AN ABSTRACT OF THE THESIS OF

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Title: EVALUATION OF FEATHER AND HAIR MEALS AS PROTEIN SUPPLEMENTS FOR RUMINANTS

Abstract approved: Redacted for Privacy

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The objectives of this study were to nutritionally evaluate various feather and hair meals (FM, HM) as protein supplements for ruminants and to study the in vitro/in vivo relationships of diets supplemented with FM and HM.

In vitro (rumen and enzymes) studies, five in vivo digestion trials and a feedlot performance trial were conducted to accomplish these objectives. FM or HM supplied 40 to 50% of the total N in the supplemented diets used for the in vivo studies.

In vitro rumen studies showed that HM was a better supplementary N source than FM or cottonseed meal (CSM). Protein supplements were better utilized at lower roughage:concentrate ratios, and urea supplementation improved the utilization of FM. Different degrees of processing had no effect on the level of N in FM. Pepsin-HCl digestibilities of crude protein (CP) and dry matter (DM) in FM increased with increasing hydrolysis period up to a point and then decreased slightly, but varying the degree of processing (57 to 78% pepsin digestibility) did not affect in vivo digestibility of FM by growing lambs.

Utilization of FM was low in *in vitro* (rumen) but high in *in vivo* trials, indicating some potential for reticulo-rumen bypass.

The final weights, average live and carcass gains, feed consumption and feed efficiency were higher for animals fed FM and HM than for those fed CSM. The FM and HM diets also had superior economic (cost) advantage in converting feed to gain as compared to the CSM diet.

In vitro enzyme nutrient digestibility generally increased with increasing enzyme:N ratios. *In vivo* CP digestion and N retention were best predicted by a pepsin-pancreatin combination. *In vitro* pepsin DM digestibility was the best predictor of *in vivo* DM and organic matter (OM) digestibilities, but *in vitro* rumen digestibility of DM gave the highest correlation with *in vivo* digestible gross energy (GE). *In vitro* digestibility of nutrients by pancreatin was a very poor predictor of *in vivo* digestibility of nutrients in ruminant diets of the type used.

This study demonstrated that FM and HM (when properly processed) were superior to CSM (on a per unit of N basis) when fed as the only protein supplement in diets for ruminants. The study also showed that *in vitro* proteolytic enzyme and rumen digestion studies can be used effectively to predict *in vivo* digestibilities of nutrients in ruminant diets.

Evaluation of Feather and Hair Meals as Protein Supplements for Ruminants

by

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A THESIS

Submitted to

Oregon State University

in partial fulfillment of
the requirements for the

degree of

Doctor of Philosophy

Completed May 4, 1981

Commencement June 1981

APPROVED:

Redacted for Privacy

Professor of Animal Science
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Date thesis is presented: May 4, 1981

Typed by Kitty Dougherty for Adeshina Oladapo Aderibigbe

ACKNOWLEDGEMENTS

I would like to express a sincere gratitude to Dr. D. C. Church for his assistance and guidance, as well as being a good friend throughout my graduate study at Oregon State University. I am also grateful to Drs. Arscott, Nakaue, O'Connor and Oldfield for serving as members of the graduate committee. Appreciation is also extended to the Lagos State Government of Nigeria and the American Fats and Protein Foundation for their financial support.

I am indebted to Kitty Dougherty for typing this thesis. A special thanks to my wife Oluyemisi Abiodun and my son Adetokunbo Olanrewaju for their patience, understanding and love during some difficult times.

TABLE OF CONTENTS

LIST OF TABLES

EVALUATION OF FEATHER AND HAIR MEALS AS PROTEIN SUPPLEMENTS FOR RUMINANTS

Running Head: Feather meal and hair meal for ruminants

Comparative Evaluation of Feather Meal and Hair Meal as Protein Supplements for Ruminants[1,2]

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Key Words: Feather Meal, Hair Meal, Digestibility, Ruminants

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[1]Oregon Agricultural Experiment Station Technical Paper No. ____.

[2]Partial support supplied by Fats and Proteins Research Foundation, Inc., Des Plaines, IL.

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SUMMARY

In vitro and two *in vivo* digestion trials were conducted to compare cottonseed meal (CSM) with feather meal (FM) and hair meal (HM) as protein supplements for ruminants. *In vitro* rumen studies compared diets with various roughage to concentrate ratios (R:C) varying from 0:100 to 100:0 with similar diets supplemented with different protein supplements (commercial FM, special FM, commercial FM plus urea and commercial HM). *In vivo* trial 1 (using 20 crossbred wether lambs) compared a high concentrate basal ration (a) with rations in which (b) CSM was added to the basal to supplement 50% of total nitrogen (CSM-50), (c) commercial FM was added to the basal to supplement 40% of total N (FM-40) and (d) commercial FM was added to the basal to supplement 50% of the total nitrogen (FM-50). Trial 2 (using 20 crossbred wether lambs) compared a high concentrate basal ration (a) with supplemented rations in which the protein supplements-(b) CSM, (c) commercial FM and (d) commercial HM, provided 50% of the N in the respective diets. *In vitro* studies showed the commercial HM as the best supplementary N source. All protein supplements were better utilized at the lower R:C ratio. Urea supplementation improved the utilization of FM. Overall mean dry matter digestion was in the order of commercial HM > special FM = commercial FM plus urea > commercial FM > basal. The commercial FM (pepsin digestibility 80%) might have been overprocessed. *In vitro* ammonia concentration suggested that FM and HM proteins may not be readily soluble in the rumen. *In vivo* trial 1 showed that all protein supplements were digested to a similar degree. However, N retention (an indirect

measure of performance) was in the order FM-40 > FM-50 > CSM > basal. Protein digestibility was significantly higher ($P < .05$) for the supplemented rations than for the basal rations in trials 1 and 2. In trial 2, the order of protein utilization (digestibility and N retention) was FM > CSM > HM > basal. The study showed that FM and HM compared well with CSM (on a per unit of N basis) for ruminants. There is a need for further investigation of the relationship between the degree of processing of FM and HM and their utilization by livestock.

INTRODUCTION

The increasing importance of by-products (especially those high in N) in ruminant diets cannot be overemphasized. The need for more environmental pollution control coupled with more vigorous competition between livestock and humans for food make it crucial that more by-products be incorporated into livestock diets. Feathers and hairs (by-products of rendering plants) are almost pure protein (85-100%). These are mostly keratins which are not readily digestible in the natural state, but steam cooking under pressure results in meals with high digestibility values.

Feather meal (FM) and hair meal (HM) have been fed successfully to all classes of livestock and poultry. Davis et al. (1961) observed that the principal chemical changes resulting from FM processing were loss of cystine, appearance of lanthionine and increased susceptibility to enzymatic hydrolysis. Moran et al. (1967) noted that the improved digestibility of FM and HM after steam hydrolysis was due to the

breakage of disulfide bonds of the cystine molecules.

The feeding of high levels of FM or HM (> 5% of diet) as protein supplements in nonruminant rations has not been very successful (Wessels, 1972; Kornegay and Thomas, 1973; Potter and Shelton, 1978; Kadirvel et al., 1979). Kornegay and Thomas (1973) suggested amino acid deficiencies and imbalances as well as low consumption as reasons for poor performance of pigs fed high levels of HM as a protein supplement. In diets of 7-day-old broiler chicks, Wessels (1972) reported that methionine was the first limiting amino acid followed by lysine, histidine and then tyrosine when FM was used as protein supplement. Potter and Shelton (1978) found that use of FM as a cystine source could spare but not substitute for methionine in turkeys' rations when fed from one day to seven weeks of age. Morris and Balloun (1973) concluded that methionine and lysine should be supplemented in broiler chicks' diet only when FM provided 5% or more protein in the diet.

Several workers (Jordan and Croom, 1957; Rakes et al., 1968; Daugherty and Church, 1978; Thomas and Beeson, 1977; Wray et al., 1979) have shown that FM or HM protein are equal to other protein supplements on a "per unit of protein" basis in rations for ruminants when fed in moderate amounts. This is understandable since amino acid balance does not have the same importance in ruminants as it has in nonruminant rations. However, some workers (Wise and Barrick, 1963; Rakes et al., 1968) have pointed out that initial palatability problems may occur when high levels of FM are used as protein supplements in ruminants' rations. Hence, some adaptation period may be required at high levels

of FM or HM supplementation.

The objectives of this study were to determine (a) the optimum roughage to concentrate ratio for the optimum utilization of FM and HM; (b) the effect of level of supplementation on the digestibility of diets containing high levels of FM and HM by wether lambs; (c) to compare cottonseed meal (CSM), FM and HM as protein supplements for wether lambs; and (d) to further investigate the effect of urea supplementation on the utilization of FM.

MATERIALS AND METHODS

In vitro digestion trials and two *in vivo* digestion trials (with wether lambs) were conducted to evaluate FM and HM as protein supplements for ruminants.

In Vitro Rumen Digestion Trials

Diets for *in vitro* studies were formulated to provide roughage to concentrate ratios (R:C) ranging from all roughage to all concentrate (Table 6). Ground barley (IFN 4-00-526, 13% crude protein) was combined with ground corn (IFN 4-02-931, 9.9% crude protein) to make the 10% crude protein concentrate diet. The roughage (10% CP) was made up of a combination of dried ryegrass (IFN 2-04-073, 14.2% crude protein) and ryegrass straw (IFN 1-04-059, 3.7% crude protein). Other compositions (% dry basis) of the R and C diets, respectively, were: dry matter (DM), 88.2 and 92.9; acid detergent fiber (ADF), 2.2 and 38.2; ether extract (EE), 3.9 and 2.1. Analyses for DM, crude protein

(CP) and EE were conducted by the methods described in AOAC (1975). ADF was determined by the method of Van Soest (1963) as described in the modified micro-procedure of Waldern (1971).

Triplicate samples (1 g dry basis) from each R:C ratio were used as substrates for the *in vitro* incubation. The unsupplemented mixtures (a) served as the negative controls. Other treatments involved those in which protein supplements were added to the control to make up 50% of the total N in the diets. The protein supplements were (b) commercial FM (pepsin digestibility 80%), (c) special FM (steam cooked at 35 p.s.i. for 45 minutes, pepsin digestibility 57%), (d) commercial FM plus urea (each provided 25% of the total N in the diet), and (e) commercial HM (pepsin digestibility 65%). Pepsin digestibility was determined by the method described in AOAC (1975). Closed *in vitro* incubations were conducted by the method described by Aderibigbe (1980). Inoculum consisted of 40 ml of a mixture of one part rumen liquor, one part of a nutrient buffer solution (McDougall, 1948) and two parts distilled water. Ammonia-N was determined using a method given by Hawk *et al.* (1954).

In Vivo Digestion Trials with Wether Lambs

Two digestion trials were conducted with crossbred wether lambs. Each trial involved 20 lambs allotted to four treatments (at random by weight) with five lambs per treatment. Trial 1 compared a high concentrate (17% CP) basal ration (a) with rations in which (b) CSM was added to the basal to supplement 50% of total N, resulting in a 25.3%

CP diet; (c) commercial FM was added to the basal to supplement 40% of total N (25.2% CP) and (d) commercial FM was added to the basal to supplement 50% of total N (28.5% CP). The high levels of protein were fed because Church (1979) has shown a good linear response between N intake and apparent digestibility. Trial 2 compared a high concentrate (8.7% CP) basal ration (a) with supplemented rations in which the protein supplements-(b) CSM, (c) commercial FM and (d) commercial HM provided 50% of the N in the respective diets. The CP concentrations (%) in these diets were: (b) 14.3, (c) 15.9, and (d) 15.6. The ingredient components of the basal for trials 1 and 2 are shown in Table 1. The chemical components of the basal and each supplement feed in trials 1 and 2 are shown in Tables 2 and 3, respectively. The daily feeding schedule for trials 1 and 2 are shown in Table 4. Daily feed was divided into two equal parts and fed at 0800 hr and 1600 hr. The basal as well as each supplement were weighed separately and thoroughly mixed together (for supplemented diets) before being fed.

Each trial consisted of a 14-day preadjustment period during which animals were kept in four covered pens bedded with wood shavings. After preadjustment, animals were housed in metabolism cages designed to allow separation of urine and feces for a 7-day adjustment period and a 10-day collection period. Animals were gradually adapted to experimental diets (from a diet of grass hay) during the preadjustment period and brought to full feed of experimental diets (ad libitum) in the first 10 days. Records were kept of feed offered and feed refused when animals were on ad libitum experimental diets. Feed offered was

reduced during the adjustment and collection periods to 80% of *ad libitum* consumption. During the collection period, total fecal and urinary excretions were collected daily for each animal. Fecal samples were weighed and urinary samples were measured. Ten percent aliquots of fecal and urinary collections were stored at 5 C for later analyses. Five ml of phosphoric acid were added to each urine collection bucket in order to minimize N loss. Water and trace mineral blocks were available to all animals *ad libitum* during the entire period.

The experimental feeds and feces were analyzed for dry matter (DM), CP, ether extract (EE) and ash by methods described in AOAC (1975). Urinary N was determined by AOAC (1975) methods. Acid detergent fiber (ADF) was determined using the method of Van Soest (1963) as described in the modified micro-procedure of Waldern (1971). N-free extract (NFE) was obtained in the usual manner except that ADF was used in the calculation rather than crude fiber. Gross energy was determined using a Parr adiabatic oxygen bomb calorimeter. Digestion coefficients for components of each diet and supplement (by difference) were determined by the methods described by Schneider and Flatt (1975).

Statistical Analysis

Data for the *in vitro* studies were analyzed statistically by use of a two way analysis of variance while those for *in vivo* studies were analyzed by use of one way analysis of variance as described by Snedecor and Cochran (1974). Treatment means were compared by use of

the LSD as described by Steel and Torrie (1980). Simple correlations between R:C and *in vitro* DM digestion as well as those between R:C and *in vitro* ammonia-N production for each treatment were conducted as outlined by Neter and Wasserman (1974).

RESULTS AND DISCUSSION

In Vitro Studies

The results of the *in vitro* dry matter digestion (DMD) for the various R:C of each treatment are shown in Table 5. For each treatment, DMD was negatively related to the R:C with r values of -.93, -.89, -.98, -.85, and -.91 for the control, commercial FM, special FM, commercial FM plus urea, and commercial HM, respectively ($P < .01$). The mean values for percent DMD (across all R:C) were 44.2, 46.1, 47.6, 47.4, and 50.0 for the control, commercial FM, special FM, commercial FM plus urea and commercial HM, respectively. A similar trend for percent DMD (HM > special FM = FM plus urea > FM > control) was generally observed for each R:C. These results showed that the commercial HM was the best supplementary N source. It may well be that the commercial FM had been overprocessed. It should also be noted that urea supplementation improved utilization of commercial FM. Daugherty and Church (1978) showed similar improved utilization of FM when supplemented with urea.

The ammonia N concentrations (NH_4-N) for the *in vitro* trials are

shown in Table 6. Contrary to the results of the DMD, NH_4-N for each of the five treatments was positively related to R:C. The r values for the plot of R:C versus NH_4-N for the treatments were: control = .84; commercial FM = .89; special FM = .87; commercial FM plus urea = .93; and commercial HM = .83 ($P < .01$). There was no specific pattern for NH_4-N among the diets. However, NH_4-N was higher for the supplemented diets than for the control diet at the lower R:C. Generally, the higher levels of NH_4-N indicate an inefficient use of N when negatively related to DMD. On the other hand, lower NH_4-N may indicate inability of rumen microbes to adequately digest the CP. The fact that no pattern for NH_4-N existed at the higher R:C suggests that FM and HM proteins may not be readily soluble in the rumen.

In Vivo Studies

The mean digestion coefficients (%) for components of each diet for trial 1 are shown in Table 7. The percents DDM and DOM among the treatments were not different ($P > .05$). However, the values were highest for the FM-40 diet. This result was expected since the basal diet was present in all the treatments and the level of protein in each diet was more than adequate for the requirement of the growing lambs. The digestion coefficient for CP was higher ($P < .05$) for the supplemented diets than for the basal diet. Among the supplemented diets, the percent DCP were not different ($P > .05$). This shows that commercial FM compares favorably with CSM as a protein supplement for growing lambs, even at the high levels of supplementation. On the contrary,

Thomas and Beeson (1977) observed higher fecal N for Hereford steers fed a 12% CP, FM and HM supplemented diet as compared to a soybean meal supplemented diet. However, the differences in the levels of protein in the different experiments are too large for adequate comparison.

The percent digestibility of EE was higher ($P < .05$) for the basal and CSM diets than for the FM diets. The low levels of EE in all diets (2.1% for the basal and 1.3% for supplemental CSM) coupled with the high level in FM (5.1%) make this of little significance. Digestibility of ash was higher ($P < .001$) for the CSM diet than for any of the other diets, indicating that CSM is a better source of digestible mineral components than FM for growing lambs. N retention expressed as centigrams per kilogram of metabolic weight (cg/kg $W^{.75}$) was not different ($P > .05$) among the diets due to large variations among the animals on each diet. However, the highest values were observed for the FM-40 (66.3) and FM-50 (64.9) diets, followed by the CSM diet (61.3) and lowest for the basal diet (52.5). When N retention was expressed as percent of N fed, the values obtained were higher ($P < .05$) for the basal and FM-40 diets than for the CSM and FM-50 diets. This is not a preferred means of comparison since N retention data are generally more meaningful when animals are fed lower levels of N than in this study.

Table 8 shows the digestion coefficients (%) for DM, OM, CP, and GE for each protein supplement in the diets of trial 1. These values were calculated by difference, a method which assumes that the digestibility of the basal diet did not change when the different

protein sources were added to it. The general trend was in the order, FM-40 > FM-50 > CSM-50.

The digestion coefficients (%) for the components measured in the diets of trial 2 are shown in Table 9. Digestibility of CP was higher ($P < .05$) for the supplemented diets than for the basal diet. Among the supplemented diets, DCP was higher ($P < .05$) for the FM-50 diet than for either the CSM-50 or the HM-50 diets. DCP for the latter diets were not different ($P > .05$). There were no significant differences among the diets ($P > .05$) for N retention either as centigrams per kilogram of metabolic weight or as percent of N fed. However, N retention per unit of metabolic weight ranged in the order FM-50 > CSM-50 > HM-50 > basal.

Table 10 shows the percent digestibilities of DM, OM, CP, and GE for each supplement of trial 2 (by difference). The order of the values obtained was: FM-50 > HM-50 > CSM-50 for each of the components. This suggests that commercial FM and commercial HM were better protein supplements (per unit of N basis) than CSM.

CONCLUSIONS

This study has shown that FM and HM compare well with CSM as protein supplements for ruminants (on a per unit of N basis). The optimum utilization of N from these supplements occurs at lower roughage to concentrate ratios. The current degree of processing of commercial FM (pepsin digestibility > 70%) may be too high for efficient N utilization. FM and HM proteins may have some bypass potential since they

are not readily soluble in the rumen.

There is a need for more research in the area of optimum amount of processing needed for best utilization of FM and HM as well as the chemistry involved so that more efficient use can be made of these meals. It is also very essential that a better, faster, and easier method of evaluating the degree of processing of feathers and hairs be developed. The method should also relate processing to *in vivo* utilization by livestock.

TABLE 1. INGREDIENT COMPONENTS OF THE BASAL DIETS FOR TRIALS 1 AND 2[a]

Ingredient	International feed number	% of Ration	
		Trial 1	Trial 2
Ground corn #2	4-02-931	53.2	65
Ryegrass straw (chopped)	2-04-073	21.8	28
Molasses (cane)	4-04-695	5.9	6
Cottonseed meal	5-01-621	17.1	-
Limestone	6-02-632	2	1

[a]1 g vitamin A (3,000,000 Iu/g)/181 kg was added to each diet.

TABLE 2. CHEMICAL COMPOSITION OF THE BASAL DIET AND THE SUPPLEMENTS FOR TRIAL 1

Item	Feedstuff		
	Basal	Cottonseed meal (CSM)	Feather meal (FM)
DM, %	90.4	90.9	94.4
Analysis, % of DM:			
Crude protein (CP)	17.2	47.2	85.5
Acid detergent fiber (ADF)	16.9	19.5	6.3
Ether extract (EE)	2.1	1.3	5.1
Ash	5.5	6.7	3.0
Nitrogen-free extract (NFE)	58.3	25.3	-
Gross energy (Kal/g)	4.4	4.7	5.6

TABLE 3. CHEMICAL COMPOSITION OF THE BASAL DIET AND THE SUPPLEMENTS FOR TRIAL 2

Item	Feedstuff			
	Basal	Cottonseed meal (CSM)	Feather meal (FM)	Hair meal (HM)
DM, %	90.1	91.1	92.8	92.9
Analysis, % of DM:				
Crude protein (CP)	8.7	40.6	84.7	90.0
Acid detergent fiber (ADF)	13.5	22.1	3.4	17.7
Ether extract (EE)	2.1	.9	6.3	3.0
Ash	4.2	6.8	3.5	2.6
Nitrogen-free extract (NFE)	71.5	29.6	2.1	-
Gross energy (Kcal/g)	4.3	4.6	5.6	5.5

TABLE 4. DAILY FEEDING SCHEDULE[a] (G DRY MATTER BASIS) FOR TRIALS 1 AND 2

Trial number and feedstuff	Treatment				
	Basal	CSM-50[b]	FM-40[c]	FM-50[d]	HM-50[e]
Trial 1					
Basal	994.2	723	813.4	813.4	-
Cottonseed meal	-	266.1	-	-	-
Feather meal	-	-	107.5	161.2	-
Total	994.2	989.1	920.9	974.6	-
Trial 2					
Basal	749.9	617.1	-	675.7	675.7
Cottonseed meal	-	132.2	-	-	-
Feather meal	-	-	-	70.6	-
Hair meal	-	-	-	-	63.2
Total	749.9	749.3	-	746.3	738.9

[a]Daily feed was divided into two equal parts and fed at 0800 and 1600 hr.

[b]Cottonseed meal supplied 50% of the total N in the diet.

[c]Feather meal supplied 40% of the total N in the diet.

[d]Feather meal supplied 50% of the total N in the diet.

[e]Hair meal supplied 50% of the total N in the diet.

TABLE 5. DRY MATTER DIGESTION (%) WHEN FEATHER MEAL OR HAIR MEAL OR A FEATHER MEAL-UREA COMBINATION WERE USED WITH VARIOUS PROPORTIONS OF ROUGHAGE:CONCENTRATE FOR IN VITRO RUMEN FERMENTATION

Roughage: concentrate ratio	Control diet[a]	Commercial feather meal[b]	Special feather meal[c]	Commercial feather meal + urea[d]	Commercial hair meal[e]
0:100	$50.4^{f,s}$	$55.7^{g,t}$	$58.1^{h,t}$	$55.6^{g,q}$	$57.7^{h,t}$
10:90	$48.8^{f,r}$	$52.5^{g,s}$	$54.4^{h,s}$	$52.5^{g,p}$	$56.3^{i,s}$
20:80	$47.4^{f,q}$	$49.8^{g,r}$	$52.2^{h,r}$	$50.2^{g,o}$	$55.0^{i,r}$
30:70	$46.3^{f,p}$	$48.0^{g,q}$	$50.3^{h,q}$	$49.6^{h,o}$	$54.2^{i,q,r}$
40:60	$45.1^{f,o}$	$46.9^{g,p}$	$49.2^{h,q}$	$50.1^{h,o}$	$53.1^{i,q}$
50:50	$44.2^{f,o}$	$45.4^{g,o}$	$48.1^{h,p}$	$49.3^{i,o}$	$51.8^{j,p}$
60:40	$44.0^{f,o}$	$44.3^{f,n}$	$46.9^{g,o}$	$46.3^{g,n}$	$49.1^{h,o}$
70:30	$41.8^{f,n}$	$42.9^{f,m}$	$45.0^{g,n}$	$45.5^{g,h,n}$	$46.5^{h,n}$
80:20	$40.4^{f,m}$	$41.3^{f,g,l}$	$41.8^{g,m}$	$41.0^{f,g,l}$	$43.4^{h,m}$
90:10	$39.5^{f,l}$	$41.1^{g,h,l}$	$40.5^{f,g,l}$	$42.6^{i,m}$	$42.1^{h,i,l}$
100:0	$38.1^{f,g,k}$	$39.0^{g,h,k}$	$37.4^{f,k}$	$39.1^{g,h,k}$	$40.2^{i,k}$
Overall Mean	44.2	46.1	47.6	47.4	50.0

[a]No added supplementary nitrogen.

[b]Pepsin digestibility 80%.

[c]Cooked at 35 p.s.i. for 45 minutes, pepsin digestibility 57%.

[d]Half supplementary N from urea and half from feather meal.

[e]Pepsin digestibility 65%.

^{f,g,h,i,j}Means in the same row (for each R:C) with different superscripts are different ($P < .05$).

^{k,l,m,n,o,p,q,r,s,t}Means in the same column (for each treatment) with different superscripts are different ($P < .05$).

TABLE 6. AMMONIA N CONCENTRATION (mg/dl) WHEN FEATHER MEAL OR HAIR MEAL OR FEATHER MEAL-UREA COMBINATION WERE USED WITH VARIOUS PROPORTIONS OF ROUGHAGE:CONCENTRATE FOR IN VITRO RUMEN FERMENTATION

Roughage: concentrate ratio	Control diet[a]	Commercial feather meal[b]	Special feather meal[c]	Commercial feather meal + urea[d]	Commercial hair meal[e]
0:100	$1.9^{f,j}$	$3.4^{g,h,j}$	$2.6^{f,g,j}$	$3.8^{h,j}$	$2.5^{f,g,j}$
10:90	$2.1^{f,j}$	$3.7^{h,i,j,k}$	$2.7^{f,g,j}$	$4.1^{i,j,k}$	$3.0^{g,h,j}$
20:80	$2.4^{f,j}$	$4.1^{h,j,k}$	$3.1^{f,g,j}$	$4.0^{g,h,j}$	$3.4^{g,h,j,k}$
30:70	$2.7^{f,j,k}$	$4.4^{h,k,l}$	$3.3^{f,g,j,k}$	$4.0^{g,h,j}$	$4.2^{g,h,k}$
40:60	$3.1^{f,k}$	$5.1^{h,i,l,m}$	$4.1^{g,k,l}$	$4.2^{g,h,j,k}$	$5.1^{i,l}$
50:50	$3.6^{f,k,l}$	$5.6^{g,m}$	$4.2^{f,l,m}$	$4.4^{f,j,k}$	$6.8^{h,m}$
60:40	$4.1^{f,l}$	$6.8^{g,n}$	$4.5^{f,l,m}$	$5.0^{f,k,l}$	$8.0^{h,n}$
70:30	$7.3^{g,m}$	$7.9^{g,h,o}$	$5.1^{f,m,n}$	$5.7^{f,l}$	$8.4^{h,n,o}$
80:20	$8.2^{g,h,n}$	$10.8^{h,p}$	$5.7^{n,o}$	$8.0^{g,m}$	$9.0^{h,o}$
90:10	$11.2^{h,i,o}$	$11.7^{i,q}$	$6.5^{f,o}$	$8.7^{g,m}$	$10.3^{h,p}$
100:0	$14.7^{g,p}$	$14.6^{g,r}$	$10.6^{f,p}$	$10.7^{f,n}$	$10.9^{f,p}$
Overall Mean	5.6	7.1	4.8	5.7	6.5

[a]No added supplementary N.

[b]Pepsin digestibility 80%.

[c]Cooked at 35 p.s.i. for 45 minutes, pepsin digestibility 57%.

[d]Half supplementary N from urea and half from feather meal.

[e]Pepsin digestibility 65%.

[f,g,h,i]Means in the same row (for each R:C) with different superscripts are different ($P < .05$).

[j,k,l,m,n,o,p,q,r]Means in the same column (for each treatment) with different superscripts are different ($P < .05$).

TABLE 7. DIGESTION COEFFICIENTS (%) FOR INDIVIDUAL COMPONENTS AND N RETENTIONS OF EACH DIET FOR TRIAL 1 (MEANS OF FIVE LAMBS)

	Diet				
Component	Basal	CSM-50	FM-40	FM-50	SEM
Dry matter (DDM)*	77.3	76.6	78.5	77.4	.6
Organic matter (DOM)*	79.1	78.0	80.3	79.0	.6
Crude protein (DCP)*	77.8[a]	80.8[b]	81.1[b]	80.1[b]	.7
Acid detergent fiber (DADF)*	46.3	43.7	48.1	45.3	1.2
Ether extract (DEE)*	91.5[b]	92.9[c]	90.0[a]	89.1[a]	.8
N-free extract (DNFE)*	88.3	88.2	89.3	88.3	.5
Ash (DAsh)***	45.3[a]	54.9[b]	47.7[a]	47.1[a]	1.3
Gross energy (DGE)*	78.2	77.2	79.5	78.4	.7
N retention (cg/kg $BW^{.75}$)*	52.5	61.3	66.3	64.9	4.9
N retention (% of N fed)*	30.3[b]	24.4[a]	28.4[b]	23.1[a]	1.9

[a,b,c]Means in the same row with different superscripts are different.

*$P < .05$

***$P < .001$

TABLE 8. DIGESTION COEFFICIENTS (%) FOR CERTAIN COMPONENTS OF EACH PROTEIN SUPPLEMENT FOR TRIAL 1 BY DIFFERENCE (MEANS OF FIVE LAMBS)

	Supplement			
Component	CSM-50	FM-40	FM-50	SEM
Dry matter (DDM)	74.9	87.4	78.0	5.4
Organic matter (DOM)	74.6	89.0	78.5	5.0
Crude protein (DCP)	83.7	86.2	82.4	5.0
Gross energy (DGE)	74.7	86.6	79.0	4.6

TABLE 9. DIGESTION COEFFICIENTS (%) FOR INDIVIDUAL COMPONENTS AND N RETENTIONS OF EACH DIET FOR TRIAL 2 (MEANS OF FIVE LAMBS)

	Diet				
Component	Basal	CSM-50	FM-50	HM-50	SEM
Dry matter (DDM)	75.4	74.7	76.5	76.1	1.2
Organic matter (DOM)	76.5	75.8	77.7	77.3	1.3
Crude protein (DCP)	65.2[a]	70.4[b]	73.6[c]	68.7[b]	1.5
Acid detergent fiber (DADF)	36.7	38.4	38.3	38.6	3.5
Ether extract (DEE)	86.1	87.6	85.9	85.6	1.1
N-free extract (DNFE)	85.1	85.3	86.3	87.7	1.1
Ash (DAsh)	50.2	52.5	49.5	49.3	1.4
Gross energy (DGE)	75.9	75.3	77.2	76.7	1.2
N retention (cg/kg $BW^{.75}$)	26.4	34.3	42.2	31.0	4.1
N retention (% of N fed)	33.1	26.5	29.4	22.2	3.2

[a,b,c]Means in the same row with different superscripts are different ($P < .05$).

TABLE 10. DIGESTION COEFFICIENTS (%) FOR CERTAIN COMPONENTS OF EACH PROTEIN SUPPLEMENT FOR TRIAL 2 BY DIFFERENCE (MEANS OF FIVE LAMBS)

	Supplement			
Component	CSM-50	FM-50	HM-50	SEM
Dry matter (DDM)	71.4	87.3	84.2	11.8
Organic matter (DOM)	72.2	89.0	85.6	11.9
Crude protein (DCP)	75.6	81.8	72.3	3.2
Gross energy (DGE)	72.7	86.2	82.8	9.6

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Running Head: Utilization of differently processed feather meals by ruminants.

Effect of the Degree of Processing on Utilization of Feather Meal by Ruminants[1,2]

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Key Words: Feather Meal, Processing, Digestibility, Ruminants

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[1]Oregon Agricultural Experiment Station Technical Paper No. ____.

[2]Partial support supplied by Fats and Proteins Research Foundation, Inc., Des Plaines, IL.

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SUMMARY

In vitro pepsin-HCl digestion, *in vitro* rumen studies, chemical analyses and three *in vivo* digestion trials were conducted to study the relationship between the degrees of feather meal (FM) processing and utilization by ruminants and to compare specially hydrolyzed FM with cottonseed meal (CSM) as N supplements in ruminants' diets. Pepsin-HCl digestion was conducted on chicken feathers hydrolyzed in the laboratory (LHF) at 15 p.s.i. for different periods (0,15,30,45,60,75, 90,105 and 120 min). The LHF were also used as N supplements for the *in vitro* rumen studies in combinations with Solka-flock (cellulose), urea and commercial FM. Each *in vivo* trial (using 20 crossbred wether lambs) compared a high concentrate basal ration (8% CP) with supplemented rations in which the protein supplements CSM (treatment 2, 14% CP) and commercial FM (treatment 3, 14% CP) supplied 50% of the N in respective diets. The commercial FM used in trials 1, 2 and 3 had 71, 78 and 78% pepsin-HCl digestibilities, respectively. Specially hydrolyzed turkey feathers (HTF) were added to the basal to supply 50% of the N in the diets (14% CP) of treatment 4 of each trial. The HTF had cooking times, pressures and pepsin digestibilities as shown: trial 1, 45 min at 35 p.s.i., 57%; trial 2, 60 min at 45 p.si., 64%; trial 3, 90 min at 45 p.s.i., 78%. The different degrees of processing had no effect on the level of N in FM. Pepsin-HCl digestibilities of CP and dry matter (DM) increased with increasing hydrolysis period up to a point and then decreased slightly. *In vitro* rumen DM digestibility showed a similar tendency. However, *in vitro* rumen DM

digestibility values were generally low, indicating that FM has some reticulo-rumen bypass potential. Urea addition increased utilization of FM protein. In vivo studies showed that varying the degree of processing (57 to 78% pepsin digestibility) did not affect utilization of the FM by growing lambs. All the FM tested compared well with CSM (on a per unit of N basis) as N supplements for growing lambs. Hence, FM protein appears to be digested mainly by proteolytic enzymes of the gastro-intestinal tract.

INTRODUCTION

Feather meal (when properly processed) has been found to be an excellent protein supplement (85 - 100% crude protein) which is comparable to cottonseed meal (CSM) or soybean meal (SBM) on a per unit of N basis in ruminant rations (Jordan and Croom, 1957; Wise and Barrick, 1963; Rakes et al., 1968; Kennett and Bull, 1972; Thomas and Beeson, 1977; Daugherty and Church, 1978; Wray et al., 1979; Aderibigbe, 1981). However, knowledge of the specific relationship between the degree of processing and utilization of this N source by ruminants is still lacking (Aderibigbe, 1981).

The current processing of feather meal (FM) involves steam cooking under pressure with constant agitation (Davis et al., 1961; Moran et al., 1967; Thomas and Beeson, 1977). Davis et al., (1961) pointed out that the standard definition adopted for FM by the Association of American Feed Control Officials specified that it should not contain less than 70% digestible crude protein as measured with pepsin-

hydrochloric acid (AOAC, 1975). This was an attempt to prevent underprocessing by manufacturers since pepsin-hydrochloric acid digestibility of FM is positively related to the time or pressure of steam cooking (Davis et al., 1961). This definition may hold for nonruminants such as swine and poultry in which protein digestibility mainly involves proteolytic enzymes of the gastro intestinal tract. In two different experiments, Morris and Balloun (1973) observed that higher degrees of processing (time and pressure) resulted in higher available amino acids and biological values for growing chicks. In ruminants, protein digestibility is primarily accomplished by microbial fermentation in the reticulo-rumen; digestibility by proteolitic enzymes is secondary (unless the protein has high reticulo-rumen bypass potential). Aderibigbe (1981) suggested that processing of FM to achieve 70% or more pepsin digestibility might be too high for optimum utilization by ruminants.

The objectives of this study were: (a) to observe the relationship between the degrees of FM processing and pepsin-hydrochloric acid digestibility; (b) to determine the minimum amount of processing needed for optimum utilization of FM, and (c) to compare FM hydrolyzed under different conditions with CSM as protein supplements for ruminants.

MATERIALS AND METHODS

Chemical analyses, in vitro pepsin digestion, in vitro rumen dry matter digestion (DMD) and ammonia concentration and three in vivo digestion trials were used to achieve the objectives of this study.

In Vitro Digestion Studies

Fresh chicken feathers collected from a processing plant were washed thoroughly with water and 200 g portions were steam cooked in a laboratory autoclave at 15 p.s.i. for 0,15,30,45,60,75,90,105 and 120 minutes. The feathers were then dried at 50 C and ground in a small Wiley mill (20 mesh screen). Triplicate portions of each FM were analyzed for CP before and after being defatted using the AOAC (1975) procedure. In vitro pepsin-hydrochloric acid digestibilities of dry matter (DM) and the crude protein (CP) of the various meals (defatted) were also conducted by the AOAC (1975) procedure.

Triplicate samples of a combination of each FM and solka-flock (cellulose) were used as substrates (20% CP) for one set (a) of in vitro rumen fermentations. Another set involved triplicate samples of a combination of each FM, urea, and solka-flock as substrates with urea and FM each supplying 50% of the total N in the 20% CP medium. The substrates for the third set of in vitro fermentations involved triplicate samples of a combination of solka-flock, commercial FM (pepsin digestibility 80%) and each of five laboratory hydrolyzed FM (0, 75,90,105 and 120 minutes). Three different ratios (25:75, 50:50 and 75:25) of laboratory hydrolyzed FM to commercial FM (LHF:CF) were used for the 14% CP medium. Inoculums for the in vitro incubations were obtained from a rumen-fistulated steer maintained on grass hay and commercial FM for two weeks before the first collection in order to adapt the rumen microbes. In vitro studies were conducted as described by Aderibigbe (1980) to obtain dry matter digestibility (DMD) and

ammonia nitrogen concentration (NH_4-N).

In Vivo Digestion Studies with Wether Lambs

Three digestion trials were conducted with crossbred wether lambs as described by Aderibigbe (1981). Each trial involved 20 lambs in four treatments of five lambs per treatment. Each trial compared a (treatment 1) basal diet (65% ground corn, IFN 4-02-931; 28% chopped ryegrass straw, IFN 2-04-073; 6% cane molasses, IFN 4-04-695; and 1% limestone flour, IFN 6-02-632 fortified with 1 g of vitamin A per 181 kg; 8% CP) with supplemented diets in which the protein supplements CSM (treatment 2; 15% CP) and commercial FM (treatment 3, 14% CP) supplied 50% of the N in respective diets. Pepsin digestibilities (AOAC, 1975) of the commercial FM used in trials 1, 2 and 3 were 71, 78 and 78%, respectively.

Treatment 4 of each of the three trials involved diets in which specially hydrolyzed turkey feathers (HTF) were added to the basal to supply 50% of the N in each diet. The experimental HTF were provided gratis by Modesto Tallow Co., Modesto, CA. The cooking times, pressures and pepsin digestibilities (AOAC, 1975) were as shown: trial 1, 45 min at 35 p.s.i., 57%; trial 2, 60 min at 45 p.s.i., 64%; trial 3, 90 min at 45 p.s.i., 78%. The chemical components of the basal and the supplements for trials 1 through 3 are shown in Table 1. The feeding schedules for trials 1 through 3 are shown in Table 2.

The experimental feeds and feces were analyzed for proximate components as described by AOAC (1975). Acid detergent fiber was

determined by the method of Van Soest (1963) as described in the modified micro-procedure of Waldern (1971). Gross energy was determined using a Parr adiabatic oxygen bomb calorimeter. Digestion coefficients for components of each diet and supplement (by difference) were calculated by the methods described by Schneider and Flatt (1975).

Statistical Analyses

Data for *in vitro* pepsin digestibility and *in vivo* nutrient digestibility were analyzed by use of a one-way analysis of variance while those for *in vitro* rumen studies were analyzed by use of a two-way analysis of variance as described by Snedecor and Cochran (1974). Treatment means were compared by use of LSD as outlined by Steel and Torrie (1980).

RESULTS AND DISCUSSION

In Vitro Studies

Table 3 shows the data obtained from the laboratory hydrolyzed chicken feathers (15 p.s.i., 0 to 120 min). The CP percentage of undefatted samples varied from a low of 82.6 (60 min) to a high of 87.6 (120 min) and probably reflected variability in fat contents of the different meals. The CP percentage of defatted meals was similar among all time periods. This shows that the degree of processing had no appreciable effect on the level of N in FM. The percent pepsin digestibility of CP increased with increasing hydrolysis time from a low of seven for the zero hydrolysis period to a high of 62.9 for the

90 min hydrolysis period and then decreased slightly to 55.6 and 49.2% for the 105 and 120 periods, respectively. Pepsin digestibility of DM also increased with increasing hydrolysis time from 12.5 (0 min) to 62.8% (90 min) and then tapered down to 55.2 and 49% for the 105 and 120 minute periods, respectively. Davis et al. (1961) observed similar increases in pepsin-HCl digestibility of CP from FM with increasing hydrolysis times at a constant pressure of 30 p.s.i. The results of the pepsin digestibility of DM merely reflect the fact that FM is almost all protein (up to 100% in some FM) and so, DM digestibility reflected protein digestibility to a large extent.

The results of the in vitro DMD of solka-flock and FM combination for the LHF (Table 3) showed a slight tendency for increasing DMD with increasing hydrolysis time. However, the values are too low and the range too narrow to be meaningful (from 22.2 for the 0 min to 26.1 for the 120 min). When the LHF and urea each supplied 50% of the total N, DMD jumped to values > 42. The DMD was significantly higher ($P < .05$) for the FM and urea supplemented groups than for the non-urea supplemented groups at all times of hydrolysis. The most surprising result was obtained from the zero period of hydrolysis which jumped to 54.4% DMD with urea addition. There was no specific relationship between hydrolysis time and DMD percentage among the urea supplemented treatments. The results of the in vitro NH_4-N concentrations were similar to those for DMD. These results show that the digestibility of FM by proteolytic enzymes increases with increasing processing up to a point. FM protein may not be easily degraded by

rumen microorganisms. Thus, FM may have some reticulo-rumen bypass potential. Urea supplementation certainly increased utilization of FM protein. Other workers have found similar increased utilization of FM protein with urea supplementation (Daugherty and Church, 1978; Aderibigbe, 1981). The DMD (%) and NH_4-N concentration obtained when three different ratios of commercial FM (pepsin digestibility 80%) and some of the LH chicken feathers were used as protein supplements are shown in Tables 4 and 5, respectively. The fact that DMD and NH_4-N concentration did not increase appreciably with increased commercial FM further supports our suggestion that FM may have some reticulo-rumen bypass potential.

In Vivo Trials

Table 6 shows the percent digestibility and N retentions for the components of the diets for trial 1. The percent DDM and DOM were not different ($P > .05$) among the diets, although the absolute values for the supplemented diets were higher than that of the basal. Crude protein digestibility (%) was higher ($P < .001$) for the supplemented diets than for the basal but the values were not different ($P > .001$) among the supplemented diets. However, the values obtained for the supplemented diets were in the order FM-50 = HTF-50 > CSM-50, suggesting that the HTF (cooked at 35 p.s.i. for 45 min, pepsin digestibility 57%) was as good as the commercial FM (pepsin digestibility 71%) or CSM as protein supplements for growing lambs.

The percent DNFE was higher for the supplemented diets than for

the control diet and also slightly higher for the CSM-50 diet than for the FM diets ($P < .05$). Values obtained for the FM diets were not different ($P > .05$). N retention, expressed as centigrams per kilogram of metabolic weight (cg/kg $W^{.75}$), was higher ($P < .05$) for the FM diets than for the basal and the CSM-50 diets which were not different ($P > .05$). The value obtained for HTF-50 diet (35.4) was higher ($P < .05$) than that obtained for the FM-50 (29.2). This further illustrates the high utilization potential of this less-processed HTF for growing lambs.

The digestion coefficients (%) and N retentions for components of the diets of trial 2 are shown in Table 7. The percent DDM was higher ($P < .01$) for the supplemented diets than for the basal diet, but there were no differences ($P > .01$) among the supplemented diets. Organic matter digestibility (%) was also higher ($P < .05$) for the supplemented diets than for the basal diet. Among the supplemented diets, DOM was significantly higher ($P < .05$) for the HTF-50 diet than for the FM-50. Values for the CSM-50 and the FM diets were not different ($P > .05$). This shows that N supplementation generally improved DM and OM digestibilities and that the HTF was more efficient in stimulating digestion than the other N supplements tested.

Crude protein digestibility was higher ($P < .001$) for the supplemented diets than for the basal diet, but the values obtained for the supplemented diets were not different ($P > .001$). This shows that the difference in the degree of processing of the two FM, as expressed by their pepsin digestibilities (78% for FM-50 versus 64% for HTF-50),

did not affect their utilization and that the FM are as good as CSM (on a per unit of N basis) when used as a partial N supplement for growing lambs. The digestibilities (%) of ADF, NFE, and GE were higher ($P < .05$) for the supplemented diets than for the basal diet. Ash digestibility was also higher ($P < .001$) for the supplemented diets than for the basal diet. Among the supplemented diets the order of DAsh was CSM-50 > HTF-50 > FM-50. This agreed with the result obtained by Aderibigbe (1981), who showed that CSM was a better source of digestible mineral components than FM. N retention, expressed as cg/kg $BW^{.75}$, was higher ($P < .01$) for the supplemented diets than for the basal diet, but the values for the supplemented diets were not different ($P > .01$). This further supports the results obtained for the DCP.

Table 8 shows the percent digestibility and N retentions for the components of the diets for trial 3. The results obtained for DCP and N retention (cg/kg $W^{.75}$) also showed higher values ($P < .01$ and $P < .05$, respectively) for the supplemented diets than for the basal with no differences among the supplemented diets ($P > .05$). However, the pepsin digestibility of the FM-50 and HTF-50 in this trial were the same (78%). Ash digestibility (%) was also higher ($P < .001$) for the supplemented diets than for the control diet with no differences ($P > .001$) among the supplemented diets.

The percent digestibilities of DM, OM, CP and GE for the protein supplements of trials 1 through 3 (by difference) are shown in Table 9. The general trend for the digestibility of these four components for

trial 1 was in the order FM > HTF > CSM. In trials 2 and 3, the trend was in the order HTF > FM > CSM.

CONCLUSIONS

These studies demonstrated that utilization of FM by growing lambs was not affected when the FM were processed at various degrees to achieve pepsin-Hcl digestibilities of between 57% and 78% nor did the degree of processing have any appreciable effect on the level of N in FM. Pepsin-HCl digestibility of the CP in LHF increased with increasing time of processing up to a point and then decreased slightly. Since utilization of FM was low in in vitro but high in in vivo studies, this indicates some potential for reticulo-rumen bypass. Utilization of FM protein was comparable to that of CSM (on a per unit of N basis) and urea supplementation increased utilization of FM protein in vitro. Although the literature suggests poor utilization of FM when fed at high levels to ruminants, our studies indicate very satisfactory utilization when FM supplied half of the dietary N. Future work should include studies of the utilization of FM protein at the lower degrees of processing (less than 57% pepsin HCl digestibility). Performance trials should also be conducted to evaluate the relationships between the degrees of processing FM and their utilization for growth by ruminants.

TABLE 1. CHEMICAL COMPOSITION OF THE BASAL DIET AND THE SUPPLEMENTS FOR TRIALS 1 THROUGH 3

Trial number and treatment	Percent dry matter (DM)	Analysis, % of DM					
		Crude protein (CP)	Acid detergent fiber (ADF)	Ether extract (EE)	Ash	N-free extract (NFE)	Gross energy (K cal/g)
Trial 1							
Basal	90.2	8.6	13.8	2.5	4.3	70.8	4.3
CSM	90.8	40.3	22.8	1.0	6.9	29.0	4.7
FM[a]	92.7	82.9	6.1	5.6	3.5	1.9	5.7
HTF[a]	94.6	87.8	10.6[d]	4.6	2.4	-	5.7
Trial 2							
Basal	88.2	8.4	15.5	3.0	4.3	68.8	4.4
CSM	86.3	46.3	23.2	1.3	7.4	21.8	4.9
FM[b]	90.6	88.2	5.5	6.1	3.2	-	5.8
HTF[b]	92.2	85.8	8.0[d]	4.3	2.9	-	5.7
Trial 3							
Basal	89.2	8.2	14.9	3.0	4.2	69.7	4.4
CSM	88.2	46.2	21.8	1.3	7.2	23.5	4.8
FM[c]	92.8	86.1	4.3	6.0	3.0	.6	5.7
HTF[c]	92.1	86.5	5.2	6.0	4.5	-	5.6

[a]Pepsin digestibility of FM was 71%; HTF was hydrolyzed at 35 p.s.i. for 45 min, pepsin digestibility, 57%.

[b]Pepsin digestibility of FM was 78%; HTF was hydrolyzed at 45 p.s.i. for 60 min, pepsin digestibility, 64%.

[c]Pepsin digestibility of FM was 78%; HTF was hydrolyzed at 45 p.s.i. for 90 min, pepsin digestibility, 78%.

[d]Because of the lower degrees of processing, some insoluble proteins appeared in the ADF fraction.

TABLE 2. DAILY FEEDING SCHEDULE[a] (G DRY MATTER BASIS) FOR TRIALS 1 THROUGH 3

Trial number and feedstuff	Treatment			
	Basal	CSM-50[b]	FM-50[c]	HTF-50[d]
Trial 1				
Basal	744.2	617.9	676.6	676.6
Cottonseed meal	-	131.7	-	-
Commercial feather meal	-	-	70.5	-
Hydrolyzed turkey feathers (45 min, 35 p.s.i.)	-	-	-	64.5
Total	744.2	749.6	747.1	741.1
Trial 2				
Basal	727.6	604.2	661.5	661.5
Cottonseed meal	-	100.5	-	-
Commercial feather meal	-	-	57.3	-
Hydrolyzed turkey feathers (60 min, 45 p.s.i.)	-	-	-	56.0
Total	727.6	704.7	718.8	717.5
Trial 3				
Basal	735.7	610.9	668.8	668.8
Cottonseed meal	-	102.8	-	-
Commercial feather meal	-	-	58.7	-
Hydrolyzed turkey feathers (90 min, 45 p.s.i.)	-	-	-	58.9
Total	735.7	713.7	727.5	727.7

[a]Daily feed was divided into two equal parts and fed at 0800 and 1600 hr.

[b]Cottonseed meal supplied 50% of the total N in the diet.

[c]Commercial feather meal supplied 50% of the total N in the diet.

[d]Specially hydrolyzed turkey feathers (cooking times and pressure shown) supplied 50% of the total N in respective diet.

TABLE 3. DATA ON CHICKEN FEATHERS HYDROLYZED WITH STEAM AT 15 P.S.I. FOR ZERO TO 120 MINUTES

Item	Length of hydrolysis, minutes								
	0	15	30	45	60	75	90	105	120
Crude protein, % dry basis	83.4	84.5	86.6	83.2	82.6	82.9	87.4	86.3	87.6
Crude protein, % in defatted feathers	90.3	92.8	93.6	92.0	90.4	91.1	91.6	91.2	91.4
Pepsin digestibility of CP %	7.0^{c}	17.0^{d}	23.6^{e}	26.4^{e}	33.9^{f}	38.1^{f}	62.9^{h}	55.6^{g}	49.2^{g}
Pepsin digestibility of DM, %	12.5^{c}	$17.3^{c,d}$	$23.0^{d,e}$	28.5^{e}	36.9^{f}	41.1^{f}	62.8^{h}	55.2^{g}	49.0^{g}
In vitro rumen DM digestibility of solka-flock and feather combination[a]	22.2^{c}	$23.6^{c,d}$	$23.8^{c,d}$	$24.1^{c,d,e}$	$26.9^{e,f}$	$24.3^{c,d,e}$	27.5^{f}	$25.1^{c,d,e,f}$	$26.1^{d,e,f}$
In vitro rumen DM digestibility of solka-flock, feather and urea combination[b]	54.4^{j}	$48.9^{h,i}$	$48.1^{h,i}$	46.4^{h}	42.8^{g}	42.6^{g}	49.5^{i}	$47.3^{h,i}$	$49.1^{h,i}$
In vitro rumen NH_4-N production from solka-flock and feather combination, centigram/liter[a]	4.2^{c}	$6.0^{c,d}$	$7.3^{c,d}$	$6.9^{c,d}$	$8.8^{c,d}$	$11.3^{c,d}$	13.2^{d}	$11.6^{c,d}$	13.2^{d}
In vitro rumen NH_4-N production from solka-flock, feather and urea combination, centigram/liter[b]	$48.2^{e,f}$	$52.8^{e,f,g,h}$	46.8^{e}	$50.3^{e,f,g}$	$56.7^{f,g,h}$	58.3^{g}	$56.8^{g,h}$	67.5^{i}	$61.0^{h,i}$

[a]Chicken feather supplied all the N in the 20% CP medium.

[b]Chicken feather and urea supplied 50:50 of the total N in the 20% CP medium.

^{c,d,e,f,g,h}Means in the same row with different superscripts for pepsin digestibility of CP and pepsin digestibility of DM are different ($P < .05$).

^{c,d,e,f,g,h,i,j}Means in the same row or in the same column with different superscripts for each of the pair of *in vitro* rumen DM digestibilities and *in vitro* rumen NH_4-N productions are different ($P < .05$).

TABLE 4. *IN VITRO* DM DIGESTIBILITY (%) OF SOLKA-FLOCK, COMMERCIAL FEATHER MEAL (CF) AND LABORATORY HYDROLYZED FEATHER MEALS (LHF)[a,b]

Ratio of LHF to CF (LHF:CF)	Length of hydrolysis of LHF, minutes 0	75	90	105	120
25:75	29.6[c,d,e]	29.3[c,d,e]	30.0[c,d,e]	31.3[d,e]	31.7[e]
50:50	27.0[c,d]	28.6[c,d,e]	29.0[c,d,e]	26.9[c]	32.2[e]
75:25	26.6[c]	26.2[c]	28.6[c,d,e]	28.2[c,d,e]	30.5[c,d,e]

[a]Various ratios of CF and LHF supplied the total N in the 14% CP medium.

[b]LHF were hydrolyzed with steam at 15 p.s.i. for periods shown; pepsin digestibility of CP from CF was 80%.

[c,d,e]Means in the same row or the same column with different superscripts are different ($P < .001$).

TABLE 5. *IN VITRO* AMMONIA N CONCENTRATION (CENTIGRAMS/LITER) OF SOLKA-FLOCK, COMMERCIAL FEATHER MEAL (CF) AND LABORATORY HYDROLYZED FEATHER MEALS (LHF)[a,b]

Ratio of LHF to CF (LHF:CF)	Length of hydrolysis of LHF, minutes				
	0	75	90	105	120
25:75	7.8	8.3	8.3	6.1	7.3
50:50	10.7	6.8	9.9	6.7	8.0
75:25	10.0	10.4	9.3	7.7	7.4

[a]Various ratios of CF and LHF supplied the total N in the 14% CP medium.

[b]LHF were hydrolyzed with steam at 15 p.s.i. for periods shown; pepsin digestibility of CP from CF was 80%.

TABLE 6. DIGESTIBILITY (%) FOR INDIVIDUAL COMPONENTS AND N RETENTIONS OF EACH DIET FOR TRIAL 1 (MEANS OF FIVE LAMBS)

	Diet				
Component	Basal	CSM-50	FM-50	HTF-50	SEM
Dry matter (DDM)*	75.6	77.2	78.1	77.2	.6
Organic matter (DOM)*	76.9	78.7	79.5	78.5	.6
Crude protein (DCP)***	57.3[a]	71.5[b]	72.8[b]	72.9[b]	1.3
Acid detergent fiber (DADF)*	37.9	40.4	42.6	41.4	1.6
Ether extract (DEE)*	86.8	86.3	86.8	87.4	.8
N-free extract (DNFE)*	86.5[a]	89.3[c]	88.4[b]	87.8[b]	.7
Ash (DAsh)*	46.2	47.6	46.6	46.0	1.4
Gross energy (DGE)*	75.3	77.1	78.2	76.8	.7
N retention (cg/kg $BW^{.75}$)*	18.5[a]	22.8[a]	29.2[b]	35.4[c]	3.2
N retention (% of N fed)*	24.4	18.8	25.1	27.2	2.4

[a,b,c]Means in the same row with different superscripts are different.

*$P < .05$

***$P < .001$

TABLE 7. DIGESTIBILITY (%) FOR INDIVIDUAL COMPONENTS AND N RETENTIONS OF EACH DIET FOR TRIAL 2 (MEANS OF FIVE LAMBS)

	Diet				
Component	Basal	CSM-50	FM-50	HTF-50	SEM
Dry matter (DDM)**	73.3[a]	77.1[b]	76.4[b]	77.7[b]	.8
Organic matter (DOM)*	74.5[a]	78.0[b,c]	77.4[b]	78.7[c]	.8
Crude protein (DCP)***	57.8[a]	71.7[b]	71.7[b]	72.4[b]	1.4
Acid detergent fiber (DADF)*	37.2[a]	46.1[c]	43.2[b]	44.5[b,c]	2.0
Ether extract (DEE)*	88.0	88.8	87.6	87.7	.8
N-free extract (DNFE)*	84.4[a]	87.8[c]	86.3[b]	87.9[c]	.8
Ash (DAsh)***	44.8[a]	58.7[c]	53.3[b]	55.3[b,c]	1.6
Gross energy (DGE)*	73.7[a]	77.2[b,c]	76.6[b]	78.0[c]	.8
N retention (cg/kg $BW^{.75}$)*	24.6[a]	38.5[b]	44.1[b]	40.8[b]	3.2
N retention (% of N fed)*	35.8	37.2	36.7	35.2	2.7

[a,b,c]Means in the same row with different superscripts are different.

*$P < .05$

**$P < .01$

***$P < .001$

TABLE 8. DIGESTIBILITY (%) FOR INDIVIDUAL COMPONENTS AND N RETENTIONS OF EACH DIET FOR TRIAL 3 (MEANS OF FIVE LAMBS)

	Diet				
Component	Basal	CSM-50	FM-50	HTF-50	SEM
Dry matter (DDM)*	74.1	74.9	76.8	77.7	1.0
Organic matter (DOM)*	75.2	75.8	77.7	78.7	1.1
Crude protein (DCP)**	55.4[a]	67.8[b]	68.2[b]	71.3[b]	2.8
Acid detergent fiber (DADF)*	37.1	39.0	43.5	44.9	2.2
Ether extract (DEE)*	87.6	90.7	87.2	88.7	.9
N-free extract (DNFE)*	85.1	86.1	86.8	87.3	.7
Ash (DAsh)***	50.8[a]	57.6[b]	56.9[b]	58.6[b]	1.2
Gross energy (DGE)*	73.9	75.7	77.1	78.3	1.1
N retention (cg/kg $BW^{.75}$)*	16.6[a]	33.0[b]	31.4[b]	35.3[b]	3.1
N retention (% of N fed)*	25.6	31.5	28.0	31.3	3.2

[a,b,c]Means in the same row with different superscripts are different.

*$P < .05$

**$P < .01$

***$P < .001$

TABLE 9. DIGESTIBILITY (%) OF CERTAIN COMPONENTS OF EACH PROTEIN SUPPLEMENT FOR TRIALS 1 THROUGH 3 BY DIFFERENCE (MEANS OF FIVE LAMBS)

	Supplement			
Trial and Component	CSM	FM	HTF[a]	SEM
Trial 1				
Dry matter (% DDM)	84.8	102.8	93.8	5.6
Organic matter (% DOM)	87.3	104.7	95.1	5.5
Crude protein (% DCP)	85.8	88.2	89.0	1.7
Gross energy (% DGE)	85.1	99.7	89.1	5.2
Trial 2				
Dry matter (% DDM)	108.2	127.0	130.0	4.5
Organic matter (% DOM)	102.0	125.1	127.9	5.8
Crude protein (% DCP)	88.4	87.0	88.1	3.0
Gross energy (% DGE)	97.5	102.3	117.8	8.9
Trial 3				
Dry matter (% DDM)	79.6	107.6	118.9	12.2
Organic matter (% DOM)	85.0	118.3	118.4	10.3
Crude protein (% DCP)	80.5	82.0	88.3	5.4
Gross energy (% DGE)	85.0	105.4	117.2	9.0

[a]The cooking times, pressures and pepsin digestibilities for the hydrolyzed turkey feathers were as shown: trial 1, 45 min at 35 p.s.i., 57%; trial 2, 60 min at 45 p.s.i., 64%; trial 3, 90 min at 45 p.s.i., 78%.

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Running Head: Performance of sheep fed feather meal and hair meal.

Performance, Carcass Traits and Cost of Gains of Lambs fed Hair Meal and Each of Three Differently Hydrolyzed Turkey Feather Meals as Protein Supplements[1,2]

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Key Words: Performance, Carcass Traits, Costs, Ewe Lambs, Wether Lambs

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[1]Oregon Agricultural Experiment Station Technical Paper No. ____.

[2]Partial support supplied by Fats and Proteins Research Foundation, Inc., Des Plaines, IL.

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SUMMARY

A feedlot performance trial was conducted for 56 days with 60 crossbred lambs (30 wether and 30 ewe lambs) allotted into six treatments of ten animals (five males and five females) per treatment. A negative control diet (no added protein supplement) was compared with similar diets having one of the following protein supplements: cottonseed meal (CSM), hair meal (HM) and three differently hydrolyzed feather meals (turkey feathers; HTF) which supplied 50% of the total N in respective diets. The wether lambs were slaughtered at the end of the feedlot trial and data were collected for carcass traits. Costs of gains of animals on each diet were also calculated. The final weights, live average daily gains and carcass average daily gains were higher ($P < .01$) for animals on HM and HTC-C (hydrolyzed at 45 p.s.i. for 90 min, pepsin digestibility 78%) diets than for those on other diets. Feed consumption also favored the HM diet. Data on feed conversion (kg feed/kg gain) showed that HM and HTF-C diets were the most efficient in converting feed to gain, but there was no sex effect on the utilization of the various diets. Dressing percentage of wether lambs was also higher ($P < .001$) for lambs fed HM and HTF-C diets than those fed CSM and HTF-A (hydrolyzed at 35 p.s.i. for 45 min, pepsin digestibility 57%) diets. The FM and HM diets had superior economic (cost) advantage in converting feed to gain as compared to the CSM diet. This study demonstrated that FM and HM (when properly processed) were superior to CSM (on a per unit of N basis) when fed as the only protein supplement in diets for growing lambs.

INTRODUCTION

Hydrolyzed feather meal (FM) and hair meal (HM) have been found to be as digestible as cottonseed meal (CSM) or soybean meal (SBM) when fed as protein supplements in ruminants' diets on a per unit of N basis (Thomas and Beeson, 1977; Daugherty and Church, 1978; Aderibigbe, 1981). Wray et al. (1979) reported no differences in daily gains (ADG), feed efficiency (FE), feed consumption (FC) or carcass characteristics among steer calves receiving FM or HM as protein supplements when compared to steers receiving SBM. Similar results were obtained by Jordan and Croom (1957) as well as Wise and Barrick (1963) when FM was compared to SBM as a protein supplement for fattening lambs and wintering calves, respectively. Thus, ruminants receiving FM or HM at moderate levels perform equally well as those receiving the oilseed meal as protein supplements.

Aderibigbe (1981) pointed out the need for relating the amount (time, steam pressure) of processing of FM and HM to their utilization by ruminants. The objectives of this study were: (a) to compare FM and HM to CSM as protein supplements for growing lambs; (b) to observe the relationship between the extent of processing of FM and their utilization by growing lambs, and (c) to evaluate the economics of using CSM, FM or HM as protein supplements for growing lambs.

MATERIALS AND METHODS

Feedlot Trial

A feedlot performance trial was conducted with 30 crossbred wether lambs and 30 crossbred ewe lambs (average weight, 30 kg) allotted into six treatments of five ewe lambs and five wether lambs (ten animals) per treatment. Animals of each treatment were separated by sex and housed in four different pens bedded with wood shavings. Treatment 1 (negative control) diet contained 64.7% ground corn, 27.9% chopped ryegrass straw, 6.3% cane molasses and 1.1% limestone and was fortified with vitamin A. The diets of treatments 2 through 6 were similar to that of treatment 1 except that protein supplements were added to supply 50% of the total N in each diet. The protein supplements were as shown: treatment 2, cottonseed meal (CSM); treatment 3, commercial hair meal (HM, pepsin digestibility 62%); treatment 4, hydrolyzed turkey feather meal A (HTF-A, hydrolyzed at 35 p.s.i. for 45 min, pepsin digestibility 57%); treatment 5, HTF-B (hydrolyzed at 45 p.s.i. for 60 min, pepsin digestibility 64%); treatment 6, HTF-C (hydrolyzed at 45 p.s.i. for 90 min, pepsin digestibility 78%). Pepsin digestibility was determined by the AOAC (1975) procedure. The ingredient components of the experimental diets are shown in Table 1. All diets were fed in pelleted (4.8 mm) form.

Animals were gradually adapted to the control diet which was fed to all animals for a 14-day preliminary period. After the preliminary period, animals were switched to experimental diets. The experimental

period lasted for 56 days. All animals were wormed for parasites at the beginning of the trial and one month later. Water and trace mineralized salt blocks were available to all animals ad libitum. The lambs were fed ad libitum and weighed at two-week intervals. Records were kept of feed fed and feed refused. The wether lambs were slaughtered at the Oregon State University Meat Science Laboratory and data were collected for carcass traits. Feed costs and costs of gains for animals of each treatment were calculated using the ingredient costs in effect at that time (9-8-80).

Chemical Analyses

Table 2 shows the chemical composition of the experimental diets. The diets were analyzed for proximate components as described by AOAC (1975). Acid detergent fiber was determined by the method of Van Soest (1963) as described in the modified micro-procedure of Waldern (1971).

Statistical Analyses

Data for animals on experimental diets (irrespective of sex) were analyzed by use of one-way analysis of variance while those which compared the sexes where analyzed by use of a two-way analysis of variance as described by Snedecor and Cochran (1974). Means were compared using the LSD as outlined by Steel and Torrie (1980).

RESULTS AND DISCUSSION

The results of the feedlot trial for all animals of each treatment

(irrespective of sex) are shown in Table 3. Although the average initial weights of animals on each diet were the same (30 kg), the final weights (FW) varied considerably. The FW were higher ($P < .01$) for the HM-50 (47.5 kg) and the HTF-C-50 (46.5 kg) than for the other treatments. The FW for the CSM-50 and the HTF-B-50 treatments were not different ($P > .01$), but were higher ($P < .01$) than those for the control and the HTF-A-50 diets. Data for the live average daily gain (LADG) and carcass average daily gain (CADG) followed similar patterns as those for the FW but at higher levels of significance ($P < .001$). These results show that FM and HM, when properly processed, are superior to CSM as protein supplements for growing lambs. However, the S-containing amino acids (high in FM and HM) may be expected to give better response in lambs than in cattle because of the need for wool growth (Doyle and Bird, 1975). The HTF-A-50 was probably underprocessed.

Feed consumption (FC) was higher ($P < .001$) for the HM-50 diet than for the other diets. Among the other diets, the order of FC was CSM-50 = HTF-C-50 = HTF-B-50 > control = HTF-A-50 ($P < .001$). These indicate that higher palatability for HM-50 diet and lower palatability for the HTF-A-50 diet might have accounted for some of the results obtained for FW, LADG and CADG. Feed conversion (kg feed/kg gain) was higher ($P < .001$) for the control diet than for the supplemented diets. Among the supplemented diets, the order was CSM-50 = HTF-A-50 > HTF-B-50 > HM-50 = HTF-C-50 ($P < .001$), indicating that the HM-50 and HTF-C-50 diets were the most efficient in converting feed to gain.

Table 4 shows the data for the feedlot trial in which comparisons were made between animals of each sex on each experimental diet. No differences were found ($P > .01$) for any of the parameters observed. Thus, there was no sex effect on the utilization of the various diets. This contradicts the results obtained by Wray et al. (1979), who showed that steer calves performed better than heifer calves when fed FM and HM as protein supplements. The mean values of the carcass traits for the wether lambs on each diet are shown in Table 5. The only differences observed ($P < .001$) were for dressing percentage (DP). DP was higher ($P < .001$) for the HM-50 and HTF-C-50 diets than for the CSM-50 and HTF-A-50 diets.

The cost data for animals on each experimental diet (irrespective of sex) are shown in Table 6. Feed costs and total costs of raising the lambs were in the order CSM-50 = HM-50 > HTF-B-50 = HTF-C-50 > HTF-A-50 > control ($P < .001$). Cost per kilogram of carcass gain was lower ($P < .001$) for the HM-50, HTF-B-50 and the HTF-C-50 diets than for the other diets, showing the cost advantage of using FM and HM as protein supplements as opposed to using CSM. Table 7 shows the cost data obtained for the two sexes under each treatment. The only differences ($P < .05$) observed between the sexes were for the cost per kilogram of carcass gain which was generally higher for the wether lambs than for the ewe lambs.

CONCLUSIONS

This study demonstrated that FM and HM (when properly processed)

are superior to CSM (on a per unit of N basis) when fed as protein supplements for growing lambs. Performance and diet palatability were lower when lambs were fed FM processed to achieve 57% pepsin digestibility. However, FM and HM processed to achieve pepsin digestibility of 62% and above were equal to or more efficient than CSM. HM appears to be a more efficient protein supplement than either FM or CSM for the performance of growing lambs.

Carcass characteristics of slaughtered lambs were not affected by type of protein supplement. Costs of carcass gains were lower for FM and HM than for CSM, showing superior economic advantage of using FM and HM as protein supplements as opposed to using CSM. Future work should investigate further into the relationship between the period of hydrolysis of HM and their utilization by ruminants.

TABLE 1. INGREDIENT COMPONENTS OF THE EXPERIMENTAL PELLETED DIETS

Ingredient	International feed number	Diet (% dry basis)[a]					
		Control	CSM-50[b]	HM-50[b]	HTF-A-50[b] 35 psi, 45 min	HTF-B-50[b] 45 psi, 60 min	HTF-C-50[b] 45 psi, 90 min
Ground corn #2	4-02-931	64.7	54.6	59.5	59.4	59.6	59.6
Ryegrass straw (chopped)	1-04-059	27.9	22.8	25.8	25.8	25.8	25.8
Molasses (cane)	4-04-695	6.3	5.3	5.3	5.2	5.3	5.3
Limestone	6-02-632	1.1	1.1	1.1	1.1	1.1	1.1
cottonseed meal	5-01-621	-	16.2	-	-	-	-
Hair meal	5-08-997	-	-	8.3	-	-	-
HTF-A (35 psi, 45 min)	5-03-795	-	-	-	8.5	-	-
HTF-B (45 psi, 60 min)	5-03-795	-	-	-	-	8.2	-
HTF-C (45 psi, 90 min)	5-03-795	-	-	-	-	-	8.2

[a] 1 g of vitamin A (3,000,000 Iu/g)/181 Kg was added to each diet.

[b] The experimental protein supplements which involved cottonseed meal, hair meal and three periodically hydrolyzed turkey feathers (cooking times and pressure shown) supplied 50% of the total N in the respective diet.

TABLE 2. CHEMICAL COMPOSITION OF THE EXPERIMENTAL DIETS

Item	Diet					
	Control	CSM-50	HM-50	HTF-A-50 35 psi, 45 min	HTF-B-50 45 psi, 60 min	HTF-C-50 45 psi, 90 min
DM (%)	91.4	91.5	91.3	91.8	91.9	92.0
Analysis, % of DM:						
Crude protein (CP)	8.8	14.7	15.0	14.9	14.7	14.7
Acid detergent fiber (ADF)	16.7	17.6	16.0	15.0	11.5	13.9
Ether extract (EE)	3.1	3.5	3.2	3.4	3.8	3.6
Ash	4.2	5.0	4.2	4.0	4.2	4.1
N-free extract (NFE)	67.2	59.2	61.6	62.7	65.8	64.9

TABLE 3. AVERAGE INITIAL WEIGHT, FINAL WEIGHT, DAILY LIVE AND CARCASS GAIN, TOTAL FEED INTAKE AND FEED CONVERSION FOR LAMBS ON EACH DIET (IRRESPECTIVE OF SEX)

	Diet						
Item (kg)	Control	CSM-50	HM-50	HTF-A-50 35 psi, 45 min	HTF-B-50 45 psi, 60 min	HTF-C-50 45 psi, 90 min	SEM
Avg. initial weight[a]	30.2	30.0	30.0	29.9	30.1	29.9	-
Avg. final weight[a]**	41.5[d]	43.7[e]	47.5[g]	42.1[d]	45.0[e,f]	46.5[g]	1.2
Avg. live daily gain[a]***	.20[d]	.24[e]	.31[g]	.22[d,e]	.27[f]	.29[f,g]	1.5
Avg. carcass daily gain[a,b]***	.09[d]	.12[e]	.14[f]	.10[d]	.12[e]	.14[f]	.7
Avg. total feed intake[c]***	74.7[d]	82.3[e]	86.1[f]	74.5[d]	80.9[e]	81.2[e]	1.7
Avg. feed conversion (kg feed per kg gain, dry weight basis)[c]***	6.7[g]	6.1[f]	4.9[d]	6.1[f]	5.4[e]	4.9[d]	.2

[a]Values are means of ten lambs (five ewe lambs and five wether lambs) fed each diet for 56 days.

[b]Means are for values obtained by multiplying individual live average daily gain by .47.

[c]Values are means of ten lambs in four pens fed each diet for 56 days.

[d,e,f,g]Means in the same row with different superscripts are different; **P < .01; ***P < .001.

TABLE 4. AVERAGE INITIAL WEIGHT, FINAL WEIGHT, DAILY LIVE AND CARCASS GAIN, TOTAL FEED INTAKE AND FEED CONVERSION FOR EWE LAMBS AND WETHER LAMBS OF EACH TREATMENT

	Diet											
	Control		CSM-50		HM-50		HTF-A-50		HTF-B-50		HTF-C-50	
Item (kg)	ewe lamba	wether lamba	ewe lamba	wether lambs	ewe lambs	wether lamba	ewe lamba	wether lamba	ewe lamba	wether lamba	ewe lamba	wether lamba
Avg. initial weight[a]	29.5	30.9	29.5	30.5	29.5	30.4	29.4	30.3	29.6	30.6	29.6	30.1
Avg. final weight[a]	41.0	42.0	43.5	43.8	46.1	49.0	43.2	41.1	44.3	45.7	45.5	47.4
Avg. live daily gain[a]	.20	.20	.25	.24	.29	.33	.24	.19	.26	.27	.28	.31
Avg. carcass daily gain[a,b]	.09	.09	.12	.11	.14	.15	.11	.09	.12	.13	.13	.14
Avg. total feed intake[c]	77.0	72.3	83.0	81.7	85.6	86.7	82.5	66.5	80.6	81.2	78.3	84.2
Avg. feed conversion (kg feed per kg gain, dry weight basis)[c]	6.8	6.6	6.1	6.1	5.2	4.7	6.0	6.2	5.5	5.4	5.0	4.9

[a]Values are means of five lamba of each sex fed each diet for 56 days.

[b]Means are for values obtained by mulitplying individual live average daily gains by .47.

[c]Values are means of five lambs of each sex in two pens fed each diet for 56 days.

TABLE 5. MEAN VALUES OF CARCASS TRAITS FOR WETHER LAMBS ON EACH DIET

Item	Diet						
	Control	CSM-50	HM-50	HTF-A-50 35 psi, 45 min	HTF-B-50 45 psi, 60 min	HTF-C-50 45 psi, 90 min	SEM
Yield grade[a]	3.6	3.5	3.8	3.1	3.5	3.6	.2
Quality grade[a,b]	12.6	12.6	12.6	11.6	13.4	12.6	.5
Leg conformation score[a,b]	12.4	12.2	12.2	12.2	12.6	12.6	.4
Backfat thickness (cm)[a]	.81	.66	.73	.56	.63	.76	.7
Kidney and pelvic fat (%)[a]	2.8	3.1	3.2	2.4	3.2	3.0	.3
Dressing (%)[a]	49.1[c,d]	48.1[c]	50.6[d]	47.8[c]	48.5[c,d]	50.8[d]	.4

[a]Values are means of five lambs fed each diet for 56 days.

[b]15 = high prime; 14 = average prime; 13 = low prime; 12 = high choice; 11 = average choice; 10 = low choice.

[c,d]Means in the same row with different superscripts are different ($P < .001$).

TABLE 6. AVERAGE COST PER KILOGRAM OF LIVE AND CARCASS GAINS FOR ALL LAMBS FED EXPERIMENTAL DIETS (IRRESPECTIVE OF SEX)[a]

Item	Diet						
	Control	CSM-50	HM-50	HTF-A-50	HTF-B-50	HTF-C-50	SEM
Avg. feed intake (kg)[b]	74.7	82.3	86.1	74.5	80.9	81.2	
Avg. cost per 100 kg of diet ($)	13.3	15.9	15.1	15.1	15.0	15.0	
Avg. feed cost ($)[b]***	9.9[d]	13.1[g]	13.0[g]	11.2[e]	12.2[f]	12.2[f]	.2
Avg. veterinary cost ($)	1.0	1.0	1.0	1.0	1.0	1.0	
Avg. yardage cost ($)	2.2	2.2	2.2	2.2	2.2	2.2	
Avg. total cost ($)[b]***	13.1[d]	16.2[g]	16.2[g]	14.4[e]	15.3[f]	15.4[f]	.2
Avg. total gain (kg)[c]	11.3	13.7	17.6	12.3	14.9	16.6	
Avg. estimated carcass gain (kg)[c]	5.3	6.4	8.3	5.8	7.0	7.8	
Avg. estimated cost per kg carcass gain ($)[c]**	2.7[f]	2.4[e]	1.8[d]	2.3[e]	2.0[d]	2.0[d]	.1

[a]Ingredient costs were obtained from Oregon State University Feed Purchase Book (9-8-80).

[b]Values are means of ten lambs in four pens fed each diet for 56 days.

[c]Values are means of ten lambs (five ewe lambs and five wether lambs) fed each diet for 56 days.

[d,e,f,g]Means in the same row with different superscripts are different; **P < .01; ***P < .001.

TABLE 7. AVERAGE COST PER KILOGRAM OF LIVE AND CARCASS GAINS FOR THE EWE LAMBS AND THE WETHER LAMBS OF EACH TREATMENT[a]

Item	Diet											
	Control		CSM-50		HM-50		HTF-A-50		HTF-B-50		HTF-C-50	
	ewe lambs	wether lambs	ewe lambs	wether lambs	ewe lambs	wether lambs	ewe lambs	wether lambs	ewe lambs	wether lambs	ewe lambs	wether lambs
Avg. feed intake (kg)[b]	77.0	72.3	83.0	81.7	85.6	86.7	82.5	66.5	80.6	81.2	78.3	84.2
Avg. cost per 100 kg of diet ($)	13.3	13.3	15.9	15.9	15.2	15.2	15.1	15.1	15.1	15.1	15.0	15.0
Avg. feed cost ($)[b]	10.3	9.6	13.2	13.0	13.0	13.1	12.4	10.0	12.1	12.2	11.8	12.7
Avg. veterinary cost ($)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Avg. yardage cost ($)	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Avg. total cost ($)[b]	13.4	12.8	16.3	16.2	16.1	16.3	15.6	13.2	15.3	15.4	14.9	15.8
Avg. total gain (kg)[c]	11.5	11.1	14.0	13.4	16.5	18.6	13.7	10.8	14.7	15.1	15.9	17.3
Avg. estimated carcass gain (kg)[c]	5.4	5.2	6.6	6.3	7.8	8.7	6.5	5.1	6.9	7.1	7.5	8.1
Avg. estimated cost per kg carcass gain ($)[c]	2.6[d]	2.8[e]	2.1[d]	2.7[e]	1.9[e]	1.7[d]	1.9[d]	2.6[e]	1.8[d]	2.2[e]	2.0	2.0

[a]Ingredient costs were obtained from Oregon State University Feed Purchase Book (9-8-80).

[b]Values are means of five lambs of each sex (in two pens) fed each diet for 56 days.

[c]Values are means of five lambs of each sex fed each diet for 56 days.

[d,e]Means in the same row for each treatment with different superscripts are different ($P < .05$).

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Running Head: *In vitro/in vivo* digestibility of ruminant diets supplemented with feather meal and hair meal.

Relationship Between *In Vitro* (Enzymatic and Artificial Rumen) and *In Vivo* Digestibility of Nutrients in Ruminant Diets Using Feather Meal and Hair Meal as Protein Supplements[1,2]

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Key Words: Enzymes, Ruminants, Digestibility, *In Vitro*, *In Vivo*, Correlation, Regression

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[1]Oregon Agricultural Experiment Station Technical Paper No. ____.

[2]Partial support supplied by Fats and Proteins Research Foundation, Inc., Des Plaines, IL.

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SUMMARY

In vitro enzymatic studies (pepsin and pancreatin) and *in vitro* rumen trials were conducted to study the relationship between *in vitro* and *in vivo* digestibility of nutrients in ruminants' diets. *In vitro* trials were conducted on triplicate samples of complete diets. The diets included those supplemented with cottonseed meal, commercial feather, special feather meal and commercial hair meal. Enzyme nutrient digestibility generally increased with increasing enzyme:N ratios. *In vivo* crude protein (CP) digestion and N retention (cg/kg $BW^{.75}$) were best predicted by pepsin-pancreatin combinations with r values of .52 and .60, respectively ($P < .05$). Percentage N retention was best predicted by *in vitro* pepsin digestion of CP. *In vitro* pepsin dry matter (DM) digestibility was the best predictor of *in vivo* and organic matter (OM) digestibilities ($r = .55$ and .61, respectively, $P < .01$). However, *in vitro* rumen digestibility of DM gave the highest correlation with *in vivo* digestible energy ($r = .64$, $P < .01$). *In vitro* digestibility of nutrients by pancreatin was a very poor predictor of *in vivo* digestibility of nutrients in ruminant diets of the type used. *In vitro* pepsin digestibility was a better predictor of *in vivo* digestibilities of diets supplemented with feather meal than those supplemented with cottonseed meal. This study showed that *in vitro* proteolytic enzyme and rumen digestion studies can be used effectively to predict *in vivo* digestibilities of nutrients in ruminant diets.

INTRODUCTION

In vitro digestibility studies are used mainly for preliminary evaluation of ruminants' diets, since digestibility is best determined with *in vivo* studies. However, in situations where facilities and adequate finance are lacking, *in vitro* studies can be very useful in evaluating ruminants' diets for their potential utilization. Higher correlations are generally achieved between *in vitro* rumen and *in vivo* digestion for forage diets rather than complete diets with moderate to high levels of concentrates.

Most studies that have been conducted to relate *in vitro* proteolytic enzyme digestibility of feed proteins (CP) to their digestibility *in vivo* have been conducted with nonruminant animals such as rats (Saunders *et al.*, 1973; Buchmann, 1979). This may be due to the fact that initial protein digestibility by ruminants involves microbial fermentation in the reticulo-rumen, while enzymatic digestion of microbial or dietary protein is secondary. However, certain proteins such as feather meal (FM) and hair meal (HM) have reticulo-rumen bypass potential (Aderibigbe, 1981), making them available for digestion by proteolytic enzymes in the abomasum and small intestine of ruminants.

Numerous workers have shown high correlations between *in vitro* rumen and *in vivo* digestibilities of dry matter (DM), organic matter (OM) and energy (GE) by ruminants, particularly with all forage diets (for example: Bowden and Church, 1962; Tinnimit and Thomas, 1976; Abe *et al.*, 1979). On the other hand, very few studies have been conducted to relate *in vitro* DM digestibility by proteolytic enzymes to *in vivo*

digestibilities by ruminants. Studies conducted in this manner have usually involved combinations of proteolytic enzymes and cellulase (Goto and Minson, 1977; McLeod and Minson, 1978).

The objectives of this study were: (a) to relate in vitro digestibilities of DM and CP in ruminants' diets by pepsin and pancreatin to in vivo digestibilities of DM, OM, CP and GE by lambs; (b) to determine the effect of enzyme to N ratios (E:N) on in vitro utilization of nutrients in ruminants' diets and relate these to their utilization in vivo; and (c) to observe the relationship between in vitro rumen DM digestibility of ruminants' diets and in vivo DM, OM and GE digestibility.

MATERIALS AND METHODS

In Vivo Digestion Trials with Wether Lambs

Feed samples were used from five digestion trials which had been conducted previously with crossbred wether lambs (Aderibigbe, 1981). Each trial involved 20 lambs allotted to four treatments (at random by weight) with five lambs per treatment. The diets fed included those supplemented with cottonseed meal (CSM), commercial FM, special FM, and commercial HM. Data were available on in vivo digestibility (%) of DM, OM, CP, GE and on N retention.

In Vitro Enzyme and Rumen Digestion Trials

Diets from the in vivo studies (20 diets) were used as substrates for the in vitro enzymatic and rumen digestion studies. Each diet was ground through a small Wiley mill (20 mesh screen) since Baumgardt

and Oh (1964) have observed increased in vitro digestibility of feed with finer grinding. Triplicate samples (1 g dry basis) from each diet were used as substrates for the in vitro studies.

Pepsin-HCl digestion studies were conducted using three enzyme to N ratios (P:N): (a) 1.4P:3.75N; (b) 1.5P:1.44N; and (c) 3P:1.44N because Buchmann (1979) has shown that the digestibility of protein from cereal grains depends on the enzyme to substrate ratio. The pepsin incubation medium included the substrate, 150 ml of HCl (pH 2.0) and the appropriate amount of pepsin (activity 1:10,000). Pancreatin digestion trials were also conducted using three enzyme to N ratios (PC:N): (a) 4PC:3.75N; (b) 1.5PC:1.44N; and (c) 3PC:1.44N. The pancreatic incubation medium was made up of the substrate, 150 ml of saturated sodium borate buffer ($Na_2B_4O_7 10H_2O$) and 1 g calcium chloride ($CaCl_2$) with the appropriate amount of pancreatin (grade II from Porcine pancreas, activity at least equivalent to NF grade). Each enzymatic incubation was conducted in a 200 ml plastic bottle placed in an oscillating water bath at 37 C for 16 hours. Both enzymes were obtained from Sigma Chem. Co., St. Louis, MO. Pepsin-pancreatin (combination) digestion trials also involved three different enzyme:N ratios for each enzyme: (a) .35P plus 1PC:3.75N; (b) 1.5P plus 1.5PC:1.44N; and (c) 3P plus 3PC:1.44N. Each substrate was incubated with pepsin and 150 ml of HCl (pH 2.0) for 8 hours. Pancreatin and 35 ml of saturated $Na_2B_4O_7 10H_2O$ and 1 g $CaCl_2$ were then added and incubation was continued for an additional 8 hours.

After incubation, the contents of each bottle (for each enzymatic

digestion) were filtered through a No. 2 Whatman filter paper. The undigested feed residue together with the filter paper was dried at 60 C for 24 hr, weighed and analyzed for total DM and N by methods described by AOAC (1975). Digestion coefficients (%) were calculated for DM and CP for each diet. In vitro rumen DM digestion studies were conducted by the method described by Aderibigbe (1980). Inoculum consisted of 40 ml of a mixture of one part rumen liquor, one part of a nutrient buffer solution (McDougall, 1948) and two parts of distilled water. Rumen liquor was obtained from a fistulated steer because Van Dyne and Weir (1964) found no differences in digestive power between cattle and sheep when 18 ruminal-fistulated steers and wethers provided inocula for in vitro digestion of ruminants' diets. Fermentation was conducted for 48 hr since Nelson et al (1976) observed that 48 hr fermentation resulted in the smallest variation among runs when studying the effects of six fermentation times on in vivo/in vitro relationships.

Statistical Analyses

Data for the in vitro studies were analyzed statistically by use of a one-way analysis of variance as described by Snedecor and Cochran (1974). Treatment means were compared by use of the LSD as described by Steel and Torrie (1980). Simple correlations between in vitro and in vivo digestions as well as multiple regression analyses were calculated as outlined by Neter and Wasserman (1974).

RESULTS AND DISCUSSION

The coefficients for digestibility of nutrients (CP, DM, OM, and GE) and N retention obtained for the *in vivo* studies (Aderibigbe, 1981) are shown in Table 1. Values are means of five wether lambs per treatment. Table 1 also shows the results of the *in vitro* rumen DM digestion. Pepsin digestibility generally increased with increasing pepsin:N ratios (Table 2). The overall means for the different pepsin:N ratios were in the order 3:1.44 > 1.5:1.44 > 1.4:3.75 ($P < .05$). The results agreed with the work of Buchmann (1979), who showed that *in vitro* enzymatic digestibility depended on the enzyme to substrate ratio. Multiple regression analysis between *in vitro* pepsin digestion of CP and *in vivo* CP digestion showed that the 1.5P:1.44N ratio was the best predictor of *in vivo* CP digestion ($r = .44$, $P < .05$). The 1.5P:1.44N also gave the highest correlations with percentage N retention and N retention expressed as cg/kg $BW^{.75}$ ($r = .52$ and .57, respectively; $P < .05$).

When pancreatin was the test enzyme (Table 3), the general trend was similar to that of pepsin. Multiple regression analysis showed that the *in vitro* CP digestibility by the 4PC:3.75N gave the highest correlation with *in vivo* CP digestibility among the three PC:N ratios, but the r value (.19) was low ($P > .05$). *In vitro* CP digestibility by the 3PC:1.44N gave the highest correlations with percentage N retention ($r = -.28$) and N retention expressed as cg/kg $BW^{.75}$ ($r = .34$), but the r values were not significant ($P > .05$). The results show that *in vitro* CP digestibility by pancreatin is a very poor predictor

of in vivo CP digestibility of ruminant diets of this type. Similar results were obtained by Buchmann (1979).

Table 4 shows the in vitro digestibility of the CP from the experimental diets using pepsin-pancreatin (combination) at three different enzyme:N ratios. The trend was similar to those of pepsin and pancreatin used alone. Multiple regression analysis showed that CP digestibility by the 1.5P plus 1.5PC:1.44N was the most highly correlated with in vivo CP digestibility ($r = .52$, $P < .05$) and in vivo N retention expressed as cg/kg $BW^{.75}$ ($r = .6$, $P < .05$). The in vitro CP digestibility by the 3P plus 3PC:1.44N was the most highly correlated with percentage N retention in vivo ($r = -.46$, $P < .05$).

Multiple regressions between all in vitro enzymatic digestibilities of CP and in vivo CP digestibility showed that the 1.5P plus 1.5PC:1.44N gave the highest correlation ($r = .52$, $P < .05$). The 1.5P plus 1.5PC:1.44N also gave the highest correlation with N retention expressed as cg/kg $BW^{.75}$ when in vitro CP digestibilities by the various enzymes were regressed with in vivo digestibility of CP ($r = .60$, $P < .05$). Multiple regressions between in vitro enzymatic CP digestion and percentage N retention (in vivo) showed that 1.5P:1.44N gave the highest correlation ($r = -.52$, $P < .05$). These results show that the in vitro protein digestibility by the 1.5P plus 1.5PC:1.44N was the best predictor of protein utilization by wether lambs.

The results of the in vitro digestibility of DM from the experimental diets by the three pepsin:N ratios are shown in Table 5. The general trend (unrelated to enzyme:N ratio) was in the order

1.5P:1.44N > 1.4P:3.75N > 3P:1.44N ($P < .05$). *In vitro* DM digestibility by the 1.5P:1.44N gave the highest correlations with *in vivo* DM, OM and GE digestibilities ($r = .55$, .61 and .63, respectively; $P < .01$) when *in vitro* DM digestibility by the three P:N ratios were regressed with each of the *in vivo* parameters.

Table 6 shows the *in vitro* pancreatin digestibility of DM from the experimental diets. DM digestibility increased with increasing pancreatin:N ratio ($P < .05$). Multiple regression between *in vitro* DM digestion by the three pancreatin:N ratios and *in vivo* DM, OM and GE digestions showed that the 1.5PC:1.44N gave the highest correlation with *in vivo* DM digestion ($r = .2$, $P > .05$). However, the 3PC:1.44N gave the highest correlations with *in vivo* OM and GE digestibilities ($r = .25$ and .33, respectively, $P > .05$).

The results of the *in vitro* digestibility of DM from the experimental diets using pepsin and pancreatin combination are shown in Table 7. The general trend (similar to that of pancreatin) was in the order 3P plus 3PC:1.44N > 1.5P plus 1.5PC:1.44N > .35P plus 1PC:3.75N ($P < .05$). *In vitro* DM digestibility by the 1.5P plus 1.5PC:1.44N was the most highly correlated with *in vivo* DM and OM digestibilities ($r = .47$ and .51, respectively, $P < .05$) among the three pepsin-pancreatin:N ratios. However, the *in vitro* DM digestibility by the 3P plus 3PC: 1.44N was the best predictor of *in vivo* GE digestibility ($r = .56$, $P < .01$). The simple correlations between *in vitro* rumen DM digestion and *in vivo* DM, OM and GE digestibilities were .54, .58 and .64, respectively ($P < .01$).

Multiple regression between *in vitro* DM digestion studies (enzymatic and rumen) and *in vivo* DM, OM and GE digestibilities showed that the *in vitro* DM digestibility by the 1.5P:1.44N was the best predictor of *in vivo* DM and OM digestibilities ($r = .55$ and $.61$, respectively, $P < .01$). However, the *in vitro* rumen digestibility of DM gave the highest correlation with *in vivo* digestible GE ($r = .64$, $P < .01$). It should be noted that *in vitro* rumen DM digestion was the best single predictor of the *in vivo* DM, OM and GE digestibilities. Table 8 shows the best prediction equations for *in vivo* utilization of nutrients from the experimental diets. The best predictors of *in vivo* parameters for diets with individual protein supplements are shown in Table 9. *In vitro* pepsin digestibility (alone) was a better predictor of *in vivo* nutrient digestibility when FM was the protein supplement than when CSM was the protein supplement.

CONCLUSIONS

This study has shown that *in vitro* enzymatic and rumen digestion studies can be used effectively to predict *in vivo* digestibilities of DM, OM, CP and GE. In general, *in vitro* digestibility of CP increased with increasing enzyme:N ratio. *In vivo* protein utilization (digestibility and N retention) was best predicted by *in vitro* CP digestibility by the pepsin-pancreatin combination (1.5P plus 1.5PC:1.44N), but *in vitro* digestibility by pancreatin is a very poor predictor of *in vivo* digestibility of nutrients in ruminants' diets. *In vivo* DM and OM digestibilities were best predicted by *in vitro* pepsin digestibility

(1.5P:1.44N) while GE digestibility (*in vivo*) was best predicted by *in vitro* rumen DM digestibility. However, the *in vitro* rumen DM digestion was the best single predictor of *in vivo* DM, OM and GE digestibilities.

TABLE 1. N RETENTION, IN VITRO RUMEN AND IN VIVO (LAMB) DIGESTIBILITIES (%) OF NUTRIENTS FROM THE EXPERIMENTAL DIETS

	In Vivo Data						
		N Retention					
Trial, protein source	Dig. CP,%	% N fed	cg/kg BW$^{.75}$	Dry matter,%	Organic matter,%	Dig. energy,%	In vitro rumen DM,%
Trial 1							
Basal[a]	77.8	30.3	52.5	77.3	79.1	78.2	48.2
CSM-50[b]	80.7	24.4	61.3	76.6	78.0	77.2	47.1
FM-40[c]	81.1	28.4	66.3	78.5	80.3	79.4	48.1
FM-50[d]	80.1	23.1	64.9	77.4	79.0	78.4	45.5
Trial 2							
Basal[a]	65.2	33.1	26.4	75.4	76.5	75.9	35.6
CSM-50[b]	70.4	26.5	34.3	74.7	75.8	75.3	41.9
FM-50[d]	73.6	29.4	42.2	76.5	77.7	77.2	37.4
HM-50[e]	72.3	68.7	31.0	76.1	77.3	76.7	42.4
Trial 3							
Basal[a]	57.3	24.4	18.5	75.6	76.9	75.3	34.3
CSM-50[b]	71.5	18.8	22.8	77.2	78.7	77.1	39.6
FM-50[d]	72.8	22.0	29.2	78.1	79.5	78.2	37.0
HTF-A-50 (35 psi, 45 min)[f]	72.9	27.2	35.4	77.2	78.5	76.8	38.6
Trial 4							
Basal[a]	57.8	35.8	24.6	73.3	74.5	73.7	31.8
CSM-50[b]	71.7	37.2	38.5	77.1	78.0	77.2	44.4
FM-50[d]	71.7	36.7	44.1	76.4	77.4	76.7	35.7
HTF-B-50 (45 psi, 60 min)[f]	72.4	35.2	40.8	77.7	78.7	78.0	37.4
Trial 5							
Basal[a]	55.4	25.6	16.6	74.1	75.1	73.9	36.9
CSM-50[b]	67.8	31.5	33.0	74.9	75.8	75.7	38.0
FM-50[d]	68.2	28.0	31.4	76.8	77.7	77.1	40.5
HTF-C-50 (45 psi, 90 min)[f]	71.3	31.3	35.3	77.7	78.7	78.3	40.8

[a]The basal diets were not supplemented.

[b]Cottonseed meal supplied 50% of the total N in the diet.

[c]Feather meal supplied 40% of the total N in the diet.

[d]Feather meal supplied 50% of the total N in the diet.

[e]Hair meal supplied 50% of the total N in the diet.

[f]Special turkey feather meal (processing pressure and time shown) supplied 50% of the total N in the diet.

TABLE 2. DIGESTIBILITY (%) OF PROTEIN FROM EXPERIMENTAL DIETS MEASURED IN VITRO WITH THREE DIFFERENT PEPSIN:N RATIOS (P:N)

Trial, protein source	P:N		
	1.4P:3.75N[a]	1.5P:1.44N	3.0P:1.44N
Trial 1			
Basal	77.6[b]	79.2[c]	81.3[d]
CSM-50	76.1[b]	78.7[c]	82.1[d]
FM-40	68.4[b]	76.9[c]	77.2[c]
FM-50	66.1[b]	76.3[c]	76.2[c]
Trial 2			
Basal	69.7[b]	72.7[c]	79.7[d]
CSM-50	71.7[b]	74.9[c]	80.9[d]
FM-50	62.0[b]	73.1[c]	76.5[d]
HM-50	59.1[b]	65.1[c]	70.7[d]
Trial 3			
Basal	68.2[b]	71.8[c]	75.1[d]
CSM-50	70.5[b]	74.8[c]	78.1[d]
FM-50	61.2[b]	72.9[c]	73.1[c]
HTF-A-50 (35 psi, 45 min)	50.3[b]	65.3[c]	66.4[c]
Trial 4			
Basal	75.4[b]	70.3[c]	80.8[d]
CSM-50	72.2[b]	73.7[b]	80.8[c]
FM-50	65.7[b]	72.1[c]	79.6[d]
HTF-B-50 (45 psi, 60 min)	55.5[b]	67.0[c]	72.2[d]
Trial 5			
Basal	74.4[b]	69.8[c]	81.3[d]
CSM-50	73.0[b]	73.8[b]	81.7[c]
FM-50	66.2[b]	71.9[c]	79.5[d]
HTF-C-50 (45 psi, 90 min)	66.2[b]	71.1[c]	78.4[d]
Overall mean	67.5[b]	72.6[c]	77.6[d]

[a]P:N was the same as that used by Buchmann (1979).

[b,c,d]Means in the same row with different superscripts are different ($P < .05$).

TABLE 3. DIGESTIBILITY (%) OF PROTEIN FROM EXPERIMENTAL DIETS MEASURED IN VITRO WITH THREE DIFFERENT PANCREATIN:N RATIOS (PC:N)

Trial, protein source	PC:N		
	4.0PC:3.75N[a]	1.5PC:1.44N	3.0PC:1.44N
Trial 1			
Basal	69.9[b]	78.0[c]	85.9[d]
CSM-50	73.3[b]	78.6[c]	87.7[d]
FM-40	50.8[b]	62.8[c]	78.2[d]
FM-50	46.0[b]	59.0[c]	76.3[d]
Trial 2			
Basal	47.8[b]	59.5[c]	69.3[d]
CSM-50	64.5[b]	69.1[c]	79.3[d]
FM-50	34.3[b]	50.2[c]	66.0[d]
HM-50	50.2[b]	50.9[b]	60.9[c]
Trial 3			
Basal	44.3[b]	58.1[c]	69.1[d]
CSM-50	63.5[b]	68.3[c]	78.9[d]
FM-50	36.2[b]	50.0[c]	64.3[d]
HTF-A-50 (35 psi, 45 min)	36.1[b]	45.8[c]	53.8[d]
Trial 4			
Basal	53.2[b]	61.1[c]	79.1[d]
CSM-50	64.3[b]	70.0[c]	83.0[d]
FM-50	39.7[b]	50.6[c]	64.4[d]
HTF-B-50 (45 psi, 60 min)	39.6[b]	50.1[c]	61.9[d]
Trial 5			
Basal	47.6[b]	60.5[c]	74.9[d]
CSM-50	61.4[b]	69.8[c]	80.9[d]
FM-50	36.7[b]	51.0[c]	63.2[d]
HTF-C-50 (45 psi, 90 min)	48.6[b]	55.5[c]	68.3[d]
Overall mean	50.4[b]	59.9[c]	72.3[d]

[a]PC:N was the same as that used by Buchmann (1979).

[b,c,d]Means in the same row with different superscripts are different ($P < .05$).

TABLE 4. DIGESTIBILITY (%) OF PROTEIN FROM EXPERIMENTAL DIETS MEASURED IN VITRO WITH THREE DIFFERENT PEPSIN PLUS PANCREATIN:N RATIOS (P PLUS PC:N)

Trial, protein source	P plus PC:N		
	.35P plus 1.0PC:3.75N[a]	1.5P plus 1.5PC:1.44N	3.0P plus 3.0PC:1.44N
Trial 1			
Basal	79.8[c]	77.3[b]	87.3[d]
CSM-50	82.4[b]	83.7[b]	88.3[c]
FM-40	70.4[b]	80.0[c]	86.5[d]
FM-50	68.1[b]	80.7[c]	86.3[d]
Trial 2			
Basal	64.6[b]	69.9[c]	79.3[d]
CSM-50	74.5[b]	79.6[c]	84.0[d]
FM-50	58.7[b]	75.2[c]	81.8[d]
HM-50	59.1[b]	69.0[c]	72.1[d]
Trial 3			
Basal	61.7[b]	71.5[c]	78.5[d]
CSM-50	73.0[b]	79.8[c]	83.4[d]
FM-50	57.0[b]	76.2[c]	79.5[d]
HTF-A-50 (35 psi, 45 min)	52.1[b]	68.7[c]	72.3[d]
Trial 4			
Basal	66.1[b]	76.2[c]	83.8[d]
CSM-50	74.5[b]	81.9[c]	85.4[d]
FM-50	59.7[b]	73.9[c]	77.8[d]
HTF-B-50 (45 psi, 60 min)	56.5[b]	73.9[c]	77.8[d]
Trial 5			
Basal	67.5[b]	70.4[c]	86.5[d]
CSM-50	75.1[b]	79.0[c]	86.9[d]
FM-50	61.2[b]	76.0[c]	84.3[d]
HTF-C-50 (45 psi, 90 min)	68.7[b]	79.1[c]	86.9[d]
Overall mean	66.5[b]	76.3[c]	82.7[d]

[a]P plus PC:N were the same as those used by Buchmann (1979).

[b,c,d]Means in the same row with different superscripts are different ($P < .05$).

TABLE 5. DIGESTIBILITY (%) OF DRY MATTER FROM EXPERIMENTAL DIETS MEASURED IN VITRO WITH THREE DIFFERENT PEPSIN:N RATIOS (P:N)

Trial, dry matter source	P:N		
	1.4P:3.75N	1.5P:1.44N	3P:1.44N
Trial 1			
Basal	31.8[b]	35.0[c]	26.6[a]
CSM-50	39.5[b]	43.5[c]	35.4[a]
FM-40	34.8[b]	40.0[c]	31.7[a]
FM-50	36.0[b]	42.1[c]	33.8[a]
Trial 2			
Basal	25.1[c]	22.6[b]	20.6[a]
CSM-50	30.3[b]	29.1[b]	25.9[a]
FM-50	28.2[b]	28.0[b]	25.4[a]
HM-50	27.3[b]	26.2[b]	23.9[a]
Trial 3			
Basal	26.0[b]	26.5[b]	18.0[a]
CSM-50	31.1[b]	32.3[b]	24.3[a]
FM-50	29.7[b]	31.5[c]	23.3[a]
HTF-A-50 (35 psi, 45 min)	26.9[b]	29.8[c]	21.5[a]
Trial 4			
Basal	25.7[b]	25.6[b]	20.2[a]
CSM-50	29.7[b]	31.5[c]	25.4[a]
FM-50	28.5[b]	30.1[c]	24.6[a]
HTF-B-50 (45 psi, 60 min)	26.9[b]	28.9[c]	23.6[a]
Trial 5			
Basal	26.0[a]	30.5[b]	25.1[a]
CSM-50	29.9[b]	30.5[b]	25.1[a]
FM-50	28.9[b]	29.2[b]	24.5[a]
HTF-C-50 (45 psi, 90 min)	28.6[b]	29.4[b]	24.1[a]
Overall mean	29.5[b]	31.1[c]	25.1[a]

[a,b,c]Means in the same row with different superscripts are different ($P < .05$).

TABLE 6. DIGESTIBILITY (%) OF DRY MATTER FROM EXPERIMENTAL DIETS MEASURED IN VITRO WITH THREE DIFFERENT PANCREATIN:N RATIOS (PC:N)

Trial, dry matter source	PC:N		
	4.0PC:3.75N	1.5PC:1.44N	3.0PC:1.44N
Trial 1			
Basal	24.5[a]	33.3[b]	40.9[c]
CSM-50	27.6[a]	37.6[b]	46.0[c]
FM-40	22.8[a]	32.7[b]	41.0[c]
FM-50	22.1[a]	32.4[b]	41.1[c]
Trial 2			
Basal	15.0[a]	25.0[b]	33.9[c]
CSM-50	19.7[a]	29.4[b]	38.1[c]
FM-50	15.5[a]	25.1[b]	34.0[c]
HM-50	19.2[a]	26.4[b]	35.3[c]
Trial 3			
Basal	18.4[a]	24.6[b]	51.3[c]
CSM-50	21.8[a]	28.0[b]	35.8[c]
FM-50	18.4[a]	25.0[b]	31.7[c]
HTF-A-50 (35 psi, 45 min)	18.6[a]	25.6[b]	32.6[c]
Trial 4			
Basal	16.9[a]	29.4[b]	38.5[c]
CSM-50	22.8[a]	32.1[b]	40.8[c]
FM-50	18.0[a]	29.8[b]	39.2[c]
HTF-B-50 (45 psi, 60 min)	18.0[a]	29.8[b]	39.1[c]
Trial 5			
Basal	28.5[a]	27.5[a]	31.5[b]
CSM-50	31.5[b]	29.7[a]	35.0[c]
FM-50	28.3[a]	27.9[a]	32.7[b]
HTF-C-50 (45 psi, 90 min)	29.5[a]	29.5[a]	34.0[b]
Overall mean	21.8[a]	29.0[b]	36.6[c]

[a,b,c]Means in the same row with different superscripts are different ($P < .05$).

TABLE 7. DIGESTIBILITY (%) OF DRY MATTER FROM EXPERIMENTAL DIETS MEASURED IN VITRO WITH THREE DIFFERENT PEPSIN PLUS PANCREATIN:N RATIOS (P PLUS PC:N)

Trial, protein source	P plus PC:N		
	.35P plus 1.0PC:3.75N	1.5P plus 1.5PC:1.44N	3.0P plus 3.0PC:1.44N
Trial 1			
Basal	19.1[a]	40.5[b]	51.5[c]
CSM-50	29.5[a]	43.6[b]	53.1[c]
FM-40	23.3[a]	44.5[b]	53.7[c]
FM-50	25.0[a]	46.2[b]	54.7[c]
Trial 2			
Basal	20.8[a]	33.2[b]	41.9[c]
CSM-50	26.4[a]	35.5[b]	43.2[c]
FM-50	24.4[a]	36.2[b]	44.6[c]
HM-50	24.3[a]	35.5[b]	43.3[c]
Trial 3			
Basal	17.0[a]	33.6[b]	39.1[c]
CSM-50	23.0[a]	35.6[b]	41.0[c]
FM-50	20.4[a]	37.0[b]	42.4[c]
HTF-A-50 (35 psi, 45 min)	20.1[a]	36.5[b]	40.6[c]
Trial 4			
Basal	20.2[a]	39.8[b]	42.6[c]
CSM-50	25.0[a]	40.5[b]	43.4[c]
FM-50	23.3[a]	42.1[b]	45.0[c]
HTF-B-50 (45 psi, 60 min)	23.0[a]	41.5[b]	44.5[c]
Trial 5			
Basal	28.9[a]	33.3[b]	44.3[c]
CSM-50	31.6[a]	34.6[b]	45.2[c]
FM-50	31.5[a]	36.3[b]	46.3[c]
HTF-C-50 (45 psi, 90 min)	32.6[a]	36.8[b]	47.2[c]
Overall mean	24.5[a]	38.1[b]	45.4[c]

[a,b,c]Means in the same row with different superscripts are different ($P < .05$).

TABLE 8. PREDICTION EQUATIONS FOR IN VIVO UTILIZATION OF NUTRIENTS FROM EXPERIMENTAL DIETS OBTAINED FROM MULTIPLE REGRESSION ANALYSES OF ALL DIETS

Item	Prediction Equation	R^2	Level of Significance
Crude protein (CP)	In vivo CP digestion = 6.4 + .84 in vitro CP digestion by 1.5P plus 1.5PC:1.44N	.27	P < .05
N retention (cg/kg $BW^{\cdot 75}$)	N retention = 1.97 in vitro CP digestion by 1.5P plus 1.5PC:1.44N - 111.93	.36	P < .05
N retention (% of N fed)	N retention = 131.14 - 1.38 in vitro CP digestion by 1.5P:1.44N	.27	P < .05
Dry matter (DM)	In vivo DM digestion = 72.21 + .14 in vitro DM digestion by 1.5P:1.44N	.30	P < .01
Organic matter (OM)	In vivo OM digestion = 72.47 + .17 in vitro DM digestion by 1.5P:1.44N	.38	P < .01
Gross energy (GE)	In vivo GE digestibility = 68.61 + .20 in vitro rumen DM digestion	.42	P < .01

TABLE 9. THE BEST PREDICTORS OF IN VIVO PARAMETERS AND R VALUES OBTAINED FROM MULTIPLE REGRESSION ANALYSES OF DIETS WITH INDIVIDUAL PROTEIN SUPPLEMENTS

Protein supplement, parameter	N	Best predictor	R	Level of Significance
Cottonseed meal	5			
Dry matter (DM)		.35P plus 1.0PC:3.75N	-.59	P < .30
Organic matter (OM)		.35P plus 1.0PC:3.75N	-.60	P < .35
Cross energy (GE)		1.5P plus 1.5PC:3.75N	.69	P < .20
Crude protein (CP)		4.0PC:3.75N	.98	P < .01
N retention (% of N fed)		3.0P:1.44N	.52	P < .36
N retention (cg/kg $BW^{\cdot 75}$)		.35P plus 1.0PC:3.75N	.96	P < .01
Feather meal	5			
Dry matter (DM)		1.5P:1.44N	.44	P < .45
Organic matter (OM)		1.5P:1.44N	.58	P < .3
Gross energy (GE)		1.4P;1.44N	.75	p < .14
Crude protein (CP)		1.5P:1.44N	.96	P < .01
N retention (% of N fed)		3.0P:1.44N	.78	P < .12
N retention (cg/kg $BW^{\cdot 75}$)		3.0P:1.44N	.92	P < .02
Special feather meal	3			
Dry matter (DM)		1.5PC:1.44N	.99	P < .05
Organic matter (OM)		1.5PC:1.44N	.99	P < .04
Gross energy (GE)		3.0P:1.44N	.99	P < .01
Crude protein (CP)		1.4P:3.75N	.99	P < .01
N retention (% of N fed)		3.0PC:1.44N	.57	P < .61
N retention (cg/kg $BW^{\cdot 75}$)		3.0P plus 3.0PC:1.44N	.28	P < .82

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