8. Assessing the Nutritive Value of Feeds – Physical Characteristics

Paul Iji and Mingan Choct

Learning objectives

On completion of this topic you should be able to:

• Explain the importance of feed analysis for designing feeding programs
• Describe various techniques for assessing feed quality.
• Describe the components of a proximate analysis

Key terms and concepts

Evaluation of feeds using their physical characteristics; Assessing nutritive quality from chemical composition; Proximate analysis; Detailed composition.

Introduction to the topic

Feeding livestock properly means providing the animals with quantities and qualities of nutrients that are appropriate for normal growth, development and maximum production. To achieve this goal, the nutrients supplied by various individual ingredients must be known. Direct evaluation of nutrient composition is by chemical analyses and the nutritive value by bioassays (feeding trials). Indirect evaluation makes use of various prediction equations and in vitro methods for both nutrient composition and nutritive value of ingredients.

The nutritive value of a feed refers to “the amount of nutrients contained in a feed that can be utilised by the animal”. In general, the greater the amount of utilisable nutrients in an ingredient, the better its nutritive value. Today, the word “feeding” in the livestock industry does not simply mean giving whatever ingredients are available to the animal: rather it is a sophisticated science that allows formulation of a ration that is nutritionally balanced and ‘least–cost’. It is therefore more important than ever to accurately evaluate all available ingredients in terms of their nutritive values for different classes of livestock.

The following discussion will cover various methods of feed evaluation and determination of nutritive value of feedstuffs, i.e. evaluation of the nutritive value of feed ingredients excluding energy and evaluation of energy utilisation and metabolism (including assessment of individual ingredients).

8.1 Evaluation of feeds using the physical characteristics

The density of grain may be related to nutritive value, in particular, for monogastrics. The commonly used measure is the “Bushel Weight”. The standard and minimum bushel weights recommended for cereal grains used in monogastrics are shown in Table 8–1.
The use of “bushel weights” as an indicator of the nutritive value of cereal grains comes from the argument that when there is a higher concentration in grains of fibrous component (husks and hulls etc.), this is directly related to lower bushel weight. It is, however, worth noting that bushel weight is also affected by many other factors such as the shape and surface dimensions of individual kernels which do not necessarily reflect nutrient content. Generally bushel weights do not correlate closely with the nutritive value of cereal grains for monogastric animals. In Australia, bushel weight is not commonly used to evaluate the nutritive quality of cereal grains.

8.2 Assessing nutritive quality from chemical composition

Some of the chemical methods that are used to characterise the energy and nutrient content of feeds will be discussed below.

Proximate analysis

There are thousands of individual compounds in feeds. There are, for example, enzymes and other proteins, sugars, fats, waxes, volatile materials (odours) pigments and toxins. To simplify feed description, we group components into a small a number of chemically or functionally similar classes. Thus, for example, nitrogenous compounds give an indication of the protein and amino acid content of a feed. The system of Proximate Analysis, which groups feed components into six different chemical fractions was devised at the Weende Experimental Station in Germany over 100 years ago. It is still in use today. Within each fraction there may be many different substances, but all behave chemically in a similar way during analysis. The six fractions identified in the ‘Proximal Analysis’ are shown in Table 8.2.

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Analysis processing</th>
<th>Constituents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (W)</td>
<td>Dry at 70–100°C</td>
<td>Water, volatile compounds</td>
</tr>
<tr>
<td>Ash (A)</td>
<td>Burn off OM at 500°C</td>
<td>Minerals</td>
</tr>
<tr>
<td>Crude protein (CP)</td>
<td>Total N analysis x 6.25</td>
<td>Protein, other NPN</td>
</tr>
<tr>
<td>Ether extract (EE)</td>
<td>Reflux with ether</td>
<td>Fats, oils, waxes, pigments, sterols</td>
</tr>
<tr>
<td>Nitrogen free lignin, starch</td>
<td>100 (W+CP+EE+CF)</td>
<td>Hemi–cellulose, cellulose, extractives</td>
</tr>
<tr>
<td>Nitrogen free lignin, starch</td>
<td>pectin, organic acids</td>
<td>(NFE)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hemi–cellulose, cellulose, non-EE in alkali or acid</td>
</tr>
</tbody>
</table>

| | | | |
| | | | |

In preparation for most feed analyses, the feed sample is dried and the loss in weight gives its water content. The dry matter is then combusted at about 550 C to oxidise the organic materials and leave the ash. The organic fraction consists of a variety of carbohydrates, fats and proteins whereas the ash consists mainly of

---

Table 8.1 The recommended minimum bushel weights for grains used in pigs and poultry. Source: McDonald et al (1995).

<table>
<thead>
<tr>
<th>Grain</th>
<th>Bushel Weights (pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard</td>
</tr>
<tr>
<td>Barley</td>
<td>48</td>
</tr>
<tr>
<td>Corn</td>
<td>56</td>
</tr>
<tr>
<td>Wheat</td>
<td>60</td>
</tr>
</tbody>
</table>

1 British Bushel = 36.368 Litre; 1 US Bushel = 35.238 Litres
minerals. In the organic fraction, the carbohydrates (found in the NFE) and fats (EE) are the primary sources of energy in animals. However, protein in excess of immediate requirements can be degraded in the tissues of animals and the constituent amino acids are deaminated: the resulting carbon skeleton can also serve as an energy source. This occurs if there is an inadequate supply of energy for maintenance or if protein is supplied in excess of the needs for protein anabolism (growth). There are other components of feed that are essential for normal growth and development and therefore it is imperative for any nutritionist to know the chemical composition of the ingredients.

**Nitrogen–free extractives** contain materials including carbohydrates that provide energy to the animal. The NFE fraction is also not particularly helpful in describing nutritionally useful components in feeds, whereas the other fractions have useful roles.

**Crude fibre** (analysed by Proximate Analysis) is frequently included in tables of feed composition, but does not bear any close relationship to the carbohydrates present in the feed, and so is not very helpful nutritionally.

An alternative method for separating feed carbohydrates found in ruminant feeds was developed in the 1960s by Dr Peter Van Soest of Cornell University. This system describes feeds in a way that is more relevant to ruminant digestion. Ingredients of feeds are classified as **totally available** to the ruminants, **partly available** and **completely unavailable**. These classes are estimated by extraction using boiling solutions of detergents and so the analysis is referred to as a “detergent extraction system”. The chemical groupings from this analysis are **neutral detergent fibre** (NDF), **acid detergent fibre** (ADF) and **lignin** (see Table 8.2). The cell solubles that are removed by the neutral detergent (‘neutral detergent solubles’) are considered to be **totally available** to the animal. The NDF component remaining is the cell walls of the plant material, and this is rather poorly digested (**partially available**). This component can be further partitioned using acid detergents into a digestible and an indigestible fraction — the indigestible or ADF component being **totally unavailable** to the animal.

**Detailed composition**

The ancient art of livestock feeding has now become a nutritional science, and as such it demands the information on quantity and quality of nutrients to be highly accurate. Economic efficiency is also another reason for this unprecedented demand for accuracy of feed composition data. The following paragraphs will cover some additional chemical analyses that are not included in the proximate analysis system.

**Amino acids:** ‘Crude protein’ analysis (by the Kjeldahl or Dumas methods) is relatively easy to perform but has severe limitations. Crude protein is an estimate of the **total nitrogen content of the feed**—it does not even determine the true protein in a feed sample. Moreover, it is not the protein **per se** but the amino acids making up the protein that are the important monomers for protein synthesis in livestock tissues. So determining the concentrations of amino acids of feeds is much more helpful. To analyse all of the 20 amino acids that are naturally present in feed proteins, three separate analyses are needed, i.e. one for the sulphur containing amino acids—methionine, cystine and cysteine, one for tryptophan, and another for the remaining 16 amino acids. A High Performance Liquid Chromatograph (HPLC) is often used although some amino acids may be analysed using a Gas Chromatograph (GC). For pig and poultry feed manufacturers need to have a complete amino acid analysis before introducing any new ingredient into their least–cost formulations. Today, many universities, research centres, government and commercial laboratories provide amino acid analytical services.

**Carbohydrates:** In the proximate analysis system, the carbohydrate fraction of feeds is included in **Crude Fibre** and **Nitrogen Free Extract**. These two terms are ambiguous. The Crude Fibre value, for instance, represents only a variable portion of the “true fibre” components. Today the term non–starch polysaccharides (NSP) is increasingly used. NSP plus lignin represent the true amount of fibre present in feeds. Most carbohydrates that occur naturally in feedstuffs are either in polysaccharide forms or in oligosaccharide forms. The bulk of the carbohydrate in cereal grains is starch and in legumes and grass is NSP.
The carbohydrates are polymers of monosaccharides joined through glycosidic linkages and are defined and classified in terms of the following structural considerations:

a) identity of the monosaccharides present;
b) monosaccharide ring forms (6–membered pyranose or 5–membered furanose);
c) positions of the glycosidic linkages;
d) configurations (α or β) of the glycosidic linkages;
e) sequence of monosaccharide residues in the chain, and
f) presence or absence of non–carbohydrate substituents.

Monosaccharides commonly present in cereal cell walls are:

a) hexoses; D–glucose, D–galactose, D–mannose;
b) pentoses; L–arabinose, D–xylose, and

The term non–starch polysaccharide (NSP) covers a large variety of polysaccharide molecules excluding β–glucans (starch). The classification of NSP was based originally on the methodology used for extraction and isolation of polysaccharides. The residue remaining after a series of alkaline extractions of cell wall materials was called cellulose, and the fraction of this residue solubilised by alkali was called hemicellulose.

The word hemicellulose was adopted because early researchers mistakenly regarded these polysaccharides as the precursors of cellulose. This is now known to be incorrect but the term is still commonly used. Some workers used the terms hemicellulose and pentosan interchangeably because the pentose–containing polysaccharides make up the bulk of hemicelluloses. Classification of carbohydrate fractions by differences in solubility lacks precision with respect to both chemical structures and biological functions. For example, the term crude fibre (CF) refers to the remnants of plant material after extraction with acid and alkali and includes variable portions of the insoluble NSP. Neutral detergent fibre (NDF) refers to the insoluble portion of the NSP plus lignin, and acid detergent fibre (ADF) refers to a portion of insoluble NSP comprised largely, but not exclusively, of cellulose and lignin. The nutritional relevance of values obtained using these methods in monogastric nutrition therefore is questionable. The complexity in the structure and confusion in the nomenclature have made it almost impossible to draw a clear–cut classification of NSP. However, NSP fall into three main groups as shown below, namely cellulose, non–cellulosic polymers and pectic polysaccharides (Figure 8.1).

Figure 8.1 The three main groups of non–starch polysaccharides. Source: UNE Database.
For human foods and monogastric feeds, starch and the various fractions of NSP are often measured. The practical implications of such analyses are enormous since the soluble fraction of NSP has anti-nutritive effect on nutrient digestion and absorption in monogastric animals, whereas some fractions of the “fibre” are less digestible in ruminants than others. Also starch resistant to amylase digestion in the small intestine can escape to the hindgut where, in ruminants, it may be fermented rapidly to cause “hindgut acidosis”, and in monogastrics, it may pass through the gut undigested. Implications of various carbohydrate fractions for digestion and absorption will be discussed elsewhere.

A detailed carbohydrate analysis in feed samples is expensive and the bad news is that most plant samples are highly variable in their carbohydrate contents due to growing conditions, farming practices, temperature and moisture during harvest and varieties.

**Lipids:** In the proximate analysis system, fat (lipid) is measured by extracting the sample with ether. It is therefore also known as ether extract (EE). But EE contains not only the fat but also organic acids, waxes, pigment and alcohols. It is known that some fatty acids, such as linoleic acid, are essential nutrients, others have specific functions. For example, a high concentrations of polyunsaturated fatty (PUFA) acid concentration in the diet reduce fat accretion in chickens and omega-3 fatty acids present in fish oil, namely docosahexaenoic (DHA) and eicosapentanoic acids (EPA), reduce fat deposition by decreasing the circulating very low density lipoprotein (VLDL) levels in the blood. Linoleic acid is generally converted to arachidonic acid, a long chain PUFA which is a precursor for the eicosanoids. Eicosanoids are local messenger molecules which regulate the rates of protein synthesis and degradation. This highlights the importance of knowing the fatty acid composition of the ingredients used in the diet.

When dealing with feed ingredients with high levels of fat, it is important to be aware of rancidity. It is due to the presence of volatile and bad-smelling acids and aldehydes which result from attack by oxygen at reactive allylic positions in the fat molecules.

**Minerals:** The total amount of minerals present in a feed is estimated by ashing the sample at 560–600°C. Part of the S and P may be lost during ashing. For pigs and poultry, the two most important elements are Ca and P. These elements can be measured using chemical methods. Specific functions of different elements have been constantly discovered. For example, insulin release is influenced by dietary trace minerals. Chromium (Cr) has been shown to be involved in normal glucose metabolism and is necessary for optimal insulin function and glucose uptake by insulin-sensitive cells. Chromium deficiency can lead to a diminished responsiveness of tissues to insulin. It is known that dietary and environmental stresses (including temperature, humidity and pathogens) can alter Cr requirement and Cr supplementation improves the performance of stressed animals. Chromium supplementation is beginning to be used commercially around the world. In Australia, some commercial feed manufacturers have started to include chromium routinely in pig diets. More and more nutritionists and veterinarians now examine the detailed mineral contents of diets for their roles in animal performance and welfare.

Minerals are important for skeletal functions but are required in smaller amounts for many other functions. They act as co–factors for enzymes and as chemical messengers for cells.
All mineral elements can be accurately quantified either by Atomic Absorption Spectrophotometry or by Inductively Coupled Plasma (ICP) techniques (Figure 8-2). Some analytical laboratories run specialised industry services for mineral analysis. Mineral contents of most grain samples do not vary enormously therefore values for one variety may be used for another because mineral analyses are not cheap. But for animal by-products and mineral samples, it is advisable to have the common mineral elements measured instead of taking book values.

Figure 8.2 Inductively coupled plasma spectrometer (ICP) that can determine up to 45 mineral elements in a single sample. Source: UNE Database.

In many cases, the nutritive value of an ingredient can be predicted from its chemical composition. However, digestion and absorption of nutrients in the gastrointestinal tract of animals are highly complex processes and the availability of nutrients contained in a feed ingredient to animals is influenced by numerous factors. These include type of livestock, breed, age, sex, production state and disease and stress.

Readings

The following readings are available on CD:


Activities Available on WebCT
Multi-Choice Questions
Submit answers via WebCT

Self Assessment Questions

1. Why is analysis of amino acids rather than total protein desirable in terms of evaluating protein quality?
2. Compare various terminologies used to describe the 'fibre' in feeds.
3. Why is it important to know the fatty acid profile in fat ingredients?

Useful Web Links
Available on WebCT

Assignment Questions
Choose ONE question from ONE of the topics as your assignment. Short answer questions appear on WebCT. Submit your answer via WebCT

References
University of New England, Animal Science Nutritional Database.