

**AUSTRALIAN
MEAT AND BONE MEAL
NUTRITIONAL
TECHNICAL
REVIEW**



Australian Meat and Bone Meal Nutritional Technical Review

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AUSTRALIAN MEAT & BONE MEAL: IN GENERAL

Introduction

Meat and Bone Meal (MBM) is the product obtained by rendering, drying and grinding of mammalian tissues and bones from animals produced for human consumption, exclusive of hair, wool, hide, except where it is naturally adhering to heads and hoofs. The recycling of these materials into MBM provides a source of high quality nutrients for use in animal feeds.

This Technical Review contains a compilation of published data relating to MBM and its use in animal feeding. The aim of this publication is to provide animal nutritionists and feed industry participants with a consolidated source of data, thus increasing their knowledge and understanding of MBM and its application as a raw material.

MBM Processing Systems

Australia has a variety of rendering systems designed to process meat industry co-products into valuable ingredients for the animal fed industry.

A survey of 114 Australian renderers in 1996 sought details of equipment used, types of raw materials and heat treatments (Sponcer, WF, pers. comm.). The following information is a summary of the principal rendering systems used in Australia based on this survey:

Table 1: Number of Australian rendering establishments using the principal rendering systems

| Number of plants | Type of rendering |
|--------------------------|-------------------|
| Batch dry rendering | 60 |
| Continuous dry rendering | 43 |
| Wet rendering | 19 |

Of the renderers surveyed, there were 122 different rendering plants being operated. Some renderers having more than one operating system on their site.

Batch Rendering

A total of 60 establishments used batch dry rendering. 29% used a pressure cycle. These plants are mostly small and most do not export but there are several larger plants that can supply pressure cooked meal if required by customers.

Typical processing conditions used in Australian batch-dry rendering systems are:

- Particle size 35 mm
- Total cooking time 90 minutes
- End point temperature 130oC

Continuous Dry Rendering

A total of 43 establishments operated continuous dry rendering. Most used the Keith Equacooker or Stampco tube-cluster type of rendering vessels. Four establishments used disc-type rendering vessels.

Typical processing conditions used in Australian continuous dry rendering systems are:

- Particle size 30 mm
- Average retention time in cooker 60 minutes
- End point temperature 130oC

Continuous Wet rendering

A total of 19 establishments operated continuous wet rendering systems. These include:

- Stord wet pressing system with disc drier
- MIRINZ low temperature rendering with cascading rotary or disc drier
- Alfa Laval with cascading rotary or batch cookers to dry meal
- Pfaudler with cascading rotary

A range of process conditions are used depending on the combination of the type of pre-heater and drier.

Effectiveness of Heat Treatments

Australia's rendering plants generally use non-pressure systems unless they are manufacturing product for a market which specifically requires a pressure cycle (such as EU). Investigations of continuous dry rendering systems without pressure treatment have shown that spore forming bacteria can be inactivated without pressure treatment at end point temperatures of 110 - 115oC (Hansen and Olgaard, 1984).

Australian rendering heat treatments are equal to or exceed model rendering systems that have been shown to be effective in inactivating spore-forming bacteria. The Australian Standard for Hygienic Rendering of Animal Products (AS5008:2001) requires plants to verify that their process inactivates spore-forming bacteria. Plants complying with this Standard are regularly audited to ensure these conditions are met.

Australian rendered product is predominantly produced from non-pressurised plants which are less likely to damage amino acid quality but provide quality assured and safe ingredients for use in animal feeds.

Quality Assurance

Australian renderers have been at the forefront of developing quality assurance to improve the integrity and ever increasing standards for food safety.

The Australian Renderers Association launched its Code of Practice in 1994 with the first companies becoming accredited shortly after. The code has been upgraded a number of times subsequently and in 2001 provided the basis for the Australian Standard for Hygienic Rendering of Animal Products (AS 5008:2001).

This standard to which all producers are required to comply, establishes clear rules to ensure:

- Documented procedures and processes are in place to assure the production of safe rendered product
- Construction of facilities provides safe and hygienic processing and prevents contamination of product.

The standard incorporates two levels of microbiological safety. Firstly a validation that the heat process used destroys nominated spore-forming bacteria and secondly that the process is monitored by means of regularly sampling and testing for the absence of Salmonella.

Surveys of the incidence of Salmonella are undertaken by the industry to measure MBM producer compliance. Individual companies are regularly audited by independent third party auditors to ensure they comply with the Standard.

In addition to the Standard the Australian Renderers Association have developed two other initiatives:

- Formal training of plant operators and management in safe and hygienic rendering techniques, (over 400 rendering plant personnel have been accredited in hygienic production of rendered animal products) and
- Bi-annual industry International Symposiums focussed on improvement to quality for its customers.

Both have contributed to significant changes to product hygiene and quality.

Australian producers of MBM were the first to adopt ISO 9000 principles and formally train plant personnel in product safety. Their record of achievement is enviable.

Microbial Presence

The raw materials used to produce MBM contain various levels of micro-organisms and the rendering process is used to destroy these potentially harmful pathogens. The types of micro-organisms which can be present prior to cooking include vegetative bacteria (Salmonella, E. coli, Campylobacter, Staphylococcus, Yersina, Streptococcus and Brucella), spore-forming bacteria (Bacillus and Clostridium) and moulds.

Vegetative Bacteria

Vegetative bacteria are relatively sensitive to heat and are reliably eliminated in rendering processes.

Spore Forming Bacteria

Spore-forming bacteria are more resistant to temperature.

It has been reported (MRC, 1997) that using continuous dry rendering equipment, Bacillus cereus inoculated into rendered material is inactivated when temperatures of 96°C are reached. Spores of Clostridium sporogenes, a particularly heat resistant spore, inoculated into rendered material were inactivated when the temperature reached 110-115°C.

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The processing temperatures used in Australian dry rendering involve heating at 100oC for about 45 to 60 minutes, followed by an increase in temperature to about 115 - 135°C. These conditions are more than sufficient to kill Salmonella and other vegetative bacteria. Salmonella may recontaminate MBM after it has been cooked during handling and storage; this is however equally likely with other raw materials such as grains and vegetable protein meals. The review of Salmonella epidemiology and control completed by Davies and Funk, 1999 recognised that raw materials such as soybean meal are often contaminated with Salmonella and that the focus placed upon Salmonella in MBM is greater than the risk analysis would warrant. The analysis of review data by Hamilton, 2002 is presented below.

Table 2: Incidence of Salmonella in Feed Ingredients

| Ingredient | Country | | | | |
|--------------------|-------------|---------|-----|--------|----------------|
| | Netherlands | Germany | USA | Canada | United Kingdom |
| Animal Proteins | 6% | 6% | 56% | 20% | 3% |
| Vegetable Proteins | 3% | 26% | 36% | 18% | 7% |
| Grains | | 3% | | 5% | 1% |
| Fish Meal | | | | 22% | 22% |

Source: Hamilton, 2002

The moisture level of meat meal between 4 and 10% provides too little moisture to support microbial growth (Troutt and Schaeffer, 2001). Work completed by the FPRF, 1999 identified that MBM samples found to be positive for Salmonella declined in percent positive samples by 2% per week from the time of manufacture. MBM once cooked and dried is not a suitable medium for Salmonella growth and recontamination post rendering does not foster increases in contamination through **Salmonella** growth.

Published data on **Salmonella** levels in raw materials identifies all raw materials as being potential sources of Salmonella. The relative risk of Salmonella contamination within the finished feed is based upon the level of incidence and the inclusion level of that ingredient within the finished feed. Shown below are risk factor calculations for a feed formulation based upon the data shown above.

Table 3: Relative Risk of Salmonella Contamination in Complete Feed

| Ingredient | Salmonella | | |
|----------------|---------------------|-------------|-------------------|
| | Amount in formula % | Incidence % | Risk Factor Range |
| Grain | 66.9 | 1.0-5.0 | .669-3.345 |
| Vegetable Meal | 24.9 | 7.0-36.0 | 1.743-8.964 |
| Fish Meal | 2.2 | 22 | 0.484 |
| Meat Meal | 3.0 | 3.0-56.0 | .09-1.68 |

Source: Hamilon, 2002

The greatest Salmonella risk is found from use of raw materials such as grains and vegetable protein meals with higher inclusion levels. Even when MBM is taken as having a potentially high incidence, it remains a lower risk due to its lower inclusion rate than vegetable protein meals.

The significance of Salmonella within feed relative to other sources of Salmonella has been identified in a study by Weigal et al, 1999. The results shown below found feed to be a significantly lower reservoir of Salmonella when compared to other associated farm sources.

Table 4: Reservoirs of Salmonella Contamination on Illinois Swine Farms

| Reservoir | Number samples | % Positive |
|-------------------|----------------|------------|
| Employee footwear | 93 | 17.2% |
| Cats | 22 | 13.6% |
| Drinking water | 33 | 12.1% |
| Mice/rodents | 59 | 10.2% |
| Floor material | 471 | 7.9% |
| Flies | 95 | 7.4% |
| Feed | 100 | 2.0% |

Source: Weigal et al, 1999

The use of pelleting and the temperature and pressure generated within the conditioning chamber and die face have been recognised for many years as being capable of reducing Salmonella levels contained within feed raw materials. These feed processing techniques together with use of organic acids have been demonstrated to effectively produce feeds free of Salmonella even when the raw materials in use are identified as containing Salmonella.

Bovine Spongiform Encephalopathy (BSE)

BSE is a chronic degenerative disease that affects the central nervous system of cattle. Since the initial disease identification in the United Kingdom in 1996, the disease has been identified within other European countries, Japan in 2001 and Canada in 2003. Due to the incubation period of 2-8 years, disease identification is delayed, the disease is however not easily passed from animal to animal and is not considered contagious.

Australia is free of BSE and all other transmissible spongiform encephalopathy (TSE) such as Scrapie and Chronic Wasting Disease. The European Commission (EC) publishes an assessment of the geographic BSE risk (GBR) for countries. Australia has received the highest GBR category 1 rating, meaning the EC considers that in Australia "it is highly unlikely that domestic cattle are (clinically or pre-clinically) infected with the BSE agent".

The GBR category I rating provides the highest level of assurance to countries importing Australian MBM that it is produced in a BSE-free country. The key measures Australia has taken to ensure it remains BSE free are:

1. Strict quarantine controls and restrictions on imports of live animals, genetic material and animal feed stuffs;
2. Implementation of a ban on the feeding of all animal protein to ruminants; and
3. Initiation of a TSE surveillance program involving comprehensive monitoring which meets the endorsed World Organisation of Animal Health (OIE) code on BSE.

Freshness

MBM contains fat which is largely in a saturated form and can be subject to oxidative rancidity. Oxidation is the degradation process that occurs at the double-bonds in fatty acid chains. Double-bonds are the unsaturated bonds and the more unsaturated a fat, the greater the potential for deterioration due to rancidity. The initial step in rancidity is the formation of free radicals which are susceptible to attack by atmospheric oxygen (and mineral oxides) to form unstable peroxide free radicals.

The practical control mechanism to prevent rancidity is through the use of antioxidants which function as free radical acceptors. Under extreme environmental conditions and where MBM is held for longer periods in storage and transport, antioxidants are used as a means of protecting MBM from rancidity.

Biogenic Amines

Biogenic amines are the breakdown products of amino acids and are found in a range of foods including fish, cheese, wine, beer, processed meat, chocolate and fruit. Biogenic amines are found in animal protein meals such as MBM, fish meal and poultry meal.

Micro-organisms containing decarboxylase enzyme convert free amino acids into biogenic amines by decarboxylation. Lysine and histidine are converted into cadaverine and histamine while ornithine, glutamine and arginine are the precursors for putrescine. The production of biogenic amines in MBM requires the presence of bacteria containing decarboxylase enzyme, free amino acids and conditions which favour microbial growth. The rendering process uses temperatures which eliminate micro-organisms and reduces moisture content which results in a stable meal product. The critical period is between animal slaughter and the initiation of the rendering process. Minimising this time period and correct storage and handling of raw materials are essential in reducing biogenic amine levels.

Biogenic amines are broken down in the digestive tract of animals by the enzymes mono-amino-oxidase and di-amino-oxidase. Pigs have a greater capacity to breakdown biogenic amines. The impact of biogenic amines upon poultry only occurs when high concentrations exceed the digestive enzymes capacity to break them down.

Experimental trials have demonstrated that biogenic amines added to poultry diets at very high levels impact upon liveweight gain and bird health (Harry et al, 1975, Brugh and Wilson, 1986, Stuart et al, 1986 and Smith, 1990). However other workers have been unable to find any affect of biogenic amines on performance (Bermudez and Firman 1998, Cowey and Cho, 1992).

These contradictory results have not clearly identified that biogenic amines found at typical levels within MBM are sufficient to reduce bird performance. The level of biogenic amines are however considered to be a good indicator of the quality of MBM and renderers have responded to nutritional concerns by adopting processing techniques to reduce biogenic amine occurrence.

An Australian study (den Brinker et al, 2003) analysing 1,445 samples for biogenic amines in animal by-product meals has been completed. The table below identifies results of this work.

Table 5: Mean concentration and range of putrescine, cadaverine and histamine in Australian by-product meals between 1994 and 1997

| Sample type | No. of samples | Putrescine (range) (mg/kg) | Cadaverine(mg/kg) (range) (mg/kg) | Histamine(mg/kg) (range) (mg/kg) |
|--------------|----------------|---------------------------------|--|---------------------------------------|
| Fish meal | 78 | 102 (7-102) | 220 (11-1340) | 570 (<5-1620) |
| Poultry meal | 387 | 82 (7-1320) | 121 (<5-1350) | 19(<5-167) |
| Meat meal | 835 | 21 (<5-695) | 29 (<5-680) | 10(<5-258) |
| Feather meal | 120 | 31 (5-267) | 42 (<5-159) | 5(<5-90) |
| Blood meal | 25 | 13 (<5-223) | 7 (<5-280) | 4(<5-36) |

Source: den Brinker et al, 2003

These results identify MBM as having lower levels of biogenic amines than levels found in fish meal and poultry meal. Many of the fish meal samples analysed were from countries of South America. Renderers of products with higher levels of biogenic amines have responded in changing processing techniques to manufacture MBM with lower levels of biogenic amines.

Chemical Residues

Australia has one of the best track records in the world for producing high quality beef and sheep meats which are chemical residue free. Australian beef and lamb is exported to all points of the globe and it must meet exacting standards in countries such as Japan and the USA. As part of the slaughter process of cattle and sheep to produce beef and sheep meats, the rendering industry utilises byproducts to produce MBM. The same animals producing chemical residue free status beef and sheep meats also result in chemical residue free MBM.

TABLE 6: Australian National Residue Survey results for 2001-2002

| | Cattle | | Sheep | |
|-----------------------|--------------|--------------|--------------|-------------|
| | No. Analyses | % above MRL* | No. Analyses | % above MRL |
| Pesticides | | | | |
| Organochlorines | 616 | Nil | 469 | Nil |
| Organophosphates | 616 | Nil | 469 | Nil |
| Synthetic Pyrethoids | 1831 | Nil | 467 | Nil |
| Benzoyl Ureas | 311 | Nil | 306 | Nil |
| Antimicrobials | | | | |
| Sulphonamides | 938 | Nil | 1328 | Nil |
| Antibiotics | 938 | Nil | 1328 | Nil |
| Anthelmintics | 310 | Nil | 300 | Nil |

* MRL = Maximum Residue Limit

Source: Australian National Residue Survey 2002

Australian livestock producers can be clearly seen as taking a positive stance with respect to chemical use and this translates into chemical residue free MBM. The fact that Australia has stringent controls on the use of agricultural chemicals and a meat testing programme to identify potential chemical residues offers a major benefit to users of Australian MBM.

Proximate Analysis of MBM

MBM is primarily considered as a high protein raw material which also has added value in supplying energy, minerals and vitamins. Because MBM is derived from animal tissues, it has been used for many years as a reliable source of amino acids. Because of the variation in the combination of raw materials being rendered, differences arise in the proximate analysis of MBM. Due to the increase in the number of sheep and cattle being supplied for human consumption and an increase in the volumes of raw materials and MBM resulting, there has been an increase in the consistency of MBM being supplied from Australian renderers. There has also been a tendency for the abattoir industry to move towards single-species plants. This has also resulted in greater consistency of product from individual processors. MBM is manufactured to meet a number of market requirements and the table below defines specifications for Australian MBM.

Table 7: Specifications of Australian MBM

| | 45% MBM | 48% MBM | 50% MBM | 55% MBM |
|---------------|----------------|----------------|----------------|----------------|
| Crude Protein | 45% Min | 48% Min | 50% Min | 55% Min |
| Fat | 15% Max | 15% Max | 15% Max | 15% Max |
| Moisture | 10% Max | 10% Max | 10% Max | 10% Max |
| Ash | 38% Max | 37% Max | 32% Max | 30% Max |

Source: NACMA, 1998

The crude protein content of meat and bone meal is specified for products being supplied, the majority of Australian MBM is supplied as a minimum 50% crude protein (as fed basis), the protein content is usually between 50% and 52% protein. Some renderers are implementing systems to fractionate MBM into higher protein (55-60%) lower ash material which is formulated for application in aquaculture and petfood feeding.

The National Research Council (NRC) defines proximate analysis data upon which their more detailed specifications (such as amino acids) are based. The following is their data.

Table 8: Nutrient composition of MBM as defined by the NRC, 1994:

| | |
|---------------|-------|
| Crude Protein | 50.4% |
| Fat | 10.0% |
| Moisture | 7.0% |
| Calcium | 10.3% |
| Phosphorus | 5.1% |

Protein Quality

Protein consists of amino acids which form complexes which gives proteins their individual characteristics and properties. The average nitrogen content of amino acids from animal protein is constant so that analysing nitrogen content allows a calculation of protein content to be made. Based upon animal proteins containing 16% nitrogen, crude protein is calculated by multiplying the nitrogen content by 6.25.

MBM has high levels of essential amino acids. The amino acid content has a high correlation with the protein content of MBM; Table 9 provides amino acid prediction equations based upon crude protein content.

Table 9: Regression Equations for MBM Predicting Amino Acid Content from Crude Protein

| Amino Acid | Equation | R Value |
|------------|------------------------|---------|
| Lysine | (%CP x 0.0673) - 0.926 | 0.83 |
| Methionine | (%CP x 0.0207) - 0.360 | 0.79 |
| Meth + Cys | (%CP x 0.0395) - 0.813 | 0.76 |
| Threonine | (%CP x 0.0502) - 0.925 | 0.91 |
| Tryptophan | (%CP x 0.0133) - 0.352 | 0.80 |
| Isoleucine | (%CP x 0.0475) - 1.007 | 0.86 |
| Leucine | (%CP x 0.0953) - 1.836 | 0.91 |
| Valine | (%CP x 0.0676) - 1.234 | 0.87 |
| Arginine | (%CP x 0.0492) + 0.906 | 0.77 |

Source: Degussa , AminoDat 2.0

Pepsin Digestibility

Protein quality can be evaluated using in vitro enzyme digestibility assays. The commonly used pepsin digestibility test has been in use since the 1950's. This analysis is based upon incubating the sample with a single proteolytic digestive enzyme pepsin, undigested protein is separated from released amino acids and peptides. The basis of the assay is to mimic the conditions of a chicken's stomach within a glass flask. The resulting calculation of digestible protein has provided an estimate of animal protein quality. It is of note that the pepsin digestibility assay is not recommended for use in assessing vegetable protein meals and complete feeds due to the carbohydrate complexes which limit the capacity of a single enzyme assay.

The official AOAC, 1984 test calls for the use of a pepsin concentration of 0.2%. Alternate lower pepsin concentrations (Parsons et al, 1997) have been shown to provide greater sensitivity in predicting in vivo protein and amino acid quality of animal protein meals. Alternate non-standard methods utilise 0.02%, 0.002% and 0.0002% pepsin concentrations. The use of lower concentration pepsin is reported by Parsons et al, 1997 to be superior in identifying differences between meat meal sources and the impact of heat treatment upon digestibility. The more dilute pepsin concentrations result in lower digestibility results. Difficulty has been found in correlating pepsin digestibility to in vivo feeding trial digestibility results (Piva et al, 2001, Ravindran et al, 2002), this has provided a reduced confidence in the use of the test.

The major advantage of pepsin digestibility assays is the use of a relatively simple, rapid and low cost assay. It continues to be used as a means of discriminating between high and low results. The pepsin digestibility test is influenced by the particle size of the material being assayed. The AOAC method requires the MBM to be ground so that all material passes through a US No. 20 mesh (0.85mm) sieve. Inadequate grinding and incubation, results in low assay results which underestimate the samples digestibility. The assay is further limited through the use of a single enzyme when the animals digestive tract in a complex system with multi-enzymes.

Utilising 0.2% pepsin within the assay, pepsin digestibility for Australian MBM will be in the range 85-92%, with some specialised MBM achieving higher digestibility. The Australian standard requires all MBM to be manufactured and supplied with a minimum 85% pepsin digestibility.

Multi-enzyme Assays

The use of a combination of enzymes has been used to assess in vitro digestibility for a wider range of protein sources. The method of Hsu et al, 1977 is the most widely used. This assay is based upon incubating samples with a combination of trypsin, chymotrypsin and peptidase; the resulting decline in pH is measured, this being found to correlate with protein digestibility in vivo.

The comparative assay work completed by Parsons et al, 1997 was completed to assess the suitability of using the multi-enzyme test to predict in vivo MBM quality. This work demonstrated that the multi-enzyme test results were not significantly correlated with in vivo protein quality.

KOH Protein Solubility Assay

This is a chemical assay (Araba and Dale, 1990), which measure the solubility of protein when samples are mixed with 0.2% KOH. The assay was developed for use with vegetable protein meals to measure over processing and protein damage caused by heat. When applied to soybean meal, canola meal and sunflower meal, protein solubility is correlated with in vivo digestibility.

The work of Parsons et al, 1997 and Ravindran et al, 2002, identified that the KOH protein solubility assay is not significantly correlated with MBM in vivo protein digestibility. Although this test is widely used within the North American feed industry, it is not recommended for use in assessing MBM quality.

Available Lysine Chemical Assays

The use of a combination of enzymes has been used to assess in vitro digestibility for a wider range of protein sources. The method of Hsu et al, 1977 is the most widely used. This assay is based upon incubating samples with a combination of trypsin, chymotrypsin and peptidase; the resulting decline in pH is measured, this being found to correlate with protein digestibility in vivo.

The comparative assay work completed by Parsons et al, 1997 was completed to assess the suitability of using the multi-enzyme test to predict in vivo MBM quality. This work demonstrated that the multi-enzyme test results were not significantly correlated with in vivo protein quality.

Near Infrared Reflectance (NIR) Analysis

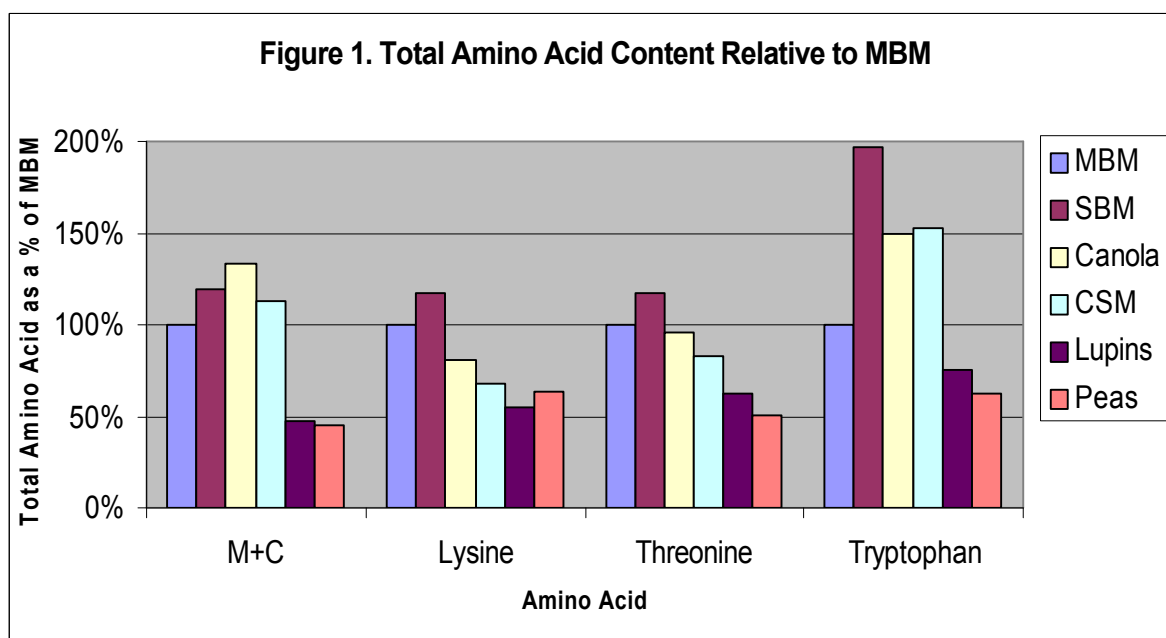
The adoption of NIR technology by the animal feed industry has lead to preliminary work calibrating NIR machines to both total and digestible amino acid content of raw materials. This area holds considerable promise as it offers a rapid and low cost means of assay. The use of NIR technology is however limited to the availability of samples of known in vivo digestibility against which correlation co-efficients can be developed.

Amino Acids

Total Amino Acids

MBM is an excellent source of amino acids as defined within Figure 1. It has high levels of Lysine and Threonine compared to most other common sources.

Amino acid analyses are completed using acid hydrolysis, followed by ion-exchange chromatography. Because tryptophan is destroyed and methionine and cystine are partially destroyed by acid hydrolysis, these amino acids are determined in separate analyses. Amino acid analysis is difficult and complicated, requiring laboratory expertise and precision which is limited to a number of specialist laboratories operating in the world. Companies supplying synthetic amino acids have retained facilities capable of providing ongoing amino acid analytical services. The greatest number of samples analysed shown within Table 11 are those provided by Addiseo, Novus and Degussa. The Degussa AminoDat 2.0 database provides a breakdown of results by MBM country of origin.



Source: Degussa AminoDat 2.0
 MBM =50% Meat & Bone Meal
 SBM=48% Soybean Meal
 Canola= 37% Canola Meal
 M+C= Methionine plus Cysteine

CSM = 36% Cottonseed Meal
 Lupins = 29% Lupins
 Peas = 25% Peas

Carnitine & Creatine

Animals have the capacity to synthesise both carnitine and creatine from other amino acids. Research in recent years has however identified the potential beneficial role supplemental carnitine and creatine can have upon animal performance and meat quality parameters. Animal tissues contain these chemical compounds and MBM supplies considerably higher levels than that found in vegetable protein meals.

Table 10: L-Carnitine concentration in feedstuffs

| Feedstuff | mg/kg | Feedstuff | mg/kg |
|--------------|-------|------------------|---------|
| Barley | 10 | Milk | 20 |
| Maize | 5 | Skim milk | 10-30 |
| Wheat | 5 | Skim milk powder | 100-300 |
| Triticale | 5 | Whey powder | 300-500 |
| Wheat bran | 15 | Fish meal | 60-120 |
| Soybean meal | 20 | Meat bone meal | 50-80 |

Source: Baumgartner and Blum, Lonza Information

| | UK-MAFF | NOVUS | ADAS | Adisseo | Syd Uni | NRC | Aust MBM Degussa | All MBM Degussa | Recommended |
|----------------------|---------|-------|------|---------|---------|------|---------------------|--------------------|-------------|
| Lysine (%) | 3.07 | 2.48 | 2.57 | 2.51 | 2.66 | 2.61 | 2.77 | 2.43 | 2.75 |
| Methionine (%) | 0.68 | 0.68 | 0.71 | 0.68 | 0.83 | 0.69 | 0.67 | 0.67 | 0.68 |
| Cysteine (%) | 0.44 | 0.70 | 0.75 | 0.49 | | 0.69 | 0.45 | 0.49 | 0.50 |
| Met + Cys (%) | 1.12 | 1.40 | 1.46 | 1.17 | | 1.38 | 1.13 | 1.16 | 1.18 |
| Threonine (%) | 1.40 | 1.67 | 1.66 | 1.56 | 1.62 | 1.74 | 1.62 | 1.58 | 1.70 |
| Tryptophan (%) | 0.34 | 0.29 | | 0.31 | | 0.27 | 0.30 | 0.32 | 0.30 |
| Isoleucine (%) | 1.35 | 1.48 | 2.03 | 1.44 | 1.72 | 1.54 | 1.27 | 1.36 | 1.45 |
| Leucine (%) | 3.69 | 3.13 | 3.02 | 2.97 | 3.43 | 3.28 | 3.21 | 2.92 | 3.20 |
| Valine (%) | 2.00 | 2.35 | 2.20 | 2.19 | 2.47 | 2.36 | 2.28 | 2.14 | 2.30 |
| Histidine (%) | 1.19 | | 1.15 | 1.04 | 1.30 | 0.96 | 1.07 | 1.02 | 1.10 |
| Arginine (%) | 4.15 | 3.51 | 3.51 | 3.41 | 3.81 | 3.28 | 3.47 | 3.36 | 3.50 |
| Glycine (%) | 7.82 | 6.54 | 6.32 | 6.15 | 7.05 | 6.65 | 6.87 | 6.63 | 6.75 |
| Serine (%) | 2.39 | 2.31 | 2.06 | 1.94 | 1.53 | 2.20 | 1.97 | 1.99 | 2.00 |
| Glycine + Serine (%) | 10.21 | 8.85 | 8.38 | 8.09 | 8.58 | 8.85 | 8.84 | 8.62 | 8.75 |
| Phenylalanine (%) | 2.02 | 1.84 | 1.71 | 1.66 | 2.13 | 1.81 | 1.79 | 1.64 | 1.80 |
| Tyrosine (%) | 1.39 | 1.29 | 1.19 | 1.13 | 1.32 | 1.20 | | 1.20 | 1.20 |
| Phe + Tyrosine (%) | 3.41 | 3.13 | 2.90 | 2.79 | 3.45 | 3.01 | | 2.84 | 3.00 |
| Aspartic acid (%) | | 3.66 | 3.47 | 3.61 | 4.18 | | 3.78 | 3.69 | 3.75 |
| Glutamic acid (%) | | 5.97 | 5.61 | 5.98 | 6.90 | | 5.81 | 5.85 | 5.85 |
| Proline (%) | | 4.34 | 3.87 | 4.09 | | | 4.30 | 4.13 | 4.20 |
| Alanine (%) | | 3.62 | 3.86 | 3.56 | 4.22 | | 3.93 | 3.63 | 3.80 |

Reference Sources:

- UK-MAFF, 1986
- Novus International, 1996
- ADAS, 1990
- Adisseo - AmiPig 2000
- Syd Uni - Bryden, W.L. and Li,X., 2002
- NRC, 1994
- Degussa AG, 2001

Ash Content

The ash component of MBM is principally the mineral derived from bone together with lesser amounts of minerals contained within animal tissues which are rendered. Bone supplies approximately 99% of the calcium and 80% of the phosphorus found within MBM, whereas 30% of the magnesium is found in non-bone component of the ash. Bone is made up largely of calcium phosphate ($\text{Ca}_3(\text{PO}_4)_2$) in an organic complex. Within MBM, calcium and phosphorus are generally within the ratio 2:1.

A negative correlation between digestible amino acid content per unit of protein and ash content has been identified by Parsons et al, 1997 and Wang and Parsons, 1998, they however found no correlation of ash content with amino acid digestibility. It was postulated by Wang and Parsons, 1998 that lower levels of digestible amino acids per unit of protein in higher ash MBM is due to increased collagen content associated with bone and a greater supply of non essential amino acids (glycine and proline) relative to essential amino acids.

Table 12: Macro Mineral content of MBM compared to soybean meal.

| Mineral | 50% MBM | 48% Soybean Meal |
|------------|---------|------------------|
| Calcium | 10.3% | 0.27% |
| Phosphorus | 5.1% | 0.62% |
| Magnesium | 1.12% | 0.30% |
| Sodium | 0.70% | 0.02% |
| Potassium | 1.45% | 1.98% |
| Chlorine | 0.69% | 0.05% |
| Sulphur | 0.50% | 0.44% |

Source: NRC, 1994

MBM is characterised as a protein meal which supplies a highly available source of phosphorus. Unlike plant materials, MBM does not contain phytic acid which binds phosphorus reducing its availability.

Table 13: The level of trace minerals supplied by MBM is compared against other raw materials in the table below.

| | Iron (mg/kg) | Manganese (mg/kg) | Copper (mg/kg) | Selenium (mg/kg) | Zinc (mg/kg) |
|--------------|-------------------------|------------------------------|---------------------------|-----------------------------|-------------------------|
| MBM | 606 | 17 | 11 | 0.31 | 96 |
| Soybean Meal | 176 | 86 | 20 | 0.27 | 55 |
| Canola Meal | 142 | 49 | 6 | 1.10 | 69 |
| Wheat | 39 | 34 | 6 | 0.33 | 40 |
| Sorghum | 45 | 15 | 5 | 0.20 | 15 |

Source: NRC, 1998

MBM supplies additional quantities of iron and zinc relative to other raw materials.

Fat Content

The amount of fat within MBM provides a valuable source of energy for animal feeding. Work completed by Smith and Allan, 1999 has provided the data below relating to the phospholipid, cholesterol and fatty acid profile from 27 analysed Australian MBM samples.

Table 14: Phospholipid, cholesterol and fatty acid profile of Australian MBM samples, data on an as fed basis.

| Gross Energy | Ash | Crude Protein | Total Lipid | Total PL | PC | Cholesterol |
|---------------------|------------|----------------------|--------------------|-----------------|-----------|--------------------|
| MJ/kg | % | % | % | % | % | % |
| 17.38 | 27.07 | 55.39 | 11.14 | 0.75 | 0.46 | 0.16 |

Fatty acid data results expressed as g of fatty acid/100g of MBM

| 16:0 | 18:0 | 18:1n-9 | 18:2n-6 | SFA | MUFA | Total |
|-------------|-------------|----------------|----------------|------------|-------------|--------------|
| 3.37 | 3.00 | 4.51 | 0.60 | 7.21 | 5.16 | 12.56 |

Source: NRC 1998

Total PL = Total phospholipid

SFA = sum of saturated fatty acids

PC = Phosphatidylcholine

MUFA = sum of mono-unsaturated fatty acids

The gross energy results of 17.38 MJ/kg (4154 kcal/kg) compares against 16.74MJ/kg (4000 kcal/kg) found by Wang and Parsons, 1998

Linoleic acid (18:2n-6) measured at 0.6% by Smith and Allan, 1999 compares against 0.36% published by the NRC, 1994. Conjugated linoleic acid has been identified as potentially affecting animal performance and it has been speculated that trace levels of conjugated linoleic acid from MBM may provide added benefit when MBM is fed to pigs and poultry (Bruerton, 2003). There is however a need to define actual levels within MBM and whether these trace levels are of significance to the animal.

Effect of Processing upon MBM Quality

Excessive heat applied to proteins reduces the availability of heat sensitive amino acids. This effect has been identified across a range of protein sources; soybean meal (Parsons et al, 1992), canola meal (Anderson-Hefermann et al, 1993), sunflower meal (Zhang and Parsons, 1994) and MBM (Skurray and Herbert, 1974, Batterham et al, 1986).

Heat treatment can result in three types of nutritional damage:

1. Total destruction of amino acids,
2. Maillard or browning reactions where free lysine reacts with certain types of sugars such as sucrose, fructose, stachyose and raffinose. Soybean meal contains considerable quantities of soluble sugars and is very susceptible to Maillard reactions during heat treatment (Coon et al., 1990). This effect in MBM is less pronounced than in oilseeds due to the low carbohydrate and reducing sugar content of MBM.
3. Cross linking between amino acids, this being found in soybean meal (Parsons et al 1992) and MBM (Piva 2001). Cross linked amino acids such as lysinoalanine formation from lysine and lantionine formation from sulphur amino acids, particularly cytiene (Robbins et al, 1980)

It can be seen that all protein meals, both animal and vegetable sources, are sensitive to heat treatment. Heat is required to reduce anti-nutritional factors such as trypsin inhibitor in soybeans and gossypol in cotton. Heat is an essential component in the manufacture of MBM; the critical factors affecting protein quality are the degree of heating and the length of time this heat is applied.

The Australian rendering industry utilises lower temperature continuous cookers, with ambient air pressure. Conditions recognised as providing a gentler heating of protein are where temperature remains below 125°C (Batterham et al, 1986), at zero psi pressure (Shirley and Parsons, 2000) and for minimal time periods (Batterham et al, 1986). In contrast, processing MBM at 133°C and 3 bars of pressure (29 psi or 200kPa) for 20 min, as required by the EC treatment directive, significantly reduces amino acid digestibility (Shirley and Parsons, 2000).

Australian MBM is not required to be manufactured under the EC treatment conditions (unless products are produced for export to the EU) as Australia is free from BSE. This provides a significant benefit to users of Australian MBM due to its higher protein quality as it has been manufactured using lower temperature and pressure conditions.

Table 15: Digestibility Coefficients of Selected Amino Acids in Meat and Bone Meal as Reported in the Literature Since 1984

| Amino Acid | 1984 | 1989 | 1990 | 1995 | 1997 | 2000 |
|--------------|------|------|------|------|------|-----------|
| Lysine % | 65 | 70 | 78 | 92 | 71 | 87.5-92 |
| Threonine % | 62 | 64 | 72 | 89 | - | 80.2-88.9 |
| Tryptophan % | - | 54 | 65 | - | 70 | 86.4 |
| Methionine % | 82 | - | 86 | 91 | - | 87.4-92 |
| Cystine % | - | - | - | 71 | - | 76.4 |

Source: Pearl, 2002

A review (Pearl 2002) of published data relating to MBM shows an improvement over time in defined amino acid digestibility co-efficients. This improvement is recognising the increased performance of renderers and the equipment and conditions under which MBM is manufactured. Most of the original digestibility work in the 1980's and early 1990's was completed using MBM sourced from batch cookers using high temperature, time and pressure conditions. More recent research work such as that of Wang and Parsons, 1998 has shown MBM manufactured under the correct conditions provides amino digestibilities in excess of 90%.

Australian renderers produce a wide range of meat meals of different composition. For example there are low ash meals made from predominately soft offal of fractionated meals, low temperature rendered meals with very high digestibility, single species bovine and ovine meals, and pressure-cooked meals to meet EU processing requirements. The variation in raw material mixes and processing conditions used at different plants creates a wide variation in products. However the outputs of individual plants can be relied on to be a consistent quality.

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POULTRY

Introduction

MBM is a valuable raw material which can be used in all classes of poultry feeding. MBM is principally considered as a protein source, but also supplies valuable levels of energy and minerals. This report provides a review of published data relating to MBM use in poultry rations.

Energy

Australia has a variety of rendering systems designed to process meat industry co-products into valuable ingredients for The gross energy supplied within MBM has been analysed to be in excess of 4000 kcal/kg (Wang and Parsons, 1998). The metabolisable energy content is directly related to the energy supplied from the fat and protein components of MBM.

The metabolisable energy (ME) content of MBM has in recent years undergone considerable reworking, resulting from views that energy levels published by the NRC appear to be too low. This issue was studied by Martosiswoyo and Jensen, 1988, who identified that the original ME determinations were based upon MBM inclusion levels in test diets at up to 40%. This is appropriate for grains but unsuitable for MBM where this inclusion level is far greater than practically applied in diets. The excessive levels of calcium and phosphorus from including 40% MBM are likely to have interfered with utilisation of nutrients supplied.

Several papers have been published which identify higher levels of ME when MBM is included in test diets at more practical levels of usage (Martosiswoyo and Jensen 1988; DeGrootte and Ketels 1988; Dale 1989). Work by Dale, 1997 was completed based upon confirming that the calculated ME supplied from MBM portions of meat and fat was duplicated in feeding trials. This work has demonstrated that a typical 50% protein MBM, containing 10% fat supplies more ME than is identified within NRC 1994:

NRC listing for MBM:

| | |
|---------------------------|-------------|
| Metabolisable energy..... | 2150kcal/kg |
| Crude Protein..... | 50.4% |
| Fat..... | 10.0% |
| Dry Matter..... | 93.0% |

Calculated ME from 10% fat:

$$7450 \text{ kcal/kg} * 0.10 = 745 \text{ kcal/kg}$$

Calculated ME from 50.4% crude protein:

$$5300 \text{ kcal/kg} \times 0.93 \times 0.79^{**} \times 0.504 = 1962 \text{ kcal/kg}$$

Sum of ME from fat and protein = 2707 kcal/kg

TME_n when meat and bone fractions assayed separately MBM beef origin 2450 kcal/kg

Source: Dale 1997

* Based upon NRC ME from animal fat.

** Based upon NRC gross energy of protein dry matter basis x average digestibility of amino acid.

The Total Metabolisable Energy (TME_n) result of 2450kcal/kg from Dale 1997, is in close agreement with 2536 kcal/kg established by Wang and Parsons 1998.

Research work has recently been completed by Firman 2003 to determine the energy availability of MBM for turkeys and broilers using various assay methods, results of this work are summarised below.

Table 1. MBM Energy Values

| ME Assay Method | ME kcal/kg as fed |
|---------------------------------|--------------------------|
| Rooster TME _n | 2572 |
| Turkey TME _n | 2482 |
| Chick Digesta AME _n | 2366 |
| Chick Excreta AME _n | 2536 |
| Chick Excreta TME _n | 2569 |
| Turkey Digesta AME _n | 2534 |
| Turkey Excreta AME _n | 2537 |
| Turkey Excreta TME _n | 2580 |

Source: Firman, 2003

These results are based upon the analysis of 12 different MBM sources utilising the assay procedures which are defined as:

- Rooster and Turkey TME_n - based upon the Sibbald (1986) method utilising adult birds tube fed feed equal to 2% of bodyweight. Both feed energy in and faecal energy out (corrected for endogenous loss) was measured by bomb calorimetry and TME_n calculated from the difference of these numbers.
- Chick and Turkey Digesta, Apparent Metabolisable Energy (AME_n) - 3 week old birds were fed a basal diet and energy determined using total faeces collection. Basal diet was then diluted (50%) by addition of the test material, energy was determined for feed and faeces to determine AME.
- Chick and Turkey Excreta AME_n - is a modification on the Digesta AME_n, where endogenous excreta is collected to adjust AME_n for endogenous loss.
- Chick and Turkey TME_n - based upon ileal content collection with chromic oxide as a marker, where chromic oxide concentration in the diet and digesta is analysed.

Firman's results confirm:

- The ME value for MBM is higher than NRC 1994.
- The ME value of MBM does not vary greatly between differing assay methods.
- There are few differences between chickens and turkeys in the ME available from MBM.

It was also postulated that higher ME levels found in this study compared to assays completed in earlier years, may also be due to improved processing procedures employed by renderers which results in increased protein digestibility.

Metabolisable energy recommendation for MBM:

2500 kcal/kg or 10.46 MJ/kg for broiler chickens

2700 kcal/kg or 11.30 MJ/kg for laying hens.

Amino Acids

MBM is recognised as being an excellent source of amino acids, the concept of utilising available amino acids recognises that amino acids consumed by the animal are not completely digested and metabolised. Methods to determine amino acid availability are various and include both in vitro and in vivo analyses, the commonest approach is to utilise digestibility studies.

With respect to in vivo digestibility, various reviews and trial comparisons have been written (Sibbald, 1987; Johnson, 1992; Dalibard and Paillard, 1995; Farrell et al., 1999; Ravindran and Bryden 1999) comparing the use of differing amino acid digestibility assays. This report does not attempt to review the merits of each assay technique; there is however a need to recognise differences when viewing results as they relate to MBM and any protein source.

The major issues relating to method of determining amino digestibility are:

- Faecal versus ileal procedures.

Use of excreta from total collection is affected by hind gut microbial fermentation and endogenous nitrogen losses. The collection of digesta from the ileum provides correction for the influence of endogenous amino acids. Ileal digesta is collected either through the use of ileal cannula or by killing the bird.

- Adult birds rather than the young chicken.

Ileal cannulation is possible with adult birds, this technique using adult cockerels is widely used in the USA, Canada and France in determining amino acid digestibilities. It has been questioned that use of adult birds is suitable for laying hens and broiler breeders but does not reflect digestibility in the rapidly growing broiler chicken. For this reason ileal digestibility assays (Ravindran et al, 1998) can be completed using 3 to 5 week old broilers, this technique being used to generate significant amounts of data within Australia and New Zealand.

- Apparent versus true digestibility

The figure below provides a representation of the difference between apparent and true ileal digestibility.

Apparent ileal amino acid digestibility % =

$$\frac{\text{Ingested amino acid} - \text{Excreted amino acid (end of ileum)}}{\text{Ingested amino acids}} \times 100$$

True ileal amino acid digestibility % =

$$\frac{\text{Ingested amino acid} - (\text{Excreted amino acid} - \text{Endogenous amino acid})}{\text{Ingested amino acids}} \times 100$$

When the ingested quantity of feed is very low, apparent digestibility underestimates the actual digestibility. True amino digestibility is not affected by feed intake. True amino acid digestibility results theoretically are higher than apparent amino acid digestibility results. It has been proposed by Bryden and Li, 2002 that if diets are being formulated to least-cost using linear programming, then apparent ileal digestibility values are the most appropriate as they take into account the endogenous cost of digestion. On the other hand, if diets are being formulated in computer simulation models, then true digestibility values will be relevant as the model should correct for the endogenous cost of digestion.

Table 2. Amino Acid Digestibility Co-efficients %

| | Chick Assays | | | Adult Cockerel Assays | |
|-------------------|--------------|----------|-----------|-----------------------|-----|
| | Syd Uni. | NZ Ileal | NZ Faecal | Degussa | NRC |
| Lysine (%) | 76 | 77.4 | 85.4 | 81 | 79 |
| Methionine (%) | 79 | 88 | 83.1 | 85 | 85 |
| Cysteine (%) | | | | 58 | 58 |
| Met + Cys (%) | | | | 74 | |
| Threonine (%) | 68 | 69.2 | 85.9 | 79 | 79 |
| Tryptophan (%) | | | | 78 | |
| Isoleucine (%) | 75 | 71 | 78.3 | 84 | 83 |
| Leucine (%) | 76 | 72.6 | 81.2 | 85 | 84 |
| Valine (%) | 73 | 79.7 | 74.6 | 83 | 82 |
| Histidine (%) | 73 | 73.3 | 76.9 | 80 | 80 |
| Arginine (%) | 76 | 81.9 | 81.2 | 84 | 85 |
| Glycine (%) | 73 | 70.2 | 80.2 | | |
| Serine (%) | 67 | 70.9 | 78.2 | | |
| Phenylalanine (%) | 75 | 75.3 | 73.1 | 83 | 84 |
| Tyrosine (%) | 73 | 69.5 | 77.4 | | |
| Aspartic acid (%) | 60 | 65.6 | 82.7 | | |
| Glutamic acid (%) | 73 | 70.2 | 80.2 | | |
| Proline (%) | | 76.4 | 81.3 | | |
| Alanine (%) | 76 | 71.7 | 84.7 | | |

Sources: Syd Uni data from Ravindran et al, 1998 apparent ileal digestibility 42 day old broiler chicks, annotated good quality MBM.

Degussa true faecal digestibility using adult cockerels

NZ data from Kadim et al, 2002 apparent ileal digestibility using 35 day old broiler chicks, NRC 1994 true faecal digestibility using adult cockerels

Excessive heat and pressure applied during processing of protein meals is known to reduce amino acid digestibility. Published work studying MBM and the effect of temperature has defined that higher processing temperatures can reduce chick growth (Kondos and McClymont, 1972). Batterham et al, 1986 and Wang and Parsons 1998a have demonstrated that amino acid digestibility is reduced with higher processing temperatures. Further work completed by Wang and Parsons 1998b has provided differentiation between high and low quality MBM and the impact of processing conditions upon amino acid digestibility, results being summarised below in Table 3. Low quality MBM was produced from processing at 152°C for 75 minutes, whilst high quality MBM was produced by processing at 132°C for 15 minutes. The extreme over processing of the low quality MBM is indicated through a moisture content of only 1.5%.

Table 3. Amino Acid Digestibility for High and Low Quality MBM

| | High Quality MBM | Low Quality MBM |
|--------------------------------------|------------------|-----------------|
| Dry Matter | 93.8% | 98.5% |
| Crude Protein | 50.1% | 57.7% |
| Total lysine | 2.87% | 2.92% |
| Total methionine | 0.73% | 0.87% |
| Total cystine | 0.61% | 0.57% |
| Lysine digestibility coefficient | 91.9% | 71.1% |
| Methionine digestibility coefficient | 91.2% | 82.8% |
| Cystine digestibility coefficient | 70.7% | 31.2% |

Source: Wang and Parsons 1998b

It should be noted that the majority of Australian MBM is manufactured under low temperature conditions, less than 125°C, utilising continuous cookers where cooking time is reduced. This results in high quality MBM where amino acid digestibility remains high. Australian rendering conditions are distinctly different to those applying to products produced to meet EC processing conditions of 133°C and 3 bars of pressure (29 psi or 200kPa) for 20 minutes. Shirley and Parsons (2000) have demonstrated the added effect pressure has upon amino acid digestibility, with lysine digestibility reducing from 76% to 68% and 41% as processing pressure was increased from 0 to 30 and 60psi. Results of Karakas et al, 2001 looking at a range of MBM samples produced in The Netherlands under EC processing procedures (133°C, 3 bar pressure for 20 min.) found ileal amino acid digestibility to fall in the range 55.6 to 64.8%. These results agree with those of Shirley and Parsons, that EC pressure processing conditions will decrease the nutritional value of MBM.

MBM produced under low temperature conditions such as those practiced within Australia results in the supply of a protein source with high digestibility levels, this exceeding 90% for lysine and methionine. The table below however takes a more conservative approach in providing digestible amino acid values for poultry. The values for chick and adult bird digestible amino acids are derived from the total amino acid values as defined within the General Section table 15 and digestibility co-efficients derived from table 2 above.

Table 4: Ileal Digestible Amino Acid Values for 50% Protein MBM.

| | Total (%) | Chick. Dig. Coeff. (%) | Chick. Dig. AA (%) | Adult. Dig. Coeff (%) | Adult. Dig. AA (%) |
|------------|-----------|------------------------|--------------------|-----------------------|--------------------|
| Lysine | 2.75 | 77 | 2.12 | 81 | 2.23 |
| Methionine | 0.68 | 84 | 0.57 | 85 | 0.58 |
| Cysteine | 0.5 | 55 | 0.28 | 58 | 0.29 |
| Met + Cys | 1.18 | 69 | 0.81 | 74 | 0.87 |
| Threonine | 1.70 | 69 | 1.17 | 79 | 1.34 |
| Tryptophan | 0.3 | 75 | 0.23 | 78 | 0.23 |
| Isoleucine | 1.45 | 75 | 1.09 | 84 | 1.22 |
| Leucine | 3.2 | 76 | 2.43 | 85 | 2.72 |
| Valine | 2.3 | 73 | 1.68 | 83 | 1.91 |
| Histidine | 1.1 | 76 | 0.84 | 80 | 0.88 |
| Arginine | 3.5 | 76 | 2.66 | 84 | 2.94 |

Nutritionists need to adopt the digestible amino acid values for MBM relative to their own database. This being either chick or adult bird ileal digestibility figures as they apply in their database to other raw materials. The chemical compounds carnitine and creatine have been identified as being essential in fat metabolism and muscle performance. Both of these compounds have been termed quasi-vitamins and they are derived from amino acid precursors:

Lysine and methionine precursors for carnitine
Methionine, glycine and arginine precursors for creatine.

Within poultry nutritional research, limited work has been completed studying the effect of supplementing diets with either carnitine or creatine. Baumgartner, 2003 reported L-carnitine supplementation to breeding roosters increased sperm concentration and increased hatchability in breeding hens. Plant based feedstuffs contain very little L-carnitine whilst animal protein meals are rich in L-carnitine, this observation has led to speculation that poultry rations containing MBM may result in additional performance benefits relative to rations based upon vegetable protein meals (Bruerton, 2003).

Minerals

The term biological availability is often applied to the mineral phosphorus; it is implied that bioavailability is a measure of the degree to which a phosphorus source can support the physiological processes of the animal. Comparative assays have commonly been used to measure phosphorus availability relative to individual phosphate sources, in this way some raw material sources can be assessed as having a relative bioavailability exceeding 100%. In poultry, tibia or toe ash content have been used as the primary measure of estimating bioavailability.

Research work (Waldroup and Adams, 1994, Sell and Jeffrey, 1996) has been completed demonstrating the biological availability of phosphorus from MBM is equivalent to that supplied from dicalcium phosphate when fed to poultry. Some research studies have indicated MBM has a lower phosphorus bioavailability (Orban and Roland, 1992); these studies have however been based upon autoclaved MBM and contained large bone fragments. The work of Sell and Jeffrey, 1996 looking at different bone particle size in MBM was able to demonstrate that MBM passing through a 10 mesh (2.03mm) screen was fully available.

The principle form of phosphorus from plant raw materials is phytate phosphorus. Phytate combines with calcium, phosphorus, magnesium, zinc and manganese making them largely indigestible when consumed by animals. Phytate phosphorus in plant materials generally exceeds 70% of the phosphorus content.

Table 5: Calcium and Phosphorus content of 50% MBM.

| Mineral | 50% MBM | Range |
|----------------------|----------------|--------------|
| Calcium | 10.3% | 8-12% |
| Phosphorus | 5.1% | 4-6% |
| Available phosphorus | 5.1% | 4-6% |

Source: NRC 1994

The use of phytase enzymes is being commercially applied to release bound phytate phosphorus. The initial research work was completed using all vegetable protein sources, this being seen as a means of increasing phosphorus availability and reducing the inclusion level of feed phosphates. The benefits of using phytase have now been identified as extending beyond increasing phosphorus availability, to encompass an increase in feed digestion and release of nutrients increasing bird performance in terms of either weight gain or feed conversion efficiency (Cabahug et al. 1999, Ravindran et al. 2000). More recent research work (Selle et al. 2003) has been completed using phytase in feeds which contain MBM. In broiler rations containing from 5 to 8.5% MBM, there remained a positive response to the inclusion of phytase. It has been suggested that use of phytase will result in reduced usage of MBM, in practical terms MBM is a supply of high quality amino acids, phytase provides additional benefit even when MBM is included within the ration to meet the bird's phosphorus requirement.

Fatty Acid Profile

The only essential fatty acid requirement that has been clearly identified for poultry is that of linoleic acid (18:2n-6). MBM contains a small amount of linoleic acid, NRC, 1994 defines MBM as containing 0.36% linoleic acid.

Recommendations for use

MBM has been widely used as a poultry raw material for many years. Within Australia due to its ready availability, the poultry industry has commonly used MBM at levels of up to 10% inclusion in broiler and layer rations. Greater numbers of feeding trials have been completed in the USA, where MBM has been studied as a substitute for soybean meal.

In several nutrition experiments completed at the University of Georgia (Fuller, 1990), MBM was used in the range 5% to 40% in a corn-soybean basal ration, results showed that broilers fed 10% MBM performed just as effectively as those receiving the corn-soybean basal ration (see Table 6).

Table 6: Effect of level of MBM on chick growth and feed conversion

| Level of MBM (% of ration) | Body wt. at 3wks (g) | Feed/gain Ratio |
|----------------------------|----------------------|-----------------|
| 0* | 503 | 1.52 |
| 5 | 529 | 1.52 |
| 10 | 515 | 1.53 |
| 20 | 474 | 1.64 |
| 30 | 484 | 1.69 |
| 40 | 484 | 1.75 |

* Corn-soy basal ration. Substitution of MBM calculated to keep energy and protein equal in all rations.

Source: Fuller 1990

More recent work has been completed by Drewyor and Waldroup 2000 at the University of Arkansas, using both a high ash 34.85% and low ash 25.87% MBM. They found that MBM could be used in broiler diets at levels higher than had been traditionally used. The high ash MBM could be used at up to 12.98% and the low ash at 17.76% with out adversely affecting body weight, feed utilisation, mortality or tibia ash content when the ration was formulated on a digestible amino acid basis.

It is recommended that when feed formulations are based upon digestible amino acids, the following inclusion levels of MBM can be used for poultry rations.

| Poultry Type | Usage Rate |
|-------------------------|------------|
| Broiler Starter | 8% |
| Broiler Grower/Finisher | 10% |
| Layer | 10% |
| Turkey | 10% |

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Introduction

Animal by-products have been important raw materials in the feeding of pigs for the last 100 years. MBM was the first supplement added to all grain rations for pig feeding and it demonstrated value for balanced ration feeding. MBM has been recognised as an excellent source of protein, energy, calcium and phosphorus. The volume of published work relating to MBM is significant and this report assists in defining the key nutritional attributes of MBM as it relates to pig feeding.

Energy

Data relating to dietary energy content of feed ingredients is required to allow formulation of pig feed diets. The pig industry utilises a number of definitions of energy:

- Gross energy (GE) being the result of combustion of the feed, with use of a bomb calorimeter to measure the energy released.
- Digestible energy (DE) which is the energy left after energy is lost in faeces.
- Metabolisable energy (ME) accounts for energy lost in faeces, urine and digestive gases.
- Net energy (NE) is equivalent to ME less an increment for heat generated through digestion.

NE provides data most closely relating to how the animal utilises nutrients for production, it is however the most difficult to measure. DE is relatively easier to measure in pigs and considerably more DE data is available on raw materials.

The GE supplied within MBM has been analysed to be in excess of 16.74MJ/kg (4000 kcal/kg) (Wang and Parsons, 1998). Smith and Allan 1999 in analysing a range of Australian MBM samples found GE to average 17.38 MJ/kg (4154 kcal/kg).

The DE content of MBM has been identified as being correlated with the crude protein and fat content, regression equations can be used to predict DE as is shown below.

$$\text{DE (MJ/kg)} = (0.021 \times \text{Crude Protein in g/kg}) + (0.048 \times \text{Ether Extract in g/kg}) - 4.63$$

Source: SCA 1987

Utilising this equation, a typical 50% crude protein and 10% fat MBM equates to a DE of 10.67 MJ/kg.

Table 1. Energy values for both meat meal and meat meal with bone.

| | Meat Meal MJ/Kg (kcal/kg) | Meat Meal with bone MJ/kg (kcal/kg) |
|----|----------------------------------|--|
| DE | 11.28 (2695) | 10.20 (2440) |
| ME | 10.86 (2595) | 9.31 (2225) |
| NE | 9.10 (2175) | 5.67 (1355) |

Source: NRC 1998

The NRC DE figures compare with other DE values for Australian MBM as documented by Edwards 1995, 12.1 MJ/kg and SCA 1997, 11.3 MJ/kg and Canadian MBM OMAF 2003, 11.3 MJ/kg.

Amino Acids

The total amino acid content of MBM does not determine the amount of each amino acid which is available to the animal to utilise. The primary factor affecting the bioavailability of amino acids is their digestibility. Table 2 provides published digestibility co-efficients for the major amino acids contained within MBM.

Table 2. Amino acid digestibility co-efficients %

| | NRC Meat Meal | NRC Meat Meal with bone | Degussa | Adisseo |
|-------------------|----------------------|--------------------------------|----------------|----------------|
| Lysine (%) | 83 | 74 | 77 | 65-84 |
| Methionine (%) | 85 | 79 | 77 | 69-85 |
| Cysteine (%) | 55 | 55 | 51 | 50-59 |
| Met + Cys (%) | | | 67 | |
| Threonine (%) | 79 | 70 | 74 | 67-81 |
| Tryptophan (%) | 73 | 60 | 73 | |
| Isoleucine (%) | 82 | 74 | 78 | 67-80 |
| Leucine (%) | 82 | 76 | 78 | 57-82 |
| Valine (%) | 79 | 74 | 76 | 57-80 |
| Histidine (%) | 82 | 75 | 76 | 63-86 |
| Arginine (%) | 88 | 81 | 85 | 75-87 |
| Phenylalanine (%) | 83 | 76 | 78 | 62-83 |
| Tyrosine (%) | 79 | 71 | | 64-83 |

Sources: NRC 1998, Degussa = AminoDat 2.0 2001, Adisseo = Williams 1995

Considerable debate has taken place relating to the difference between digestibility and availability of amino acids, much of this being generated through Australian research work completed by Ted Batterham at Wollongbar Research Station. Within the review of this subject by Batterham, 1992, the argument is made that digestible amino acids are not necessarily available to the animal to utilise. Batterham was able to demonstrate that it is possible for amino acids to be digested and absorbed in forms that are not utilised by the animal. Digestibility is determined using ileal cannulated pigs and collection studies whilst availability is determined using slope-ratio assays. The comparative results of digestible and available lysine from the work of Batterham is shown in Table 3.

Table 3. Comparison of digestibility and availability of lysine (%) in feed ingredients for pigs.

| Ingredient | Digestibility | Availability |
|-----------------------|----------------------|---------------------|
| Soybean meal | 89 | 90 |
| Cottonseed meal | 66 | 29 |
| Meat meal | 78 | 68 |
| Field peas | 96 | 92 |
| Overcooked field peas | 84 | 47 |

Source: Batterham 1992, Batterham 1993.

The range in levels of lysine availability was found by Batterham to be significant, these being shown in Table 4. MBM was found to range from 97% down to 42% availability. The significant aspect of this work was in demonstrating the influence processing temperature has upon amino acid availability.

Table 3. Comparison of digestibility and availability of lysine (%) in feed ingredients for pigs.

| Protein Concentrate | Mean | Range |
|-------------------------|------|-----------|
| Blood meal (ring-dried) | 1.08 | 1.03-1.13 |
| Cottonseed meal | 0.34 | 0.27-0.43 |
| Lupin-seed meal | 0.55 | 0.37-0.74 |
| MBM | 0.68 | 0.42-0.97 |
| Rapeseed meal | 0.87 | 0.77-0.97 |
| Soybean meal | 0.88 | 0.80-0.98 |
| Sunflower meal | 0.60 | 0.54-0.66 |

Source: Batterham 1992.

A study looking at the effect of heat upon lysine availability was completed by van Barneveld, 1993 using field peas as the protein concentrate, heat was applied using a forced air dehydrator. Results of lysine digestibility and availability are shown within Table 5. This work was able to demonstrate that slope-ratio assays can be used to reflect the utilisation of ileal digestible lysine in heat damaged proteins. The effect of heat on lysine availability of field peas was seen to commence at 110°C, this lower temperature effect is believed to be due to the Maillard reaction with the higher levels of carbohydrates contained within peas.

Table 5. The digestibility and availability of lysine in raw field peas heated to defined temperatures.

| | 0° | 110° | 135° | 150° | 165° |
|---------------|----|------|------|------|------|
| Digestibility | 92 | 97 | 92 | 93 | 84 |
| Availability | 96 | 74 | 77 | 56 | 47 |

Source: van Barneveld 1993.

Excessive heat and pressure applied during processing of MBM is known to reduce amino acid digestibility. The work of Batterham, 1986 which looked at the effect of processing treatment of MBM is used in some publications as an argument against using MBM in pig rations. The results of this work demonstrated that MBM manufactured under modern low temperature rendering conditions provides a highly digestible and available (up to 97%) source of lysine and other amino acids. It was concluded by Batterham, 1992 that:

- Digestibility was similar to availability for high quality feedstuffs, digestibility overestimates availability for low quality ingredients which have been heat damaged.
- It is possible to produce high quality MBM provided pressure is avoided and the final end point temperature does not exceed 125°C.

This conclusion is drawn from processes that involved applying an end-point temperature of 125°C for four hours. Higher temperatures applied for a short time could also result in high quality MBM. The results from Batterham are in agreement with work completed in poultry by Wang and Parsons, 1998 demonstrating lysine and methionine ileal digestibilities exceeding 90% for high quality MBM.

Table 6. Lysine availability of MBM processed under differing conditions

| Processing treatment | Conditions | Lysine Avail. Pigs (%) | Lysine Avail. Chicks (%) |
|--------------------------------|---|------------------------|--------------------------|
| Wet rendering | Control high quality wet rendered meal | 97 | 93 |
| Early pressure | Early stage processing 141°C 275kPa 30min End stage cooking 125°C atmospheric pressure | 74 | 78 |
| Late pressure | Late stage processing 141°C 275kPa 30min End stage cooking 125°C atmospheric pressure | 46 | 63 |
| Long end point | Final temperature 125°C cooking extended for 4 hours | 84 | 86 |
| Long end point and temperature | Final temperature 150°C cooking extended for 4 hours | 38 | 31 |

Source: Batterham 1986

In a series of experiments completed at the University of Kentucky (Taylor et al., 1998 a, 1998b, 1999a, 1999b), MBM was used to replace monosodium phosphate in corn-soy pig diets. Ileal amino acid digestibilities for rations are summarised below in Table 7. The research group concluded that the amino acids lysine, threonine, tryptophan and methionine, in diets in which MBM supplied all of the supplemental Ca and P, were 99% as digestible as the amino acids in corn-soybean meal diets in which the Ca and P were supplied from monosodium phosphate and calcium carbonate.

Table 7. Summary of University of Kentucky ileal amino acid digestibilities (%).

| Lysine | Lysine | Threonine | Threonine | Tryptophan | Tryptophan | Methionine | Methionine |
|---------------|---------------|------------------|------------------|-------------------|-------------------|-------------------|-------------------|
| MSP* | MBM** | MSP | MBM | MSP | MBM | MSP | MBM |
| 87.5 | 87.0 | 80.2 | 79.7 | 86.4 | 85.4 | 87.4 | 87.0 |

Source: Taylor et al., 1998 a, 1998b, 1999a, 1999b.

Note: Corn-soy base ration where phosphorus was supplied from either MSP = Monosodium phosphate or MBM = Meat and bone meal.

It should be noted that the majority of Australian MBM is manufactured under lower temperature conditions, utilising continuous cookers where cooking time is reduced. This results in high quality MBM where amino acid digestibility remains high. Australian rendering conditions are distinctly different to those applying to products produced to meet EC processing conditions of 133°C and 3 bars of pressure (29 psi or 200 kPa) for 20 minutes. Shirley and Parsons, 2000 have demonstrated the added effect pressure has upon amino acid digestibility, with lysine digestibility reducing from 76% to 68% and 41% as processing pressure was increased from 0 to 30 and 60psi. Results of Karakas et al., 2001 looking at a range of MBM samples produced in The Netherlands under EC processing procedures (133°C, 3 bar pressure for 20 min.) found poultry ileal amino acid digestibility to fall in the range 55.6 to 64.8%. These results agree with those of Shirley and Parsons and Batterham, that EC pressure processing conditions will decrease the nutritional value of MBM.

MBM produced under low temperature conditions, such as those practiced within Australia, results in the supply of a protein source with high digestibility levels, this exceeding 90% for lysine and methionine. The table below provides recommendations for digestible amino acid values for pigs.

Table 8 Ileal digestible amino acids and available lysine values for 50% protein MBM.

| | Total (%) | Pig Dig. Coeff. (%) Average* MBM | Pig Dig. AA (%) Average MBM | Pig Dig. Coeff. (%) High Quality** MBM | Pig Dig. AA (%) High Quality MBM |
|---------------|------------------|---|------------------------------------|---|---|
| Lysine | 2.75 | 77 | 2.12 | 92 | 2.53 |
| Avail. Lysine | 2.75 | 75 | 2.06 | 90 | 2.48 |
| Methionine | 0.68 | 77 | 0.52 | 91 | 0.62 |
| Cysteine | 0.5 | 51 | 0.26 | 71 | 0.36 |
| Met + Cys | 1.18 | 67 | 0.79 | 84 | 0.99 |
| Threonine | 1.70 | 74 | 1.26 | 91 | 1.55 |
| Tryptophan | 0.3 | 73 | 0.23 | 90 | 0.27 |
| Isoleucine | 1.45 | 78 | 1.09 | 96 | 1.39 |
| Leucine | 3.2 | 78 | 2.43 | 96 | 3.07 |
| Valine | 2.3 | 76 | 1.68 | 94 | 2.16 |
| Histidine | 1.1 | 76 | 0.84 | 94 | 1.03 |
| Arginine | 3.5 | 85 | 2.66 | 96 | 3.36 |
| Phenylalanine | 1.80 | 78 | 1.40 | 93 | 1.67 |

* Average MBM utilises Degussa AminoDat 2.0 digestibility co-efficients

** High quality MBM utilises digestibility co-efficients derived from Batterham (1992) and Wang and Parsons (1998).

Nutritionists need to adopt the digestible amino acid values for MBM relative to their own database and the supply of MBM. Where MBM in use is known to be sourced from a manufacturer utilising low temperature rendering equipment, the higher digestible amino acid data shown above can be utilised. Where rendering conditions are unknown, use of the average MBM data is more applicable.

In recent years there has been an increasing amount of work studying the effect of supplementing pig feeds with the chemical compounds, carnitine and creatine. These compounds resemble amino acids and their precursors are amino acids. Lysine and methionine act as the precursors for carnitine and methionine, glycine and arginine act as precursors for creatine. In addition to the animal having capacity to synthesise these compounds, dietary intake supplies the pig's requirements. Some reference sources refer to carnitine and creatine as quasi-vitamins due to their essential roles in metabolism.

Carnitine is required within the animals' system to use fat as a fuel source. The young pig has a limited capacity to synthesise carnitine and is dependent upon dietary carnitine intake. Supplementing pig diets with L-carnitine has been found to increase reproductive performance (Eder et al., 2001) and reduce backfat and increase lean meat deposition in growing-finishing pigs (Owen et al., 2001).

The role of creatine is in energy metabolism and is a normal constituent of muscle. Creatine monohydrate provides ATP for muscle contraction and metabolism. Supplementing pig feeds with creatine has been found to increase weight gain in pigs immediately prior to slaughter (Maddock et al., 2002) and improve pig meat quality (James et al., 2002).

It has been speculated by Bruerton, 2003 that the use of animal protein meals such as MBM within pig feeds may offer additional benefits through the higher supply of carnitine and creatine relative to that supplied from vegetable proteins and grains. This view is supported by the work of Lyvers-Peffer and Odle (2002) demonstrating in young pigs significantly faster growth and higher feed intake on diets formulated with animal proteins compared to diets based upon vegetable proteins.

Minerals

There is considerably more work completed studying phosphorus bioavailability from MBM in poultry than in pigs. Work in pigs has not been clear, with some studies such as that of Burnell et al., 1989 indicating MBM has a low phosphorus availability, between 63 to 69%, this was however attributed to approximately 30% of the P in the MBM studied being in large particles, 4mm or greater. It has also been postulated that poultry can utilise physical grinding within their gizzard to increase large particle digestion, this being more applicable to laying hens than broiler chickens. The NRC (1998) defines MBM phosphorus bioavailability as being 90%.

Research work completed in recent years at the University of Kentucky (Taylor et al. 1998a, 1998b, 1999a, 1999b), was aimed at defining the bioavailability of MBM relative to feed phosphates. This work identified ileal and total tract apparent digestibilities of Ca and P is summarised in Table 9. The digestibility values where MBM replaced monosodium phosphate as the P source were in the range 92 to 99%.

Table 9. Summary of ileal and total tract digestibility (%) of calcium and phosphorus in diets.

| Ileal Ca | Ileal Ca | Total tract Ca | Total tract Ca | Ileal P | Ileal P | Total tract P | Met Total tract P hione |
|----------|----------|----------------|----------------|---------|---------|---------------|-------------------------|
| MSP* | MBM** | MSP | MBM | MSP | MBM | MSP | MBM |
| 58.3 | 53.5 | 40.1 | 37.2 | 72.7 | 41.6 | 28.3 | 28.0 |

Source: Taylor et al. 1998a, 1998b, 1999a, 1999b

Increasing MBM particle size has been indicated as reducing the availability of P within pig diets. Results of work (Taylor et al., 1998b) comparing differing particle sizes is shown within Table 10, this data did not support the contention that increasing particle size reduced MBM P bioavailability. The basal diet was a corn-soy ration containing 0.34% phosphorus, using monosodium phosphate as the P source. MBM treatments were obtained through grinding the MBM through differing screen sizes, these being 6, 8 or 12 mesh screens providing particle sizes of 471, 535 and 635 microns respectively.

Table 10. Relative phosphorus bioavailability estimates of MBM of varying particle sizes.

| Item | 6 mesh size | 8 mesh size | 12 mesh size |
|----------------|-------------|-------------|--------------|
| Femur strength | 83.8 | 101.6 | 90.5 |
| MM strength | 87.5 | 94.2 | 86.7 |
| MM ash, g | 85.6 | 86.9 | 91.2 |
| Average | 85.7 | 94.2 | 89.5 |

MM = metacarpals and metatarsals.

Source: Taylor et al., 1998b

The specification for Australian MBM is for 98% to pass through a 10 mesh (2mm) screen, the data above would indicate that MBM of this particle size has a high bioavailability for its calcium and phosphorus content.

Table 11. Recommended calcium and phosphorus content of 50% MBM.

| Mineral | 50% MBM | Range |
|----------------------|---------|-------|
| Calcium | 10.3% | 8-12% |
| Phosphorus | 5.1% | 4-6% |
| Available phosphorus | 4.6% | 4-6% |

Recommendations for use

MBM has been widely used as a raw material in pig feeding for the last 100 years. Within Australia due to its ready availability, the pig industry has commonly used MBM at levels of up to 10% inclusion in pig rations. This level of feeding is considerably higher than that practiced in North America and Asia where greater reliance is placed upon the use of vegetable protein meals in combination with feed phosphates.

In the feeding of early weaned pigs, use of MBM is restricted due to the inclusion of more highly digestible ingredients such as whey and skim milk powders, fish meal and blood meal. Without the commercial availability of spray-dried plasma, alternate materials such as use of bovine colostrum has been evaluated (Dunshea et al. 2002). Of note is the fact Australian diets for early weaned pigs are formulated containing up to 5% MBM. Usage of MBM within grower, finisher and breeding pigs is higher as shown below.

Table 12. Recommended usage levels of MBM within pig feeds.

| Pig Type | Maximum Usage |
|-----------------|---------------|
| Early Weaner | 5% |
| Weaner | 8% |
| Grower/Finisher | 10% |
| Breeder | 10% |

Source: Taylor et al. 1998a, 1998b, 1999a, 1999b

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AQUACULTURE

Introduction

Aquaculture has been the fastest growing food production sector for more than a decade. Growth is however dependant on fishmeal derived from capture fisheries, which is virtually static in volume available for use. The need to replace fishmeal in aquaculture is recognised internationally and has recently been reviewed by Tidwell and Allan, 2003.

There have been extensive studies completed to demonstrate that Australian Meat & Bone Meal (MBM) can be used as a replacement for part of the fishmeal used in most fish and prawn diets. Tests conducted have demonstrated that 2/3 of the fishmeal in diets for prawns (crustacean) and silver perch (fresh water omnivorous) and all the fish meal for barramundi (warm water carnivore) can be replaced by MBM without adverse effect on fish productivity (Williams et al., 1997). Moreover high dietary inclusions of MBM did not detract from the taste of the finished product. The review by El-Sayed, 1999 identified MBM as being able to replace 75-100% of fish meal used in tilapia diets.

The selection of the MBM is important to ensure consistency particularly with respect to ash and protein levels. The information which follows is aimed to assist in the selection of the best product for particular applications.

Energy

Both protein and lipids are the available energy sources for fish. The value of carbohydrate as an energy source is variable depending on the species. For example Nile tilapia and catfish as omnivorous species digest over 70% of the gross energy of uncooked starch but rainbow trout, a cold water carnivore digest less than 50% (NRC, 1993). Fibrous material is generally poorly digested by fish and MBM is low in fibre.

Prawns do not tolerate high levels of fat in their diet and the fatty acid composition can have a marked effect on growth. Feed formulators may set a maximum level in the feed of 9% so it is important that where MBM is used the final composition of the fatty acids is known (Smith, 2001).

Energy concentration is the prime nutritional consideration in formulating fish diets. Lipid is the key energy source but there is also a key relationship between energy and protein. This ratio varies depending on species from 81 for Catfish to 112 for Bass (% digestible protein to digestible energy kcal/g) (NRC, 1993).

The following data are given for meat and bone meal for various species:

Table 1: Energy of MBM:

| | Dry Matter % | DE MJ/kg Trout | DE MJ/kg Trout | Crude Protein % | Crude Fat % | Crude Fibre % | Ash % |
|-----|------------------------|---------------------------------|---------------------------------|---------------------------|-----------------------|-------------------------|-----------------|
| MBM | 94 | 13.33 | 12.26 | 50.9 | 9.7 | 2.4 | 29.2 |

Source: NRC, 1993

Smith and Allan, 1999 completed a survey of a range of Australian MBM samples which provided the results shown in Table 2.

Table 2: Analytical results from samples of Australian MBM, results on an as fed basis.

| | Dry Matter % | Gross Energy MJ/kg | Ash % | Crude Protein % | Total Lipid % | Total PL % | PC % | Cholesterol % |
|---------|------------------------|-------------------------------------|-----------------|---------------------------|-------------------------|----------------------|----------------|-------------------------|
| Average | 96.0 | 18.1 | 28.2 | 57.7 | 11.6 | 0.78 | 0.48 | 0.17 |

Source: Smith and Allan 1999

PL= Phospholipids PC=Phosphatidylcholine

Digestibility co-efficients for energy from Australian MBM are reported as 75.5% (average for prawn) (Williams et al., 1997) and 78.0% (average for silver perch) (Allan et al., 2000). Applying these to the above average gross energy indicates digestible energy in the range 13.7 to 14.1 MJ/kg.

The study (Smith and Allan, 1999) also analysed the fatty acid composition and the following results were obtained:

Table 3: Summary of Fatty Acids in Australian MBM

| | 16:0 | 18:0 | 18:1n-9 | 18:2n-6 | SFA | MUFA | Total |
|---------|-------------|-------------|----------------|----------------|------------|-------------|--------------|
| Maximum | 3.51 | 3.12 | 4.70 | 0.63 | 7.51 | 5.38 | 13.08 |
| Minimum | 1.45 | 1.26 | 2.10 | 0.11 | 3.12 | 2.16 | 5.80 |
| Average | 2.09 | 1.93 | 3.01 | 0.22 | 4.44 | 3.31 | 8.02 |

Source: Smith and Allan, 1999

SFA= Saturated Fatty Acids MUFA= Mono-unsaturated Fatty Acids

Recommendations:

The levels of digestible energy quoted by NRC (12.2-13.3 MJ/kg) seem low when compared to more recent Australian studies. This discrepancy would seem related to ash and protein content of the MBM.

The following recommendations are related to protein and ash content.

Low ash (<28%) and high protein (>55%) MBM: DE = 13.7-14.1 MJ/kg

Higher ash (>28%) and lower protein (>50%) MBM: DE = 12.2-13.3 MJ/kg.

Amino Acids

The level and balance of amino acids required by fish is most likely to be met by proteins akin to fish i.e. fishmeal. The ability of other protein sources to meet the essential and total amino acid needs of a particular aquatic species depends on requirement and digestibility factors.

Excess dietary protein is generally catabolised preferentially over carbohydrates and fats and used for energy (NRC, 1993). It is important to formulate diets with care and to minimise cost of overuse of protein.

The following table provides NRC levels of amino acids found in MBM used for fish feed:

Table 4: Amino Acid Composition of MBM (%).

| | Crude Protein | Arg | His | Isol | Leu | Lys | Met | Cys | Phe | Tyr | Thr | Try | Val |
|-----|----------------------|------------|------------|-------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| MBM | 50.0 | 3.37 | 0.96 | 1.43 | 3.00 | 2.67 | 0.65 | 0.50 | 1.70 | 1.09 | 1.65 | 0.30 | 2.45 |
| MBM | 55.6 | 3.60 | 0.89 | 1.64 | 2.85 | 2.93 | 0.66 | 0.59 | 1.72 | 1.17 | 1.64 | 0.34 | 2.52 |

Source: NRC, 1993

There have been a number of studies examining the amino acid digestibility for different species. The table below provides a comparison between different species.

Table 5: Digestibility of Amino Acids (%) in MBM for prawns, catfish, perch and trout.

| | Prawns | Catfish | Perch | Trout |
|---------------|---------------|----------------|--------------|--------------|
| Arginine | 45-65 | 71 | 86 | 69-86 |
| Histidine | 59-61 | 75 | 83 | 93-99 |
| Isoleucine | 55-56 | 77 | 80 | 81-94 |
| Leucine | 54-55 | 79 | 84 | 91-98 |
| Lysine | 52-62 | 83 | 92-97 | |
| Methionine | 60-64 | 76 | 84 | 89-98 |
| Cystine | 35-50 | 70 | | |
| Phenylalanine | 56-57 | 82 | 83 | 88-98 |
| Tyrosine | 59-74 | 78 | 86 | 94-99 |
| Threonine | 58-52 | 70 | 85 | 94-99 |
| Valine | 53-57 | 80 | 82-96 | |
| Average | 55.5-57.1 | 74.3 | 84 | |

Sources: Williams et al., 1997, Wilson and Robinson, 1982, Stone et al., 2000, Bureau et al., 1999.

In a study of the digestibility of various feed raw materials using silver perch, the average digestibility co-efficients for nitrogen for two sources of MBM are given as 72.7% (Allan et al., 2000). Cho and Kaushik, 1990 identified the protein digestibility of MBM in trout feeding to be 85%. The work of Bureau et al., 1999 and 2000, confirmed protein digestibility of MBM to be in the range 83-89% for trout.

The amino acid digestibility co-efficient of MBM for omnivorous and carnivorous species is high 74-84%, whilst that for crustaceans has been identified as being lower 55-57%. However Forster et al., 2003 has demonstrated that MBM can be used to replace up to 25% of Norwegian fish meal content of shrimp diets without impacting growth, digestibility studies completed suggest MBM has a higher amino digestibility in shrimp than that identified by Williams et al., 1997.

Stone et al., 2000 completed a comparison between lamb and beef MBM fed to silver perch, results are identified in table 6. This work found that silver perch have similar amino acid digestibility co-efficients for both beef and lamb MBM.

Table 6: Apparent availability co-efficients of amino acids from lamb and beef MBM fed to silver perch

| | Beef MBM | Lamb MBM |
|----------------------|-----------------------|-----------------------|
| Crude Protein | 49.2 | 54.3 |
| Ash | 36.0 | 34.5 |
| | Dig Co-eff (%) | Dig Co-eff (%) |
| Alanine | 68.3 | 72.6 |
| Arginine | 72.0 | 76.0 |
| Cystine | 71.7 | 75.0 |
| Glutamine | 75.3 | 81.6 |
| Glycine | 65.2 | 64.5 |
| Histidine | 72.0 | 87.0 |
| Isoleucine | 73.2 | 83.8 |
| Leucine | 77.0 | 84.4 |
| Lysine | 73.6 | 83.4 |
| Methionine | 82.0 | 83.8 |
| Phenylalanine | 73.4 | 82.2 |
| Proline | 68.0 | 67.5 |
| Tyrosine | 72.6 | 76.8 |
| Threonine | 74.7 | 83.3 |
| Serine | 80.2 | 84.8 |
| Valine | 74.6 | 80.5 |
| Average | 73.5 | 79.6 |

Source: Stone et al 2000

The proportion of fish meal used within USA channel catfish diets has reduced from 8-10% in 1990 to less than 3% currently (Tidwell and Allan, 2003). It has been proposed by Tacon et al., 1998 that increased use of animal by-products provides a practical means to decrease aquaculture's use of fish meal. Whilst the use of MBM in ruminant diets has been banned, Tacon and Forester, 2002 have proposed that the evolutionary distance between ruminants and cold blooded fish and crustaceans could provide a safe outlet and use for animal protein meals.

Bureau et al., 2000 increased the level of MBM in trout feeds to replace herring meal. Incorporation of 24% MBM (providing 25% of total digestible protein) in the diet resulted in growth rates equivalent to herring meal.

Recommendations:

The amino acid digestibility co-efficients vary by fish species. For crustaceans nutritionists should use an amino digestibility factor of 55-57%, whilst for omnivorous and carnivorous species the digestibility factors are substantially higher between 75 and 85%.

Minerals

Calcium and phosphorus are directly involved in the development and maintenance of the skeletal system. Fish however absorb calcium from their environment and rely entirely on calcium present in water during dietary deprivation. (NRC, 1993).

Phosphorus must however be supplied in the diet at varying levels depending on the fish species and the phosphorus form and availability. More recent strategies relating to aquaculture production is in reducing levels of phosphorus and nitrogen in farm effluent water (Hardy and Gatlin, 2002), to lower phosphorus excretion by fish requires accurate data on the bioavailability of phosphorus in common feed ingredients. Feed ingredients such as fish meal and MBM contain relatively high levels of phosphorus, this coming from the bone component. Plant materials although lower in phosphorus content have the phosphorus stored as phytate-phosphorus which reduces phosphorus digestion and adds to the load of excreted phosphorus.

Table 7. Phosphorus levels and apparent digestibility co-efficients for rainbow trout in selected feed ingredients.

| Feed Ingredient | Total Phosphorus (%) | App. Dig. Co-efficient (%) |
|-------------------------|----------------------|----------------------------|
| Herring meal | 2.2 | 45-52 |
| Menhaden meal | 3.5 | 36 |
| Poultry by-product meal | 2.2 | 48-62 |
| Meat and bone meal | 5.6 | 27 |
| Corn gluten | 0.5 | 8.5 |
| Soy protein concentrate | 0.8 | <30 |

Source: Sugiura and Hardy, 2000

The following table provides data on the major minerals supplied by MBM.

Table 8. Mineral Content of MBM

| | Ca | P | K | Cl | Mg | Na | S | Cu | Fe | Mn | Se | Zn |
|-----|------|-------|-------|-------|-------|-------|-------|-------|-------|-----------|------------|----------|
| MBM | 9.4% | 4.58% | 1.13% | 0.74% | 1.13% | 0.73% | 0.26% | 1.50% | 1.50% | 508 mg/kg | 12.5 mg/kg | 89 mg/kg |

Source: NRC, 1993

For most species the phosphorus requirement is in the range 0.5% to 0.9% of available phosphorus. Availability of phosphorus in MBM ranges from 30% for carp to 70% for most other fish species (Akiyama, 1988).

Availability of phosphorus from plant proteins is generally poor. MBM however has good digestibility and care is needed to ensure that excess is not provided in the diet from MBM and excreted as a potential pollutant. For this reason when using higher inclusions of MBM a lower ash MBM should be selected. This also has the advantage of higher protein levels.

Recommendations for use

There are a number of variables which require consideration when selecting the best level of inclusion of MBM in fish diets. The most important of these are:

- Species being fed, and
- MBM specification with reference to crude protein and ash levels.

Varying levels of replacement of MBM for fish meal are achievable, resulting in a significant reduction in diet cost.

The maximum replacement of fish meal with MBM is recommended as:

- Carp, tilapia and perch (fresh water omnivorous) 75-100%
- Barramundi (warm water carnivore) 100%
- Trout and salmon (cold water carnivores) 25%
- Prawn and shrimp (crustaceans) 25%

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Introduction

Dogs and cats are the most popular companion animals world-wide. Dogs are classified as omnivorous-carnivores and cats true carnivores. As domesticated animals they are dependant on their owners to provide the essential nutrients they require: failure to do so may result in deficiency symptoms, disease or death. Both also have a relatively high requirement for protein at maturity.

Commercially prepared pet foods are thought to have developed from the 1860's when the first "dog cake" is said to have been developed in England by James Spratt. From the early 1900's dry dog biscuits were marketed in the USA, canned dog food in the 1920's and extruded dry foods from the 1950's. Cat food is thought to have appeared from the 1960's (Hendriks, 1999). Meat and bone meal is an important ingredient in most dry petfoods.

Today's pet food provides a large range of products to suit changing life stages (growth, maturity and geriatric) and so-called nutraceuticals for the management of various diseases and conditions. The palatability of the food is important and influenced by many factors. The perception of the owner is also important in purchase and ongoing use of a product.

The criteria for selection of the best and most nutritious ingredients are a little different to diets for pigs and poultry, being based more on palatability, appearance and nutritional completeness and balance (Hendriks, 1999).

Formulating a complete and balanced pet food requires at least three sets of information

- a set of nutrient requirement tables
- the chemical composition of the ingredients
- an appreciation of the bioavailability of nutrients in the dietary ingredients

(Morris & Rogers,1994).

Nutrient requirements used are largely based on tables provided by organisations such as the National Research Council (NRC, 1985 and 1986) and the annual publication of the American Feed Control Officials (AAFCO). NRC is expected to publish a revised edition later in 2003.

Data on the composition of ingredients is provided in tables from various sources such as NRC (NRC 1985 and 1986) and Murray et al., 1998.

Bioavailability of nutrients and palatability are thought to be essential components of diet formulation. AAFCO provide a set of testing protocols with strict guidelines to establish nutritional adequacy of a diet.

Private research and testing of products by various pet food companies occurs with much of this information being held by the individual companies. An example is Waltham Centre for Pet Nutrition, a division of Mars UK Ltd. Waltham also shares some of its information with organisations such as NRC and publishes data of interest to veterinarians in the magazine, WALTHAM Focus.

For many pet food companies while their feeds are based on NRC and AAFCO data, their formulations will be modified according to their own research and animal feeding trials.

Energy

Various methodologies have been proposed for estimating the energy content of pet foods. The energy content of a food for dogs can be calculated using the modified Atwater constants in the following equation (AAFCO, 1997):

$$\text{ME (kJ/100g as fed)} = 14.64 \times \% \text{ crude protein} + 35.56 \times \% \text{ crude fat} + 14.64 \times \% \text{ carbohydrate.}$$

Carbohydrate is assumed to be nitrogen free extract and there is no allowance made for any contribution from fibre. There is debate over the applicability of this equation due to varying feed energy densities, the range of live weights and body compositions of different breeds and life stage (Costa, 1997).

Kienzle, 1998 and 2002 has provided predictive equations based upon gross energy and crude fibre content to predict apparent digestibility of energy, this having application for both cats and dogs. Castrillo et al., 2001 has identified correlations between apparent energy digestibility (GED) and crude fibre; $\text{GED (\%)} = 94.00 - 4.40 \times \text{CF (\%DM)}$.

Using in vivo trials, Laflamme, 2001 has claimed the most accurate equations for estimating ME (KJ/kg) are:

For canned cat foods: $((16.32 \times \text{protein}) + (32.22 \times \text{fat}) + (12.55 \times \text{NFE}))$;

For dry cat foods: $((\text{GE} \times 1.209) - 1.911) \times 4.184$ or $((0.075 \times \text{g fat}) + 2.766) \times 4.184$

For dry dog foods: $\text{GE} = (24 \times \text{g protein}) + (38 \times \text{g fat}) = (17 \times \text{g NFE})$, then $\% \text{ energy digestibility} = 91.2 - (1.43 \times \text{crude fibre in dry matter})$, then $\text{ME} = (\text{GE} \times \% \text{ energy digestibility}) - (4.34 \times \text{g protein})$.

Cats are true carnivores and do not tolerate high carbohydrate diets. This is emphasized by the fact that essential nutrients taurine, pre-formed Vitamin A and arachidonic acid are only found in significant quantities in animal tissues. In addition to these, arginine, vitamin D and niacin are also essential nutrients for cats and also found in mammalian tissue. (Hendriks, 1999).

As can be seen from some typical proximate analysis data relating to MBM shown in Table 1, fat is an important constituent of MBM and therefore as an energy source in pet foods. Together with the protein content, MBM is an important source of energy for pet foods.

Table 1- Typical proximate analyses of MBM used in petfoods, data expressed on a dry matter basis.

| | NRC, 1985 | NRC, 1986 | Costa, 1997 |
|--------------------|------------------|------------------|--------------------|
| Crude protein (%) | 54.1 | 53.9 | 51.0 |
| Ether extract (%) | 10.4 | 10.7 | 12.37 |
| Crude fibre (%) | 2.4 | 2.6 | 2.41 |
| N free extract (%) | 1.7 | - | 6.68 |
| Ash (%) | 31.5 | 35.0 | 34.07 |
| Ca (%) | 11.06 | 8.7 | |
| P (%) | 5.48 | 4.4 | |
| Fe (mg/kg) | 735 | 700 | |

The ME content of a food is a valid expression of the energy available to the dog and a basis for comparisons of the feeding value of various foodstuffs. ME values have however not been determined for dogs or cats, NRC 1985 provides no energy data for ingredients used within dog foods. NRC, 1986 provides an ME figure of 2371 kcal/kg for MBM.

In a study conducted by Murray et al., 1997, dog diets formulated to AAFCO guidelines based on different protein sources were compared. MBM was compared to various alternative raw materials including fresh beef and defatted soybean meal. The study involved both total and ileal digestibilities, a summary of the results are shown in Table 2.

Table 2. Digestibility comparison between diets fed to dogs containing MBM, fresh beef and soybean meal.

| Raw material | MBM | Fresh Beef | Soybean Meal |
|-------------------------------|------------|-------------------|---------------------|
| Ileal digestion | | | |
| Dry Matter | 75.4 | 76.3 | 71.9 |
| Organic Matter | 83.9 | 84.7 | 80.9 |
| Crude Protein | 79.9 | 80.4 | 79.5 |
| Fat 91.0 | 92.6 | 91.2 | |
| Gross Energy | 85.3 | 86.2 | 82.9 |
| Total tract digestion% | | | |
| Dry Matter | 83.3 | 84.4 | 83.1 |
| Organic Matter | 90.8 | 92.2 | 90.2 |
| Crude Protein | 88.2 | 89.8 | 88.3 |
| Fat | 92.9 | 93.5 | 92.9 |
| Gross Energy | 90.8 | 92.2 | 90.3 |

Source: Murray et al., 1997

Diets containing MBM were highly digested, MBM proved to be of high nutritive value compared to fresh beef and rendering did not affect the MBM digestibility.

Amino Acids

Although companion pets are for most of their life mature, protein is needed to replace the natural turnover of epithelial surfaces, hair and other body tissues and in secretions. Additional protein is needed for growth, pregnancy, lactation and wound healing. The protein quality in terms of amino acid profile and digestibility are therefore most important. Animal proteins generally have a more balanced amino acid profile, with a greater proportion of essential amino acids and better digestibility than plant proteins. Plant proteins are identified as having a number of drawbacks, these being presence of anti-nutritional factors (lectins, tannins, trypsin inhibitors, oligosaccharides) and their impact upon digestion within pet foods (Patil and Fahey, 1999)

Dietary protein in excess of the body's requirements is converted to fat and stored as adipose tissue.

Cats exhibit a number of nutritional peculiarities and require a higher level of protein than other mammals. They are sensitive to arginine-deficiency diets and also have a specific need for the amino-sulphonic acid taurine. Morris, 2002 provides a review on the idiosyncratic nutrient requirements of cats.

Table 3: Typical Amino Acid Levels in MBM

| Constituent | NRC 1985 | NRC 1986 | Murray et al 1998 |
|----------------------------------|----------|----------|-------------------|
| Crude Protein | 54.1 | 53.9 | 51.9 |
| Essential Amino Acids | | | |
| Arginine | 3.75 | 3.80 | 3.4 |
| Histidine | 1.04 | 1.08 | 1.2 |
| Iso-leucine | 1.76 | 1.80 | 1.6 |
| Leucine | 3.29 | 3.33 | 3.4 |
| Lysine | 3.11 | 3.14 | 2.7 |
| Methionine | 0.70 | 0.71 | 0.7 |
| Phenylalanine | 1.83 | 1.84 | 1.8 |
| Threonine | 1.77 | 1.78 | 1.7 |
| Tryptophan | 0.32 | 0.33 | |
| Valine | 2.63 | 2.61 | 2.3 |
| Non-essential amino acids | | | |
| Cystine | 0.53 | 0.70 | 1.4 |
| Glycine | | 6.96 | 5.9 |
| Tyrosine | 0.85 | 0.96 | 1.2 |

In a study comparing meat meal to corn gluten meal in cat diets meat meal was found to be superior. (Funaba, 2002). As an initial step corn gluten meal was compared to fish meal, the apparent digestibility and nitrogen balance did not differ.

Table 4. Comparison MBM and corn gluten meal in cat diets.

| Variable | Meat Meal | Corn Gluten Meal |
|---------------------------------|-----------|------------------|
| Food Intake (gm/Kg BW/day) | 21.2 | 18.1 |
| Dry Matter Digestibility (%) | 78.3 | 71.6 |
| Nitrogen Absorbed & Retained(%) | 37.0 | 20.2 |

Source: Funaba, 2002

Meat meal was superior to corn gluten meal as a protein source in dry foods formulated for cats, dry-matter digestibility and nitrogen utilisation were higher. Cats consumed more of the meat meal diet than the corn gluten meal resulting in higher intakes of nitrogen and some macro-minerals. In addition the meat meal diet provided higher digestibility and utilization of nutrients. These two effects led to higher retention of nutrients and a conclusion that animal origin meat meal is nutritionally superior to plant origin corn gluten meal.

It was also concluded that the meat meal diet should be better for maintaining activity in the urea cycle. Cats readily develop arginine deficiency because arginine synthesis for the urea cycle is lower in the kidney of cats and therefore essential in the diet.

Ileal digestibility results for dogs are significantly lower than faecal digestibility (Hendriks and Sritharan, 2002). Although the large intestine of the dog is relatively short, microbial fermentation within the large intestine is sufficient to result in the faecal digestibility method to be inaccurate in measuring amino acid digestibility.

Ileal amino acid digestibility research work in dogs and cats is limited; reliance has been placed upon equivalent studies completed in pigs and poultry. The work of Johnson et al., 1998 was able to demonstrate that use of the precision-fed cecectomised rooster assay can be used for predicting amino acid digestibility among animal meals for dogs. Within this study Johnson et al. studied a number of animal by-products and found that ileally cannulated dog assay yielded results for amino acid digestibilities that were highly correlated ($r = 0.87-0.92$) with those of the rooster assay.

Table 5. Ileal amino acid digestibility of diets fed to dogs containing various protein sources.

| Raw material | MBM | Fresh Beef | Soybean Meal |
|---------------------------|------|------------|--------------|
| AA Digestibility % | | | |
| Arginine | 91.6 | 92.4 | 91.5 |
| Histidine | 82.8 | 84.1 | 82.1 |
| Isoleucine | 88.7 | 88.4 | 86.6 |
| Leucine | 88.1 | 88.5 | 86.7 |
| Lysine | 86.8 | 87.2 | 86.3 |
| Methionine | 91.7 | 91.0 | 90.1 |
| Phenylalanine | 79.9 | 80.6 | 78.6 |
| Threonine | 76.3 | 77.3 | 74.0 |
| Valine | 86.9 | 86.3 | 85.5 |
| Alanine | 86.8 | 86.6 | 85.1 |
| Aspartate | 78.0 | 80.8 | 78.7 |
| Cystine | 75.3 | 72.6 | 73.0 |
| Glutamate | 87.1 | 88.5 | 87.0 |
| Glycine | 79.3 | 82.5 | 76.2 |
| Proline | 81.4 | 80.2 | 78.4 |
| Serine | 79.3 | 80.2 | 77.9 |
| Tyrosine | 80.1 | 78.7 | 77.0 |
| TEAA | 86.1 | 86.2 | 84.6 |
| TNEAA | 81.7 | 82.5 | 80.0 |
| TAA | 83.8 | 83.8 | 82.0 |

Source: Murray et al. 1997.

The work of Murray et al., 1997 concluded that MBM provided amino acids which were highly digestible. They also concluded that their work supported the premise that diets containing animal-based by-products are generally more digestible than diets containing protein sources of plant origin.

Extensive work in both pigs and poultry has identified higher processing temperatures as reducing amino acid digestibility. Johnson et al., 1998 using a low temperature MBM found a high level of digestibility in both cecectomised roosters (84%) and cannulated dogs (82%). With this study MBM with either high or low ash content did not influence digestibility.

Minerals

Macro and trace minerals are essential in the diets of pets. Their functions include bone and teeth growth and maintenance, blood clotting, nerve and muscle function, enzymes, acid-base balance, electrolytes, pigmentation and blood and hormonal function.

The likelihood of deficiencies are relatively low and while generally ash levels in the finished feed for dogs is only in the order of 4 to 5%, frequently ash levels may exceed this requirement. There is no apparent relationship between excess dietary ash and clinical disease in dogs (NRC, 1985). High dietary ash may however compromise diet quality.

Some minerals are toxic if fed in large quantities. Minerals are known to affect the lower part of the urinary system of cats, the most common condition called urolithiasis. Management of the condition is dietary via magnesium levels and the addition of urinary acidifiers (Hendriks, 1999).

The ash content of MBM plays an important part in the mineral nutrition of the dog. As the ash content between different suppliers may vary it is important that these levels are known when formulating diets. Higher levels of MBM may be used when the ash content is lower.

This factor is also important when formulating cat food. Indeed quite high levels can be utilised for low ash meat meal as discussed in 5.3 above (Funaba, 2002).

Magnesium is probably the mineral of the most concern in cat nutrition, and especially for male cats because of its role in the formation of struvite uroliths (magnesium ammonium phosphate). Low ash MBM which supplies lower levels of magnesium are preferred for cat foods.

Palatability

A significant effort on diet formulation by commercial pet food manufacturers is focussed on palatability. If a diet is not ingested it does not provide nutrients to the animal.

Palatability is said to be influenced by many factors including food texture, composition, ingredients, smell, taste, temperature, past experience of the animal, heat treatment, etc. Little information is present in the literature on palatability testing for dogs and cats. Much of the data gathered by commercial manufacturers is kept in-house and not published. (Hendriks, 1999).

The owner's perception of the diet is another important criterion as it strongly determines repurchase. Such attributes may include consistency, colour, smell and appearance.

MBM is generally known to have a positive palatability affect in pet food diets. Efforts to maintain these attributes are a focus of suppliers of MBM, maintaining short "kill to cook" times is a feature of Australian MBM.

Where MBM is stored or not used expeditiously it is generally advisable to add anti-oxidants to preserve fat quality and flavour. Typically anti-oxidants are used in dry pet food as ethoxyquin, BHT, BHA or as Vitamin E present as the various chemical forms of natural tocopherols. (Costa, 1997).

Labelling

An important criterion in the selection of raw materials is the ability to use the origin of the material on product labels. The levels of inclusion to enable use of the name depend on the laws or regulations of the particular jurisdiction.

Commonly Australian MBM is beef (bovine), lamb (ovine) or possibly mixed species. Where this aspect is important a specification should be requested with the supplier.

Allergenic reactions are often identified in diets containing soybean protein and also wheat and beef. For such reasons ovine meal has become popular as a major ingredient in any "hypoallergenic" foods as they are less frequently associated with such adverse reactions. (Costa, 1997). Australia is the major supplier of ovine meals to the world market.

Recommendations for use

In order to supply a crude protein level of 20% in a typical dog food, empirically up to 40% of 50% crude protein MBM could be added. This is effectively reduced however to account for other ingredients such as cereal grains which are required for functionality in the extrusion process.

Typically levels of 20-25% MBM inclusion in dog foods are used depending on other raw materials available. The life stage of the pet is also important, whether growing, pregnant or lactating.

In cat diets the levels of inclusion will depend on the ash content of the MBM. For low ash MBM (<20%) higher levels can be used again dependant on the choice and availability of alternative raw materials.

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