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The effects of dietary acid detergent fibre content on the performance of finishing lambs

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Abstract

This study investigated the effects of incremental increases in acid detergent fibre (ADF) content on the nutrient digestibility and performance of South African Mutton Merino wether lambs fed low-fibre finishing diets. Four dietary treatments were formulated with similar nutritional compositions, but with ADF concentrations of 46.8, 59.3, 63.8, and 79.9 g/kg dry matter. The digestibility study was conducted over seven days, while the production study was conducted over 67 days, after which the lambs were slaughtered. Significant differences between treatment means were declared at a 5% probability level. A high ADF concentration (79.9 g/kg) increased the finishing diet's neutral detergent fibre and ADF digestibility. None of the other nutrients or dry matter digestibility values were affected by the change in ADF concentration. However, a low ADF concentration (46.8 g/kg) resulted in a significantly lower (more efficient) lamb feed conversion ratio, and less metabolisable energy was used for live weight gain. Carcass characteristics were unaffected by the dietary treatments. In conclusion, lamb performance was positively affected by a low ADF content in low-fibre finishing diets with a similar neutral detergent fibre content. More research is required to evaluate the effects of different ADF concentrations in high-fibre diets on nutrient digestibility and the performance of wether lambs.

Keywords: carcass, digestibility, growth, soybean hulls, wheat bran

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Introduction

Although natural pasture is the main feed source for the sheep industry worldwide, the finishing of lambs in feedlot systems is an increasingly common practice. Sheep feedlots in South Africa have become a lucrative strategy to add value to lambs for slaughter (van der Merwe *et al.*, 2020). For efficient production, feedlot research has focused on reducing the forage levels in finishing diets, and, consequently, the energy-for-gain costs, as high-grain diets result in more efficient growth (Fimbres *et al.*, 2002). Metabolic disorders can be avoided by replacing part of the forage fibre in high-concentrate rations (rations with a forage:concentrate ratio of 30:70) with non-forage fibre sources such as wheat bran (Milis & Liamadis, 2008). Roughages are less digestible and contain less available energy than concentrates (grains), and are likely to have a more variable nutrient content (Mertens, 2002). It is also possible to feed low (15%) neutral detergent fibre (NDF) diets to finishing lambs without affecting their

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health or production negatively (Gallo *et al.*, 2019). There are thus multiple reasons to reduce the fibre content of lamb finishing diets to a minimum.

Fibre quality in animal nutrition is well defined in the literature. Digestibility, consumption, and the ability to provide nutrients are important characteristics of fibre quality (Cheeke, 2005). No single measure of forage quality can fully represent this concept (Gomes *et al.*, 2011), although plant maturity and lignification are thought to influence fibre quality the most (NRC, 2007). Much research has focused on determining the fibre content that will meet dietary needs and maximise production performance in animals. According to Van Soest (1994), the evaluation of any laboratory measurement by statistical correlation has limitations, and this is especially the case for dietary fibre. Oba & Allen (1999) stated that the NDF digestibility of roughage is an important parameter for forage quality because of the varied degradability of fibre in the rumen, and NDF digestibility thus ultimately influences animal performance. However, Scholtz *et al.* (2009) found that the acid detergent fibre (ADF) content of lucerne (*Medicago sativa*) hay had a major influence on milk yield production potential in dairy cows fed mixed rations, suggesting that fibre quality is also closely related to the ADF content, as well as to the lignin and ash content. Blaxter *et al.* (1961) noted that the quality of hay sources was related to their apparent digestibility and energy content, and as forage digestibility in ruminant animals is influenced by the lignification of the forage (Jalali *et al.*, 2012), this forms an integral part in determining forage quality. The digestive consequences of dietary fibre are therefore determined primarily by the degradability of the cell wall components, in relation to their physico-chemical structure (Gidenne & Bellier, 2000).

Data linking the quality of a fibre source and related effects with small ruminant performance are still required. Recently, Macdonald *et al.* (2023) reported that fibre sourced from high-quality lucerne hay and soybean hulls, as well as low-quality maize stover and *Eragrostis tef*, affected lamb performance, with quality correlated with overall digestibility. The main roughage quality parameters referred to in the literature are forage maturity (Gerson *et al.*, 1986), type of forage/fibre source (French *et al.*, 2000; Macdonald *et al.*, 2023), physically effective NDF (Costa *et al.*, 2021), and digestible fibre content (Papadomichelakis *et al.*, 2010). Reducing the fibre content of finishing lamb diets to a minimum (15% NDF) seems to be acceptable, with no detrimental effects on performance or carcass quality (Costa *et al.*, 2021). Therefore, this study determined the effects of increasing the dietary ADF concentrations in standard low-fibre finishing diets containing similar NDF concentrations on the performance and carcass quality of South African Mutton Merino (SAMM) lambs (*Ovis aries*).

Materials and methods

Both the production and digestibility studies were conducted at the Paradys experimental farm of the University of the Free State, Bloemfontein, South Africa. All procedures conducted during this study were approved by the Interfaculty Animal Ethics Committee for Animal Experimentation at the University of the Free State (Animal Experiment No. UFS-AED2016/0038).

Experimental animals, trial design, and housing

The production study included 60 SAMM wether lambs. The lambs had an initial average live weight of 27.4 ± 3.2 kg (mean ± standard deviation), and were stratified and blocked according to weight and randomly allocated to the four dietary treatments. This resulted in a randomised trial design with n = 15 lambs per treatment (one lamb per replicate). For the digestibility study, 32 lambs with an average initial live weight of 42.5 ± 4.1 kg were randomly allocated to the same four dietary treatments (n = 8 lambs per treatment, one lamb per replicate), using the same trial design.

All the lambs underwent a standard health and vaccination programme prior to the study, as commonly practiced in the commercial feedlot sector in South Africa. The lambs were injected with an antiparasitic remedy, dosed for tapeworm, and inoculated against pulpy kidney (enterotoxaemia), malignant oedema, black quarter, tetanus, and pasteurellosis (pneumonic and septicaemic pasteurellosis).

All the lambs were housed individually in 1.404 m^2 pens on elevated wooden slatted floors within a naturally ventilated building. The building was properly washed and disinfected before the start of the study and each pen was cleaned twice a week.

Experimental diets and trial procedures

Four experimental diets were formulated to contain incrementally increasing ADF concentrations but similar nutritional compositions (Table 1). Focus was placed on keeping the NDF content as low as possible and similar between the treatments; however, an adequate NDF content to maintain rumen health was ensured. Smith (2008) indicated that the inclusion of 150–200 g NDF/kg dry matter (DM), or 130–150 g of physically effective NDF/kg DM of lucerne, milled through a 12.5 mm screen, satisfied the NDF requirements of lambs fed finishing diets. Gallo *et al.* (2019) similarly noted that 15% NDF in lamb finishing diets was acceptable.

Table 1 The physical and chemical compositions of four experimental diets with incremental increases in the acid detergent fibre (ADF) content

	Treatment diets			
	CONTROL	**ADF1**	**ADF2**	**ADF3**
Physical composition (g/kg as is):				
Maize meal	590.5	590.5	590.5	590.5
Molasses syrup	18.9	45.7	72.6	99.4
Soybean hulls	-	58.0	116.1	174.1
Wheat bran	269.9	180.0	90.0	-
Soybean meal	60.9	60.9	60.9	60.9
Urea	0.7	3.3	6.0	8.6
Soybean oil	26.6	25.0	23.3	21.6
Wheat germ oil	-	3.5	7.1	10.6
Limestone	15.0	11.5	8.0	4.5
Monocalcium phosphate	-	4.1	8.2	12.3
Ammonium chloride	10	10	10	10
Salt	5	5	5	5
Premix	2.5	2.5	2.5	2.5
Total	1000	1000	1000	1000
Chemical composition (g/kg dry matter):				
Dry matter	887.4	886.9	882.6	877.5
Organic matter	948.9	949.1	939.8	942.5
Crude protein	172.5	163.5	179.6	171.7
Non-structural carbohydrate	566.8	548.5	552.2	555.9
Neutral detergent fibre	158.3	170.2	143.5	150.0
Acid detergent fibre	46.8	59.3	63.8	79.9
Ether extract	55.9	63.6	63.4	63.0
Ash	51.1	50.9	60.2	57.5
Calcium	8.8	6.5	8.9	8.1
Phosphorus	4.4	5.5	5.8	6.9

Soybean hulls and wheat bran were the two by-product feed sources that were used to provide the incremental increases in the dietary ADF content. Chen *et al.* (2014) described wheat bran as a cereal fibre source and soybean hulls as a legume fibre source. These products are also referred to as non-forage fibre sources, and have the nutritional characteristics of both roughages and concentrates, containing substantial amounts of soluble fibre, protein, and energy (Guo *et al.*, 2021). Wheat bran (low ADF) contains, on average, 460 g NDF/kg DM and 130 g ADF/kg DM, and soybean hulls (high ADF) contain, on average, 620 g NDF/kg DM and 460 g ADF/kg DM (NRC, 2007). As the soybean hull content was increased, the wheat bran content was decreased, resulting in incremental increases in the ADF content of the diets. The treatment diets were therefore described according to their ADF concentrations as the control (CON: 46.8 g ADF/kg DM), ADF1 (59.3 g ADF/kg DM), ADF2 (63.8 g ADF/kg DM), and ADF3 (79.9 g ADF/kg DM) treatments. The diets were formulated following recommendations to avoid urinary calculi, and 1% ammonium chloride was thus included (Soto-Navarro *et al.*, 2003).

The treatment diets were fed to the lambs in a mash form, as processed. No feed additives or rumen modifiers that may have affected the rumen environment were included in the diets. Fresh, clean water was available *ad libitum* to all the lambs.

The production study was conducted over 67 days, and at the onset (day 0), the lambs underwent a standard adaptation period. Lucerne hay was provided *ad libitum* and the amount of each treatment diet provided was increased by 100 g/lamb/day for 10 days. The lambs were fed twice daily, at 08:00 and 16:00, and feed intake was recorded on a weekly basis. Each lamb's average daily gain (ADG) was calculated by dividing the live weight gained by the 67 days of the trial. The feed conversion ratio (FCR) for each lamb was calculated by dividing the DM intake by its respective ADG.

The digestibility study was conducted over a seven-day period, after diet adaptation, and faecal bags were used for faecal collection. The lambs were offered the same experimental diets as in the production study. A sequential method of feed allocation was followed, by providing each animal with a 15% refusal level to avoid variation in the voluntary feed intake and using a preceding three-day moving average for feed intake. The lambs were treated the same as during the production study and fed twice daily (08:00 and 16:00). Feed refusals were collected every morning, just before the 08:00 feeding, and the faeces voided were collected twice daily, before feeding at 08:00 and 16:00.

Chemical analysis

All samples were analysed for DM according to the Association of Official Analytical Chemists (AOAC) method 934.01 for chemical procedures (AOAC, 1990). The DM content of the feed was determined in the physical form in which the feed was presented to the lambs. The crude protein (CP) content was calculated as the nitrogen content × 6.25 and was determined according to AOAC method 990.03. The ash (AOAC 942.05), organic matter (OM), total ADF (AOAC 973.18), and total lipid/ether extract (EE, AOC 920.39) content were also analysed according to the methods described by the AOAC (1990). The non-structural carbohydrate (NSC) content and NDF (Procedure A) analytical fraction were determined according to the methods of Van Soest *et al.* (1991). The NDF content was analysed using an ANCOM$^{200/220}$ Fibre Analyser (ANCOM Technology Corp., Fairport, NY, USA). The gross energy content was determined using a Leco® AC500 Isoperibol Calorimeter (Leco Corp., St. Joseph, MI), following ASTM (ASTM, 2009) standard D5865 (Cantrell *et al.*, 2010). The digestible energy (DE) content was calculated as the total MJ of energy excreted in the faeces minus the total MJ of energy consumed in the feed, and the metabolisable energy (ME) content was calculated from the DE values by multiplying the DE by a factor of 0.81 to compensate for energy losses in urine and methane gas (McDonald *et al.*, 2011). Energy losses from urine and combustible gases are highly predictable, and therefore DE and ME values are highly correlated (NRC, 2007).

Carcass evaluation

At the end of the production study, all the lambs were slaughtered at a commercial abattoir. Cold carcass weights were recorded after 24 hours of refrigeration at 2 °C, according to the methods described by Fisher & De Boer (1994), and the cold carcass weights were used to determine the dressing percentages. The external length, shoulder circumference, and buttock circumference of each carcass were also recorded.

Meat evaluation was performed on the left side of each carcass. All carcasses were split between the 12th and 13th ribs (thoracic vertebra), and the fat depth was measured 45 and 110 mm from the mid dorsal line using a calliper (Electronic digital calliper; Omni-Tech) (Carson *et al.*, 1999). The area of the *Musculus longissimus lumborum* was traced directly onto transparent film between the 12th and 13th ribs (Edwards *et al.*, 1989), the traced outline was scanned with a scale bar, and the eye muscle area was measured using a video image analysis system (Soft Imaging System: analysis® 3.0). The video image analysis system was calibrated using the scale bar.

Statistical analysis

Data were analysed as a completely randomised design using the general linear model procedure of the Statistical Analysis System (SAS) program (SAS, 1999). Means were compared using the LSMEANS/DIFF function, with treatments as the fixed effects. For post hoc analysis, Tukey's honest significant difference test was used to identify significant differences between treatment means, and significance was declared at a 5% probability level.

The model used for analysis was:

$$Y_{ij} = \mu + t_i + \varepsilon_{ij}$$

where: Y_{ij} is the individual observation (dependent variable) for the ith treatment (independent variable) and the jth random error, μ is the general effect, t_i is the effect of the ith treatment, and ε_{ij} is the random variation or experimental error. The treatment effect (dietary ADF content) during this study was defined as i_1 = CON (46.8 g/kg), i_2 = ADF1 (59.3 g/kg), i_3 = ADF2 (63.8 g/kg), and i_4 = ADF3 (79.9 g/kg), presented on a DM basis.

Results and discussion

Nutrient digestibility

The effects of increasing the ADF content of low-fibre finishing diets fed to SAMM wether lambs are presented in Table 2.

Table 2 The effects of increasing the acid detergent fibre content of South African Mutton Merino wether lamb finishing diets on apparent nutrient digestibility and the metabolisable energy content

Parameters	Treatment diets (mean ± standard deviation)[1]					
	CON	ADF1	ADF2	ADF3	*P*-value	CV (%)
DMI (g/sheep/day)	1301 ± 186	1337 ± 401	1280 ± 306	1280 ± 306	0.9801	23.78
Digestibility coefficients						
Dry matter	0.82 ± 0.03	0.81 ± 0.05	0.81 ± 0.03	0.84 ± 0.03	0.5512	4.14
Organic matter	0.83 ± 0.03	0.83 ± 0.05	0.83 ± 0.03	0.85 ± 0.03	0.4784	3.90
NSC	0.96 ± 0.01	0.96 ± 0.02	0.96 ± 0.02	0.95 ± 0.02	0.7198	1.75
Crude protein	0.79 ± 0.03	0.78 ± 0.06	0.77 ± 0.04	0.76 ± 0.03	0.4358	5.21
NDF	0.42^{b} ± 0.09	0.43^{b} ± 0.14	0.37^{b} ± 0.09	0.59^{a} ± 0.11	0.0033	24.85
ADF	0.33^{b} ± 0.12	0.40^{b} ± 0.15	0.43^{b} ± 0.13	0.64^{a} ± 0.14	0.0005	29.90
Ash	0.59 ± 0.08	0.61 ± 0.12	0.63 ± 0.05	0.62 ± 0.03	0.7030	12.53
Ether extract	0.84 ± 0.05	0.88 ± 0.05	0.85 ± 0.04	0.82 ± 0.03	0.1467	5.37
Dietary energy content						
ME (MJ/kg DM)	11.12 ± 0.43	11.27 ± 0.73	10.99 ± 0.42	11.59 ± 0.40	0.1244	4.54

[a,b] Means with different superscripts in the same row differ significantly (P <0.05). [1]The ADF concentrations (g/kg DM) in the treatment diets were: CON = 46.8 g/kg, ADF1 = 59.3 g/kg, ADF2 = 63.8 g/kg, and ADF3 = 79.9 g/kg. CON: control, ADF: acid detergent fibre, CV: coefficient of variation, DMI: dry matter intake, NSC: non-structural carbohydrate, NDF: neutral detergent fibre, ME: metabolisable energy

The differences in the dietary ADF content did not affect the voluntary DM intake of the lambs. Therefore, voluntary feed intake was not a possible cause for any significant differences in diet nutrient digestibility. A high-fibre content in ruminant diets reduces ruminal degradation and decreases passage rate and intake (Amorim *et al.*, 2023). However, intake is more closely related to the rate of digestion than to digestibility *per se*, although the two measures are related (McDonald *et al.*, 2011). The lack of a treatment effect on the DM intake in this study could be the result of the low and similar NDF content of the four treatment diets. The effect of NDF on fermentation becomes less important as the level of NDF declines (Getachew *et al.*, 2004).

The NDF and ADF digestibilities of the ADF3 diet were significantly higher than those of the other three diets. Similarly, Guo *et al.* (2021) fed Hu lambs increasing levels of either beet pulp (lower NDF and ADF) or soybean hulls (higher NDF and ADF), and found that feeding soybean hulls increased the ADF, but not NDF, digestibility. A negative correlation between the ADF content and the extent to which feed is digested has been previously reported (Van Soest, 1994; McDonald *et al.*, 2011), which is in contrast with the results of our study. Van Soest (1965) explained that lignin, ADF, and cell wall constituents were the main parameters related to fibre digestibility, more so than intake. However, it is difficult to confirm the negative correlation of ADF with digestibility from the available results. Both the NDF and ADF digestibilities were influenced to the same extent, were limited to one treatment, and were highest in the ADF3 diet. In addition, the effect of NDF on *in vitro* rumen fermentation becomes negligible as the level of NDF in the diet declines (Getachew *et al.*, 2004). Even though the NDF and ADF digestibilities of the ADF3 diet were higher than those of the other treatment diets, this increase in fibre digestibility was not of sufficient magnitude to affect the ME content of the diets (Table 2).

Soybean hulls are a by-product feed, and are low in lignin and highly digestible (López & Fernández, 2014), despite containing a high ADF content in relation to their NDF content (NRC, 2007). Ludden *et al.* (1995) found that the NDF in soybean hulls was more digestible than that in other forages, and Vasta *et al.* (2008) established that soybean hulls are rich in digestible fibre and pectin. Significantly higher NDF and ADF digestibilities were found for treatment ADF3, which had a high ADF content, than for the other treatments (Table 2). It is consequently incorrect to assume that whenever a fibre source is high in ADF, its digestibility will be low or negatively affected. However, it is difficult to make conclusive recommendations based on only one set of lambs and a short trial period.

Hejazi *et al.* (1999) described soybean hulls as a highly digestible dietary fibre source, and peanut hulls as a relatively indigestible dietary fibre source for lambs. However, the authors' only reference to dietary fibre quality was the high or relatively indigestible fibre content, not the chemical composition. The inclusion of peanut hulls in the diet resulted in decreases in the NDF (46.8% versus 30.4%), DM (80.4% versus 76.8%), and OM (81.7% versus 77.9%) digestibilities (Hejazi *et al.*, 1999). The diets contained, on average, 179.3 g NDF/kg when formulated using soybean hulls and 209.8 g NDF/kg when formulated using peanut hulls. Even though the NDF content of the soybean hull-based diet was comparable to that of the current study (Table 1), the same effect on chemical digestibility was not found.

Anatomical and physical features vary among plant species and at different stages of growth (Flint, 1994). The fibre content of a by-product feed thus has different physical and chemical properties to that of forage NDF. Fibre particles from lucerne hay, for example, have small dimensions and high density, whereas soybean hull density is low (López & Fernández, 2014). These differences in anatomical structure cause forages to have a wider range of digestibilities than any other ruminant feed type (Minson, 1990). Differences in NDF digestion may therefore be related to the nature of the NDF (Ludden *et al.*, 1995). Macdonald *et al.* (2023) found that fibre sources with a comparable NDF and ADF content included in standard finishing lamb diets varied significantly in their DM and nutrient digestibilities, with these being higher for better-quality (lucerne hay and soybean hulls) fibre sources than lower-quality (maize stover and *E. tef*) fibre sources.

Readily fermentable carbohydrates may also reduce the microbial digestion of hemicellulose more than that of cellulose (Dixon & Stockdale, 1999). The provision of large quantities of starch influences rumen microbial ecology, decreasing cellulolytic organism activity (Dove, 2002) by decreasing the rumen pH (Minson, 1990). This was probably not the case in the present study, as both the dietary fibre and NSC content compared well between the treatments (Table 1), and this can thus not be factored into the differences in NDF and ADF digestibility found in this study. However, it is difficult to comment on the possible influence of pH on fibre digestibility in this study because rumen pH was not measured.

The NSC, CP, ash, and EE digestibilities were not affected by the dietary ADF content (Table 2). Generally, cereal grains are highly digestible, although the extent of digestibility varies among animal species and depends on the quality of the grain (Kellems & Church, 2010). At least 90% of the starch in oats, barley, or wheat is fermented in the rumen (Ørskov, 1986), and the starch in these grains is more degradable than the starch in maize (Gulmez & Turkmen, 2007). However, because of this slower rate of digestion, up to 40% of maize starch escapes fermentation in the rumen (Ørskov, 1986). The NSC content of the dietary treatments was primarily obtained from maize meal inclusion (590.5 g/kg). High-concentrate diets fail to stimulate salivary secretion and produce a rumen environment with a lower pH, favouring more acid-tolerant, starch-digesting organisms, such as amylolytic bacteria (NRC, 2007; Kucuk *et al.*, 2008). This explains the high and comparable NSC digestibility found in this study.

Dixon & Stockdale (1999) suggested that the decrease in whole-tract digestibility may not be as great as the decrease in cell wall digestibility in the rumen, indicating that there are compensatory increases in digestibility elsewhere in the tract. Sheep have the capacity to compensate for reduced fibre digestion in the rumen with increased retention time in the rumen and/or increased digestion in the large intestine (Dixon & Stockdale, 1999). The digestibility results of the current study are representative of the whole tract, and more research regarding the current treatments' effects on the rumen metabolic environment is thus proposed.

Lamb performance and carcass characteristics

The effects of increasing the ADF content of low-fibre finishing diets on SAMM wether lamb performance are presented in Table 3, and on lamb carcass characteristics in Table 4.

The dietary treatments did not affect the DM or ME intakes of the wether lambs in the production study. As found in the digestibility study, the DM intakes of the treatment groups in the production study were similar (P >0.05). The lack of a treatment effect on the dietary ME content (Table 2) probably resulted in the lack of effect on the lamb ME intake in the production study. The feed intakes of the lambs in the production study also varied less (CV = 11.65%) than those found in the digestibility study (CV = 23.78%), probably because of the longer feeding period. Sheep have pre-digestive behaviours such as sorting and altering DM intake (Hejazi *et al.*, 1999), and, according to Blaxter *et al.* (1961), it therefore takes time to establish stable intakes, making a minimum of 15 days necessary for sheep feeding trials.

In addition, feed intake is regulated more by nutrient satiety and energy requirements than by the volume of non-digestible OM consumed (Blaxter *et al.*, 1961). Blood volatile fatty acid concentrations are responsible for this chemostatic regulation of intake (Cheeke, 2005). Only when the DE content of the diet is less than 10.46 MJ/kg DM is sheep feed intake regulated by gut fill (Haddad & Husein, 2004). Consequently, the lack of effect of the dietary treatments on the DM intake found in the current study is to be expected, based on the high and comparable ME content (Table 2), and the low NDF content (Table 1), of the dietary treatments.

The similar DM and ME intakes were associated with a lack of treatment effects on the final weights of the lambs and the ADG. Although the ADG of the lambs on the CON diet was higher than for the other treatments, this difference was non-significant (P = 0.0629). The CON lambs also had a significantly lower (more efficient) FCR than the ADF3 lambs. This was also associated with a highly significant treatment effect on the ME utilised for growth, with the CON lambs utilising the ME of the low-fibre finishing diets more efficiently for production than the ADF1 and ADF3 lambs. As the performance rate (ADG) increases, the feed efficiency (FCR and ME utilised for weight gain) also tends to increase, because a smaller portion of the ingested nutrients is used for maintenance and a larger percentage is available for growth (Kellems & Church, 2010).

In contrast with the results of this study, Macdonald *et al.* (2023) found that the dietary fibre source affected the DM intake, ME intake, and ADG of finishing lambs fed standard, high-concentrate diets with a similar NDF and ADF content. Specifically, they found that lucerne hay resulted in better performance than soybean hulls, maize stover, or *E. tef*, in a study focusing on the quality of the roughage and not a differing ADF content (Macdonald *et al.*, 2023). Allen (2000) similarly found significant increases in the DM intake and milk yield of dairy cows with an increase in NDF digestibility but with a similar NDF and CP content. However, it could be argued that this result was related to the forage used, as well as the higher NDF inclusion levels, in contrast with the current study, which used grain by-products as fibre sources, at low inclusion levels. Oba & Allen (1999) stated that NDF digestibility influenced animal performance, but noted that many other dietary factors also affected DM intake and milk yield. This concurs with our finding that even though the NDF and ADF digestibilities were higher for the ADF3 diet than the CON diet, this was not reflected in the growth efficiency of the lambs.

Hejazi *et al.* (1999) found that feeding soybean hulls (containing highly digestible fibre) and peanut hulls (a relatively indigestible fibre source) to lambs did not influence their DM intake and ADG. Moreover, when goats were fed diets containing incremental levels of ADF (provided by chopped lucerne hay, increased in relation to a ground maize/soybean meal concentrate), no differences were found in DM intake, body weight change, or milk production between the treatments (Santini *et al.*, 1991). However, while the dietary ADF content was the independent variable examined by Santini *et al.* (1991), the NDF content also increased as the lucerne hay content increased. This in contrast with the current study, where the NDF content of the diets was similar (Table 1).

Table 3 The effects of increasing the ADF content[1] of low-fibre finishing diets on the intake and performance of South African Mutton Merino wether lambs

Parameters	Treatment diets (mean ± standard deviation)[1]					
	CONTROL	ADF1	ADF2	ADF3	*P*-value	CV (%)
Intake						
Dry matter intake (g/sheep/day)	1267 ± 137	1231 ± 132	1272 ± 185	1200 ± 119	0.5031	11.65
Metabolisable energy intake (MJ/sheep/day)	12.97 ± 1.43	12.77 ± 1.42	12.88 ± 1.90	12.69 ± 1.31	0.9616	11.89
Performance						
Initial weight (kg)	27.39 ± 3.26	27.76 ± 3.27	27.46 ± 3.36	27.06 ± 3.16	0.9502	11.89
End weight (kg)	47.53 ± 5.24	45.34 ± 4.48	46.34 ± 5.69	43.90 ± 4.88	0.2618	11.10
Average daily gain (g/sheep/day)	301 ± 53	262 ± 55	282 ± 51	251 ± 50	0.0629	19.07
Feed conversion ratio (kg DMI/kg weight gain),	4.30^{b} ± 0.58	4.78^{ab} ± 0.51	4.57^{ab} ± 0.45	4.87^{a} ± 0.59	0.0231	11.57
MJ metabolisable energy intake/kg live weight gain	43.95^{b} ± 5.82	49.52^{a} ± 4.83	46.26^{ab} ± 4.57	51.51^{a} ± 6.15	0.0016	11.28

[a,b] Means with different superscripts in the same row differ significantly (P <0.05). ADF: acid detergent fibre, CV: coefficient of variation.
[1]The ADF concentrations (g/kg dry matter) in the treatment diets were: CONTROL = 46.8 g/kg, ADF1 = 59.3 g/kg, ADF2 = 63.8 g/kg, and ADF3 = 79.9 g/kg.

Table 4 The effects of increasing the ADF content[1] of low-fibre finishing diets on the carcass characteristics of South African Mutton Merino wether lambs

Parameters	Treatment diets (mean ± standard deviation)[1]					
	CONTROL	ADF1	ADF2	ADF3	*P*-value	CV (%)
Cold carcass weight (kg)	22.43 ± 3.18	21.43 ± 2.28	22.32 ± 3.22	20.78 ± 2.62	0.3494	13.09
Dressing percentage (%)	47.09 ± 2.25	47.25 ± 1.09	48.08 ± 2.18	47.29 ± 1.82	0.5011	3.97
Shoulder circumference (cm)	75.20 ± 3.08	75.13 ± 2.43	76.04 ± 3.36	74.57 ± 2.41	0.5833	3.77
Buttock circumference (cm)	63.50 ± 3.23	63.33 ± 2.68	63.93 ± 3.55	62.37 ± 3.38	0.6080	5.09
Carcass length (cm)	61.17 ± 2.10	60.13 ± 2.95	60.64 ± 2.43	60.27 ± 1.62	0.6221	3.84
M. longissimus lumborum width (mm)	67.34 ± 4.77	65.97 ± 4.59	66.15 ± 3.79	67.19 ± 4.96	0.7895	6.84
M. longissimus lumborum depth (mm)	25.48 ± 4.15	25.27 ± 2.91	25.96 ± 3.28	25.98 ± 2.59	0.9171	12.81
M. longissimus lumborum area (mm^2)	1560 ± 298	1566 ± 183	1551 ± 243	1564 ± 224	0.9983	15.43
Fat thickness (45 mm)[2]	3.42 ± 1.02	3.82 ± 1.23	3.55 ± 1.23	3.38 ± 1.51	0.7702	35.60
Fat thickness (110 mm)[2]	7.22 ± 2.27	7.95 ± 1.66	7.85 ± 2.15	7.70 ± 1.84	0.7555	25.97

ADF: acid detergent fibre, CV: coefficient of variation. [1]The ADF concentrations (g/kg dry matter) in the treatment diets were: CONTROL = 46.8 g/kg, ADF1 = 59.3 g/kg, ADF2 = 63.8 g/kg, and ADF3 = 79.9 g/kg. [2]Fat thickness measured 45 mm and 110 mm from the mid dorsal line between the 12th and 13th thoracic vertebra, respectively.

Scholtz *et al.* (2009) found that in dairy diets, the ADF content of the lucerne hay used was the parameter most closely related to milk yield potential, and was one of the markers in the multiple linear equations used to accurately predict milk production (R^2 = 0.96). Scholtz (2008) reported that the milk yield of Holstein cows decreased by 5.4% and 3.4% for each per cent increase in the ADF and NDF content of the lucerne hay, respectively. This effect of the ADF content on animal performance is comparable to the results of the current study, as the low ADF content of the CON diet resulted in significantly higher growth efficiency (Table 3), compared to the ADF1 and ADF3 treatments. Even though the effect on the ADG was not significant, the same tendency was found.

The dietary ADF content had no significant effect on any of the carcass characteristics measured (Table 4). Despite the lack of effect of the dietary treatments on the DM intake, ME intake, and final live weight (Table 3), the lack of treatment effect on the carcass characteristics is difficult to explain, considering the significant influence of the dietary treatments on lamb growth efficiency.

Hejazi *et al.* (1999) similarly found that using either soybean hulls or peanut hulls as fibre sources had no effects on the carcass characteristics of lambs (chilled carcass weight, fat depth, and dressing percentage). The higher energy intake associated with feeding concentrate rations typically results in heavier animals with fatter carcasses when grown over a predetermined time (French *et al.*, 2000). However, Casey & Webb (1995) found that feeding wethers a high energy diet (11.76 MJ ME/kg DM) rather than a medium energy diet (10.18 MJ ME/kg DM) did not affect the carcass fat percentage, even when a significantly faster growth rate was recorded. Therefore, even when energy intake and growth are affected, any responses in terms of carcass characteristics are not guaranteed. Nonetheless, the energy content of a diet can influence carcass fatness (Bhatt *et al.*, 2011). Propionate is gluconeogenic, which means that an increase in the production of this volatile fatty acid could result in an increase in the deposition of intramuscular fat. Fat accretion also uses a high proportion of glucose for its synthesis (Ladeira *et al.*, 2014). However, no conclusion can be drawn in this regard because the rumen volatile fatty acid concentration was not measured in the current study, and this thus needs further investigation.

Macdonald *et al.* (2023) found that the fibre source used (lucerne hay, soybean hulls, maize stover, or *E. tef*) in standard finishing lamb diets with a comparable NDF and ADF content significantly affected the cold carcass weight, dressing percentage, shoulder and buttock circumference, *M. longissimus lumborum* depth and area, and *M. longissimus lumborum* fat thickness measured 110 mm from the mid dorsal line, with these parameters being higher for the higher quality fibre sources (lucerne hay and soybean hulls). However, these diets differed from the current study, as they were higher in NDF, and only the fibre source, not the ADF, differed between the treatments.

Conclusions

The NDF and ADF digestibilities of the low-fibre finishing lamb diets tested in this study were increased by a high ADF content, which is in contrast with most previous literature. However, the increase in digestibility associated with the increase in the soybean hull content of the diet was consistent with the literature. It is therefore incorrect to assume that any fibre source high in ADF will have a negative effect on fibre digestibility in finishing lambs. Nonetheless, the lamb growth efficiency parameters (FCR and ME utilised for weight gain) were improved by a low ADF content.

Plant sources differ in both their fibre structure and their degree of lignification. The hemicellulose, pectin, and lignin content, as well as the undegradable NDF content, were not evaluated in this study. These variables should be considered before recommendations are made, as the effects on fibre digestibility and animal performance sometimes seem unpredictable. Available data regarding ADF chemical parameters as quality assessments and their effects on animal performance in literature appear to be variable and limited.

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Authors' contributions

O.B.E., A.V.F., and A.H. designed the experiment and O.B.E. carried out the research trial. M.D.F. completed the statistical analyses. O.B.E. and A.H. structured the scientific content and O.B.E. drafted the manuscript. A.V.F. and A.H. assisted with the experimental design and research trial, while all authors provided editorial suggestions and approved the final manuscript. A.H. conducted the meat quality analysis.

Conflicts of interest

The authors declare that there is no conflict of interest.

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