.35   | 16.64   | 14.10   | 0.40  | 0.90   | 0.26      |
| Carcass Shrink Percentage | 32.42   | 31.13   | 30.86   | 33.25   | 0.76  | 0.79   | 0.34      |
| Dressing Percentage     | 38.55   | 40.70   | 40.60   | 39.86   | 0.63  | 0.58   | 0.36      |
| Longissimus Muscle Area, cm² | 13.76   | 13.87   | 15.32   | 12.47   | 0.36  | 0.43   | 0.93      |
| Fat Depth at the 12th Rib, mm | 2.17    | 1.92    | 1.93    | 1.77    | 0.06  | 0.39   | 0.21      |

† Based on the orthogonal contrast for equally spaced treatments (n = 6 animals per experimental group). SEM = standard error of the mean.

4. Discussion

4.1. Feed Composition

The nutrient content of hay varies with the maturity of the plant harvested and the method of harvest, storage, and many other factors. The CP and TDN in the BGH used in this trial were greater than the values provided in the Nutrient Requirement of Dairy Cattle (2001) [26] (5% CP and 52–55% TDN), whereas the NDF and ADF values were less than the values in the same book (73% NDF and 36% ADF) [27]. In another report, Preston et. al. (2016) observed the DM (89%), CP (10%), ADF (32%), NDF (72%), and TDN (53%) [28]. The difference might be due to the growing conditions and harvesting time. The nutrient composition of the ethanol coproducts varied with the raw materials’ factors, such as grain type, grain variety, and grain quality, as well as processing factors, such as grind procedure, fineness, and duration [27,29,30]. However, the nutrient composition of the LF-DDGS used in this trial was similar to the LF-DDGS reported by other authors [17,31].

Even though all of the experimental diets were formulated to be iso-nitrogenous, the greater CP in the diet with 30% LF-DDGS might be because we used standard book values for the other ingredients while calculating the nutrient composition of the grain mixes.

The increase in the ADF and NDF concentrations with the increase in the inclusion of a percentage of LF-DDGS in the grain mixes was expected due to the 9.71% ADF and 25.28% NDF in the LF-DDGS used to formulate the diets. The non-fiber carbohydrate (NFC) and TDN values and the net energy for growth decreased in the grain mixes with the inclusion rate of the LF-DDGS, which were also expected because of the decreased NFC (33.80%) in the LF-DDGS that was used in this trial and the increasing amount of ADF with an increase in the inclusion rate of the LF-DDGS.

The NRC (2007) [32] recommends 5% crude fat for growing goats, and the greater amount of fat in the diet will inhibit rumen function in ruminants [33]. One of the concerns of feeding DDGS is the increased fat content (9–13%). In LF-DDGS, as the fat is reduced due to the fact of oil extraction, the fat content becomes suitable for a ruminant diet. In this experiment too, the fat content of all of the diets remained less than 5%, even though the fat content increased with an increase in the LF-DDGS inclusion (Table 2). Other researchers also noted a similar increase in the fat percentage with increase in the percentage of reduced-fat DDGS (Mjoun et al., 2010; Nelson, Hohertz, DiCostanzo, & Cox, 2014). This might be because of the lower crude fat content in the other ingredients included in the formulated grain mixes used in this experiment.

Another concern with feeding DDGS is the greater concentration of phosphorous and sulfur [34]. However, having increased phosphorus in the LF-DDGS can decrease the cost of animal feeds, because phosphate is a relatively high-cost ingredient. The recommended phosphorconcentration in a goat diet is from 0.14 to 0.25% of the diet (on a DM basis) (NRC 2007) [32], and the sulfur content should not be more than 0.3% of the total diet (on a DM basis) [34]. The general recommendation for the calcium:phosphorous ratio for
livestock is 1:1 to 2:1. But the phosphorous content was greater than the calcium in the grain mixes used in this experiment. The BGH (which was 50% of the total diet in this experiment) contained 0.46% Ca and 0.19% P, which reduced the percentage of P in the total diet. However, there was still a greater P content than Ca in the total diet with 20% and 30% LF-DDGS. Thus, it is recommended to adjust the Ca:P ratio by supplemental Ca while formulating the grain mixes.

In a review by Drewnoski et al. (2014) [35], the authors noted that sulfur-induced polio-encephalomalacia (S-PEM) is a common risk with a DDGS ration in cattle. However, the risk of S-PEM can be reduced by including a minimum of 7–8% NDF (on a DM basis) in the diet with 0.4% sulfur or more [35]. In this study, the sulfur content in the grain mixes were more than the recommended. However, no symptoms of S-PEM or other unusual symptoms were noticed, which could be because of a reduction in the sulfur percentage due to the inclusion of 50% BGH and also due to the presence of more NDF (42.06%) in the BGH.

An additional concern for feeding any byproduct including LF-DDGS is the mycotoxin content. The mycotoxin content in the LF-DDGS used in this experiment was not evaluated, which is recommended in further research.

4.2. Dry Matter Intake, Growth Performance, and Efficiency

There are no published results available on DMI using LF-DDGS in goats. Thus, comparisons were made with other ruminant species and traditional DDGS (high-fat DDGS) in ruminant species, including goats. Therefore, the results presented in the current study should be treated with caution.

Similar to our research findings, Mjoun et al. (2010) [16] found no difference in the DMI in mid-lactating cows when reduced-fat DDGS was included in the diet at 0%, 10%, 20%, and 30% on a DM basis [16]. Nelson et al. (2010) [36] also found no difference for the DMI when reduced-fat DDGS were incorporated at 0%, 15%, 30%, and 45% of the diet. In contrast, Testroet et al. (2018) reported an increased DMI ($p < 0.01$) in lactating Holstein dairy cows when supplied with 20% reduced-fat DDGS than the control diet with no reduced-fat DDGS. Similarly, Ramirez-Ramirez et al. (2016) [37] also reported an increase in DMI ($p < 0.01$) when 30% DDGS or 30% reduced-fat DDGS was supplemented to lactating Holstein cows in comparison to no DDGS supplementation in the diet. In an experiment by Gurung et al. (2009) [13], the DMI of growing Kiko x Spanish male goats supplied with 0%, 10%, 20%, and 30% DDGS were similar ($p = 0.62$). Similarly, in a recent paper by Dahmer et al. (2022) [38], no difference was found for the DMI of Boer goats when supplied with 33% DDGS compared to 0% DDGS. Sorensen et al. (2021) [15] also reported no difference in the DMI when 0%, 33%, 66%, or 100% soybean meal was replaced by DDGS in the finishing rations of Boer cross goats.

In contrast to this research, Dahmer et al. (2022) [38] found a decrease in the average daily gain when 33% DDGS was included in the diet of Boer kids for 21 days compared with 0% DDGS. However, Sorensen et al. (2021) [15] found a linear increase in the average daily gain (0.19, 0.22, 0.22, and 0.28 g/day for 0%, 10%, 20%, and 30% corn DDGS) with an increased DDGS inclusion in Boer cross goats of age 70 days for a trial for 47 days. In contrast with the findings of this research, Sorensen et al. (2021) [15] observed a difference ($p < 0.05$) in the gain-to-feed ratio when the Boer goat kids were fed 0% or 10% DDGS (0.18 and 0.19 for 0% and 10%, respectively) in comparison to kids fed with 20% or 30% DDGS (0.22 and 0.28 for 20% and 30%, respectively).

4.3. Rumen Fermentation and Blood Metabolites

Volatile fatty acids are the major energy source for ruminants including goats. Similar to our findings, Benchaar et al. (2013) [39] found a similar decrease in the acetate concentration with an increasing amount of DDGS (0, 10, 20, and 30% inclusion on a DM basis) fed to dairy cows. A decrease in the concentration of propionic acid was expected because of the decreasing nonfiber carbohydrate (NFC) with an increasing amount of LF-DDGS.
However, Benchaar et al. (2013) [39] reported a linear increase in the propionic and butyric acid with an increased concentration of DDGS in the diets of dairy cows \((p < 0.05)\). The optimal A:P ratio in ruminants is more than 2.2 to 1 [40]. In this trial, the A:P ratio was greater than three in all of the experimental groups.

The feed ingredients should not affect the health of the animals, and the blood biochemistry can reflect the overall health of animals. All blood metabolites in the serum of the goats in all of the experimental groups in this study were within the normal range, even though some of them tended to follow a linear increase or decrease with an increased LF-DDGS concentration in their diet. In agreement with the results of this study, Gurung et al. (2009) [13] reported an increasing concentration of cholesterol at 41.2, 66.2, 76.5, and 83.2 mg/dL when DDGS was fed to the Kiko × Spanish male goats at 0%, 10%, 20%, and 30% inclusion rates, respectively. An increase in the cholesterol concentration could be attributable to the increased fat concentration with the increase in the experimental diets. However, a narrow range of increase in the serum cholesterol concentration in this research in comparison to what was reported by Gurung et al. (2009) [13] might be due to the use of LF-DDGS with less fat (5.75%) in this experiment rather than the higher fat DDGS (11.93%) by Gurung et al. (2009) [13].

Hammond (1983) [41] reviewed that one of the factors for an increase in the serum BUN concentration is the increase in dietary nitrogen intake. The linear increase in the BUN with a narrow range in this experiment might be due to the slight increase in the protein concentration (Table 2) in the experimental diet with an increasing amount of LF-DDGS inclusion. Gurung et al. (2009) [13] reported no difference in the BUN concentration when DDGS was fed to the Kiko × Spanish male goats at 0%, 10%, 20%, and 30% inclusion rates. The increased starch in the diet increased the serum glucose concentration of the ruminants [42]. Thus, the observed decrease in the serum glucose concentration in this experiment might be due to the decrease in the starch in the diet as the LF-DDGS was increasingly replacing corn in the experimental diets.

### 4.4. Carcass Characteristics

The findings of this research regarding carcass traits were in agreement with the findings by Dahmer et al. (2022) [38], where they found no difference in the dressing percentage, LMA, and fat thickness when the Boer goats were fed with either 0% DDGS or 33% DDGS diets for 21 days. Gurung et al. (2009) [13] also reported similar findings in Kiko × Spanish male goats of 4–5 months of age fed with 0%, 10%, 20%, and 30% DDGS diets. Furthermore, in agreement with these research findings, Sorensen et al. (2021) [15] also reported no effect on the carcass traits in Boer cross goats fed with 0%, 10%, 20%, and 30% DDGS levels. However, the dressing percentage of the goats observed (39–41%) in this experiment were less than reported by Dahmer et al. (2022) [38] (47–48%), Gurung et al. (2009) [13] (42–45%), and Sorensen et al. (2020) [15] (49–50%) in male goats. Factors such as age, slaughter weight, diet, castration, sex, genotype, and gut fill influence the goat dressing percentage [43]. The plane of nutrition and gut fill might be reasons for this experiment’s low DP.

The observed LMA was similar to the LMA reported by Sorensen et al. (2020) [15] (11.60, 13.10, 13.30, and 13.50 cm² for the 0, 10, 20, and 30% DDGS amounts, respectively) in Boer cross male goats. However, the observed LMA values were greater than those reported by Gurung et al. (2009) [13] at 9.75, 10.25, 9.50, and 9 cm² in Kiko × Spanish goats fed with 0%, 10%, 20%, and 30% DDGS-containing diets.

In a trial by Dahmer et al. (2022) [38], the back fat thickness was only 1.1 mm for the Boer goats fed 0% DDGS and 1.0 mm for the goats fed 33% DDGS, which is less than the back fat thickness observed in this experiment. This might be because the fat content in the diet provided to the goats by Dahmer et al. (2022) [38] was 2–3%, whereas the fat content in this experiment was 4–5%.
5. Conclusions

The results suggest that at least up to 30% LF-DDGS can be included in a male goat diet, completely replacing soybean meal and partly replacing corn without affecting the production performance and carcass characteristics. At an LF-DDGS concentration greater than 10% of the total diet, the Ca:P ratio should be adjusted by additional Ca supplements. LF-DDGS has the potential to be a sustainable alternative protein source for meat goats as long as it is competitively priced. Further research is also warranted to determine the effect of the inclusion of LF-DDGS higher than 30% as well as its economic inclusion rate.

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References

1. Renewable Fuels Association. Annual Ethanol Production. 2021. Available online: https://ethanolrfa.org/markets-and-statistics/annual-ethanol-production (accessed on 4 October 2022).

2. United States Department of Agriculture (USDA); National Agricultural Statistics Service (NASS). Grain Crushings and Co-Products Production; USDA-NASS: Washington, DC, USA, 2022; ISSN 2470-9913.

3. Cooper, G.; McCaherty, J.; Huschitt, E.; Schweark, R.; Wilson, C. 2021 Ethanol Industry Outlook. Renew. Fuels Assoc. 2021, 1–40.

4. Shurson, G. Dry-Grind Production of Ethanol, Distillers Corn Oil, and Corn Co-Products. In DDGS Handbook 2019, 4th ed.; U.S. Grains Council: Washington, DC, USA, 2019; p. 12.

5. Shurson, J.; Noll, S. Feed and Alternative Uses for DDGS. J. Gender Agric. Food Secur. 2016, 1, 1–22.

6. Schingoethe, D.J. Utilization of DDGS by cattle. In Proceedings of the 27th Western Nutrition Conference, Winnipeg, MB, Canada, 19–20 September 2006; pp. 61–74.

7. Buenavista, E.; Siliveru, K.; Zheng, Y. Utilization of Distiller’s Dried Grains with Solubles: A Review. J. Agric. Food Res. 2021, 5, 100195. [CrossRef]

8. Lumpkins, B.S.; Batal, A.B.; Dale, N.M. Evaluation of Distillers Dried Grains with Solubles as a Feed Ingredient for Broilers. Poult. Sci. 2004, 83, 1891–1896. [CrossRef] [PubMed]

9. Abd El-Hack, M.E.; Mahrose, K.M.; Attia, F.A.M.; Swelum, A.A.; Taha, A.E.; Shewita, R.S.; Hussein, E.S.O.S.; Alowaimer, A.N. Laying Performance, Physical, and Internal Egg Quality Criteria of Hens Fed Distillers Dried Grains with Solubles and Exogenous Enzyme Mixture. Animals 2019, 9, 150. [CrossRef] [PubMed]

10. Damasceno, J.L.; Rocha, C.S.; Eyng, C.; Broch, J.; Savaris, V.D.L.; Wachholz, L.; Tesser, G.L.S.; Avila, A.S.; Pacheco, W.J.; Nunes, R.V. Corn Distillers’ Dried Grains with Solubles to Feed Broiler Chickens from 22 to 42 D of Age. J. Appl. Poult. Res. 2020, 29, 573–583. [CrossRef]

11. Sándor, Z.J.; Révész, N.; Lefler, K.K.; Čolović, R.; Banjac, V.; Kumar, S. Potential of Corn Distiller’s Dried Grains with Solubles (DDGS) in the Diet of European Catfish (Silurus Glanis). Aquac. Rep. 2021, 20, 100653. [CrossRef]

12. Caldas, J.V.; Hilton, K.; Mullienix, G.; Xuemei, D.; England, J.A.; Coon, C.N. Corn Distillers Dried Grains with Solubles: Nutrient Analysis, Metabolizable Energy, and Amino Acid Digestibility in Broilers. J. Appl. Poult. Res. 2020, 29, 1068–1083. [CrossRef]
13. Gurung, N.K.; Solaiman, S.G.; Rankins, D.L.; McElhenney, W.H. Effects of Distillers Dried Grains with Solubles on Feed Intake, Growth Performance, Gain Efficiency and Carcass Quality of Growing Kiko x Spanish Male Goats. *J. Anim. Vet. Adv.* 2009, 8, 2087–2095.

14. Gurung, N.K.; Solaiman, S.G.; Rankins, D.L.; Kendricks, A.L.; Abdelrahim, G.M.; McElhenney, W.H. The Effects of Distillers Dried Grains with Solubles on Apparent Nutrient Digestibility and Passage Kinetics of Boer-Spanish Castrated Male Goats. *J. Appl. Anim. Res.* 2012, 40, 133–139. [CrossRef]

15. Sorensen, R.J.; Stewart, S.S.; Jones, C.K.; Crane, A.R.; Lattimer, J.M. Efficacy of corn dried distillers grains with solubles as a replacement for soybean meal in Boer-cross goat finishing diets. *Small Rumin. Res.* 2021, 106411. [CrossRef]

16. Mjoun, K.; Kalscheur, K.F.; Hippen, A.R.; Schingoethe, D.J.; Little, D.E. Lactation Performance and Amino Acid Utilization of Cows Fed Increasing Amounts of Reduced-Fat Dried Distillers Grains with Solubles. *J. Dairy Sci.* 2010, 93, 288–303. [CrossRef]

17. Jacela, J.Y.; de Rouchey, J.M.; Dritz, S.S.; Goodband, R.D.; Nielssen, J.L.; Sulabo, R.C.; Thaler, R.C.; Brandt, L.; Little, D.E.; et al. Amino Acid Digestibility and Energy Content of Deoiled (Solvent-Extracted) Corn Distillers Dried Grains with Solubles for Swine and Effects on Growth Performance and Carcass Characteristics. *J. Anim. Sci.* 2011, 89, 1817–1829. [CrossRef] [PubMed]

18. AOAC (2007) Official Methods of Analysis. 18th Edition, Association of Official Analytical Chemists, Gaithersburg-References-Scientific Research Publishing. Available online: https://www.scirp.org/doi/10.17336/ReferencePapers.aspx?ReferenceId=175336 (accessed on 17 October 2022).

19. Goering, H.K.; Van, P.J. Forage Fiber Analyses. *U.S. Dep. Agric.* 1975, 379, 387–598.

20. Erwin, E.S.; Marco, G.J.; Emery, E.M. Volatile Fatty Acids Analyses of Blood and Rumen Fluid by Gas Chromatography. *J. Dairy Sci.* 1961, 44, 1768–1771. [CrossRef]

21. Hall, M.B.; Nennich, T.D.; Doane, P.H.; Brink, G.E. Total Volatile Fatty Acid Concentrations Are Unreliable Estimators of Treatment Effects on Ruminal Fermentation in *Vivo*. *J. Dairy Sci.* 2015, 98, 3988–3999. [CrossRef]

22. USDA Institutional Meat Purchased Specifications for Fresh Goat. *U.S. Dep. Agric.* 2001, 11, 31–32.

23. SAS/STAT®9.1 User’s Guide; SAS Institute Inc: Cary, NC, USA, 2004; pp. 1731–1906.

24. Serum Biochemical Analysis Reference Ranges-Special Subjects-Merck Veterinary Manual. Available online: https://www.merckvetmanual.com/special-subjects/reference-guides/serum-biochemical-analysis-reference-ranges?autoredirectid=19885 (accessed on 4 October 2022).

25. Chemistry (Cobas!) Cornell University College of Veterinary Medicine. Available online: https://www.vet.cornell.edu/animal-health-diagnostic-center/laboratories/clinical-pathology/reference-intervals/chemistry (accessed on 10 September 2022).

26. National Research Council. *Nutrient Requirements of Dairy Cattle: Seventh Revised Edition, 2001*; The National Academies Press: Washington, DC, USA, 2001. [CrossRef]

27. Cottle, D. (Ed.) Nutrient Composition of Feeds. In *International Sheep and Wool Handbook*; Nottingham University Press: Nottingham, UK, 2010; Volume 1, pp. 711–716.

28. Preston, R.L. 2016 Feed Composition Table. *Beef Mag.* 2016, 16–34.

29. Spiehs, M.J.; Whitney, M.H.; Shurson, G.C. Nutrient database for distillers dried grains with solubles produced from new ethanol plants in Minnesota and south Dakota. *J. Anim. Sci.* 2020, 80, 2639–2645.

30. Shurson, G. Nutrient Composition and Variability of Reduced-Oil Corn DDGS Sources. In *DDGS Handbook 2019*, 4th ed.; U.S. Grains Council: Washington, DC, USA, 2019; pp. 29–41.

31. Curry, S.M.; Navarro, D.M.D.L.; Almeida, F.N.; Almeida, J.A.S.; Stein, H.H. Amino Acid Digestibility in Low-Fat Distillers Dried Grains with Solubles Fed to Growing Pigs. *J. Anim. Sci. Biotechnol.* 2014, 5, 27. [CrossRef]

32. National Research Council. *Nutrient Requirements of Small Ruminants: Sheep, Goats, Cervids, and New World Camelids*; The National Academies Press: Washington, DC, USA, 2007. [CrossRef]

33. Palmquist, D.L. Regulating Lipid Metabolism to Increase Productive Efficiency. *J. Nutr.* 1994, 124, 1371S. [CrossRef]

34. Jud Heinrichs; Geoff Zanton Opportunities and Challenges of Feeding Distillers Grains. Available online: https://extension.psu.edu/opportunities-and-challenges-of-feeding-distillers-grains (accessed on 30 August 2022).

35. Drewnoski, M.E.; Pogge, D.J.; Hansen, S.L. High-Sulfur in Beef Cattle Diets: A Review. *J. Anim. Sci.* 2014, 92, 3763–3780. [CrossRef]

36. Effects of Feeding Reduced-Fat Modified Distillers Grains with Solubles on Dietary Energy Values, Finishing Cattle Performance and Beef Quality Characteristics—AURI. Available online: https://auri.org/research-reports/effects-of-feeding-reduced-fat-modified-distillers-grains-with-solubles-on-dietary-energy-values-finishing-cattle-performance-and-beef-quality-characteristics/ (accessed on 27 November 2022).

37. Ramirez-Ramirez, H.A.; Castillo Lopez, E.; Jenkins, C.J.R.; Aluthge, N.D.; Anderson, C.; Fernando, S.C.; Harvatine, K.J.; Kononoff, P.J. Reduced-Fat Dried Distillers Grains with Solubles Reduces the Risk for Milk Fat Depression and Supports Milk Production and Ruminal Fermentation in Dairy Cows. *J. Dairy Sci.* 2016, 99, 1912–1928. [CrossRef] [PubMed]

38. Dahmer, P.L.; Mcdonald, F.B.; Chun, C.K.Y.; Zumbaugh, C.A.; Jones, C.K.; Crane, A.R.; Kott, T.; Lattimer, J.M.; Chao, M.D. Evaluating the Impact of Feeding Dried Distillers Grains with Solubles on Boer Goat Growth Stability, Meat Color Stability, and Antioxidant Capacity. *Transl. Anim. Sci.* 2022, 6, 1–9. [CrossRef]
39. Benchaar, C.; Hassanat, F.; Gervais, R.; Chouinard, P.Y.; Julien, C.; Petit, H.V.; Massé, D.I. Effects of Increasing Amounts of Corn Dried Distillers Grains with Solubles in Dairy Cow Diets on Methane Production, Ruminal Fermentation, Digestion, N Balance, and Milk Production. *J. Dairy Sci.* 2013, 96, 2413–2427. [CrossRef] [PubMed]

40. Rumen Acidosis-Dairy Cattle. Available online: http://livestocktrail.illinois.edu/dairynet/paperDisplay.cfm?ContentID=215 (accessed on 10 September 2022).

41. Hammond, A.C. The Use of Blood Urea Nitrogen Concentration as an Indicator of Protein Status in Cattle. *Bov. Pract.* 1983, 18, 114–118.

42. Piccioli-Cappelli, F.; Loor, J.J.; Seal, C.J.; Minuti, A.; Trevisi, E. Effect of Dietary Starch Level and High Rumen-Undegradable Protein on Endocrine-Metabolic Status, Milk Yield, and Milk Composition in Dairy Cows during Early and Late Lactation. *J. Dairy Sci.* 2014, 97, 7788–7803. [CrossRef]

43. Assan, N. Some Factors Influencing Dressing Percentage in Goat Meat Production. *Sci. J. Rev.* 2015, 4, 156–164. [CrossRef]