Source of the Variation in Meat and Bone Meal Nutritional Quality

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ABSTRACT : The gross composition, gross amino acid content, apparent ileal amino acid digestibility and apparent ileal digestible amino acid content from 64 commercially produced meat and bone meals were statistically analysed. The samples were produced by 22 plants over a 2.5 year period with eight plants using batch dry rendering and 14 plants using low temperature rendering. A linear model with method and time of year (period) as fixed effects, plant within method as a random effect and sheep percent as a covariate was fitted to the composition data. The majority of the variation in the gross composition, amino acid digestibility and digestible amino acid content was explained by differences between plants using the same method. Neither rendering season nor origin of the raw materials contributed significantly to the observed variation in meat and bone meal protein quality. Rendering method (low temperature or batch rendering) had a significant effect on the variation observed in gross fat content, gross energy content, pepsin nitrogen digestibility, protein solubility and total lanthionine content. The digestibility of a number of amino acids and the apparent digestible content of arginine, cysteine, aspartic acid, proline and hydroxyproline were also significantly affected by rendering method. On average, batch dry and low temperature rendering systems produce meat and bone meals of similar nutritional quality. The variation between plant and within plant, however, is large, indicating that purchasing meat and bone meal from the same plant does not guarantee a consistent quality. ***(Asian-Aust. J. Anim. Sci. 2004. Vol 17, No. 1 : 94-101)***

Key Words : Meat and Bone Meal, Nutritional Quality, Variability, Amino Acid Digestibility, Rendering

INTRODUCTION

Meat and bone meal is a co-product of the meat industry and its composition and protein quality are affected by the raw materials used, the rendering processes used (batch dry, continuous dry or low temperature rendering) and the processing conditions employed during rendering. Skurray and Herbert (1974) showed that there is a marked difference in the composition and protein quality of meat meals derived from hard (sheep heads, beef heads and trotters) compared to soft offals (sheep guts and rumens). Dawson and Savage (1983) found that the protein quality (true ileal digestibility, biological value (BV) and net protein utilisation (NPU)) of meat and bone meals were more affected by type of offal than the rendering process used. Johnson and Parsons (1997) investigated the effect of raw material source on the protein efficiency ratio (PER) and net protein ratio (NPR) of growing chickens and reported that raw material source influenced both PER and NPR values for animal meals. The latter authors also found that ash content and processing temperature affect the PER and NPR of meat and bone meals.

Several authors have investigated the role of the processing conditions used in the production of meat and bone meal (Herbert et al., 1974; Dawson and Savage, 1983; Batterham et al., 1986; Knabe et al., 1989; Donkoh et al., 1994; Shirley and Parsons, 2000). In general, increased pressure and temperature lowers the protein quality of meat and bone meals. Herbert et al. (1974) found, however, that meat and bone meal produced under three different experimental processing conditions had no detrimental effect on the growth rate of chickens. Skurray and Herbert (1974) reported an increase in nutritive value of meat and bone meal derived from hard offals with prolonged pressure cooking. The effect of rendering method (batch dry, continuous dry and low temperature rendering) on the protein quality of meat and bone meal is confounded by the effects of the pressure and temperature used by the various methods. Haugen et al. (1985) reported an interaction between offal type and processing temperature for meat and bone meals produced by a commercial rendering plant.

In a recent study (Hendriks et al., 2002), we reported a large variability in the protein quality of meat and bone meals produced in New Zealand, believed to originate from the factors affecting the production of meat and bone meal as discussed above. The aim of the present study was to quantify the contribution of a number of factors including raw material origin, season and rendering system to the total variability in protein quality of commercially produced meat and bone meal.

MATERIALS AND METHODS

Meat and bone meals

A total of 94 meat and bone meal samples were obtained from 17 rendering companies throughout New Zealand over a 2.5 year period. The sampling procedure and origin of the samples have been described by Hendriks et al. (2002). The majority of samples were manufactured by one of two rendering methods, batch dry (BD) rendering and

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continuous low temperature (LT) rendering. A total of 64 samples for which complete data were available were used in the present study. The data recorded for each sample included type of rendering system, animal species origin of the raw materials, production date and gross chemical composition as supplied by the rendering company. The 64 meat and bone meal samples were produced over a nine-month period of the year, and data were combined into three 3 month periods with period 1 (start of season) from Sept to Nov, period 2 from Dec to Feb and period 3 from March to May (end of season). The composition of each meat and bone meal sample was recorded as the percentage of sheep (mutton and lamb), cattle (calves and beef) and other (including pork, fish, poultry and venison). The amount of the 'other' species was found to have no effect on the nutritional composition, and was therefore not included in the model. The percentage sheep in the meat and bone meal was inversely related to the percentage cattle, and had a significant effect on the nutritional composition; 'sheep percent' was used as a covariate as a representative description of meat and bone meal composition.

In a typical BD rendering system, raw materials are ground to less than 2.5 cm and batch-fed into steam-jacketed cookers. The material is heated under pressure before the fat is removed and the remaining material is dried (Ockerman and Hansen, 2000). The batch dry rendering systems used to produce the meat and bone meals in the present study were commercially operated. Cooking temperatures ranged from 100 to 130°C, with pressures in the region of 40 psi. Low temperature rendering systems, also called mechanical dewatering systems, render material at 60 to 90°C in a relatively short time (10 to 30 min) (Taylor et al., 1995; Ockerman and Hansen, 2000). Raw material is minced and passed to the cooker where the material is heated and the liquid tallow removed by a continuous screw press along with water, before being centrifuged. The remaining material (containing approximately 40% moisture) is then dried in a cooker. The low temperature rendering systems used to produce the meat and bone meals in the present study were all commercially operated. Rendering temperatures and times ranged from 85 to 95°C and 2 to 10 min, respectively. Drier temperatures and times of the defatted material ranged from 96 to 130°C and 20 min to >3 h (average 86 min), respectively.

Chemical analysis

All *in vitro* analyses were carried out as previously described by Hendriks et al. (2002). These included dry matter, ash, nitrogen (crude protein), sulphur, lipids, amino acids, gross energy, protein solubility, pepsin nitrogen digestibility and bone content. Compositional data determined by the rendering plant included: dry matter, crude protein, fat and ash.

Apparent ileal amino acid digestibility

The apparent ileal amino acid digestibility of the meat and bone meal samples was determined using weaned male Sprague Dawley rats as described in Hendriks et al. (2002). Briefly, the rats were housed in family weaning groups in cages and fed commercial rat pellets for 14 days. Rats were then transferred to individual cages and trained to eat a lactic casein-based synthetic diet for three weeks. After this training period the rats were fed the meat and bone meal diets as a single daily meal (3 h *ad libitum* access) for a further eight days. Six rats were used for the evaluation of each meat and bone meal sample. The meat and bone meal diets were formulated to contain 100 g crude protein and 65 g fat per kg of diet, with meat and bone meal as the sole source of protein, and maize oil contributing the extra fat. Chromic oxide (3 g kg^{-1}) was added to each meat and bone meal diet as an indigestible marker. The remainder of the diet comprised of minerals, vitamins, cellulose and corn flour (for composition see Hendriks et al., 2002). After eight days on the meat and bone meal containing diet, rats were euthanased, the digesta from the terminal ileum collected, and the pooled freeze-dried ileal digesta samples of the six animals subjected to chemical analyses. Apparent ileal digestibility was calculated for each amino acid in each meat and bone meal sample.

Statistical analyses

Gross composition data from the plant laboratory (where available) and analytical laboratory (Massey University, Palmerston North, New Zealand) were subject to correlation analysis (PROC CORR, SAS 1999). Repeatability was calculated as the ratio of the within plant variation over the sum of the within and between plant variances. The variance components were calculated after correction for the period factor (PROC VARCOMP, SAS 1999).

To examine the causes of the variation in the meat and bone meals, a number of descriptive variables were used. As all the plants were using only one rendering method (i.e. there was no plant with two different rendering systems), plant was set as a random effect within rendering method (plant (method)). A linear model with method and time of year (period) as fixed effects, plant (method) as a random effect and sheep percent as a covariate was fitted to the composition data. Before ANOVA, the data were tested for homogeneity of variance. Effects were considered significant at a probability level of 5%.

RESULTS

There was a highly significant ($p<0.001$) correlation between the gross compositional data from analyses carried

Table 1. The variation in nutrient composition, *in vitro* digestibility data, gross amino acid, amino acid nitrogen and sulphur amino acid content of 64 meat and bone meal samples

Component	Gross			Digestibility (%)			Digestible content (%)		
	Mean	SD[1]	CV[2]	Mean	SD	CV	Mean	SD	CV
Dry matter (%)	95.3	0.02	0.02						
Crude protein (N×6.25) (%)	56.7	5.8	10.3						
Fat (%)	10.0	2.9	29.0						
Ash (%)	28.1	7.1	25.3						
Gross energy (kJ/g)	17.2	2.1	12.2						
Pepsin N digestibility (%)	90.0	3.3	3.7						
Protein solubility (%)	25.4	16.1	64.4						
Bone content (ml)	57.2	15.2	26.6						
Sulphur (%)	0.38	0.14	36.8						
Essential amino acids (%):									
Arginine	3.97	0.39	9.8	74.1	10.5	14.2	2.95	0.57	19.3
Histidine	1.01	0.19	18.8	58.0	13.8	23.8	0.60	0.21	35.0
Isoleucine	1.54	0.27	17.5	71.8	9.1	12.7	1.12	0.29	25.9
Leucine	3.39	0.55	16.2	73.2	9.1	12.4	2.50	0.60	24.0
Lysine	2.92	0.43	14.7	74.3	9.3	12.5	2.19	0.50	22.8
Methionine	0.87	0.20	23.0	75.8	9.5	12.5	0.67	0.20	29.9
Phenylalanine	1.81	0.30	16.6	75.5	8.6	11.4	1.37	0.32	23.4
Threonine	1.88	0.31	16.5	59.4	11.1	18.7	1.12	0.34	30.4
Valine	2.34	0.36	15.4	70.2	9.5	13.5	1.65	0.41	24.8
Semi-essential amino acids (%):									
Cysteine	0.41	0.13	31.7	54.1	16.0	29.6	0.22	0.10	45.5
Tyrosine	1.29	0.25	19.4	70.8	10.1	14.3	0.92	0.26	28.3
Non-essential amino acids (%):									
Alanine	4.01	0.30	7.5	69.0	9.9	14.3	2.77	0.51	18.4
Aspartic acid	4.15	0.55	13.3	46.0	15.7	34.1	1.92	0.83	43.2
Glutamic acid	6.51	0.73	11.2	65.8	10.2	15.5	4.30	0.97	22.6
Glycine	6.93	0.63	9.1	59.6	11.6	19.5	4.10	0.89	21.7
Proline	4.41	0.33	7.5	60.9	11.0	18.1	2.66	0.53	19.9
Serine	2.13	0.27	12.7	54.8	11.9	21.7	1.17	0.34	29.1
Hydroxylysine	0.33	0.04	12.1	41.2	14.9	36.2	0.13	0.05	38.5
Hydroxyproline	2.60	0.44	16.9	58.3	13.1	22.5	1.49	0.37	24.8
Lanthionine	0.06	0.06	100.0	-	-	-	-	-	-
Amino acid nitrogen (%)	7.64	0.63	8.1	65.0	10.0	15.4	5.00	1.00	20.0
Sulphur amino acids (%)	1.28	0.30	24.2	67.6	10.7	15.8	0.89	0.28	31.5

[1] Standard deviation. [2] Coefficient of variation.

out by the rendering plant and by the analytical laboratory. Correlations for fat, crude protein and ash were 0.77, 0.79 and 0.89, respectively. There was a reasonable amount of variation within plants in the gross composition of the meat and bone meal, repeatabilities ranged from 0.14 to 0.88 (average 0.45). When each method was examined separately, a much lower repeatability was recorded for the LT rendering system compared with the BD rendering system. Repeatabilities in the LT rendering system for gross compositional data ranged from 0.00 to 0.88 (average 0.25) and the BD rendering system from 0.14 to 0.90 (average 0.53). Repeatabilities were much lower for the digestible amino acid content (overall 0.00 to 0.38, average 0.23; LT 0.00 to 0.43, average 0.18; BD 0.00 to 0.63, average 0.38) and the amino acid digestibility (overall 0.00 to 0.52, average 0.30; LT 0.00 to 0.26, average 0.11; BD 0.00 to 0.56, average 0.36).

The variation in nutrient composition and *in vitro* digestibility data of the 64 New Zealand meat and bone meal samples are presented in Table 1. There was a high variability for all the components measured, with the exception of dry matter and pepsin N digestibility.

The difference between BD and LT rendering systems in gross amino acid content of the 64 meat and bone meal samples as well as the factors contributing to the variation are shown in Table 2. Rendering plant within method was the major contributor to the variation in gross composition, explaining 42 to 82% (partial R^2) of the variation in the gross composition, and 42 to 77% of the variation in the amino acid content. Rendering method (BD and LT) explained a significant amount of the variation observed in the fat content (partial R^2: 36%), gross energy content (partial R^2: 12%) and protein solubility (partial R^2: 69%). Rendering method only explained 0 to 2% of the amino

Table 2. The variation between batch dry (BD) and low temperature (LT) rendering systems in the gross nutrient composition of 64 meat and bone meal samples, and the factors affecting the variation

	BD		LT		R^2	Partial R^2			
	LS mean	SE	LS mean	SE		Method	Plant (method)	Comp.[1]	Period
Dry matter (%)	95.61	0.24	95.25	0.19	75	2	72***	0	1
Crude protein (Nx6.25) (%)	56.69	0.65	57.39	0.50	86	0	67***	5***	13***
Fat (%)	11.82	0.37	8.81	0.28	80	36***	44***	0	0
Ash (%)	26.72	0.72	28.71	0.55	88	4***	82***	1*	1
Gross energy (kJ/g)	18.01	0.22	16.84	0.17	88	12***	75***	1	1
Pepsin N digestibility (%)	88.78	0.62	90.56	0.48	60	8*	46*	0	6
Protein solubility (%)	39.99	0.91	14.72	0.71	96	69***	26***	0	0
Bone content (ml)	57.06	2.40	54.79	1.85	71	0	62***	3*	6*
Sulphur (%)	0.35	0.02	0.41	0.02	67	4*	60***	3	1
Essential amino acids (%):									
Arginine	4.02	0.06	3.97	0.05	74	1	60***	2	11***
Histidine	1.01	0.04	1.03	0.02	79	0	71***	6**	1
Isoleucine	1.54	0.03	1.55	0.03	81	0	76***	3*	2
Leucine	3.39	0.07	3.44	0.05	84	0	77***	5**	2
Lysine	2.86	0.06	2.98	0.04	80	1	74***	4**	1
Methionine	0.85	0.03	0.91	0.03	65	0	59***	5	2
Phenylalanine	1.78	0.04	1.85	0.03	83	1	77***	3**	1
Threonine	1.92	0.04	1.88	0.03	79	1	70***	5**	3
Valine	2.33	0.05	2.37	0.04	76	0	71***	4*	1
Semi-essential amino acids (%):									
Cysteine	0.39	0.02	0.43	0.01	77	1	64***	3*	9**
Tyrosine	1.32	0.03	1.30	0.02	85	1	76***	6***	2
Non-essential amino acids (%):									
Alanine	4.00	0.06	4.03	0.04	57	1	55**	0	1
Aspartic acid	4.13	0.09	4.22	0.07	70	0	63***	4*	3
Glutamic acid	6.65	0.11	6.48	0.08	74	2	64***	4*	5*
Glycine	6.86	0.11	6.93	0.09	64	1	56**	1	5
Proline	4.48	0.07	4.37	0.05	55	2	48*	1	4
Serine	2.19	0.04	2.13	0.03	76	2	62***	5**	6*
Hydroxylysine	0.32	0.01	0.33	0.01	78	1	67***	7**	3
Hydroxyproline	2.61	0.07	2.55	0.05	72	0	65***	6**	1
Lanthionine	0.114	0.006	0.041	0.004	87	40***	42***	4***	1
Amino acid nitrogen (%)	7.66	0.09	7.67	0.07	74	0	65***	3	6*
Sulphur amino acids (%)	1.24	0.05	1.34	0.04	71	1	62***	43*	5*

[1] Composition of the meat and bone meal. * p<0.05, ** p<0.01, *** p<0.001.

acid content with the exception of lanthionine (partial R^2: 40%). Both the composition of the meat and bone meal and the period of the year had a small but significant effect in a number of cases on the gross nutritional composition. BD rendering produced meat and bone meal with more fat, less ash, higher protein solubility, and less sulphur compared to LT rendering. The gross amino acid composition was similar between the two methods, with the exceptions of lanthionine (higher in BD rendering).

The variation between BD and LT rendering in the apparent ileal amino acid digestibility measurements of the 64 meat and bone meal samples and the factors contributing to the variation are presented in Table 3, with the digestible amino acid content in Table 4. Similar to that found for the gross nutrient composition (Table 2), the rendering plant within method was a major contributor to the variation both in the *in vivo* amino acid digestibility (partial R^2: 32 to 64%) as well as the digestible amino acid content (partial R^2: 25 to 78%). The rendering plant explained more variation in the digestible content for the essential and semi-essential amino acids (partial R^2: 54 to 78%) compared to non-essentials (partial R^2: 25 to 61%). Rendering method had a significant effect on the digestibility and digestible content of some of the amino acids. The average digestibility of alanine, glycine, hydroxyproline, arginine and phenylalanine were all higher ($p<0.05$) in BD rendered compared to LT rendered meals with aspartic acid and cysteine significantly lower. Rendering season had no significant ($p>0.05$) effect on the digestibility of amino acids (partial R^2: 0 to 3%) or the digestible amino acid content (partial R^2: 0 to 6%).

Although rendering method did not appear to contribute

Table 3. The variation between batch dry (BD) and low temperature (LT) rendering systems in the *in vivo* apparent ileal digestibility of 64 meat and bone meal samples, and the factors affecting the variation

	BD		LT		R^2	Partial R^2			
	LS mean	SE	LS mean	SE		Method	Plant (method)	Comp.[1]	Period
Essential amino acids (%)									
Arginine	76.8	1.7	70.3	1.4	67	15***	52**	0	0
Histidine	55.6	2.9	57.9	2.3	45	0	41	3	0
Isoleucine	71.4	1.6	70.3	1.2	63	0	62***	0	0
Leucine	73.1	1.6	71.5	1.2	63	1	61***	0	0
Lysine	73.6	1.5	72.9	1.3	63	1	62***	0	0
Methionine	75.7	1.6	75.4	1.3	62	0	62***	0	0
Phenylalanine	75.8	1.4	73.4	1.1	67	3*	64***	0	0
Threonine	56.5	2.1	58.6	1.7	56	0	55**	0	1
Valine	69.3	1.8	68.7	1.4	58	0	57**	0	0
Semi-essential amino acids (%)									
Cysteine	50.9	3.2	58.0	2.5	51	10**	41	0	0
Tyrosine	69.1	1.8	69.7	1.4	62	0	61***	0	1
Non-essential amino acids (%)									
Alanine	69.5	1.8	66.2	1.4	59	6*	52**	0	0
Aspartic acid	35.7	2.9	49.6	2.4	55	17***	37	0	0
Glutamic acid	65.1	2.0	64.1	1.5	55	1	54**	0	0
Glycine	61.4	2.5	55.8	1.9	45	9*	34	0	3
Proline	60.4	2.1	58.2	1.7	57	4	52**	0	1
Serine	51.4	2.5	54.0	2.0	46	0	45	0	1
Hydroxylysine	41.9	3.3	37.3	2.6	40	4	32	1	3
Hydroxyproline	59.8	2.7	54.1	2.1	49	10**	37	0	1
Amino acid nitrogen (%)	65.1	2.0	63.1	1.5	53	2	51*	0	0
Sulphur amino acids (%)	65.8	2.0	68.8	1.6	57	4*	53**	0	0

[1] Composition of the meat and bone meal. * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

significantly to the variation in the composition/quality of the meat and bone meal samples. within each method the variation between plants differed (Figure 1). In general. BD rendering plants produced meat and bone meals with less variation between samples in gross nutrients, amino acid digestibility and digestible amino acid content. Low temperature rendering showed a higher variation among plants for most of the measured nutritional components.

DISCUSSION

Rendering processes/plant variation

In the present study. rendering method made only a small contribution to the overall variation in gross nutrient content. amino acid digestibility and digestible amino acid content (Table 2 to 4), with some notable exceptions. The majority of the variation was associated with the rendering plant as indicated by the large variation between plants using the same method [plant (method) variable. On average. 63. 51 and 58% of the total variation was explained by the variation between plants using the same method for gross nutrient content (Table 2), amino acid digestibility (Table 3) and digestible amino acid content (Table 4), respectively. The variation between plants using the same rendering method excludes the effects of rendering method. season and offal of the animal species rendered. but contained the variation associated with operation of the rendering system. differences between plants in the animal parts being rendered. differences in carcass meat yield. handling and treatment of rendered material prior to rendering. etc. It has been shown that the operation (rendering times, temperatures and pressures) of the rendering system (Kondos and McClymont. 1972; Batterham et al., 1986), the composition (Skurray and Herbert, 1974) as well as the handling (Bremner. 1976) of raw materials before rendering can contribute to the variation in nutritional quality of meat and bone meal. Although no data was obtained on the handling of raw materials. there was a large range in temperatures. times and pressures used during the rendering process within each method. The repeatability analyses furthermore showed that there was a large variation within plant for meat and bone meal gross nutrient content. amino acid digestibility and digestible amino acid content. The present study showed that there is a large variation in meat and bone meal nutritional quality not only between plants but also within plant (inter-plant variation).

Processing method

Noteworthy in the present study is the significant

Table 4. The variation between batch dry (BD) and low temperature (LT) rendering systems in the apparent ileal digestible amino acid, nitrogen and sulphur amino acid content, of 64 meat and bone meal samples, and the factors affecting the variation

	BD		LT		R^2	Partial R^2			
	LS mean	SE	LS mean	SE		Method	Plant (method)	Comp.[1]	Period
Essential amino acids:									
Arginine	3.09	0.08	2.82	0.06	76	10***	61***	1	4
Histidine	0.57	0.03	0.62	0.03	67	0	60***	6**	0
Isoleucine	1.10	0.04	1.11	0.03	78	0	76***	1	1
Leucine	2.48	0.08	2.51	0.06	80	0	77***	3*	0
Lysine	2.11	0.07	2.21	0.05	78	0	75***	2	1
Methionine	0.64	0.03	0.70	0.03	69	1	65***	2	1
Phenylalanine	1.35	0.04	1.38	0.03	80	0	78***	2	0
Threonine	1.09	0.06	1.13	0.04	68	0	65***	2	2
Valine	1.62	0.07	1.67	0.05	71	0	69***	2	0
Semi-essential amino acids:									
Cysteine	0.19	0.02	0.25	0.01	69	10***	54***	0	4
Tyrosine	0.91	0.03	0.92	0.03	81	0	77***	3*	0
Non-essential amino acids:									
Alanine	2.78	0.10	2.68	0.07	59	3	56**	0	1
Aspartic acid	1.51	0.16	2.13	0.12	59	13**	46*	0	0
Glutamic acid	4.34	0.17	4.21	0.13	66	2	61***	1	2
Glycine	4.20	0.20	3.85	0.15	42	6	29	1	6
Proline	2.70	0.10	2.54	0.08	58	6*	49*	0	2
Serine	1.12	0.07	1.17	0.05	55	0	51*	1	2
Hydroxylysine	0.13	0.01	0.12	0.01	37	3	25	4	5
Hydroxyproline	1.57	0.08	1.36	0.06	45	10**	28	2	5
Amino acid nitrogen	4.99	0.18	4.89	0.14	62	1	59**	0	2
Sulphur amino acids	0.83	0.05	0.95	0.04	70	3	63***	1	2

[1] Composition of the meat and bone meal. * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

difference and contribution of the processing method to the overall variation in the gross fat content, which was higher with the BD compared to the LT rendering system (Table 2, Figure 1). This indicates that the BD rendering system is less effective/efficient in extracting fat from raw materials compared to the LT rendering system. As a result of the higher fat content, the gross energy content was also higher in meat and bone meals produced by the BD rendering system.

Raw material

Species origin of the offal as well as rendering season did not contribute significantly to the overall variation in meat and bone meal nutritional quality. The influence of raw material composition on the nutritional quality of meat and bone meal has been found to be larger compared to the influence of processing (Skurray and Herbert, 1974; Dawson and Savage 1983) although Haugen et al. (1985) did not find a significant effect of raw material composition on the availability of amino acids. Higher ash levels in meat and bone meal are associated with a lower nutritional quality of the protein (Johnson and Parsons, 1997; Hendriks et al., 2002). This reduction in protein quality is the result of a decrease in essential amino acids per unit of protein instead of a direct effect of a high ash content (Shirley and Parsons, 2001).

Nutritional quality

In this study, plants using the BD rendering system produced on average meat and bone meals with a lower nutritional quality but there was less variation between plants. The gross content of lysine and phenylalanine were significantly higher in BD rendered meat and bone meals. Interestingly, the apparent ileal digestibility of five amino acids was significantly higher in BD rendered meat and bone meals with apparent ileal cysteine and aspartic acid digestibilities significantly lower. Low temperature rendering has been found to result in meat and bone meals with a higher protein quality. Dawson and Savage (1983) found that semi-continuous rendering produced, with one exception, meals with higher digestible nitrogen content and had significantly higher BV's and NPU values compared to BD rendered meals. Donkoh et al. (1994) measured the true ileal nitrogen digestibility of eight commercial meat and bone meals and reported that the BD rendered meals had lower digestibility values compared to LT rendered meals in all except one case. Figure 1 shows that the plants producing the highest and lowest quality meat and bone meal both used the LT rendering system. Previously it was reported (Hendriks et al., 2002) that

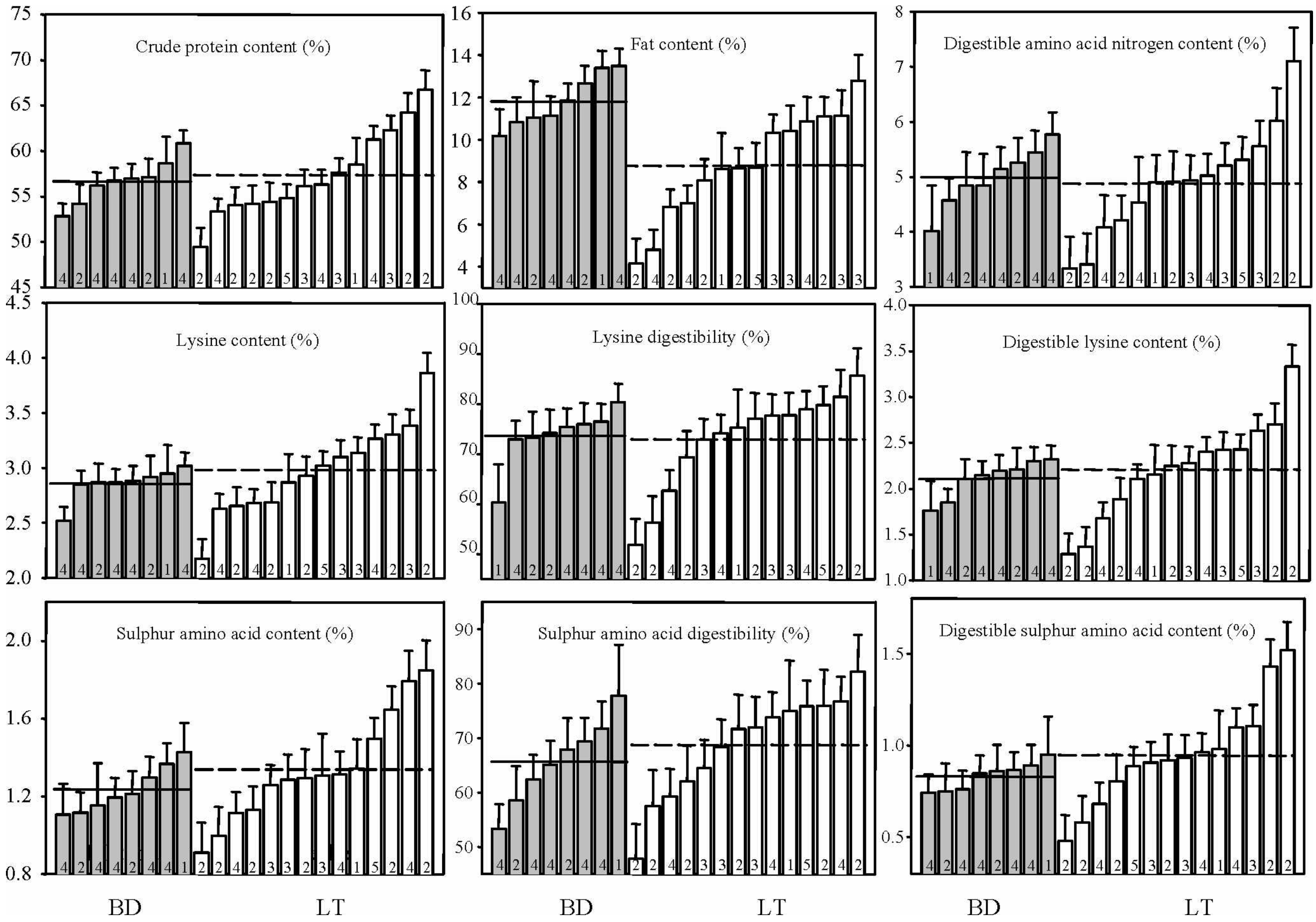

Figure 1. The variation between plants in the composition of meat and bone meals rendered by the BD (solid bar) and LT (open bar) system. Each bar represents the average value (LSmean+SEM) for one rendering plant, with the number of samples from each plant at the base of each bar. The solid and dashed lines are the average values for all BD and LT rendering systems, respectively.

lanthionine, an amino acid formed upon heat treatment of cysteine with a hydroprotein, was not correlated to the digestibility of protein in commercially produced meat and bone meals. The lanthionine content in the present study was significantly higher in meat and bone meals produced by the BD rendering system, which seems to indicate that with this system, protein is more severely heat-treated. Unexpectedly however, average protein solubility was significantly higher in meat and bone meals produced by the BD rendering system where processing method contributed 40% of the variation.

There is limited information on the importance of factors known to contribute to the nutritional variation of commercially produced meat and bone meals. Skurray and Herbert (1974) prepared 11 meals from hard and soft offals of sheep and cattle, and rendered the offals by pressure-cooking at different times and pressures/temperatures. These authors found that there was a greater influence of raw materials on meat meal quality compared to processing. Meat and bone meals exposed to more severe processing conditions were found to have an increased nutritive value as measured by a chicken growth assay. In another study, Herbert et al. (1974) determined the nutritive value of meat and bone meals prepared with a commercial batch dry rendering system with variable cooking times and temperatures. Using three different types of chicken growth assay, they concluded that the experimental processing conditions had no detrimental effects on the meat and bone meal nutritional quality. Haugen et al. (1985) studied the effect of processing temperature and offal type on amino acid availability of meat and bone meals in pigs. Batch dry rendering soft (mainly organs), hard (structural components and bone) and a combination of soft and hard offals at two different temperatures (115 and 132°C), these authors found a significant offal type×temperature interaction. The availability of amino acids was generally higher for soft offals at the low temperature than at the high temperature while hard offals were not affected by processing temperature. No significant main effects of offal type and temperature were found. These results are in contrast to those obtained by Shirley and Parsons (2000). These authors found that the true digestibility of most amino acids in chickens (especially cysteine) was decreased with increasing pressure/temperature and time. Similarly, Kondos and McClymont (1972) and Johnson and Parsons (1997) found that processing temperature decreases the nutritive value of meat and bone meal as measured by different bioassays (chicken growth, PER, NPR and *Tetrahymena pyriformis* growth). Similarly, Batterham et al., (1986) found that the pressure and temperature applied during batch dry rendering have significant effects on lysine availability for pigs, rats and chickens.

Conclusions

A number of practical implications can be derived from the present study. On average, batch dry and low temperature rendering systems produce meat and bone meals of similar nutritional quality. With low temperature rendering, however, there may be increased risk of BSE (bovine spongiform encephalopathy) prions remaining active in the final product (Taylor et al., 1995; Somerville et al., 2002). New Zealand and Australia are free of BSE and therefore either processing method would be acceptable for the production of meat and bone meal from raw materials sourced in either of these countries. Although the knowledge of heat resistance of BSE prions is still incomplete (Casolari, 1998), in countries with BSE risk the low temperature rendering is not recommended. The fat content in batch dry rendered meat and bone meals is slightly higher compared to low temperature rendering systems. A strategy of purchasing meat and bone meals from plants using the batch dry rendering system provides a more consistent quality of product in terms of digestible amino acid content. Purchasing meat and bone meals from plants using the low temperature rendering system provides more opportunity to obtain higher quality products. However, the inter- and intra- plant variation is large, indicating that purchasing meat and bone meal from the same plant does not guarantee a consistent high or low quality. A rapid and inexpensive assay measuring meat and bone meal nutritional quality would be highly advantageous.

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