Effect of Pressure Processing on Amino Acid Digestibility of Meat and Bone Meal for Poultry

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ABSTRACT In the future, it may become desirable or required to process meat and bone meal (MBM) under pressure to reduce human health concerns associated with bovine spongiform encephalopathy (BSE). Therefore, three experiments evaluated the effects of different processing pressures on the digestibility of amino acids (AA) in MBM when the pressure processing was done after typical rendering (Experiments 1 and 2) or during the initial rendering process of raw materials (Experiment 3). Processing pressures varied from 0 to 60 psi in experimental or commercial feather meal cookers. Increasing pressure during processing reduced MBM Cys concentrations in Experiments 1 and 2. True digestibilities of most AA were significantly decreased by increasing pressures in Experiments 1 and 2, and reductions were generally largest for Cys and Lys, particularly Cys, and increased with severity as pressure increased. For example, in Experiment 1, Cys digestibility decreased from 65 to 50 to 15%, and Lys digestibility decreased from 76 to 68 to 41% as the MBM was processed at 0, 30, and 60 psi, respectively, for 20 min. When the pressure processing occurred during the initial rendering of the MBM raw material (Experiment 3), a significant reduction in digestibility of most AA was observed only at 60 psi, and the decrease was much less than that observed in Experiments 1 and 2. Our results indicate that pressure processing of MBM decreases the digestibility of AA for poultry. Thus, pressure processing of MBM to reduce potential BSE infectivity will likely decrease the nutritional value of the MBM.

(*Key words*: meat and bone meal, pressure processing, amino acid, poultry)

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INTRODUCTION

Concerns over bovine spongiform encephalopathy (BSE) and its possible link to new variant Creutzfeldt-Jakob disease prompted the Food and Drug Administration to ban the feeding of mammalian-derived meat and bone meal (MBM) to ruminants (United States Code of Federal Regulations, 1997). Both BSE and new variant Creutzfeldt-Jakob disease are fatal neurological diseases caused by mutant, heat-stable prion proteins (Prusiner, 1997; Godon and Honstead, 1998). Conventional rendering processes do not inactivate prion proteins; however, pressure processing can reduce their infectivity (Taylor et al., 1995). Currently, the European Union requires that all animal by-product meals be processed at 133 C and 30 psi (207 kPa) for 20 min. This process attempts to make MBM a safer feed ingredient for animals, thereby making animal meats safer for human consumption.

Protein quality and amino acid (AA) digestibility of MBM can be influenced by variation in raw materials, processing system, processing temperature, and processing time (Skurray and Herbert, 1974; Parsons et al., 1997; Wang and Parsons, 1998). Animal protein meals such as MBM are commonly processed with either continuous or batch-dry rendering; however, pressurized steam is used to process other proteinaceous feedstuffs, such as feathers (Papadopoulos,1989; El Boushy et al., 1990). Little research has evaluated the effect of pressure processing on the protein quality of animal meals other than feather meal. McNaughton et al. (1977), using a chick growth assay, showed that increased pressure from 15 to 45 psi (103 to 310 kPa) during processing of poultry by-product meal (including feathers) for 15 min decreased bioavailable Lys concentrations from 3.77 to 1.52%, respectively. Further decreases in bioavailable Lys were observed when processing time was increased to 30 min. Batterham et al. (1986), also using a chick growth assay, showed that the Lys bioavailability coefficient decreased from 59% in conventionally rendered MBM processed at 125 C for 4 h to 44% in MBM that was pressure processed at 40 psi (141 C; 276 kPa) for 30 min. The results of the latter two studies indicate that

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Abbreviation Key: AA = amino acid; BSE = bovine spongiform encephalopathy; MBM = meat and bone meal.

pressure processing of poultry by-product meal and MBM may decrease bioavailability of AA.

Processing MBM at 133 C and 30 psi (207 kPa) for 20 min, as required by the European Union, can decrease BSE infectivity, but research also shows that this process does not inactivate all of the mutant prion proteins that cause BSE in cattle (Taylor, 1989; Taylor et al., 1995). Consequently, future regulations in the US may include similar or more stringent pressure processing conditions for the rendering of MBM. Such processing may reduce the bioavailability of AA and protein quality of MBM, thereby diminishing its value as a protein supplement in animal feeds. Therefore, the objective of this study was to evaluate the effect of various processing pressures and, to a lesser extent, times on the digestibility of AA in MBM.

MATERIALS AND METHODS

Meat and Bone Meals

In Experiment 1, seven MBM samples from one large batch (11,000 kg) of commercially rendered beef MBM were processed in 1,364 kg aliquots at various pressures (gauge), temperatures, and times in an experimental batch-cooker.[2] The processing treatments were as follows: 0 psi (94 C) for 20 min, 15 psi (121 C; 103 kPa) for 20 min, 15 psi (121 C; 103 kPa) for 30 min, 30 psi (133 C; 207 kPa) for 20 min, 30 psi (133 C; 207 kPa) for 30 min, 45 psi (147 C; 310 kPa) for 20 min, and 60 psi (144 C; 413 kPa) for 20 min. The first treatment consisted of cooking the MBM for 20 min with no pressure to determine if heat processing alone would have any effect on AA digestibility. In Experiment 2, commercially rendered beef MBM was processed in a commercial feather meal cooker[3] at 45 psi (145 C; 310 kPa) for 20 min or 60 psi (152 C; 413 kPa) for 20 min. In Experiment 3, raw materials from a beef slaughter plant were pressure processed in an experimental cooker at 30 psi (207 kPa) for 20 min or 60 psi (413 kPa) for 20 min. No processing temperature data were provided in Experiment 3, and the company that did the processing requested its name to be kept confidential. Thus, Experiments 1 and 2 differed from Experiment 3 in that the pressure processing in Experiments 1 and 2 was done on MBM that had already been commercially rendered (as done in the European Union), whereas in Experiment 3, pressure processing was done during the initial rendering or cooking of the raw materials.

Ingredient Analysis

All MBM samples were analyzed for DM, CP (N × 6.25), ash, and gross energy by using procedures of the Association of Official Analytical Chemists (AOAC, 1980). After hydrolysis of samples in 6 *N* HCl for 24 h at 110 C, concentrations of AA, excluding Trp, were analyzed by ion-exchange chromatography[4] (Spackman et al., 1958). By using a modification of the procedure of Moore (1963), Met and Cys were oxidized with performic acid, diluted with deionized water, lyophilized, and analyzed separately with ion-exchange chromatography. Selected MBM samples were analyzed for Trp by ion-exchange chromatography after hydrolysis in LiOH.[5]

Bioassays to Determine True Amino Acid Digestibility

To determine the true digestibility of AA in the MBM samples, the precision-fed rooster assay of Sibbald (1986) was used. Single Comb White Leghorn roosters were 65 wk of age. The roosters had been cecectomized at 25 wk of age (Parsons, 1985). All surgical and animal care procedures were approved by the University of Illinois Laboratory Animal Care Advisory Committee. The roosters were housed in individual cages with raised wire floors in an environmentally controlled room with a daily photoperiod of 16 h light and 8 h darkness. Feed was withdrawn from the roosters for 24 h prior to the experiment to remove any residual feed from the gastrointestinal tract. After the 24-h withdrawl, four roosters were crop intubated with 30 g of a MBM sample, and excreta were collected for 48 h after intubation. To correct for endogenous AA excretion, excreta were collected from cecectomized roosters that were deprived of feed during the experimental period. All excreta samples were lyophilized, weighed, ground to pass through a 60-mesh screen, and analyzed for AA content.

Statistical Analysis

Data from all experiments were subjected to ANOVA procedures using SAS® (SAS Institute, 1985) for a completely randomized design. Statistical significance of differences among individual treatments was determined using the least significant difference test after the overall ANOVA treatment effect was determined to be significant ($P < 0.05$) with the Fisher's protected F-test (Steel and Torrie, 1980). In addition, the effects of increasing processing pressures on AA digestibility were assessed with regression analyses to determine linear, quadratic, and cubic effects (SAS Institute, 1985).

RESULTS AND DISCUSSION

The results of the current study indicate that pressure processing of MBM will likely decrease its protein quality. Pressure is not used in the normal commercial processing of MBM. Most MBM are processed with batch cooker systems or continuous rendering systems (Franco and Swanson, 1996). Neither of these uses pressurized steam. Batch cookers are arranged in multiple units

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[2]Processed by Dupps Co., Germantown, OH 45327-0189.

[3]Processed by G. A. Wintzer & Sons Co., Wapakoneta, OH 45895.

[4]Amino acid analysis performed with a Beckman 6300 Analyzer, Beckman Instruments Corp., Palo Alto, CA 94302.

[5]Performed by Degussa Corporation, Allendale, NJ 07401.

TABLE 1. Proximate analysis of meat and bone meals processed under different pressures; Experiments 1, 2, and 3[1]

Treatment[2]	Temperature	DM	Ash	CP	Fat	Gross energy
	(C)	(%)				(kcal/kg)
Experiment 1						
0/0	0	93.8	24.3	52.8	11.1	4,278
0/20	94	96.3	23.9	54.2	11.0	4,341
15/20	117	97.0	24.6	55.9	11.2	4,314
15/30	121	96.8	24.4	56.2	11.3	4,360
30/20	133	94.6	24.5	53.7	11.4	4,261
30/30	131	96.7	24.9	57.7	11.0	4,405
45/20	147	90.4	23.4	52.4	10.4	4,022
60/20	144	95.2	26.9	53.6	10.9	4,334
Experiment 2						
0/0	0	94.0	23.2	52.7	12.1	4,328
45/20	145	96.8	24.8	56.2	12.3	4,440
60/20	152	95.2	23.4	53.7	12.0	4,469
Experiment 3						
0/0	NM[3]	97.1	34.4	50.4	11.8	3,573
30/20	NM	95.7	34.6	50.2	11.3	3,494
60/20	NM	93.9	33.5	50.3	13.2	3,497

[1]Ash, CP, fat, and gross energy values are on an as-fed or air-dry basis.

[2]The first number indicates the processing pressure in pounds per square inch (gauge), and the second number indicates the length of processing time in min. The 15, 30, 45, and 60 pounds per square inch correspond to 103, 207, 310, and 413 kPa, respectively.

[3]NM = not measured.

wherein the cooker is charged with the proper amount of raw material, the material is cooked, and then the cooked material is discharged. The material is usually cooked for 2 to 3 h at a final temperature of 121 to 135 C (Franco and Swanson, 1996). A continuous rendering system consists of a single continuous cooker in which raw material is fed into and discharged out of the cooker at a constant rate. The total processing times (cooker and dryer) may vary from less than 30 min to 4 h, and the processing temperatures normally vary from 110 to 135 C among different systems (Wang and Parsons, 1998).

When proteins are processed with heat or pressurized steam, AA may be destroyed or altered and thus made unavailable to an animal's metabolism (Bjarnason and Carpenter, 1970; Kondos and McClymont, 1972; Wang and Parsons, 1998). In the current study, DM, ash, CP, fat, and gross energy concentrations in MBM were not affected by processing pressure or time as shown in Table 1. The latter agrees with previous research on processing of feather meal by El Boushy et al. (1990) and Latshaw (1990). However, pressure processing had variable effects on the physical appearance of the MBM and AA concentrations. Increasing the processing pressure in all three experiments darkened the color of the MBM from light tan to a dark, ground coffee color in Experiments 1 and 2 and to a deep brown carmel color in Experiment 3. In Experiment 1 (Table 2), an increase in processing pressure and time to 45 psi for 20 min resulted in decreased Cys concentration, with no consistent effect on any other AA. When the MBM samples were processed at 60 psi for 20 min, total concentrations of most AA, especially Cys, were reduced. Thus, the greatest effect of pressure processing was observed for Cys, in which Cys concentration decreased by 49%, from 0.51% to 0.26%, as pressure increased from 0 to 60 psi. A decrease in Cys concentration (approximately 25%) was also found in Experiment 2 (Table 3) as processing pressure increased from 0 to 60 psi. In contrast, there was no consistent effect of pressure processing for all other AA in Experiment 2 or for all AA evaluated in Experiment 3 (Table 2).

The reason for the large effect of pressure processing on Cys concentration in MBM is unknown. However, substantial destruction or reduction of Cys concentration has been documented for feather meal that is routinely processed at high pressures of 45 to 60 psi (El Boushey et al., 1990; Latshaw, 1990). Parsons et al. (1992) also observed a moderate decrease in Cys concentration in soybean meal with increased autoclaving time at 15 psi and 120 C. Awonorin et al. (1995) further showed that Cys concentrations in poultry by-product offal were reduced from 1.5 to 0.9% as processing time increased from 30 to 90 min at 140 C.

Digestibilities of AA for Experiment 1 are shown in Table 4. Cooking the MBM for 20 min with no added pressure (0/20) had no significant ($P < 0.05$) effect on digestibility of any AA. Processing MBM at 15 psi for 20 min resulted in a significant decrease ($P < 0.05$) in digestibility of most AA in comparison to the control MBM (0/0). At 20 min of processing time, increasing the processing pressure further had no additional effect ($P > 0.05$) on AA digestibility until 60 psi, at which the digestibilities of all AA, especially Cys, were markedly reduced ($P < 0.05$). This response resulted in a significant ($P < 0.05$) cubic effect of pressure for all AA except Asp, which was linear. The largest effect of increasing pressure was observed for Cys, for which digestibility de-

TABLE 2. Amino acid concentrations in meat and bone meals processed under different pressures; Experiment 1[1]

Amino acid	Processing treatment (pressure/time)[2]							
	0/0	0/20	15/20	15/30	30/20	30/30	45/20	60/20
	(%)							
Asp	4.30	4.28	4.36	4.42	4.41	4.29	4.20	3.76
Thr	1.82	1.84	1.88	1.80	1.88	1.79	1.79	1.57
Ser	2.08	2.12	2.23	1.83	2.12	2.01	2.03	1.69
Glu	6.99	7.04	7.17	7.18	7.22	7.15	6.97	6.50
Pro	4.36	4.37	4.50	4.67	4.46	4.60	4.42	4.14
Ala	4.20	4.18	4.30	4.30	4.31	4.36	4.16	4.01
Val	2.49	2.46	2.47	2.72	2.69	2.48	2.48	2.35
Ile	1.74	1.73	1.73	1.93	1.86	1.78	1.72	1.62
Leu	3.68	3.68	3.72	3.81	3.93	3.72	3.67	3.41
Tyr	1.34	1.33	1.36	1.34	1.41	1.35	1.34	1.20
Phe	2.02	2.01	2.04	2.12	2.09	2.04	1.96	1.84
His	1.15	1.14	1.11	1.25	1.19	1.11	1.10	1.02
Lys	3.12	3.09	3.06	3.20	3.17	3.04	2.97	2.70
Arg	3.86	3.74	3.89	3.84	3.90	3.89	3.74	3.45
Met	0.85	0.82	0.90	0.85	0.87	0.82	0.81	0.80
Cys	0.51	0.53	0.49	0.44	0.46	0.42	0.39	0.26
Trp	0.38	NM[3]	0.38	NM	0.39	NM	0.39	0.37

[1]Values are on an as-fed or air-dry basis.

[2]The first number indicates the processing pressure in pounds per square inch (gauge), and the second number indicates the length of processing time in min. The 15, 30, 45, and 60 pounds per square inch correspond to 103, 207, 310, and 413 kPa, respectively.

[3]NM = not measured.

creased from 65 to 15% as pressure increased from 15 to 60 psi, respectively. When evaluating the effect of increased processing time, effects of AA digestibility were different at 15 and 30 psi. An increase in time from 20 to 30 min at 15 psi had no significant effect on AA digestibility; however, an increase in time from 20 to 30 min at 30 psi decreased the digestibility of most AA ($P < 0.05$).

In Experiment 2 (Table 5), pressure processing had a significant impact upon AA digestibility in MBM processed in a commercial feather meal cooker. As pressure increased from 0 to 45 or 60 psi for 20 min, a significant reduction ($P < 0.05$) in digestibility of all AA was observed. Digestibilities of most AA at 45 psi were generally similar to those at 60 psi, resulting in a significant ($P < 0.05$) quadratic effect of pressure. In contrast, Cys

TABLE 3. Amino acid concentrations in meat and bone meals processed under different pressures; Experiments 2 and 3[1]

Amino acid	Processing treatment (pressure/time)[2]					
	Experiment 2			Experiment 3		
	0/0	45/20	60/20	0/0	30/20	60/20
	(%)			(%)		
Asp	4.18	4.03	4.29	3.42	3.66	3.74
Thr	1.69	1.70	1.74	1.34	1.48	1.50
Ser	1.69	1.87	1.78	1.56	1.88	1.78
Glu	6.74	6.74	7.05	5.84	6.29	6.49
Pro	4.63	4.36	4.67	4.46	4.88	5.06
Ala	4.21	4.15	4.46	3.56	3.85	3.95
Val	2.64	2.44	2.88	1.93	1.90	2.11
Ile	1.79	1.67	1.91	1.25	1.19	1.36
Leu	3.66	3.65	3.91	2.70	2.89	2.97
Tyr	1.23	1.28	1.29	0.88	1.02	1.01
Phe	2.03	1.96	2.15	1.46	1.56	1.62
His	1.24	1.13	1.24	1.10	1.06	1.18
Lys	3.07	2.85	3.02	2.35	2.39	2.51
Arg	3.57	3.57	3.74	3.38	3.60	3.83
Met	0.74	0.76	0.75	0.55	0.63	0.58
Cys	0.46	0.31	0.35	0.40	0.42	0.39
Trp	0.40	0.41	0.39	0.25	0.26	0.25

[1]Values are on an as-fed or air-dry basis.

[2]The first number indicates the processing pressure in pounds per square inch (gauge), and the second number indicates the length of processing time in min. The 30, 45, and 60 pounds per square inch correspond to 207, 310, and 413 kPa, respectively.

TABLE 4. True amino acid digestibility coefficients for meat and bone meals processed under different pressures; Experiment 1[1]

Amino acid	Processing treatment (pressure/time)[2]								Pooled SEM
	0/0	0/20	15/20	15/30	30/20	30/30	45/20	60/20	
	(%)								
Asp	59.3[a]	55.0[ab]	49.0[bc]	46.0[bcd]	45.9[bcd]	36.0[e]	40.9[cde]	26.3[f]	3.24
Thr	80.7[a]	78.3[ab]	76.0[abc]	70.9[cd]	76.1[abc]	67.5[d]	73.1[bcd]	54.5[e]	2.18
Ser	83.2[a]	79.4[ab]	77.7[abc]	69.4[d]	78.4[abc]	72.3[cd]	77.5[abc]	55.0[e]	2.15
Glu	77.7[a]	76.2[ab]	72.4[b]	71.0[b]	74.1[ab]	65.5[c]	71.7[b]	55.8[d]	1.80
Pro	76.1[a]	72.0[ab]	68.4[bcd]	69.4[abcd]	71.7[ab]	63.0[de]	70.0[abc]	60.3[e]	2.33
Ala	79.1[a]	76.8[ab]	74.5[b]	73.9[bc]	76.2[ab]	69.6[c]	73.9[bc]	61.4[d]	1.57
Val	76.6[a]	74.3[ab]	70.7[b]	72.6[ab]	75.0[ab]	64.6[c]	70.6[c]	56.6[d]	1.76
Ile	78.7[a]	76.4[ab]	72.7[b]	74.6[ab]	76.3[ab]	67.1[cd]	72.0[bc]	56.9[e]	1.69
Leu	82.4[a]	80.4[ab]	77.3[b]	76.9[b]	79.5[ab]	71.9[c]	76.6[b]	63.6[d]	1.44
Tyr	84.2[a]	77.7[ab]	76.7[abc]	73.8[bc]	78.2[ab]	69.4[c]	76.5[abc]	53.2[d]	2.67
Phe	89.2[a]	86.9[ab]	84.5[b]	83.7[bc]	85.9[ab]	79.4[cd]	83.8[bc]	69.1[e]	1.56
His	78.0[a]	75.5[ab]	70.7[b]	73.2[ab]	72.1[b]	65.0[cd]	69.9[bc]	52.8[e]	1.92
Lys	75.5[a]	72.1[ab]	67.3[bc]	66.1[c]	67.6[bc]	54.4[d]	62.4[c]	41.3[e]	1.98
Arg	85.3[a]	84.3[ab]	83.4[abc]	82.8[abc]	85.6[a]	80.4[c]	84.6[ab]	73.3[d]	1.30
Met	80.6[a]	76.5[ab]	76.3[ab]	74.0[bc]	76.5[ab]	69.6[cd]	74.7[bc]	62.3[e]	1.84
Cys	64.8[a]	56.8[ab]	48.1[bcd]	39.8[de]	50.1[bc]	30.1[f]	45.5[cd]	14.8[g]	3.21
Trp[3]	72.0	NM[4]	65.0	NM	65.1	NM	60.6	55.4	. . .

[a–g]Means within a row with no common superscripts are significantly different ($P < 0.05$).

[1]Mean values of four cecectomized roosters per sample.

[2]The first number indicates the processing pressure in pounds per square inch (gauge), and the second number indicates the length of processing time in min. The 15, 30, 45, and 60 pounds per square inch correspond to 103, 207, 310, and 413 kPa, respectively.

[3]Trp values are calculated from one pooled excreta sample of four cecectomized roosters.

[4]NM = Not measured.

digestibility was substantially lower ($P < 0.05$) at 60 than at 45 psi, resulting in a linear effect ($P < 0.05$) of pressure. As observed in Experiment 1, an increase in pressure processing had the largest effect on Cys, for which digestibility decreased from 67 to 23% as pressure increased from 0 to 60 psi.

TABLE 5. True amino acid digestibility coefficients for meat and bone meals processed under different pressures; Experiment 2

Amino acid	Processing treatment (pressure/time)[2]			Pooled SEM
	0/0	45/20	60/20	
	(%)			
Asp	56.1[a]	31.4[b]	32.5[b]	1.18
Thr	78.9[a]	65.6[b]	62.7[b]	1.07
Ser	78.3[a]	69.4[b]	61.6[c]	1.09
Glu	75.5[a]	62.2[b]	61.3[b]	0.81
Pro	74.6[a]	63.9[b]	63.3[b]	1.23
Ala	78.1[a]	66.7[b]	67.8[b]	0.52
Val	78.0[a]	64.1[c]	66.9[b]	0.57
Ile	79.7[a]	65.8[b]	67.6[b]	0.64
Leu	81.6[a]	70.5[b]	70.4[b]	0.55
Tyr	81.5[a]	72.5[b]	69.1[b]	1.59
Phe	89.6[a]	78.6[b]	77.8[b]	0.64
His	73.5[a]	57.8[b]	59.2[b]	2.11
Lys	70.4[a]	48.2[b]	51.3[b]	1.43
Arg	84.4[a]	78.5[b]	77.9[b]	0.55
Met	76.8[a]	65.1[b]	63.1[c]	0.57
Cys	67.0[a]	35.8[b]	22.6[c]	4.24
Trp[3]	78.8	66.6	60.8	. . .

[a–c]Means within a row with no common superscripts are significantly different ($P \leq 0.05$).

[1]Mean values of four cecectomized roosters per sample.

[2]The first number indicates the processing pressure in pounds per square inch (gauge), and the second number indicates the length of processing time in min. The 45 and 60 pounds per square inch correspond to 310 and 413 kPa, respectively.

[3]Trp values are calculated from one pooled excreta sample of four cecectomized roosters.

The application of pressure during the initial rendering of the raw materials in Experiment 3 (Table 6) had less of an effect on MBM AA digestibility than that observed in Experiments 1 and 2. Processing MBM at 30 psi for 20 min had no significant effect ($P > 0.05$) on the digestibility of any AA, whereas increasing the pressure to 60 psi significantly reduced ($P < 0.05$) the digestibility of most AA evaluated. Although there was a depression in AA digestibility at 60 psi, the magnitude of the reduction was much less than that observed at 60 psi in Experiments 1 and 2. The less severe effect of pressure processing in Experiment 3 was probably due to the differences in processing method. By combining the pressure treatment with the initial cooking of the raw materials, the total length of processing time was less than that for the MBM samples in Experiments 1 and 2 in which the pressure processing was done after the MBM had already undergone the normal cooking or rendering process. The high fat and moisture contents of the raw materials might also have protected the protein from the adverse effects of pressure processing.

Our results clearly indicate that pressure processing of MBM has a negative effect on AA digestibility. These results agree with the very limited previous work on pressure processing of poultry offal (McNaughton et al., 1977) and MBM (Batterham et al., 1986). The exact mechanism by which pressure processing decreases AA digestibility is unknown, but it may be associated with racemization of AA or cross-linking between AA. With

TABLE 6. True amino acid digestibility coefficients in meat and bone meals processed under different pressures, Experiment 3[1]

Amino acid	Processing treatment (pressure/time)[2]			
	0/0	30/20	60/20	Pooled SEM
	(%)			
Asp	60.9[a]	57.8[a]	45.1[b]	1.25
Thr	82.4[a]	80.8[ab]	76.1[b]	1.61
Ser	80.6	80.0	76.5	1.65
Glu	80.6[a]	79.3[ab]	76.7[b]	1.06
Pro	77.4	76.9	75.3	1.63
Ala	80.3	80.5	79.3	1.05
Val	82.2[a]	82.0[a]	78.2[b]	1.09
Ile	85.2[a]	85.1[a]	81.0[b]	1.21
Leu	86.4[a]	86.2[a]	82.7[b]	0.92
Tyr	83.7	80.3	78.7	1.87
Phe	97.6[a]	96.9[a]	93.9[b]	0.88
His	71.5[a]	70.1[ab]	66.1[b]	1.69
Lys	80.2[a]	79.1[a]	71.5[b]	1.09
Arg	85.9	85.9	86.9	0.88
Met	85.3[a]	84.7[a]	80.0[b]	1.18
Cys	63.8	65.5	52.9	4.03
Trp[3]	76.0	74.3	64.0	. . .

[a–b]Means within a row with no common superscript are significantly different ($P \leq 0.05$).

[1]Mean values of four cecectomized roosters per sample.

[2]The first number indicates the processing pressure in pounds per square inch (gauge), and the second number indicates the length of processing time in min. The 30 and 60 pounds per square inch correspond to 207 and 413 kPa, respectively.

[3]Trp values are calculated from one pooled excreta sample of four cecectomized roosters.

severe heat processing of protein, L-AA may undergo isomerization, changing into D- and meso-isomers, that are indigestible and nutritionally unavailable to an animal's metabolism (Baker and Harter, 1978; Hayashi and Kameda, 1980; Lewis and Baker, 1995). For example, Hayase et al. (1975) showed that roasting casein at 110 C for 20 min racemized Lys (L to D) from 2.0 to 88.0%, Asp from 4.3 to 71.0%, and Glu from 0.0 to 69.0%. In addition to racemization, peptide-bound AA may become cross-linked during heat processing. Cross-linking is a form of the Maillard reaction, comprised of a reaction between a carbonyl group such as Asp (deaminated and reduced) and a free amino group such as the ε-amino group of Lys (Ford and Shorrock, 1971). It was shown in the latter study with rats that bioavailability of several AA was reduced in protein from heat-damaged cod fillets that contained substantial amounts of cross-linked AA.

Our results indicated that the greatest negative effect of processing pressure on AA digestibility was for Cys. Previous research in our laboratory has shown that the digestibility of Cys in MBM is generally lower and more variable than other AA and is the AA most affected by increased processing temperature (Wang and Parsons, 1998). The large effect of pressure on Cys digestibility in MBM does not agree with previous studies on oilseed meals in which the digestibility of Lys is most affected by autoclaving at 15 psi (Parsons et al., 1992; Fernandez and Parsons, 1996). Generally, effects of heat and pressure processing are expected to be greatest for Lys due to its susceptibility to the Maillard reaction. The reduced relative effect of pressure on Lys vs. Cys digestibility in MBM might have resulted partly because the concentration of reducing sugars necessary for the Maillard reaction are low and are rapidly eliminated in MBM during the initial rendering (Skurray and Cumming, 1974a,b).

The results of Experiment 3 suggest that the negative effects of pressure on AA digestibility can be ameliorated if pressure cooking is done during the initial rendering of raw materials. However, as Taylor et al. (1994, 1995) have reported, this process may be less effective in inactivating BSE prion proteins. The latter may be due to the high moisture and fat contents of the raw materials, which can reduce the effect of heat damage in heat processed proteins (Fennema, 1996).

The results of our study indicate that pressure processing of MBM decreases the digestibility of AA. Thus, any attempt to reduce the potential BSE infectivity of MBM by pressure processing is likely going to decrease the protein quality and nutritional value of the MBM.

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