

The use of ammoniated maize residue to replace maize meal in fattening diets for lambs

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Milled (13 mm screen) maize residue containing 35% moisture was treated with 4% anhydrous ammonia on roughage dry matter in a stack for 50 days. Performance of lambs was measured in a 2 × 5 factorial experiment with two treatments (untreated and ammoniated) at five concentrate levels (0, 20, 40, 60 and 80%). Digestibility and rumen characteristics were measured in 10 ruminally cannulated wethers in two 5 × 5 latin square designs. Rumen volume and flow rate were determined using Cr-EDTA. Feed intake, average daily gain, and feed conversion were all improved by ammoniation at the 0 and 20% concentrate levels ($P < 0.05$) with the differences at the 40 and 60% levels being not significant. Ammoniation led to a reduced rumen digesta mass and increased dressing percentage. The increase in *in vivo* digestibility owing to ammoniation was higher at low concentrate levels and lower than that measured *in vitro*. Rumen pH was decreased by feeding concentrate as well as by feeding ammoniated roughage at all concentrate levels ($P < 0.05$). High rumen ammonia-N levels were recorded on ammoniated diets but N digestibility on these diets was reduced. Ammoniation tended to decrease retention time of water, rumen fluid volume, and flow rate out of the rumen. *S. Afr. J. Anim. Sci.* 1985, 15: 27–32

Gemaalde (13 mm sif) mieliereste met 35% vog is met 4% anhidriese ammoniak op ruvoer droë materiaal vir 50 dae in 'n mied behandel. Groei van lammers is gemeet in 'n 2 × 5-faktoriaalproef met twee behandelings, nl. onbehandeld en behandel, en vyf kragvoervlakke, nl. 0, 20, 40, 60 en 80%. Verteerbaarheid en rumeneienskappe is op 10 gekannuleerde hamels in twee 5 × 5-latynse-vierkantontwerpe gemeet. Cr-EDTA is as merker vir rumenvolume en vloeitempobepalings gebruik. Voerinnome, gemiddelde daaglikse toename en voeromset is almal verbeter deur ammonifisering by die 0 en 20% kragvoerpeile ($P < 0.05$). Verskille by die 40 en 60% kragvoerpeile was nie betekenisvol nie. Ammonifisering het gelei tot verlaagde rumendigestamassa en verhoogde uitslagpersentasie. Die verhoging in *in vivo* verteerbaarheid as gevolg van ammonifisering was groter by lae kragvoerpeile en laer as dié gemeet *in vitro*. Hoë rumenammoniakpeile is op gearmonifiseerde diëte gemeet, maar die N-verteerbaarheid van hierdie diëte is verlaag. Ammonifisering het geneig om retensietyd van water, rumenvloeistofvolume en vloeitempo te verlaag. *S.-Afr. Tydskr. Vee*. 1985, 15: 27–32

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Introduction

Chemical procedures for improving the nutritive value of straws have been of interest since the work of Lehman (1895), Godden (1920) and Beckmann (1921). The positive effect of ammonia treatment on straw was first reported by Nikolaeva (1941) and more research was conducted by Chomyszyn, Bielinski & Slabon (1961) and Bergner & Marienburg (1971). A shortage of fodder in Scandinavia because of drought in the seasons of 1975 and 1976 accelerated interest in the ammoniation of straw (Sundstøl, Kossila, Theander & Thomsen, 1978).

Feed intake and performance of ruminants is usually improved when the roughage portion of their diets is ammoniated. These improvements are, however, variable. Increases in *in vivo* digestibility owing to ammoniation are often smaller than increases in *in vitro* digestibility (Singh & Jackson, 1971; Jackson, 1977; Oji & Mowat, 1979) although Lawlor & O'Shea (1979) recorded similar increases both *in vivo* and *in vitro*.

The increased crude protein resulting from ammoniation of roughage is not of uniform availability and value. Al-Rabbat & Heaney (1978) reported increased N retention in animals fed ammoniated roughage, whereas Oji, Mowat & Winch (1977) and Garrett, Walker, Kohler & Hart (1979) recorded lower N retention in animals receiving ammoniated rice straw and maize residue respectively than when receiving the untreated roughages. This aspect is possibly confused by unnecessarily high N contents of diets containing ammoniated roughage leading to excessive N intakes by animals (McIntyre, 1970).

Although ammoniation usually leads to increased intake of roughages by animals, a number of researchers have reported reduced intakes of roughage after ammoniation (Rounds, Klopfenstein, Waller & Messersmith, 1976; Waldo, 1977; Al-Rabbat & Heaney, 1978; Klopfenstein, 1978). Improved performance of animals receiving ammoniated roughage is dependent upon the concentrate level of the diets fed (Horton, 1979; Garrett, *et al.*, 1979).

In view of this, it is of practical significance to determine the nature of the relationship between level of ammoniated maize residue in the diet and animal response. Experiments were designed to ascertain to what extent ammoniated maize residue could be included in fattening diets with beneficial effect and to identify factors which might limit the response of animals to such roughage. A preliminary account of this research was presented at the Herbivore Nutrition Symposium (Seed, 1983).

Experimental procedure

Treatment of maize residue

Maize residue, obtained from a combine harvester, which included leaves, stalks (excluding the lower quarter), plumes, cob leaves and cobs without kernels, was hammermilled to pass a 13 mm screen and ammoniated using the 'stack method' (Norsk Hydro/NOFO, 1977). Water was sprayed over the maize residue to increase the moisture content to approximately 35%. Anhydrous ammonia (NH₃) was injected into the stack at a treatment level of 4% of roughage dry matter. The stack was opened after 50 days and the treated material sun-dried before being stored in hessian sacks.

Diet formulation

Three mixtures were formulated using either untreated maize residue, ammoniated maize residue, or maize meal (Table 1).

Table 1 Percentage composition of the three mixtures used to formulate the experimental diets

Ingredient	Percentage composition (as fed)		
	Mixture 1	Mixture 2	Mixture 3
Untreated maize residue	81	-	-
Ammoniated maize residue	-	83	-
Maize meal	-	-	82
Fish meal	10	10	10
Molasses	5	5	5
NaCl	1	1	1
K ₂ SO ₄	1	1	1
Urea	2	-	1

Fish meal, molasses, urea, NaCl, and K₂SO₄ were added to satisfy the protein and mineral requirements of growing lambs (NRC, 1975). Monensin (Romensin, Elanco, South Africa) was included in all mixtures at a level of 150g/t. These three mixtures were then combined to form 10 experimental diets which contained either the untreated or ammoniated maize residue mixtures with 0, 20, 40, 60 or 80% of the concentrate mixture and fed unpelleted to the experimental animals.

Growth trial

Sixty-two South African Mutton Merino (SAMM) wether lambs were randomly allotted to the diets in a 2 × 5 factorial design. Eight lambs were allotted to each of the diets containing 20 and 80% concentrate and five lambs to each of the other diets. All lambs were housed in individual crates and randomly placed throughout the metabolism house to minimize environmental effects. Animals were adapted to their diets for 21 days and the average starting mass was 21,5 kg. The groups receiving untreated maize residue with 0 and 20% concentrate were withdrawn after 91 days owing to poor performance. All other groups were sacrificed once lambs had attained slaughter mass. The optimum slaughter mass for SAMM lambs fed high concentrate diets is reported to be 40 kg (Boshoff, 1981). In order to obtain similar empty body mass for carcass comparison, a regression equation proposed by Meissner, De la Rey, Gerhard & van der Westhuizen (1976) which relates percentage digestible energy in the diet to mass of rumen digesta, was used to determine the slaughter mass of each group. Data were analyzed statistically after both 91 days and the end of the trial. Rumen digesta mass was determined directly after slaughter and cold carcass mass was

measured after 24 h in cold storage. Diets were fed *ad libitum* and dry matter intake and mass gain were recorded weekly.

Digestibility trial

Ten ruminally cannulated SAMM wether lambs were allotted to two 5 × 5 latin square designs. Collection periods lasted 10 days and were preceded by 18-day adaptation periods. Feed was offered *ad libitum* during both adaptation and collection periods. During the 10-day collection periods, rumen fluid samples were drawn on the first and last days, while intake and faecal output were measured on the remaining 8 days. Animals were fed three times daily at 07h00, 12h00, and 16h00. Orts were removed once daily and combined for each animal. Daily faecal excretion was determined using faeces collection bags. A 10% representative sample of the daily excretion of each lamb was combined and frozen until required for later chemical analysis. Feed, ort, and faecal samples were analysed for dry matter and N according to standard procedures (AOAC, 1970). Apparent *in vivo* dry matter digestibility and faecal N expressed as a percentage of total N intake were calculated.

The retention time of water in the rumen, rumen water volume, and flow rate from the rumen was calculated using Cr-EDTA as soluble marker and the equations of Warner & Stacy (1968). Rumen fluid samples were drawn from various sites in the rumen before dosing of the soluble marker, and then 1, 3, 5, 7 and 9 h after dosing. The pH was immediately measured with a glass electrode, strained samples were then acidified with 1N-H₂SO₄ and frozen for Cr and NH₃ analysis. For rumen NH₃-N analysis, samples were centrifuged for 15 min at 3000 rpm and the supernatant immediately analysed using an Autoanalyser (Industrial method No 334-74 W/B; Technicon Industrial Systems, 1977).

Cr was determined by atomic absorption spectrophotometry. Rumen pH and NH₃-N measurements are presented as the mean of the six measurements taken over the 9-h period.

During their 140-day confinement to the metabolism house for the purpose of this trial, the condition of four wethers was poor on separate occasions. All the data for these animals for the periods concerned were discarded on the grounds of poor feed intake, with a correspondingly high retention time of water in the rumen and a high *in vivo* dry matter digestibility.

Data were analysed statistically by analysis of variance procedures. The *t* test (Snedecor and Cochran, 1967) was applied to determine whether differences between untreated and ammoniated diets were significant. Analysis of covariance was applied to the dressing percentage observations in order to eliminate slaughter mass as a possible source of bias.

Results

Ammoniation with 4% anhydrous ammonia increased the *in vitro* organic matter digestibility (IVOMD) of maize residue from 55,3% to 67,0% and the crude protein (CP) content from 3,6% to 12,7%. Samples taken from the top and bottom layers of the stack did not differ significantly in terms of either IVOMD or CP.

Growth trial

The mean daily dry matter intake (DMI), average daily gain (ADG) and feed conversion figures measured after 91 days and at the end of the trial (183 days) are shown in Tables 2 and 3.

Concentrate level in the diet had a significant effect on all

Table 2 Mean feed intake (DMI), gain (ADG), and feed conversion figures measured after 91 days in lambs fed untreated or ammoniated maize residue at various concentrate levels

	DMI (g)		ADG (g)		Feed conversion (kg)	
	Untreated	Ammoniated	Untreated	Ammoniated	Untreated	Ammoniated
Concentrate (%)						
0	496	828 ^b	44	141 ^b	12,5	6,03 ^b
20	548	858 ^b	79	156 ^b	7,35	5,60 ^a
40	749	797	129	153	5,98	5,28
60	812	820	143	165	6,55	4,98
80	830	780	192	154 ^a	4,45	5,23
Significance of the effect of concentrate	$P=0,0001$	$P=0,3051$	$P=0,0001$	$P=0,6361$	$P=0,0002$	$P=0,1438$
SE	23,6	23,8	7,2	5,4	0,44	0,25

Significance of effect of ammoniation ^a $P<0,05$ ^b $P<0,01$ **Table 3** Mean feed intake (DMI), gain (ADG) and feed conversion figures measured after 183 days in lambs fed untreated or ammoniated maize residue at various concentrate levels

	DMI (g)		ADG (g)		Feed conversion (kg)	
	Untreated	Ammoniated	Untreated	Ammoniated	Untreated	Ammoniated
Concentrate (%)						
0	- ^b	916	-	140	-	6,82
20	-	879	-	144	-	6,29
40	896	842	143	153	6,36	5,49
60	838	839	163	166	5,40	5,07
80	888	853	202	168 ^a	4,51	5,19
Significance of the effect of concentrate	$P=0,9451$	$P=0,3205$	$P=0,0454$	$P=0,0385$	$P=0,0132$	$P=0,0047$
SE	29,6	18,7	10,9	5,0	0,25	0,18

Significance of effect of ammoniation ^a $P<0,05$ ^bLambs withdrawn after 91 days owing to poor performance**Table 4** Mean rumen digesta mass (RDM), dressing percentage and feed conversion to carcass gain in lambs fed untreated or ammoniated maize residue at various concentrate levels

	RDM (kg)		Dressing %		Feed conversion to carcass gain	
	Untreated	Ammoniated	Untreated	Ammoniated	Untreated	Ammoniated
Concentrate (%)						
0	- ^c	5,97	-	41,2	-	14,63
20	-	4,79	-	44,5	-	11,59
40	5,30	4,24 ^a	41,2	45,2 ^b	13,97	9,88 ^b
60	4,53	4,08	43,4	45,4	10,08	9,35
80	4,21	3,93	44,5	45,6	8,09	8,50
Significance of the effect of concentrate	$P=0,0044$	$P=0,0039$	$P=0,0606$	$P=0,0087$	$P=0,0001$	$P=0,0001$
SE	0,12	0,17	0,60	0,36	0,33	0,37

Significance of effect of ammoniation ^a $P<0,05$ ^b $P<0,01$ ^cLambs withdrawn after 91 days owing to poor performance

parameters after 91 days when untreated maize residue was fed ($P<0,01$) but not when ammoniated diets were fed. ADG and feed conversion at 183 days was improved ($P<0,05$) by the addition of concentrate on both untreated and ammoniated diets. A significant concentrate \times treatment interaction

occurred ($P<0,01$).

Ammoniation improved all parameters at the 0% ($P<0,01$) and the 20% ($P<0,05$) concentrate levels while differences at the higher concentrate levels were not significant ($P>0,05$). ADG was decreased on the ammoniated 80% concentrate diet

Table 5 Mean feed intake, dry matter digestibility (DMD) and faecal N measured in lambs fed untreated or ammoniated maize residue at various concentrate levels

Concentrate (%)	DMI (g)		DMD (%)		Faecal N (%)	
	Untreated	Ammoniated	Untreated	Ammoniated	Untreated	Ammoniated
0	746	1003 ^b	62,4	66,8 ^b	19,4	34,6 ^b
20	834	966 ^a	66,6	70,9 ^b	20,8	29,7 ^b
40	963	1281 ^b	71,8	74,5	18,7	27,2 ^b
60	1179	1200	76,9	75,3	18,3	25,8 ^b
80	1038	1204 ^a	78,4	78,7	21,8	22,0
Significance of effect of concentrate	$P=0,0012$	$P=0,0001$	$P=0,0001$	$P=0,0004$	$P=0,3968$	$P=0,0050$
SE	25,1	7,2	0,5	0,4	0,6	0,6

Significance of effect of ammoniation ^a $P<0,05$ ^b $P<0,01$ $(P<0,05)$.

The mean rumen digesta mass (RDM) determined at slaughter, dressing percentage and feed conversion to carcass gain are shown in Table 4. Concentrate level affected these parameters on both untreated and ammoniated diets ($P<0,01$) except for dressing percentage when untreated maize residue was fed. There was a tendency for differences between untreated and ammoniated maize residue diets to decrease with an increase in concentrate level, with the differences at the 40% concentrate level being significant ($P<0,05$).

Digestibility trial

The mean daily dry matter intake, mean apparent *in vivo* dry matter digestibility (DMD) and faecal N expressed as a percentage of total N intake are shown in Table 5. Ruminal pH and ammonia-N levels are shown in Table 6. Level of concentrate in the diet had a significant effect ($P<0,01$) on all parameters except faecal-N of wethers fed untreated maize residue and ruminal ammonia on both types of roughage. There was again the tendency for differences between untreated and ammoniated diets to be greater at the lower concentrate levels. The average ruminal ammonia level for ammoniated diets was 224 mg/l which was not different ($P>0,05$) to that for untreated diets (210 mg/l).

There was a tendency for reduced rumen water volume and retention time of water (Table 7) when roughage was ammoniated although this effect was only significant at the 0% concentrate level ($P<0,05$). The level of concentrate also

reduced ruminal water volume significantly only on untreated diets ($P<0,05$). Flow rate of water from the rumen was reduced by increasing concentrate level and by ammoniation at the 0 and 20% concentrate levels ($P<0,05$).

Discussion

Dry matter intake of diets by lambs was increased by ammoniation. This effect was more pronounced at low concentrate levels to the extent that concentrate level in ammo-

Table 6 Mean rumen pH and rumen NH₃-N levels measured in lambs fed untreated or ammoniated maize residue at various concentrate levels

Concentrate (%)	Rumen pH		Rumen NH ₃ -N (mg/l)	
	Untreated	Ammoniated	Untreated	Ammoniated
0	6,75	6,44 ^b	229	232
20	6,59	6,44 ^a	224	243
40	6,47	6,24 ^b	203	250 ^a
60	6,21	6,06 ^a	214	199
80	6,18	5,94 ^b	180	230 ^a
Significance of effect of concentrate	$P=0,0001$	$P=0,0001$	$P=0,1274$	$P=0,4319$
SE	0,02	0,02	5,9	7,6

Significance of effect of concentrate ^a $P<0,05$ ^b $P<0,01$ **Table 7** Rumen water volume, retention time, and flow rate measured in lambs fed untreated or ammoniated maize residue at various concentrate levels

Concentrate (%)	Water volume (l)		Retention time (h)		Flow rate (l/d)	
	Untreated	Ammoniated	Untreated	Ammoniated	Untreated	Ammoniated
0	5,27	4,00 ^a	10,5	9,1	12,37	10,27 ^a
20	4,01	3,78	8,7	10,9	11,20	8,43 ^a
40	3,91	3,34	9,1	7,6	10,75	10,63
60	3,69	2,95	8,9	7,8	10,43	9,49
80	3,60	3,39	10,7	9,7	8,65	8,48
Significance of effect of concentrate	$P=0,0461$	$P=0,3937$	$P=0,4625$	$P=0,3168$	$P=0,0237$	$P=0,5081$
SE	0,17	0,16	0,4	0,5	0,30	0,47

Significance of effect of ammoniation ^a $P<0,05$

niated diets had no effect on feed intake ($P>0,05$) whereas it did when untreated diets ($P<0,01$) were fed. The small decrease in feed intake recorded in animals receiving ammoniated roughage and 80% concentrate may possibly be due to chronic acidosis resulting from the high proportion of readily fermentable carbohydrate in this diet (Slyter, 1976). In view of the fact that Rounds, *et al.* (1976) and Klopfenstein (1978) reported reduced intake of ammoniated maize cobs unless a fermented feed, such as silage which possibly bound any excess ammonia, was included in the diet, an aeration procedure which results in low levels of free ammonia in treated roughage is perhaps necessary to ensure high intakes of such roughage.

In agreement with the work of Oji, *et al.* (1977), Horton (1979) and Hadjipanayiotou (1982), increases in *in vivo* digestibility, average daily gain and feed conversion ratio were apparent at low but not at high concentrate levels. This may be attributed to the comparatively small contribution of ammoniated maize residue to the total digestible dry matter intake of the latter diets. It is also evident that the increase in *in vivo* digestibility at low concentrate levels was lower than that measured *in vitro* (11,7 percentage units). This was possibly caused by a lower rumen pH ($P<0,05$) measured on ammoniated diets (Terry, Tilley & Outen, 1969) and also a reduced retention time in the rumen (Van Soest, 1975).

Dressing percentage, expressed as cold carcass mass as a percentage of slaughter mass, was increased by ammoniation of maize residue ($P<0,05$). A reduced rumen digesta mass owing to ammoniation ($P<0,05$) could partially explain this effect. However, the lower ruminal pH ($P<0,05$) and lower retention time of water measured on these diets is probably related to an increased molar percentage of propionic acid in the rumen (Isaacson, Hinds, Bryant & Owens, 1975) and therefore a more efficient utilization of metabolizable energy for fattening (Armstrong & Blaxter, 1957). This supports the contention that the higher dressing percentage indicates a higher fat content in carcasses of lambs fed ammoniated diets (Berg & Butterfield, 1976).

The high ruminal ammonia-N levels measured on ammoniated diets compare well with the results of Oji, Mowat & Buchanan-Smith (1979) and were well above that required for maximal growth rates of ruminal micro-organisms (Satter & Slyter, 1974). The increased faecal-N excretion measured at all except the 80% concentrate level show, however, that some N in ammoniated roughage is unavailable. This could possibly be explained by the colour change reaction that occurs during ammoniation in which carbonyls generated during the decomposition of carbohydrates complex with available amino groups presumably rendering a fraction of the true protein indigestible (Van Soest, 1969). Chomyszyn & Ziiolecka (1972) contend that conditions of temperature and pressure at which ammonia is applied, affects availability.

The reduced retention time of water measured in ammoniated diets, although not significant, follows a similar pattern to the feed intake figures and is supported by the significantly reduced retention times of water and particulate matter on ammoniated maize residue diets measured by Oji, *et al.* (1979). Shorter retention times of water result in increased yields of microbial protein per unit carbohydrate fermented in the rumen (Isaacson, *et al.*, 1975) and also a larger portion of the more undegradable dietary true protein sources escaping degradation (Miller, 1973). In view of the fact that ammoniated roughage provides NPN in the rumen, both these phenomena would be advantageous.

All growth data indicate that animals receiving ammoniated

maize residue with only protein and mineral supplementation performed similarly to animals receiving untreated roughage and 40% concentrate. The results also show that ammoniated maize residue can be included in fattening diets for lambs with beneficial effect provided that not more than 60% concentrate is included. The high acceptability of diets containing ammoniated maize residue can perhaps be attributed to post treatment aeration. The discrepancy between increases in *in vitro* and *in vivo* digestibility and the effect of treatment conditions on N availability warrant further attention.

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