Effect of thermal ammoniation and heat treatment on the faecal and ileal digestibility and utilization of birdproof grain sorghum by pigs

T.S. Brand*, H.A. Badenhorst, and F.K. Siebrits
Animal and Dairy Science Research Institute, Private Bag X2, Irene 1675, Republic of South Africa
J.P. Hayes
Department of Poultry Science, University of Stellenbosch, Stellenbosch 7600, Republic of South Africa

Received 28 October 1988; accepted 27 April 1989

Two experiments were conducted to (i) determine the effect of thermal ammoniation (NH_3BPS) and heat treatment (HBPS) of birdproof sorghum (BPS) on energy and N metabolism, measured with intact and ileo-rectal anastomosed pigs and (ii) to evaluate NH_3BPS and untreated BPS in a growth trial with pigs. DM digestibility, energy digestibility and DE and ME contents of BPS were significantly ($P \leq 0,01$) improved with 5,5, 8,3, 12,7 and 12,4% by thermal ammoniation whereas the ileal digestibility values of DM and energy and the DE and ME contents were increased by 10,8, 14,3, 18,6 and 19,6% respectively. Heat treatment of BPS led to an improvement of 5,8, 9,1, 12,7 and 14% respectively. Apparent digestibility of N was significantly ($P \leq 0,05$) improved by 17,9% with ammoniation, while the apparent ileal digestibilities of HBPS and NH_3BPS were increased significantly ($P \leq 0,01$) by 101,6 and 158,8% respectively. The same trend was observed in the case of true digestibility values. Apparent and true N retention increased from 5,2 to 5,9 g/day and from 7,9 to 8,7 g/day, respectively, due to ammoniation. Apparent ileal N retention increased significantly ($P \leq 0,01$) from −4,3 to 3,4 and 3,8 g/day, whereas true ileal N retention increased from 0,16 to 7,3 and 8,3 g/day for HBPS and NH_3BPS. Pigs fed NH_3BPS, however, were found to have 5,3% lower DM intakes and 2% poorer feed utilization ratios, and gained 5% less in livemass than pigs fed untreated BPS.

Twee eksperimente is uitgevoer om (i) die invloed van termiese ammonifisering (NH_3BPS) en hittebehandeling (HBPS) van voëlbestande graansorghum (BPS) op energie en N-metabolisme, soos gemeet met intakte- en ileo-rektale-anastomose-gemodifiseerde varke, te bepaal en (ii) om NH_3BPS en onbehandelde BPS in 'n groeistudie met varke te evalueer. DM-verteerbaarheid, energie-verteerbaarheid, VE-inhoud en ME-inhoud van BPS is betekenisvol ($P \leq 0,01$) verbeter deur termiese ammonifisering met 5,5, 8,3, 12,7 en 12,4% onderskeidelik, terwyl die ileale verteerbaarheidswaardes van DM en energie en die VE- en ME-inhoud met onderskeidelik 10,8, 14,3, 18,6 en 19,6% verhoog is. Hittebehandeling van BPS het 'n verhoging van 5,8, 9,1, 12,4 en 14% onderskeidelik tot gevolg gehad. Skynbare fekale verteerbaarheid van N is betekenisvol ($P \leq 0,05$) met 17,9% verhoog deur ammonifisering, terwyl die skynbare ileale verteerbaarheid van HBPS en NH_3BPS betekenisvol ($P \leq 0,01$), 101,6 en 158,8% hoër was as dié van BPS. Dieselfde tendens het voorgekom by die ware verteerbaarheidswaardes. Skynbare en ware N-retensie is onderskeidelik verhoog vanaf 5,2 tot 5,9 g/dag en vanaf 7,9 tot 8,7 g/dag as gevolg van ammonifisering. Skynbare ileale N-retensie is betekenisvol ($P \leq 0,01$) verhoog vanaf −4,3 tot 3,4 en 3,8 g/dag, terwyl die ware ileale N retensie toegeneem het vanaf 0,16 tot 7,3 en 8,3 g/dag vir HBPS en NH_3BPS. NH_3BPS-gevoerde varke het egter 5,3% laer DM innames, 2% swakker voeromset en 5% swakker groei getoon as die varke wat onbehandelde BPS gevoer is.

Keywords: Ammoniation, heat, ileal digestibility, ileo-rectal anastomosis, N balance, pigs, sorghum, tannin content

* To whom correspondence should be addressed at present address: Winter Rainfall Region, Private Bag, Elsenburg 7607, Republic of South Africa

Introduction

Birdproof sorghum (BPS) contains a high percentage of tannin (1,13 ± 0,38% with a range of 0,29 — 1,94%; Kemm, Ras & Daiber, 1984). Tannins, however, depress growth rate and resulted in poor feed efficiency ratios (Kemm *et al.*, 1984). The deleterious effects of tannins in the diet seem to be related to their interaction with dietary proteins (Mitaru, Reichert & Blair, 1984). Tannin-protein complexes are believed to be responsible for growth depression, low protein digestibility and also inhibition of important digestive enzymes (Deshpande, Cheryan & Salunkhe, 1986). A number of methods have been tried to overcome nutritional problems associated with high-tannin feeds, e.g. water treatment, alkali treatment, removal of tannin by addition of absorbants, formalin treatment and urea supplementation. Significant progress in removing tannins from feed has been made in recent years. However, some aspects of their economical field application remain to be elucidated, namely the cost of chemicals used, loss of dry matter during the removal process (Kumar & Singh, 1984), and the practical application of the process.

Recently, great progress was made with ammoniation of grain sorghum to neutralize the detrimental effects of tannin (Price, Butler, Featherson & Rogler, 1978; Ford & Hewitt, 1979a; Ford & Hewitt, 1979b; Price, Butler, Rogler & Featherson, 1979; Reichert, Flemming & Schwab, 1980). However, most of these techniques are not particularly practical, entailing moistening the grain, which complicates the process. Recently, Swiegers, Davies, Kühn & Slabbert (1987) described a process of thermal ammoniation using the commercial An-Stra-Verter® oven in which they used both whole and ground sorghum at two moisture levels, which were treated at four different ammoniation levels. They found that the physical condition of the grain had no influence on the

results, whereas an increase in moisture content resulted in a decrease in tannin content, but with no effect on digestibility. They concluded that ammoniation at a level of 1,5% NH_3 in the atmosphere resulted in the best deactivation of tannin, reducing the tannin content of BPS from 1,33 to 0,33% and improving *in vitro* digestibility by 6%. Brand, Hayes, Erasmus & Siebrits (1989), using the same procedure, found with roosters that thermal ammoniation improved dry matter (DM) digestibility by 4,7%, true metabolizable energy (TME) content by 1,1 MJ/kg and true lysine and methionine availability by 25 and 51,3% respectively. Polyphenol content was reduced from 1,24 to 0,55%.

This study was therefore conducted to determine the effect of thermal ammoniation and heat treatment of BPS on (i) apparent N digestibility and apparent N retention across the entire digestive tract as well as up to the terminal ileum, (ii) true N digestibility and true N retention across the entire digestive tract and up to the terminal ileum, and (iii) to evaluate the effect of NH_3-treated and untreated high-tannin grain in the diet on the performance of growing pigs.

Experimental Procedures

Digestion trial

Grain sorghum with a polyphenol content of 1,24% was used in this study. The polyphenol content was determined by the modified Jurumanis procedure as described by Daiber (1975). The sorghum was milled through a 3-mm screen, divided into three batches and treated as follows:

1. BPS (no treatment applied).
2. BPS thermally ammoniated in a commercial An-Stra-Verter® oven (NH_3BPS) at a level of 15 g NH_3 /kg DM for 24 h at 90°C (Brand *et al.*, 1989).
3. The same process as in 2, but no ammonia gas was let into the chamber (HBPS).

A nitrogen-free source (NFD), consisting of maize starch mixed with wheat straw to contain the same crude fibre content as the above sources, was used to correct the protein digestibility values for endogenous N contribution.

Sixteen Large White boars with a mean livemass of 40 kg were used as experimental animals. Eight of the boars were modified surgically according to the ileo-rectal anastomosis technique as suggested by Fuller & Livingstone (1982) and used by Picard, Bertrand, Genin & Maillard (1984), Schumann, Souffrant & Gebhardt (1986) and Henning, Noel, Hermann, Wünsche & Mehnert (1986). The procedure was used to collect digesta from the distal small intestine without any cannulation. The terminal ileum was transected and anastomosed to the side of the descending colon just proximal to the rectum. Ileal digesta was obtained from the anus. Following surgery, the pigs were allowed a 14-day recuperation period during which time they had free access to a 18% crude protein (CP) sorghum diet.

Thereafter, the eight normal and the eight modified pigs were randomly allocated to the different treatments (BPS, HBPS, NH_3BPS and a NFD supplemented with a commercial mineral and vitamin mixture). Four, 4 × 4 latin-square designs were used. Pigs were subjected to a 14-day trial period consisting of a 7-day preliminary period and a 7-day collection period, during which time faeces and urine were collected, while pigs were housed in metabolism crates. Pigs had free access to water at all times. A daily amount of 1500 g air-dry meal was fed to each pig in two equal portions at 08h00 and 13h00. Procedures followed in collection and analyses of faeces and urine samples were described in detail by Kemm & Ras (1971).

Diets, as well as urine and faeces samples, were chemically analysed for DM and nitrogen by standard AOAC methods (AOAC, 1984). Gross energy determinations were carried out on a CP 400 adiabatic bomb calorimeter. True protein digestibility was determined by subtracting the endogenous secretions, derived when the animals were fed the protein-free diet, from the protein excreted on the three dietary treatments.

Differences between treatment means were tested for significance by analysis of variance (Snedecor & Cochran, 1980).

Growth trial

The growth trial was carried out with 20 Large White × Landrace × Duroc pigs (10 gilts and 10 boars), approximately 69 days of age, and with a livemass of 21,9 ± 4,3 kg. They were individually housed in flat-deck type cages (1,6 m × 1 m), fitted with a self-feeder and equipped with an automatic water nipple. The room temperature was not controlled and fluctuated between 20° and 30°C. The pigs were randomly allotted to the two experimental treatments. The experimental diet, containing either NH_3BPS or untreated BPS as grain source (Table 1), was fed *ad libitum* to 10 pigs per diet (5 of each sex). The trial ended when the pigs were slaughtered at a livemass of 89,4 ± 3,0 kg. Feed intake and livemass were measured every four days. The allometric autoregressive model for description of growth as proposed by Roux (1976), and described by Siebrits (1986), was used to calculate mean livemass gains for the growth interval 30 — 90 kg live mass. The procedures followed were described in detail by Kemm *et al.* (1984).

Results and Discussion

The effect of different treatments on the chemical composition of BPS is presented in Table 2. Treatment with NH_3 reduced the polyphenol content of the grain by 55,6%, while the CP content of BPS increased from 11,5 to 13,6%. Heat treatment *per se* led to a small increase in CP content (2,1%) and a small decrease in tannin content (8,6%). This was possibly due to residual ammonia in the oven. Brand and Cloete (1985) also found with the heat treatment of whole oats grain that the N content of the grain was increased, although no ammonia was led into the chamber of the An-Stra-Verter® oven. The decrease in tannin content due to heat treatment was rather small, which confirmed the results of Glennie, Daiber & Taylor (1982), who

Table 1 Composition of experimental diets on an air-dry basis (%)

Ingredient	Amount
Sorghum[a]	60,3
Wheaten bran	18,0
Soyabean oilcake	13,4
Fish meal	4,8
Fine salt	1,0
Feed lime	1,9
Synthetic lysine	0,3
Minerals & vitamins	0,2
Composition (calculated)	
Protein	16,0%
Lysine	0,9%
Methionine & cystine	0,5%
Tryptophan	0,2%
DE	13,2 MJ/kg
Crude fibre	6,3%
Fat	6,5%
Ca	0,8%
P	0,6%

[a] Respectively untreated bird-proof and thermal ammoniated grain sorghum for the two different diets.

Table 2 Chemical composition[a] of the test components

Treatment	Dry matter (%)	Crude protein (%)	Tannin (%)
BPS	90,16	11,50	1,24
HBPS	91,32	11,75	1,14
NH_3BPS	90,22	13,63	0,55

[a] On DM basis.

concluded from their study that dry-heating of sorghum grain did not reduce the amount of assayable tannins.

Energy metabolism data

Energy metabolism data for the normal and surgically modified pigs are summarized in Table 3. Data of animals which wasted more than 200 g feed per day, were discarded. Ammoniation improved DM digestibility, energy digestibility, digestible energy (DE) and metabolizable energy (ME) content of BPS significantly ($P \leq 0,01$) by 5,5, 8,3, 12,7 and 12,4% respectively. DM digestibility, energy digestibility and DE content were slightly raised by heat treatment, while ME content was significantly ($P \leq 0,05$) improved by 6,2%. In the case of the ileo-rectal anastomosed pigs, DM digestibility, energy digestibility, DE and ME contents were respectively improved by 10,8, 14,3, 18,6, and 19,6% by thermal ammoniation, whereas heat treatment *per se* led to an improvement of 5,8, 9,1, 12,4, and 14%. These improvements found with thermal ammoniation were

Table 3 Energy metabolism data for the three different diets for normal and surgically modified pigs

	Experimental diets		
Experimental animals	BPS	HBPS	NH_3BPS
Normal pigs			
DM intake, g DM/day	1320	1332	1332
GE intake, MJ/day	22,4 ± 0,4	23,3 ± 0,4	23,4 ± 0,3
DM digestibility, %	$82,4^{1}$ ± 3,4	84,4 ± 2,0	$86,9^{2}$ ± 1,4
Energy digestibility, %	$79,3^{1}$ ± 4,1	$82,0^{a}$ ± 2,0	$85,9^{b2}$± 1,9
DE, MJ/kg DM	$13,4^{1}$ ± 0,7	$14,3^{a}$ ± 0,4	$15,1^{b2}$± 0,3
ME, MJ/kg DM	$12,9^{a1}$± 0,7	$13,7^{b1}$± 0,4	$14,5^{2}$± 0,4
Ileo-rectal anastomosed pigs			
DM intake, g DM/day	1266	1313	1330
GE intake, MJ/day	21,5 ± 1,7	23,0 ± 0,6	23,3 ± 0,1
DM digestibility, %	70,7 ± 4,3	74,8 ± 0,6	78,4 ± 3,3
Energy digestibility, %	66,6 ± 8,7	72,7 ± 4,2	76,1 ± 3,4
DE, MJ/kg DM	$11,3^{a}$± 1,0	$12,7^{a}$± 0,1	$13,4^{b}$± 0,6
ME, MJ/kg DM	10,7 ± 1,0	12,2 ± 0,2	12,8 ± 0,7

[a,b] Denote significant ($P \leq 0,05$) differences within rows.
[1,2] Denote significant ($P \leq 0,01$) differences within rows.

slightly higher than the improvements of 2,5% in DM digestibility found by Reichert *et al.* (1980) with rats (BPS treated with 0,25 N NH_4OH for 48 h at 25°C) and the improvements with thermal ammoniation of 4,7% in DM digestibility and 8,7% in true ME found by Brand *et al.* (1989) in studies with roosters. The improvements in digestibility and energy content are mainly due to the reduction in tannin content. Thermal ammoniation also causes ammonolysis of ester groups (Buettner, Lechtenberg, Hendrix & Hertel, 1982), which further improves digestibility. Savage, Smith & Briggs (1980) found that the micronization of sorghum resulted in markedly higher *in vitro* starch availability. This affect, probably contributed to heat, may also play a role in the improved digestibility of heat and NH_3-treated BPS. The improved digestibility found with heat-treated grain may also be a result of the small decrease in tannin content.

The proportion of DM digested in the large intestine decreased from 14,2 for BPS to 11,3 and 9,8% for HBPS and NH_3BPS respectively, while energy digestion decreased from 16% to 11,3 and 11,4%. It appears that treatment with either heat or NH_3 improved disappearance from the small intestine, which was probably due to the improvement in digestibility. The proportion of DM and energy disappearing from the large intestine for the BPS diet (14,2 and 16%) was in accordance with the 14,4 and 17% found by Keys & De Barthe (1974) and Haydon, Knabe & Tanksley (1984), who used a 70% and a 76,6% sorghum diet respectively. It is clear, from Table 4, that the differences between estimates of DE content, as measured with the normal and ileo-rectal anastomosed pigs, were 16, 11,2 and 11,2% for the BPS, HBPS and NH_3BPS diets respectively, while the corresponding differences for ME content were 17, 10,9 and 11,7%.

Table 4 Difference in apparent energy and dry matter digestibility between the entire digestive tract and at the terminal ileum

Item	Experimental diets		
	BPS	HBPS	NH_3BPS
Difference in DM digestibility, %	11,7[a]	9,6[a]	8,5[b]
Difference in energy digestibility, %	12,7[a]	9,3[a]	9,8[b]
Difference in DE, MJ/kg	2,1[a]	1,6[a]	1,7[b]
Difference in ME, MJ/kg	2,2[a]	1,5[a]	1,7[c]

[a] Denote significant ($P \leq 0,01$) differences between faecal and ileal values.

[b] Denote significant ($P \leq 0,05$) differences between faecal and ileal values.

[c] Denote significant ($P \leq 0,10$) differences between faecal and ileal values.

Nitrogen metabolism data

The faecal and ileal nitrogen metabolism data for the different diets are summarized in Tables 5 and 6 respectively. Relatively large differences were found between individual pigs in the different treatments, especially in the case of the ileo-rectal anastomosed pigs. These were possibly due to factors such as the low food intake, variation in food intake, the relatively high and variable moisture content of digesta and the possible influence of tannin in the diets on N digestion and retention. N intake differed significantly ($P \leq 0,01$) between diets, which was the result of the increase in N due to ammoniation. Thermal ammoniation significantly ($P \leq 0,05$) increased the apparent faecal digestibility of N from 59,9 to 70,6%, whereas heat *per se* caused an improvement of 2% (see Table 5). The apparent ileal N digestibility of BPS, however, was significantly ($P \leq 0,01$) improved

Table 5 Faecal nitrogen metabolism data for the different diets

Item	Experimental diets		
	BPS	HBPS	NH_3BPS
DM intake, g/day	1315	1330	1331
Sorghum N content, %	1,82	1,88	2,18
N intake, g/day	23,9[1] ± 0,5	25,0[2] ± 0,5	29,0[3] ± 0,4
N excretion:			
1. Faeces, g/day	9,7 ± 2,1	9,6 ± 1,3	8,6 ± 1,6
2. Urine, g/day	9,1[1] ± 1,9	10,71 ± 2,1	14,6[2] ± 2,3
3. Total, g/day	18,8 ± 0,2	20,3 ± 0,9	23,2 ± 1,5
Apparent N digestibility, %	59,9[a] ± 8,4	61,5[a] ± 4,8	70,6[b] ± 5,5
Apparent N retention, g/day*	5,2 ± 0,5	4,7 ± 0,8	5,9 ± 1,3
Apparent N retention, % of N intake	21,5 ± 1,9	18,8 ± 3,4	20,3 ± 4,6
Apparent N retention, % of digested N	36,7 ± 6,0	31,0 ± 7,9	28,9 ± 6,8
N excretion with NFD**:			
1. Faeces, g/day	0,94 ± 0,3	0,94 ± 0,3	0,94 ± 0,3
2. Urine, g/day	1,94 ± 0,6	1,94 ± 0,6	1,94 ± 0,6
3. Total, g/day	2,8 ± 0,8	2,8 ± 0,8	2,8 ± 0,8
True N digestibility, %	63,3[a] ± 8,4	65,1[a] ± 4,8	73,7[b] ± 5,5
True N retention, g/day***	7,9 ± 0,5	7,4 ± 0,9	8,7 ± 1,3
True N retention, % of N intake	32,8 ± 1,7	29,6 ± 3,4	29,9 ± 4,7
True N retention, % of digested N	52,5 ± 7,3	45,9 ± 8,5	40,8 ± 7,0
Biological value****	0,50 ± 0,1	0,46 ± 0,1	0,41 ± 0,1
Corrected N intake*****, g/day	24,0 ± 0,5	24,2 ± 0,4	24,2 ± 0,3
Corrected apparent N digestibility, %	59,5 ± 8,4	60,2 ± 5,0	64,8 ± 6,5
Apparent N retention, % of corrected N intake	21,6 ± 1,9	19,4 ± 3,5	24,3 ± 5,5
Corrected true N digestibility, %	63,3 ± 8,4	64,0 ± 5,0	68,5 ± 6,6
True N retention, % of corrected N intake	32,8 ± 1,7	30,5 ± 3,5	35,9 ± 5,6
Corrected biological value	0,50 ± 0,1	0,48 ± 0,10	0,53 ± 0,1

* [N intake − (faecal N + urinary N)].

** Nitrogen free diet.

*** [N intake − {(faecal N + urinary N) − (EUN + MFN)}].

**** Biological value: $\frac{\text{N intake} - (\text{faecal N} - \text{MFN}) - (\text{urinary N} - \text{EUN})}{\text{N intake} - (\text{faecal N} - \text{MFN})}$

***** Dietary crude protein corrected for increased nitrogen due to ammoniation.

MFN Metabolic faecal nitrogen.

EUN Endogenous urinary nitrogen.

[a,b] Denote significant ($P \leq 0,05$) differences within rows.

[1,2,3] Denote significant ($P \leq 0,01$) differences within rows.

Table 6 Ileal nitrogen metabolism data for the different diets

Item	Experimental diets		
	BPS	HBPS	NH_3BPS
DM intake, g/day	1128	1273	1185
Sorghum N content, %	1,82	1,88	2,18
N intake, g/day	20,6[1] ± 5,0	23,9[2] ± 2,5	25,8[3] ± 3,8
N excretion:			
1. Faeces, g/day	15,4[a] ± 4,4	11,7 ± 2,6	8,8[b] ± 2,0
2. Urine, g/day	9,4 ± 3,0	8,9 ± 2,6	13,2 ± 4,8
3. Total, g/day	24,8 ± 6,3	20,5 ± 4,7	22,0 ± 6,6
Apparent N digestibility, %	25,5[1] ± 6,0	51,4[2] ± 9,0	66,0[3] ± 4,2
Apparent N retention, g/day*	–4,3 ± 2,2	3,4[2] ± 2,8	3,8[2] ± 3,6
Apparent N retention, % of N intake	–21,0[1] ± 9,6	15,0[2] ± 12,9	16,1[2] ± 15,2
Apparent N retention, % of digested N	–87,3[1] ± 43,9	26,9[2] ± 24,3	23,6[2] ± 21,4
N excretion with NFD**:			
1. Faeces, g/day	1,92 ± 0,4	1,92 ± 0,4	1,92 ± 0,4
2. Urine, g/day	2,48 ± 0,9	2,48 ± 0,9	2,48 ± 0,9
3. Total, g/day	4,4 ± 0,8	4,4 ± 0,8	4,4 ± 0,8
True N digestibility, %	35,41 ± 7,6	59,5[2] ± 9,1	73,6[3] ± 4,8
True N retention, g/day***	0,16[1] ± 2,2	7,9[2] ± 2,8	8,3[2] ± 3,6
True N retention, % of N intake	1,8[1] ± 10,3	33,6[2] ± 14,4	33,5[2] ± 17,1
True N retention, % of digested N	0,95[1] ± 18,6	46,0[2] ± 16,5	54,9[2] ± 18,7
Biological value****	0,03[1] ± 0,3	0,55[2] ± 0,2	0,45[2] ± 0,2
Corrected N intake*****, g/day	20,6 ± 5,0	23,2 ± 2,5	21,5 ± 3,2
Corrected apparent N digestibility, %	25,4[1] ± 5,8	49,9[a2] ± 9,2	59,2[b2] ± 5,0
Apparent N retention, % of corrected N intake	–21,0[1] ± 9,5	15,5[2] ± 13,3	19,3[2] ± 18,3
Corrected true N digestibility, %	35,3[1] ± 7,6	58,2[a2] ± 9,4	68,3[b2] ± 5,7
True N retention, % of corrected N intake	1,8[1] ± 10,4	34,7[2] ± 15,0	40,1[2] ± 20,6
Corrected biological value	0,04[1] ± 0,3	0,58[2] ± 0,2	0,58[2] ± 0,3

* [N intake − (faecal N + urinary N)].

** Nitrogen free diet.

*** [N intake − {(faecal N + urinary N) − (EUN + MFN)}].

**** Biological value: $\frac{\text{N intake} - (\text{faecal N} - \text{MFN}) - (\text{urinary N} - \text{EUN})}{\text{N intake} - (\text{faecal N} - \text{MFN})}$

***** Dietary crude protein corrected for increased nitrogen due to ammoniation.

MFN Metabolic faecal nitrogen.

EUN Endogenous urinary nitrogen.

[a,b] Denote significant ($P \leq 0,05$) differences within rows.

[1,2,3] Denote significant ($P \leq 0,01$) differences within rows.

from 25,5 to 51,4 and 66% by heat and ammoniation respectively. The improvement in N digestibility was a result of the lower excretion rate of N in the faeces and ileal digesta (Tables 5 & 6). The same trend occurred in the case of true N digestibility, where the true faecal digestibility of N was significantly ($P \leq 0,05$) improved from 63,3 to 73,7% by thermal ammoniation, while the true ileal digestibility was significantly ($P \leq 0,01$) improved from 35,4 to 59,5 and 73,6% by heat and thermal ammoniation respectively. The improvement in apparent N digestibility due to ammoniation found in our studies with normal pigs (18,6%) was considerably lower than the 49,2% improvement found by Reichert *et al.* (1980), in studies with rats, in which 0,025 N NH_4OH was used. The improvement in true N digestibility found with the ileo-rectal anastomosed pigs (107,9%) was, however, considerably higher than the 38,9% improvement found by Ford & Hewitt (1979b), who treated their grain with 1,97% NH_3 and who used the chick ileal analysis procedure. The improvement in N digestibility due to heat contrasted strongly with the reduction in digestibility found by other researchers such as Mitaru & Blair (1984) and Mitaru, Reichert & Blair (1985). The latter found a 44% reduction in true digestible protein of boiled BPS, measured at the terminal ileum of broiler cockerels.

Apparent retention consequently increased from 5,2 to 5,9 g/day with thermal ammoniation despite a 60,4% increase in urinary N excretion ($P \leq 0,01$). The apparent N retention of untreated BPS (5,2 g/day) agreed well with the value of 4,9 g/day found by Kemm, Daiber & Ras (1981). The tendency of N excretion in urine to increase with treated grain occurred in both studies. True N retention increased from 7,9 to 8,7 g/day, although the difference was not significant. In contrast to this, the N retention, as measured in the ileal digesta,

represents a more accurate reflection of N metabolism, because the N absorbed in the caecum and colon of the pig was not used for protein synthesis but was excreted in the urine (Zebrowska, 1973 & 1975; Just, Jorgensen & Fernandez, 1981). Thermal ammoniation, as well as heat, significantly ($P \leq 0,01$) improved N retention from −4,3 to 3,4 and 3,8 g/day respectively, while true N retention was significantly ($P \leq 0,01$) improved from 0,16 to 7,9 and 8,3 g/day respectively (Table 6). Glennie *et al.* (1982) also stated that heat treatment of grain sorghum might affect N retention. They found that pigs retained N better from a diet of 70% sorghum grain when the grain was presented in a micronized form. It is clear, from data presented in Tables 5 and 6, that the N excreted in the faeces and ileal digesta decreased with thermal ammoniation, as a result of an improvement in DM digestibility.

N retention, measured with the faecal analysis method and expressed as a percentage of either N intake or digested N, decreased with thermal ammoniation, a finding which is in contrast to that found for NaOH treatment (Kemm & Ras, 1985), but in agreement to that found for paraformaldehyde treatment (Kemm *et al.*, 1981; 1984). This phenomenon is possibly due to the increase in NPN as a result of the treatments, and illustrates that digested N was, therefore, better utilized when untreated BPS was used, rather than HBPS and NH_3BPS. Hence N retention, measured by the ileal analysis method, expressed as a percentage of either N intake or digested N, showed a tendency to increase ($P \leq 0,10$) with both heat and NH_3 treatment, probably as a result of the low N retention measured at the terminal ileum for the BPS diet. The faecal N metabolism data, expressed in terms of the biological value, show values of 0,50, 0,46 and 0,41 for BPS, HBPS and NH_3BPS respectively, while the corresponding biological values, measured at the terminal ileum, were 0,03, 0,55 and 0,45. In the latter case, the difference was significant ($P \leq 0,01$) for treated grain.

Treatment of the grain increased the N content of the HBPS and NH_3BPS diets and, therefore, complicated the interpretation of results. If the N content of treated grain was taken to be equal to that of its untreated counterpart when calculating the results, treatment resulted in lower N digestibility values. The difference, when measured by the faecal analysis procedure (see Table 5), was not significant. Measurement at the terminal ileum showed that the difference between heat- and NH_3-treated BPS was only significant at the 5% level, instead of the 1% level, as found with the uncorrected data (Table 6). True N retention expressed as a percentage of the corrected N intake was 32,8, 30,5 and 35,9% for the BPS, HBPS and NH_3BPS diets respectively, when measured at the end of the entire digestive tract and 1,8, 34,7 and 40,1%, when measured at the end of the terminal ileum. The corrected biological values were 0,50, 0,48 and 0,53 respectively when calculated with faecal analysis data and 0,04, 0,58 and 0,58 when based on ileal analysis data. The difference between treated and untreated grain was highly significant ($P \leq 0,01$) in the latter case.

Table 7 presents the differences between faecal and ileal metabolism data. It is clear from the data that, with an improvement in N digestibility, the amount of N that disappeared in the large intestine decreased. It is also clear that thermal ammoniation improved digestion in the small intestine.

Table 7 Difference between faecal and ileal nitrogen metabolism data

	Experimental diets		
Item	BPS	HBPS	NH_3BPS
Difference in apparent N digestibility, %	34,0[a]	10,1[b]	4,6
Difference in apparent N retention, g/day	9,5[a]	1,3	2,1
Difference in true N digestibility, %	27,9[a]	5,6	0,1
Difference in true N retention, g/day	7,74[a]	−0,5	0,4
Difference in corrected apparent N digestibility, %	34,1[a]	10,3[c]	5,6
Difference in corrected true N digestibility, %	28,0[a]	5,8	0,2

[a] Denote significant ($P \leq 0,01$) differences between faecal and ileal values.
[b] Denote significant ($P \leq 0,05$) differences between faecal and ileal values.
[c] Denote significant ($P \leq 0,10$) differences between faecal and ileal values.

Growth trial

The statistical parameters calculated from the growth data were subjected to a two-way analysis of variance. The mean values of the statistical parameters used are presented in Table 8. A significant difference ($P \leq 0,05$) was found between sexes in the value of ρ, but no significant differences were found in the α and μ values or the slope (b) and intercept (a) values between treatments or sex. The parameters in Table 8 were used to

Table 8 Statistical parameters used in calculating the data presented in Table 9

	Statistical parameters				
	$\bar{\rho}$	$\bar{\alpha}$	$\bar{\mu}$	$\bar{a}$	$\bar{b}$
Treatment	ln/4 days	ln (MJ)	ln (MJ)	DE*×mass	DE×mass
Boars					
Untreated BPS	0,941	8,860	6,379	0,738	−1,391
NH_3-treated BPS	0,943	8,733	6,357	0,727	−1,315
Gilts					
Untreated BPS	0,934	8,720	6,391	0,699	−1,191
NH_3-treated BPS	0,940	8,784	6,398	0,700	−1,165

ρ Slope of autoregression.
α Asymptote of cumulative DE intake.
μ Mean initial ln (cumulative DE intake) value.
a Mean intercept of ln (livemass) – ln (cumulative DE) regressions.
b Mean slope of ln (live mass) – ln (cumulative DE) regressions.
* Digestible energy (MJ/kg).

calculate separate values for DM intakes, gain in live mass and utilization efficiencies of feed of each of the two sexes within a treatment. Data in Table 9 represent values calculated for each treatment. The pigs fed treated grain consumed 5% less DM, had 2% poorer feed conversion ratios and gained 5% less in livemass than pigs fed untreated grain. The differences were not significant. Gilts in both treatments gained significantly ($P \leq 0,01$) less weight per day, and had significantly ($P \leq 0,01$) poorer feed conversion ratios than the boars (see Table 9).

Table 9 Means ± *SD* (n = 5) for growth, DM intake and feed utilization data calculated for the growth interval 30 — 90 kg livemass for 10 gilts and 10 boars of Large White × Landrace × Duroc-type pigs

	Diet	
Measurement	Untreated BPS	NH_3-treated BPS
Livemass gain (g/day)		
Boars	896[a] ± 30	782[a] ± 101
Gilts	735[b] ± 60	773[b] ± 72
Treatment means	816 ± 94	777 ± 88
	(100)	(95)
Feed utilization (kg/kg gain)		
Boars	2,87[a] ± 0,10	2,95[a] ± 0,19
Gilts	3,43[b] ± 0,12	3,28[b] ± 0,24
Treatment means	3,06 ± 0,46	3,12 ± 0,27
	(100)	(102)
DM intake (g DM/day)		
Boars	2573 ± 125	2289 ± 180
Gilts	2514 ± 188	2527 ± 176
Treatment means	2544 ± 162	2408 ± 214
	(100)	(95)

[a,b] Denote significant ($P \leq 0,01$) differences within columns.

Conclusions

Treatment of sorghum with ammonia increased the N content and complicated interpretation of the results. It can be assumed that this ammonia was excreted as urea. To correct interpretations of the digestibility coefficients for CP in the diets, it was necessary to adjust N intake to exclude N contribution due to ammoniation. However, it can be concluded that heat as well as thermal ammoniation, with or without correction for NPN contribution, had an advantageous effect on the energy and nitrogen metabolism of pigs fed high-tannin sorghum. This study thus confirms earlier results (Brand *et al.*, 1989), that thermal ammoniation improves the digestibility of BPS. However, it contrasted strongly with results of other researchers (Mitaru *et al.*, 1985; Mitaru & Blair, 1984; Price, Hagerman & Butler, 1980) who found that heat had a deleterious effect on the digestibility of BPS. The improvement found in this study was possibly due to the effect of residual ammonia in the oven during heat treatment of the grain, which also explains the increase in nitrogen and reduction in tannin content.

The improvement in energy and nitrogen metabolism of high-tannin sorghum due to ammoniation was, however, not expressed in terms of a higher growth rate and a better feed efficiency. This phenomenon may be attributed to several reasons such as a poor understanding of the mechanism by which tannin depresses protein utilization, and the mechanisms by which the different treatments inactivate tannin. It is, therefore, possible that the poor growth and feed efficiency may be attributed to different reactions which could occur during treatment. The Maillard reaction between the free carboxyl groups of reducing sugars and the free amino group of lysine (Hurrell & Carpenter, 1974) occurs when temperatures are high (± 90°C) with moderate moisture (Mauron, 1972). Sulphur-containing amino acids, especially cystine and cysteine, are also rapidly degraded when the protein in food is heated (Bjarnason & Carpenter, 1970). Alkali treatment of proteins, expecially when combined with heat, leads to the formation of lysinoalanine, involving cystine and lysine in the reaction (Bohak, 1964; De Groot & Slump, 1969). These linkages do not limit the adverse effect to only the involved amino acids, but also to the availability of other amino acids, resulting in depressed utilization of the treated grain.

Therefore, according to this study, it seems that thermal ammoniation, under these specific conditions of treatment, is unable to improve the nutritive value of BPS. However, it is possible that ammoniation at a lower treatment temperature, and / or at a higher moisture level, may have an advantageous effect on the nutritive value of BPS, considering the reduction of tannin content obtained by ammoniation. Although Swiegers *et al.* (1987) did not find any difference between milled and whole grain with respect to the efficiency of the ammonia treatment, it is also possible that treatment of whole grain may result in a bigger reduction of tannin content. According to Glennie (1988) the more densely-packed, milled material is less pervious to ammonia gas than intact grain. This may result from a wide dispersion of tannins in the milled material, in contrast to their concentration in the well-defined subcutaneous layer of the intact grain. In the dispersed form they are therefore more reactive and more exposed to ammonia treatment.

Acknowledgements

The authors thank Mrs J. Behrens, Mrs H. Groenewald and Mr A.C. Adams for chemical analysis and energy determinations, Mr M.N. Ras for assistance with the digestion trial and the statistical analyses, Dr E.H. Kemm for valuable guidance with the planning and criticism of the experiment, Newtech Manufacturers for treatment of the grain and Dr J.G. van der Walt for performing the surgery on the pigs. Messrs T. Modungwana and Z. Thwala are thanked for the feeding and care of the animals.

References

AOAC, 1984. Official methods of analysis (13th edn.). Association of Official Analytical Chemists, Washington DC.

BJARNASON, J. & CARPENTER, K.J., 1970. Mechanisms of heat damage in proteins. 2. Chemical changes in pure proteins. *Br. J. Nutr.* 24, 313.

BOHAK, Z., 1964. N^{ϵ} –(DL–2–amino–2–carboxy-ethyl)–L–lysine, a new amino acid formed with alkali treatment of proteins. *J. Biol. Chem.* 239, 2878.

BRAND, A.A. & CLOETE, S.W.P., 1985. Personal communication. Winter Rainfall Region, Private Bag, Elsenburg 7607, Republic of South Africa.

BRAND, T.S., ERASMUS, JANA S., SIEBRITS, F.K., & HAYES, J.P., 1989. Effect of thermal ammoniation and heat treatment of high-tannin grain sorghum on the TME value for roosters and relative nutritive value for rats. *S. Afr. J. Anim. Sci.* 19, 125.

BEUTTNER, M.R.,, LECHTENBERG, V.L., HENDRIX, K.S. & HERTEL, J.M., 1982. Composition and digestion of ammoniated tall fescue (*Festuca arundinacea* cv. Shreb) hay. *J. Anim. Sci.* 54, 173.

DAIBER, K.H., 1975. Enzyme inhibition by polyphenols of sorghum grain and malt. *J. Sci. Food Agric.* 26, 1399.

DE GROOT, A.P. & SLUMP, P., 1969. Effects of severe alkali treatment of proteins on amino acid composition and nutritive value. *J. Nutr.* 98, 45.

DESHPANDE, S.S., CHERYAN, M. & SALUNKHE, D.K., 1986. Tannin analysis of food products. *CRC Critical Reviews Food Sci. Nutr.* 24(4), 401.

FORD, J.E. & HEWITT, D., 1979a. Protein quality in cereals and pulses. 3. Bioassays with rats and chickens on sorghum (*Sorghum vulgare* Pers.), barley and field beans (*Vicia faba* L.). Influence of polyethylene glycol on digestion of the protein in high-tannin grain. *Br. J. Nutr.* 42, 325.

FORD, J.E. & HEWITT, D., 1979b. Protein quality in cereals and pulses. 2. Influence of polyethylene glycol on the nutritional availability of methionine in sorghum (*Sorghum vulgare* Pers.), field beans (*Vicia faba* L.) and barley. *Br. J. Nutr.* 42, 317.

FULLER, M.F. & LIVINGSTONE, R.M., 1982. Annual report of studies in Animal Nutrition and Allied Sciences. Rowett Research Institute, Vol 39.

GLENNIE, C.W., 1988. Personal communication. Council for Scientific and Industrial Research, Pretoria.

GLENNIE, C.W., DAIBER, K.H. & TAYLOR, J.R.N., 1982. Reducing the tannin content of sorghum grain by heat. *S. Afr. Food Review* June 1982, p. 51.

HAYDON, K.D., KNABE, D.A. & TANKSLEY, T.D., 1984. Effects of level of feed intake on nitrogen, amino acid and energy digestibilities measured at the end of the small intestine and over the total digestive tract of growing pigs. *J. Anim. Sci.* 59, 717.

HENNING, U., NOEL, R., HERMANN, U., WÜNSCHE, J. & MEHNERT, E., 1986. Nutritional studies on pigs with ileorectal anastomosis. *Arch. Anim. Nutr.* 36:7, 585.

HURRELL, R.F. & CARPENTER, K.J., 1974. Mechanisms of heat damage in proteins. 4. The reactive lysine content of heat damaged material as measured in different ways. *Br. J. Nutr.* 32, 589.

JUST, A., JORGENSEN, H. & FERNANDEZ, J.A., 1981. The digestive capacity of the ceacum-colon and the value of nitrogen absorbed from the hindgut for protein synthesis in pigs. *Br. J. Nutr.* 32, 479.

KEMM, E.H. & RAS, M.N., 1971. The use of dried molasses in porker rations. *S. Afr. J. Anim. Sci.* 1, 9.

KEMM, E.H. & RAS, M.N., 1985. A comparison between sodium hydroxide treated and untreated bird-proof sorghum in pig growth diets. *S. Afr. J. Anim. Sci.* 15, 1.

KEMM, E.H., DAIBER, K.H. & RAS, M.N., 1981. 'n Vergelyking tussen formaldehied behandelde en onbehandelde voëlproef graansorghum in varkgroeimeel. *S.-Afr. Tydskr. Veek.* 11, 7.

KEMM, E.H., RAS, M.N. & DAIBER, K.H., 1984. Nutrient digestibility and performance of pigs fed sorghum varying in polyphenol concentration and maize as grain sources. *S. Afr. J. Anim. Sci.* 14, 1.

KEYS, J.E. & DE BARTHE, J.V., 1974. Site and extent of carbohydrate, dry matter, energy and protein digestion and the rate of passage of grain diets in swine. *J. Anim. Sci.* 39, 57.

KUMAR, R. & SINGH, M., 1984. Tannins: Their adverse role in ruminant nutrition. *J. Agric. Food Chem.* 32, 447.

MAURON, J., 1972. Protein and amino acid functions. Ed. Bigwood, E.J., Pergamon Press, Oxford.

MITARU, B.N. & BLAIR, R., 1984. Comparative effects of cooking and high moisture storage of sorghums on protein digestibility in rats. *Nutr. Rep. Int.* 30, 397.

MITARU, B.N., REICHERT, R.D. & BLAIR, R., 1984. Nutritive value of reconstituted sorghum grains for weaning pigs. *J. Anim. Sci.* 58, 1211.

MITARU, B.N., REICHERT, R.D. & BLAIR, R., 1985. Protein and amino acid digestibilities for chickens of reconstituted and boiled sorghum grains varying in tannin contents. *Poultry Sci.* 64, 101.

PICARD, M., BERTRAND, GENIN, SOLANGE, F. & MAILLARD, M., 1984. Digestibilité des asides aminés. Intérêt de la technique du Shunt ileo-rectal chez le porc. *Journées rech. Porcine en France* 16, 355.

PRICE, M.L., BUTLER, L.G., FEATHERSON, W.R. & ROGLER, J.C., 1978. Detoxification of high-tannin sorghum grain. *Nutr. Rep. Int.* 17, 229.

PRICE, M.L., BUTLER, L.G., ROGLER, J.C. & FEATHERSON, W.R., 1979. Overcoming the nutritional harmful effects of tannin in sorghum grain by treatment with inexpensive chemicals. *J. Agric. Food Chem.* 27, 441.

PRICE, M.L., HAGERMAN, ANN E. & BUTLER, L.G., 1980. Tannin in sorghum grain: Effect of cooking on chemical assays of antinutritional properties in rats. *Nutr. Rep. Int.* 21, 761.

REICHERT, R.D., FLEMMING, S.E. & SCHWAB, D.J., 1980. Tannin deactivation and nutritional improvement by anaerobic storage of H_2O, HCl or NaOH treated grain. *J. Agric. Food Chem.* 28, 824.

ROUX, C.Z., 1976. A model for the description and regulation of growth and production. *Agroanimalia* 8, 83.

SAVAGE, G.P., SMITH, W.C. & BRIGGS, P.A., 1980. A note on the influence of the micronization and polyethylene glycol on the nutritional value of brown sorghum for growing pigs. *Anim. Prod.* 30, 157.

SCHUMANN, B., SOUFFRANT, W.B. & GEBHARDT, G., 1986. Untersuchungen zur stickstoff- und aminosäurenresorption im dünndarm von wachsenden schweinen. *Arch. Anim. Nutr.* 6, 491.

SIEBRITS, F.K., 1986. Application of the allometric autoregressive growth description in studies of growth and body composition. *Pig News and Information* 7, 413.

SNEDECOR, G.W. & COCHRAN, W.G., 1980. Statistical methods (7th edn.). The Iowa State University Press, Ames, Iowa, USA.

SWIEGERS, J.P., DAVIES, S.J., KÜHN, G. & SLABBERT, N., 1987. Bepaling van die optimum behandelingstoestande vir die ammonisering van graansorghum. 26ste Kongres van die S.-Afr. Ver. vir Diereproduksie. Pretoria, 6—9 April 1987.

ZEBROWSKA, T., 1973. Digestion and absorption of nitrogenous compounds in the large intestine of pigs. *Rocz. Nauk. Rol. B.* 95, 85.

ZEBROWSKA, T., 1975. The apparent digestibility of nitrogen and individual amino acids in the large intestine of pigs. *Rocz. Nauk. Rol. B.* 87, 117.