

Nutritional quality of wet distillers' grains co-ensiled with whole-plant maize and its feeding value for lambs

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ABSTRACT: The high moisture content of wet distillers' grains with solubles (WDGS) has limited its feeding value despite the relatively high nutritive value. The co-ensiling with whole-plant maize, as a complementary feed, was evaluated for growing lambs by formulating diets whose contents were: whole plant maize silage (WPMS) + sunflower oilcake meal (SOM) (control, WPMS + SOM), whole plant maize silage + dried distillers' grains (WPMS + DDGS), and whole-plant maize (WPM) co-ensiled with WDGS (WPM – WDGS). Rumen fermentation parameters and *in situ* degradability of the diets were evaluated using three cannulated Merino wethers in a cross over 3 × 3 Latin square design experiment that lasted 39 days. Concurrently, feed intake and growth performance of South Africa Mutton Merino lambs (29.7 ± 3.6 kg) were evaluated over 45 days. The WPMS + DDGS diet had a lower rate of dry matter degradation ($p < 0.05$) compared to the WPMS + SOM and WPM–WDGS diets. However, the rapidly fermentable fraction, as well as the progressively fermentable fraction of the diet dry matter, was not different ($p > 0.05$). No differences in rumen volatile fatty acid, ammonia nitrogen concentration nor rumen pH of the wethers as a result of diet differences were observed. Lambs consuming the WDGS-based diet had a lower average daily intake and average daily gain ($p < 0.05$) compared to lambs consuming the DDGS and WPM–based diets. However, the feed conversion ratio was not affected by diet differences ($p > 0.05$). In conclusion, co-ensiling WDGS with whole-plant maize provides the opportunity for the long-term storage and utilization of WDGS in lamb feeding.

Keywords: average daily gain, growth performance, silage, rumen fermentation, sheep

Introduction

The production of ethanol as a biofuel from maize results in the generation of distillers' grains plus solubles (DGS) as a by-product (Ahern et al., 2016). Distillers' grains with or without solubles are generally characterized by high protein, fat and neutral detergent fibre (NDF) (Akayeza et al., 1998) which can, therefore, be considered a valuable feed option for ruminants. Furthermore, they contain a higher proportion of rumen undegradable protein (RUP) and have a lower starch content compared to the source grain (Souza et al., 2016) which is particularly important to adequately meeting the nutrient needs of fast-growing or high-producing animals.

However, when DGS is fed at high inclusion levels, the concentration of nitrogen, phosphorus and sulphur intake can exceed animal requirements often resulting in reductions in both intake and reduced liver copper stores (Salim et al., 2014). Despite being an economical and good quality feed, the high moisture content of wet distillers' grains with solubles (WDGS) imposes storage, transport and high perishability constraints on farmers (Anderson et al., 2015; Moyo et al., 2016; Ranathunga et al., 2018). The high moisture content of WDGS easily results in the formation of mold, losing quality after four days under normal handling conditions (Souza et al., 2016; Moyo et al., 2016). Drying WDGS (40–70 % moisture) to produce dried distillers' grains with solubles (DDGS, 10 – 13 % moisture) is costly and the heat processing during drying

also renders DDGS more susceptible to protein damage and poor amino acid availability (Cao et al., 2009).

Blending WDGS with forages creates a complementary nutrient profile by enhancing higher physically effective fiber (Arias et al., 2012). Equally, the ensiling of WDGS provides an opportunity to extend the shelf life (Garcia and Kalscheur, 2006). However, previous studies have shown that the silage quality of WDGS was low due to high moisture content and, thus, co-ensiling with dry feedstuffs was necessary (Buckner et al., 2010; Moyo et al., 2016). Such blends create a diluting effect by reducing moisture while an appropriate balance with other nutrients can render the final feed more suitable to meet the nutrient requirements of animals to be fed (Ranathunga et al., 2018). The study aimed to improve the feeding value of WDGS by enhancing the storage duration and overall utilization of WDGS by lambs. It was hypothesized that co-ensiling WDGS with whole maize plants would improve the feeding value of WDGS for growing lambs. Therefore, the objective of the study was to evaluate the effect of co-ensiling WDGS with whole maize plants with rumen fermentation as well as *in situ* dry matter degradability and growth performance of SA Mutton Merino lambs.

Materials and Methods

This study followed the guidelines stipulated in the South African National Standard 10,386 on the care and

use of animals for scientific purposes and was approved by the Animal Ethics Committee under approval number EC070412-016.

Ensiling procedure

Whole-plant maize (WPM, Pioneer phb 3442 hybrid) was harvested from the experimental farm in Pretoria, South Africa (SA), at the hard dough stage, 10 cm above ground, and chopped to 10 mm with a silage harvester. Wet distillers' grains with solubles (WDGS) and DDGS were supplied by a commercial ethanol plant in Ventersdorp, SA. Weighted portions of chopped WPM were ensiled alone or blended with WDGS (65:35 wt wt⁻¹ as-fed basis) to produce WPM - WDGS. The two silage treatments were ensiled in bulk using plastic bags (0.8 m × 1.05 m), filled and compacted to the same density, sufficiently eliminating air and creating anaerobic conditions. These silo bags were subsequently stored under the same condition in a dark room with the temperature maintained in a range between 22 and 28 °C for 120 days, based on the recommendation from for the previous silage analysis trial (Moyo et al., 2016). At the end of the ensiling period, the silage bags were opened and sampled after the top 5 cm had been discarded. Samples obtained were stored at -20 °C until subsequent analysis. Silage quality parameters such as pH, buffering capacity, water-soluble carbohydrates, and lactic acid were analyzed as previously reported by Moyo et al. (2016). The chemical composition of the maize silage, WPM - WDGS, fresh WDGS and DDGS is shown in Table 1.

Diet formulation

Three diets were formulated to meet the requirements of growing SA Mutton Merino lambs which gained at least 250 g d⁻¹ nourished by either the whole plant maize silage or whole-plant maize-WDGS blend or DDGS. Maize meal, sunflower oil cake meal (SOM) and mineral salt were included to balance the nutrients. The diets were i) whole plant maize silage (WPMS) + sunflower oil cake meal (WPMS + SOM), ii) whole-plant maize silage + dried distillers' grains plus solubles (WPMS + DDGS), iii) whole-plant maize co-ensiled with wet distillers' grains plus solubles (WPM - WDGS). The

ingredient and chemical compositions of the diets are presented in Table 2.

Rumen fermentation and in situ dry matter degradability evaluation

Three rumen-cannulated Merino wethers (bodyweight, 75 kg ± 4.4 kg; age, 3.8 ± 0.4 years) were housed in individual pens. Each sheep was randomly allocated to one of the three experimental diets in a 3 × 3 Latin square design for three 13 d periods with a 10 d adaptation period and 3 d of data collection. Animals were fed once daily at 06h00 while water was freely available. During each period, rumen was sampled at 2 h intervals after feeding over the equivalent of a 24 h period. On day 1, the rumen was sampled at 06h00, 12h00, 18h00 and 00h00, while on day 2, samples were taken at 08h00, 14h00, 20h00 and 02h00. On day 3, sampling was done at 10h00, 16h00, 22h00 and 04h00. The rumen fluid was extracted via the rumen cannula using a suction pump. Representative samples of the rumen fluid were collected at different locations from within the rumen using a suction pump fitted with a 0.02 mm sieve and conducted into 500 mL plastic containers. After using four layers of cheesecloth to strain the rumen fluid, the rumen pH was analysed using a pH meter while samples were separately acidified and frozen for subsequent analysis of ammonia nitrogen and volatile fatty acid (VFA).

At the end of the rumen fermentation study, *in situ* degradability of the diets was evaluated by placing 5 g (Dry matter, DM basis) of each diet inside the rumen of cannulated wethers, using Dacron bags (size, 55 mm × 45 mm; pore size, 50 µm). The quantity of feed was adjusted so that the weight of both wet and dried feeds was equal (on DM basis), measured into the bags and subsequently inserted into the rumen of each cannulated sheep in a cross over 3 × 3 Latin square design. During each cycle, each bag was suspended with nylon strings to a round stainless-steel disc (135 g, 4 cm diameter and 5 mm thick) with ten evenly spaced small holes drilled through the periphery of the disc. The disc was tied to a 30 cm nylon string which was secured at the rumen cannulae. Samples were incubated for different time periods (2, 4, 6, 8, 12, 24, and 48 h), and withdrawn at the same time (sequential addition). A total of 2 bags per time interval, as well as 2 blank bags (to correct for

Table 1 – Chemical composition of distillers' grains and whole plant maize silage.

Parameter, g kg ⁻¹ DM	WDGS	WPM	DDGS	Whole plant maize silage	Sunflower oil cake meal
Dry matter	251	350	909	370	921
Crude protein	334	84.9	348	67.5	419
Neutral detergent fiber	519	533	558	454	347
Ether extract	155	80.9	93	64.1	14.5
Calcium	2.9	4.1	3.6	2.9	5.4
Phosphorus	8.5	2.6	6.8	1.8	11.3

WDGS = wet distillers' grains with solubles; WPM = whole-plant maize; DDGS = dried distillers' grains with solubles.

Table 2 – Raw materials and nutrient composition of diets for Merino lambs.

Raw materials, g kg ⁻¹	¹ Dietary treatments		
	WPMS + SOM	WPMS + DDGS	WPM – WDGS
Whole plant maize silage	754	677	–
Maize meal	41	76	25
WPM – WDGS	–	–	911
DDGS	–	238	–
Sunflower oil cake meal	195	–	55
Limestone (36 %)	5	4	4
Monocalcium phosphate	5	5	5
Chemical composition			
DM, g kg ⁻¹	381	430	337
ME, MJ kg ⁻¹ DM	9.2	11.1	10.3
CP, g kg ⁻¹ DM	154	144	150
NDF, g kg ⁻¹ DM	439	468	466
ADF, g kg ⁻¹ DM	251	264	269
EE, g kg ⁻¹ DM	38.5	38.7	42.0
Ca, g kg ⁻¹ DM	5.76	4.95	5.82
P, g kg ⁻¹ DM	4.33	3.16	3.77

The formulation was based on the NRC (1985) requirements (BW: 30 kg lamb; DM: 1.45 kg; ME: 14.1 MJ; CP: 200 g; Ca: 6.8 g; P: 3.18 g); ¹WPMS + SOM, whole plant maize silage + sunflower oil cake meal; WPMS + DDGS, whole plant maize silage mixed with dried distillers' grains with solubles at feeding (63: 27 wt wt⁻¹ as-fed basis); WPM – WDGS, whole-plant maize co-ensiled with wet distillers' grain with solubles (63: 27 wt wt⁻¹ as-fed basis).

DM sticking to the bags), was inserted into the rumen corresponding to 16 bags per sheep. Bags for 0 h as well as the incubated bags, upon removal from the rumen, were immediately washed with cold water under a running tap and subsequently placed in a washing machine for 10 min (Peyrat et al., 2014). Bag samples were dried in the oven at 60 °C for approximately 48 h and weighed thereafter. Differential weights of blank bags were subtracted from the residual at each incubation time. Dry matter degradation constants were estimated by fitting dry matter degradability values into the Ørskov and McDonald, (1979) nonlinear model:

$$y = a + b(1 - e^{-ct}) \quad (1)$$

where y = disappearance of DM at time t , a the rapidly soluble (washing loss) fraction, b the slowly degradable fraction, and c the rate (% h⁻¹) of degradation of fraction 'b'. These degradation constants were used to estimate effective degradability (ED) using the equation:

$$ED = a + [bc/(k + c)] \quad (2)$$

where k is the passage rate from the rumen, estimated at 2 and 5 % h⁻¹ (Ørskov and McDonald, 1979).

Growth performance evaluation

A total of twenty-four SA Mutton Merino ram lambs weighing 29.7 ± 3.6 kg were used to evaluate the effect of the following diets: i) WPMS + SOM, ii) WPMS +

DDGS and, iii) WPM – WDGS on intake and growth performance. Before the start of the trial, lambs were dosed against internal parasites and vaccinated against pulpy kidney and *Pasteurella*. The lambs were stratified by weight, randomly allocated into three dietary treatments in a completely randomized design, and housed individually in pens and diets were made accessible *ad libitum* while fresh water was always available. Lambs were fed the experimental diets for an initial 10 d adaptation period by a gradual introduction of the experimental diets followed by 45 d of growth performance. Concurrently, lamb body weight was monitored weekly. Animals were fed to approximately 110 % of previous day intake and the daily ration for each animal was weighed and offered in three instalments at 06h00, 13h00, and 21h00 while the refusals and spills from the previous day were collected, weighed and recorded before the next feeding. Samples of each feed offered were collected from each weekly batch, bulked and stored at -20 °C. Equally, feed refusals were sampled weekly per animal, bulked across the trial period and preserved for analysis. Bulked feed and refusals were mixed and sub-sampled for analysis with three feed samples and twenty-four refusal samples analyzed.

Chemical analysis

Samples of the diets (WDGS, DDGS, WPMS) and refusals were analyzed according to the AOAC official method of analysis for DM (ID 934.01), ash (ID 999.11), ether extract (ID 920.39) and N (ID 968.06) adopting the Kjeldahl method (AOAC, 2000) where crude protein is estimated by N × 6.25. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) concentrations were using the method of Van Soest et al. (1991). Both NDF and ADF were analysed using the ANKOM filter bag technique and expressed exclusive of residual ash. Rumen ammonia nitrogen (using the phenol-hypochlorite spectrophotometric method) and VFA (using the gas chromatography method) were analyzed as described by Adejoro et al. (2020). Calcium concentration was measured with an Atomic Absorption Spectrophotometer following the AOAC official method 935.13 while phosphorus concentration was measured using an Auto Analyzer II according to the AOAC official method 965.17. Acid detergent insoluble crude protein (ADICP) and 30 h *in vitro* NDF digestibility were determined as described by Robinson et al. (2004). The ME of diets were predicted based on DM, OM, EE, CP, ADICP, NDF and 30 h *in vitro* NDF digestibility of the feedstuffs using the equation of Robinson et al. (2004).

Statistical analysis

Data on fermentation parameters, degradability and growth performance were expressed as least square means and analyzed using the PROC MIXED procedure in SAS (Statistical Analysis System, version 9.3). The

model statement for the rumen fermentation and degradability trial included:

$$Y_{ijk} = \mu + P_i + A_j + T_k + e_{ijk} \quad (3)$$

where, Y_{ijk} = mean of individual observation, μ , the overall mean, P_i , the effect of period ($i = 1, 2, 3$), A_j , the effect of animal ($j = 1, 2, 3$), T_k , the effect of diets, and e_{ijk} , the residual error. Period, animal, and animal-treatment interaction were random effects while the treatment was a fixed effect. The model statement for the growth performance includes:

$$Y_{ij} = \mu + B_i + T_j + e_{ij}$$

where, Y_{ij} = mean of individual observation, μ , the overall mean, B_i , the block effect, T_j , the effect of treatment and e_{ij} , the residual error. Block effect was a random effect while the treatment/diet effect was a fixed effect. Mean separation was ascertained by Bonferroni's test and significant differences declared at $p < 0.05$.

Results

The DM concentration of final diets ranged from 337 – 430 g kg⁻¹, registering lowest in the WPM – WDGS blend and highest in the WPMS + SOM diet (Table 2). However, the metabolizable energy (ME) concentration of the diets showed that the WPMS + SOM diet had the lowest ME of 9.2 MJ kg⁻¹ DM. WPM – WDGS was intermediate with ME of 10.3 MJ kg⁻¹ and WPMS + DDGS had 11.1 MJ kg⁻¹ DM. However, WPMS + SOM had a slightly higher crude protein (CP) of 154 g kg⁻¹ while WPMS + DDGS and WPM – WDGS had 144 g kg⁻¹ and 150 g kg⁻¹, respectively.

The average daily intake (ADI) of lambs was different across the treatments ($p < 0.05$) with lambs consuming less dry matter per day and per metabolic body weight of WPM-WDGS (Table 3). Final body weight and average daily gain (ADG) were affected by diet differences ($p < 0.05$). Lambs consuming the WDGS-based diet had lower final weight and lower ADG compared to lambs consuming the WPMS + SOM or WPMS + DDGS diets. However, the overall feed

conversion ratio (FCR) showed no differences between dietary treatments ($p > 0.05$).

There were no differences ($p > 0.05$) in the proportion of rapidly degradable fraction and the slowly degradable fraction as shown by the values of 'A' and 'B', respectively, of the *in situ* degradability kinetics (Table 4). However, the rate of degradation ('c') was different across the diets ($p < 0.05$). The degradation rate for WPMS + DDGS was significantly lower than that of WPMS + SOM and WPM – WDGS. At a rumen flow rate of 2 % h⁻¹, there were significant differences ($p < 0.05$) across the diets in terms of effective degradability (ED) with the WPMS + SOM diet having higher ED while the WPM – WDGS diet had the lowest ED. Meanwhile, at a flow rate of 5 % h⁻¹, effective degradability was not affected by differences in diet ($p > 0.05$).

There were wide fluctuations in rumen pH in wethers over time consuming WPMS + SOM and WPM – WDGS compared to wethers consuming WPMS + DDGS (Figure 1). Lower pH was recorded in wethers

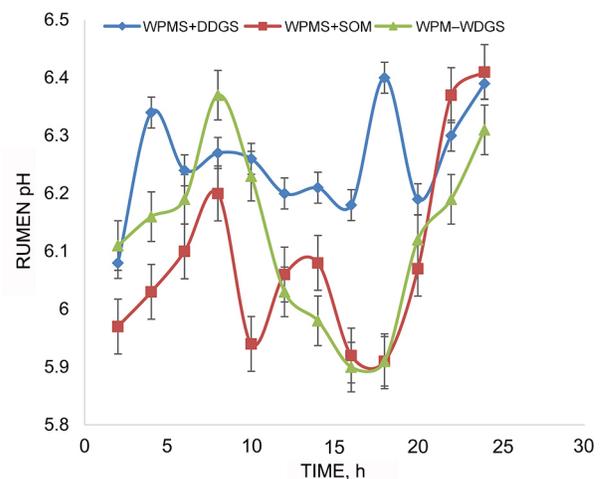


Figure 1 – Post feeding changes in rumen pH of Merino wethers as influenced by (a) whole plant maize silage + sunflower oilcake meal diet (WPMS + SOM); (b) whole plant maize silage + dried distillers' grains plus solubles diet (WPMS + DDGS), and (c) whole-plant maize co-ensiled with wet distillers' grains with solubles diet (WPM – WDGS).

Table 3 – Effect of feeding dried or wet distillers' grains with whole plant maize silage on intake and growth performance of Merino lambs.

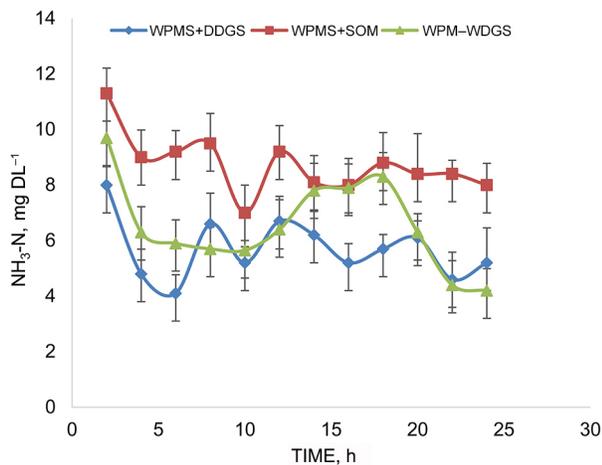
Parameter	¹ Dietary treatments			² SEM
	WPMS + SOM	WPMS + DDGS	WPM – WDGS	
Average daily intake (ADI), g d ⁻¹	1290 ^a	1280 ^a	910 ^b	45.0
ADI, g kg ⁻¹ BW ^{0.75}	99.0 ^a	95.7 ^a	73.1 ^b	0.16
Initial bodyweight (kg)	32.4	31.8	31.0	0.69
Final bodyweight (kg)	41.8 ^a	42.2 ^a	39.9 ^b	1.31
Average daily gain, g d ⁻¹	209 ^b	231 ^a	198 ^b	13.8
Feed conversion ratio	6.17	5.54	4.60	0.63

¹WPMS + SOM, whole plant maize silage + sunflower oilcake meal; WPMS + DDGS, whole plant maize silage + distillers' dried grains with solubles DGS (63: 27 wt wt⁻¹ as-fed basis) based diet; WPM-WDGS, whole-plant maize co-ensiled with wet distillers' grain with solubles (63: 27 wt wt⁻¹ as-fed basis) based diet; ²SEM, Standard error of the mean. ^{abc}Means with different superscripts across a row are significantly different ($p < 0.05$).

Table 4 – Ruminal dry matter degradation kinetics of diets based on wet or dried distillers' grains with solubles.

² Parameter	¹ Dietary treatments			³ SEM
	WPMS + SOM	WPMS + DDGS	WPM – WDGS	
a	287	278	295	0.76
b	475	486	443	0.71
c	0.055 ^a	0.043 ^b	0.057 ^a	0.01
ED ₍₁₎	635 ^a	608 ^c	623 ^b	0.08
ED ₍₂₎	535	501	531	0.22

¹WPMS + SOM, whole plant maize silage + sunflower oil cake-based diet, WPMS + DDGS, whole plant maize silage + distillers' dried grains with solubles-based diet, WPM – WDGS, whole-plant maize co-ensiled with wet distillers' grains-based diet; ²a, b and c, based on the equation $y = a + b(1 - e^{-ct})$, y = degraded DM at time t (h); 'a', rapidly degradable fraction; 'b', slowly degradable fraction, and 'c', rate of degradation of fraction b. ED, the effective degradability based on equation $ED = a + (bc/(c + k))$, where k is outflow rate. ED₍₁₎ when k = 2 % h⁻¹, and ED₍₂₎ when k = 5 % h⁻¹; ³SEM = Standard error of the mean; ^{a,b,c}Means across a row with different superscripts differ significantly ($p < 0.05$).

**Figure 2** – Post feeding changes in rumen NH₃-N of Merino wethers as influenced by (a) whole plant maize silage + sunflower oilcake meal based diet (WPMS + SOM), (b) whole plant maize silage + dried distillers' grains with solubles based diet (WPMS + DDGS), and (c) whole-plant maize co-ensiled with wet distillers' grains with solubles based diet (WPM – WDGS).

consuming WPMS + SOM and WPM – WDGS at 18 h after feeding. Wethers consuming WPMS + DDGS had slightly higher rumen pH throughout the time periods. Wethers consuming the WPMS + SOM based diet produced higher ammonia concentrations over time compared to wethers consuming the WPMS + DDGS and WPM – WDGS diets (Figure 2). Ammonia concentration was highest at 2 h post-feeding and decreased thereafter across the diets. The average rumen pH and ammonia nitrogen concentration, as well as total VFA (TVFA) concentration, were no different across the different diets (Table 5). The molar proportions of VFA showed that acetate, propionate and valerate concentration were not affected by dietary treatments. However, butyrate concentration was varied between diets ($p < 0.05$) with animals consuming the WPMS + DDGS diet having a higher butyrate concentration compared to the WPMS + SOM and WPM – WDGS based diets. Branched-chain VFA (Isobutyrate + Isovalerate) concentration, as well as acetate: propionate ratio showed no differences between treatments ($p > 0.05$).

Discussion

Feed DM is a very important characteristic as it may affect voluntary feed intake and the general performance of animals (Moyo et al., 2016). According to Dewhurst (2013), maximum DM intake of maize silage occurred at a DM concentration of approximately 500 g kg⁻¹, with a DM concentration below 250 g kg⁻¹ resulting in significantly lower feed intake. In this study, the DDGS based diet had the highest DM concentration (430 g kg⁻¹), followed by WPMS + SOM diet (381 g kg⁻¹) while the WPM – WDGS diet had the lowest DM concentration (337 g kg⁻¹). The dilution effect of whole plant maize silage and other ingredients resulted in WPM – WDGS having a higher DM compared to the fresh WDGS which had a DM of 251 g kg⁻¹. The CP and NDF values reported for WPM – WDGS in this study are slightly lower, compared to the 165 g kg⁻¹ and 531 g kg⁻¹,

Table 5 – Ruminal fermentation characteristics of Merino wethers consuming wet or dried distillers' grains with whole plant maize silage.

Parameter	¹ Treatments			³ SEM
	WPMS + SOM	WPMS + DDGS	WPM – WDGS	
pH	6.1	6.3	6.0	0.10
NH ₃ -N (mg 100 mL ⁻¹)	6.24	4.10	4.72	2.63
Total VFA (mmol L ⁻¹)	81.9	71.7	71.3	4.43
VFA molar proportion (mol 100 mol ⁻¹)				
Acetate	68.5	66.1	70.5	1.03
Propionate	20.4	20.4	18.7	0.02
Butyrate	8.95 ^b	11.2 ^a	8.18 ^b	0.13
Valerate	0.89	0.96	1.03	0.18
² Branched-chain VFA	1.20	1.44	1.56	0.28
Acetate: propionate ratio	3.35	3.25	3.77	0.25

¹Diets were based on the NRC (2000) requirements on a DM basis. WPMS + SOM, whole plant maize silage + sunflower meal; WPMS + DDGS, whole plant maize silage + distillers' dried grains with solubles (63: 27 wt wt⁻¹ as-fed basis) based diet; WPM – WDGS, whole-plant maize co-ensiled with wet distillers' grain with solubles (63: 27 wt wt⁻¹ as-fed basis) –based diet; ²Isobutyrate + Isovalerate; ³SEM = Standard error of means; ^{a,b,c}Means with different superscripts across a row are significantly different ($p < 0.05$).

respectively, reported by Anderson et al. (2015). The DM differences between the treatments are proportional to the dry matter of added mixtures as seen by higher DM in the DDGS diet compared to the WDGS diet. The higher NDF concentration in both diets containing distillers' grains may be attributable to the high concentration of readily digestible NDF in distillers' grain which contain a high NDF (440 g kg⁻¹) and low lignin concentration (42 g kg⁻¹) allowing for the NDF to be reasonably digestible (Vander Pol et al., 2009).

The high moisture content and possible low pH feedstuffs may result in significantly lower ADI in animals consuming WDGS (Anderson et al., 2006). Although all diets in the present study had a DM concentration below 50 %, ADI was significantly lower in the WDGS diet compared to other diets, which may be due to the proportion of fermented feeds in the overall ration as noted by Kuoppala et al., (2009). Anderson et al. (2006), observed that ADI tended to be lower in dairy cows consuming wet or dried DDS compared to the control diet. Larson et al. (1993) reported a decrease in DM intake in growing lambs with a WDGS inclusion level of 40 % with a diet DM of 347 g kg⁻¹. The ADI per unit metabolic body weight (g kg⁻¹ W^{0.75}) for lambs fed the WDGS diet followed this similar trend and was lower compared to lambs consuming WPMS + DDGS or WPMS + SOM diets (Table 3). This may be attributable to the lower diet DM of 337 g kg⁻¹ which fell below the 500 g kg⁻¹ suggested by Dewhurst et al. (2013). Other factors that could affect silage intake include sulphur concentration, the rate of fermentation and particle breakdown as well as clearance from the rumen (Dewhurst, 2013). Generally, NDF may be negatively correlated with DM intake. However, in this study, the slight differences in diet NDF did not seem to have any effect on ADI as shown by the intake of animals consuming the DDGS and WPMS + SOM diets.

In the current study, lambs consuming WPM - WDGS had significantly lower ADG but the overall efficiency of feed utilization was no different from that of the animals consuming WPMS + SOM and WPMS + DDGS as shown by the FCR. The complementary effect of diet components was seen to play a significant role in improving WDGS's feeding values (Souza et al., 2016) such as an increase in DM and overall nutrient composition. Comparing wet or dried DGS as a supplement in growing steers consuming alfalfa hay plus sorghum silage, Ahern et al. (2016) found that there were no differences in the form in which DGS was supplemented in terms of growth performance. The caloric density of the DGS may also play a significant role in influencing the ADG of animals (McKeown et al., 2010) and this may be related to the higher ME of the DDGS (11.1 MJ kg⁻¹) and WDGS (10.3 MJ kg⁻¹) diets, compared to the whole plant maize silage diet (9.2 MJ kg⁻¹). Ponce et al. (2016) observed that increasing the levels of WDGS did not affect beef cattle performance in terms of ADG or FCR, in either moderate or high roughage diet scenarios. Studies with sheep showed that the inclusion of DDGS up to 15 % of diet

either also had no effect on ADG nor FCR (McEachern et al., 2009; Obeidat, 2018), and did not improve ADG (Curzaynz-Leyva et al., 2019). It has been reported that DGS has higher NDF and ADF digestibilities compared to traditional roughage sources and this may have ensured efficient utilization of nutrients in lambs (Nuez Ortin and Yu, 2009). The complementary effect of co-ensiling WPM with WDGS or a mixture of MS and DDGS may have ensured that diet differences were minimal and did not influence overall feed utilization. The co-ensiling of WPM with WDGS may also have prevented the loss of soluble nutrients usually lost through the formation of effluents when WDGS is ensiled alone (Alves et al., 2011). This study validates the previous study of Gunn et al. (2013) who noted that the preservation characteristics of WDGS can be enhanced by co-ensiling with marginal-quality feeds with higher DM content.

The degradation parameters reported in Table 4 showed that fractions 'a' and 'b' were similar across the diets. Cao et al. (2009) had observed that dried DGS was lower in fraction "a" and higher in fraction "b" compared to the wet DGS due to the process of drying DGS. Nevertheless, the source grain, distillation or subsequent drying processes have been noted as being capable of influencing the degradability parameters of DGS (Alshdaifat and Obeidat, 2019). Higher acid detergent insoluble nitrogen in DDGS is associated with heat damage occurring during the drying process resulting in lower degradability (Ham et al., 1994; Curzaynz-Leyva et al., 2019). The DDGS diet had a lower rate of degradation 'C' fraction compared to the WPM - WDGS diet in this study. However, Cao et al. (2009) observed a similar rate of degradation between wet and dried DGS. In this study, the effective degradability of the DDGS diet was lower than that of the WDGS and MS diets when the rumen flow rate was 2 % h⁻¹, but no differences were observed when the flow rate was 5 % h⁻¹.

The diets fluctuated only slightly in pH across the sampling time intervals, from 5.9 - 6.4, with MS and WDGS-based diets producing the lowest pH at approximately 15 - 18 h post-feeding. According to Erfle et al. (1982), ruminal pH could vary between 5 and 7, depending on the type of diet consumed and time of sampling. The rise in pH after 20 h post-feeding in all diets indicated a decline in VFA production due to reduced fermentable organic matter as had been similarly observed by Ramirez et al. (2012). However, overall rumen pH of the sheep fed the three experimental diets did not differ significantly. Corrigan et al. (2008) indicated that cattle fed 40 % WDGS (DM basis) in diets which consisted of dry rolled maize with alfalfa hay, had a lower ruminal pH than the diet without WDGS. Contrary to these reports, in the study by Arias et al. (2012) no difference in pH was observed in beef steers consuming co-ensiled whole plant maize silage and WDGS at 27 % (DM basis), compared to steers consuming whole plant maize silage and soybean meal.

The ruminal pH values are indicative that the silages in this study did not induce any form of acidosis. It was observed that the low starch and high NDF in DGS reduced the risk of pH decline (Whitney et al., 2014).

Although the average ammonia nitrogen concentration did not differ between the three diets, $\text{NH}_3\text{-N}$ concentration changes over a 24 h period showed wide fluctuations with values varying from 4.2 to 10.3 mg 100 mL⁻¹. At 2 h post-feeding, all diets had a peak concentration of $\text{NH}_3\text{-N}$, but declined rapidly thereafter, a finding similar to that reported by May et al. (2007). Sheep fed the WPMS + SOM diet had a slightly higher ruminal $\text{NH}_3\text{-N}$ concentration compared to those offered the DDGS- and WDGS diets although the difference was not obvious at 22 h post-feeding. The higher ammonia concentration in the WPMS + SOM-based diet could probably be due to the slightly higher CP content or the inclusion of SOM, a feed with higher rumen CP degradability compared to DGS (Chrenková et al., 2014). The rate and extent of dry matter and crude protein degradability are positively correlated with an increasing level of rumen $\text{NH}_3\text{-N}$ from 10 to 24 mg 100 mL⁻¹ (Can et al., 2011; Adejoro et al., 2019). Lower ammonia nitrogen in the WPMS + DDGS and WPM - WDGS diets may also be indicative of improved bacterial utilization of ammonia nitrogen, resulting in increased synthesis of microbial crude protein (Bitencourt et al., 2011). Ruminal microbial protein represents a significant proportion of absorbable protein in ruminants.

The TVFA results reported in this study (Table 5) are consistent with the results reported by Ham et al. (1994) where TVFA production did not differ between both growing or finishing cattle consuming either a 40 % DDGS or a 40 % WDGS (DM basis) based ration. However, in a study by May et al. (2007), cattle fed DDGS with whole plant maize silage had lower TVFA compared to the control of animals consuming whole plant maize silage mixed with steam-flaked maize. The TVFA concentration from the current study was not affected by feeding DGS in either the dry or wet form. This observation agrees with the report of Schingoethe et al. (2009) where the form in which DGS is fed did not affect animal performance in the majority of studies reviewed. It has been previously noted that the NDF of DGS is highly digestible (Ponce et al., 2016) and this may have sustained TVFA production at levels comparable with the lambs consuming the WPMS + SOM diet. Previous studies have noted that total VFA is not usually affected by DGS supplementation when diet CP and digestible NDF are sufficient to sustain rumen fermentation (Vander Pol et al., 2009; Arias et al., 2012). Similar to the current study, Arias et al. (2012) did not observe any differences in acetate, propionate or A/P ratio between animals consuming wet or dried DGS. Equally, Ramirez et al. (2012) did not observe any difference in either the A/P ratio or the isovalerate concentration with 30 % DDGS inclusion in a dairy ration but only a slight shift from acetate to the propionate proportion.

Conclusion

Feeding wet distillers' grains with solubles co-ensiled with whole-plant maize resulted in lower daily intake and lower daily gain in lambs compared to feeding the dried form. However, the feed conversion efficiency was not affected by feeding wet or dried DGS-based diet. Furthermore, the extent of *in situ* rumen degradability of diets, as well as rumen ammonia and pH, were not significantly different from animal to animal.

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Authors' Contributions

Conceptualization: van Niekerk, W.A.; Hassen, A. **Data acquisition:** Moyo, R. **Data analysis:** Coertze, R.; Moyo, R.; Hassen, A.; Adejoro, F.A. **Design of methodology:** van Niekerk, W.A.; Hassen, A.; Moyo, R. **Writing and editing:** Moyo, R.; Adejoro, F.A.; Hassen, A.; van Niekerk, W.A.; du Toit, C.J.L.

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