Foreword

This new publication by Rick Kleyn is a welcome addition to those intimately involved in poultry nutrition and feeding. It has been some time since there has been a balanced overview of modern concepts of basic nutrition together with practical application for on-farm feeding management. For some time Rick Kleyn has undertaken a training seminar in poultry nutrition for professionals in Southern Africa and beyond. This book represents material for this course that has evolved over 15 years of development. Rick Kleyn is a consulting nutritionist, most active in Africa but also spends time in most countries in Europe and so his wealth of practical world-wide knowledge is reflected in this book. There are 18 main Chapters starting with all the main nutrient classes and then application of this information in separate Chapters on broiler, broiler breeder and layer nutrition. The unique attribute of the book is found in the following 7 chapters that detail such current important topics as ingredient evaluation, enzyme use, nutrition and health and quality assurance as well as an interesting unique critique of the "scientific process". Being a practicing nutritionist the author provides very interesting inside information on the hands-on process of feed formulation which to my knowledge is missing in most other texts on poultry nutrition. Overall, a very readable and informative text on all aspects of poultry feeding and feed program development. The text will be of use not only to commercial nutritionists but also to students involved in all aspects of poultry production, and most other professionals in the various poultry industries.

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Sections

Nutrition and nutrients

Fact
Essential nutrients cannot be synthesised by the bird and must be supplied in the diet.

The science of nutrition can be defined as 'the process of providing a population of animals with a diet that allows for effective function of the metabolic pathways required for growth, maintenance, work, immunity and reproduction'. Nutrition encompasses the procurement, ingestion, digestion and absorption of the chemical elements that serve as food. In addition, it includes the transport of these elements to all regions within the animal organism in the physical and chemical forms most suitable for assimilation and use by the cells. The primary concern of any nutritionist is to ensure that the diets being offered to an animal contain sufficient quantities of each nutrient in order for it to function, produce and reproduce normally. Nutrition is a quantitative science, requiring not only an accurate description of the molecular details of digestion, metabolism and excretion but also an accurate estimation of their rates. Most importantly, nutrition is an economic science in that whatever is done in nutritional terms may have a direct bearing on the profit and loss of the poultry operation.

The monogastric digestive system operates in the stomach and small intestine, which is well adapted to dealing with lipids, sugars, starches and proteins (see Chapter 7). The highly efficient caecal and large intestinal digestive system operates through the help of a substantial bacterial population, which will deal with nutrients in plant tissues high in non-starch polysaccharides. Birds can readily discriminate the different nutritive values of a wide variety of feedstuffs, which enables self-choice feeding and the automatic balancing of the daily diet.

The Oxford dictionary defines a nutrient as 'any substance, which provides for, or contributes towards, nourishment'. These substances are mostly of organic origin (plants and animals) but may also be minerals. Increasingly, nutrients (vitamins and amino acids) are being manufactured by chemical processes and these synthetic nutrients are playing an ever-increasing role in nutrition. Nutrients are components of the diet that have specific functions within the body and contribute to tissue maintenance, growth and health of the animal. ***Essential nutrients*** are those components required by the animal that cannot be synthesised in sufficient quantities to meet the animal's requirement. It is, therefore, essential that they be supplied in the diet. ***Non-essential nutrients*** on the other hand can be synthesised by the body in sufficient quantities . Fine Along with energy, all animals have requirements for each of the 6 classes of nutrient, namely, water, carbohydrate, fat (lipid), protein, vitamins and minerals.

Increasingly, there is talk of what are being called nutricines. These are defined as molecules that are not traditional nutrients yet have important biochemical functions. Examples would be organic acids and enzymes. In the past, we would have called these non-nutritional additives. Some authors refer to nutrients such as essential fatty acids as nutricines, but this is not strictly correct.

In its broadest sense, nutrition is governed by the laws of physics, the most important of which is the First Law of Thermodynamics, which states that matter and energy are always conserved. They cannot be created or lost. Stated differently, everything the animal consumes is accounted for: it is either undigested (lost via the faeces) or it is absorbed and used by the body, with byproducts being excreted in the urine, faeces and through respiration or lost as heat. It has already been mentioned that all fauna share much of the same DNA and, more importantly, the complex biochemical pathways that constitute metabolism. These are unlikely to change through genetic selection, so the likelihood that we will be able to change the way in which chickens utilise nutrients and energy at the cellular level probably does not exist.

Michael Pollan (2008) believes that we have entered the age of 'nutritionism'. He defines it in the following way: Nutritionism is not the same as nutrition. As the -ism suggests, it is not a scientific subject but an ideology. Ideologies are ways of organising large swathes of life and experiences under a set of shared but unexamined assumptions. A reigning ideology is a little like the weather – all pervasive and virtually impossible to escape.

A classic example of nutritionism was the widespread belief that cholesterol in eggs caused an increase in heart disease – now something known to be untrue. Another example would be the belief that the protein level of a diet or ingredient is its most important attribute, or that its fat content is its least desirable attribute. Sadly, marketing departments often do not understand the difference between nutrition and nutritionism.

Nutrition is not complicated. In its simplest terms the feed we offer our birds contains only a few elements. These are:

- Water.
- Energy to fuel all life processes.
- Nutrients (protein, fat, vitamins and mineral), which are the building blocks of all tissue.
- Non-nutritive additives (medication, enzymes and colourants).

Similarly, the bird's needs are simple. They eat their food for:

- Maintenance – staying alive, largely determined by body size.
- Growth, which includes the skeleton, lean tissue, fat tissue and feathers.

Water

Fact
Transports nutrients & metabolites as well as regulating metabolic and cellular function.

Water is often called the fundamental nutrient. Whereas animals may survive for considerable periods without food, without water they would soon die. Water is required by the body for the maintenance of body temperature and for almost all metabolic processes. In nutritional terms, water is the single most important nutrient that we feed to animals yet, in most instances, it is taken completely for granted and, therefore, often neglected. Water usually receives attention only when mechanical problems occur.

The role of water

Water constitutes the major component of both cells and the extra-cellular environment. It does, in fact, sustain life. It has a number of roles:

- Transportation of nutrients (glucose, amino acids, minerals, vitamins).
- Transportation of gas, in particular, oxygen and carbon dioxide.
- Transportation of wastes towards those organs (kidney and liver) responsible for their elimination.
- Transportation of hormones, from the gland in which they are produced to target organs.
- Regulation of cellular homeostasis.
- Adjustment of body temperature.
- Maintenance of mineral homeostasis.
- Excretion of end products of digestion (particularly urea), anti-nutritional factors ingested with the diet and drugs and drug residues.

Water sources

The animal obtains water from three sources:

Drinking water

A borehole, well or the community water supply usually serves as the water source. Water from a borehole or well differs from place to place and can be seen as a type of customised product. It is often advisable to analyse the water source annually, particularly, prior to building a new facility and after periods of heavy rains. This is a good way to see if any contamination from surface runoff has occurred. High bacteria counts may also occur if the borehole is not properly protected from surface drainage water. Well water should be tested for the total bacteria level, the coliform bacteria level, and for the faecal coliform bacteria level (indication of faecal contamination). The levels indicated in Tables 2.3,2.5, 2.6 are unlikely to be exceeded if water comes from a main supply. Water from boreholes may, however, have excessive nitrate levels and often high bacterial counts due to runoff from fertilised plants or sewage treatment fields that are poorly designed, improperly constructed or located too close to the borehole.

Water in feeds

With very few exceptions – notably oil and synthetic vitamins – all feeds contain some water. When feed is sold as meal the moisture content is about 12%, whereas in the case of fruit and green grass it may be as high as 75%. Although water is a nutrient in its own right, the amount of water contained in any feed has no bearing on the quality of the other nutrients. It serves only to dilute the nutrients in the diet.

Metabolic water

Water is by far the largest single constituent of the body and represents about 70% of total body weight. Of this body water, about 70% is inside the cells of the body and 30% in the fluid surrounding the cells and in the blood. This balance is important since dehydration of the animal will alter these critical proportions. The water content of the body is associated with its protein content. As an animal ages, its body-fat content increases (the protein content decreases) and its body water content as a percentage of body weight will decrease.

Water losses

The animal loses body water via four routes:

- In expired air during respiration.
- From the skin surface through perspiration and insensible water loss. Remember, birds do not have sweat glands.
- In the faeces.
- In urine.

Water intake

Since drinking water is supplied *ad libitum* to poultry, dehydration should, in theory, not occur. The adverse effects of reduced water intake are often a result of a concomitant reduction in feed intake. Drinking behaviour is closely associated with feed intake, so any factors affecting intake will indirectly influence water intake. Water intake is influenced by the following factors:

Strain or genetic factors

There are differences in water consumption between different strains of bird. These discrepancies are most probably due to differences in metabolism, growth rates and body weight.

Energy

Fact
Energy is designated as work or anything that can be converted to work.

Energy is the common currency of nutrition.

This chapter will discuss the energy metabolism of the bird. Energy is often described as the 'fuel of life' and the principle 'currency' of nutrition. The term ***energy*** is a combination of two Greek words: ***en***, meaning 'in' and ***ergon*** meaning 'work'. In the physical sciences, energy is designated as work or anything that can be converted to work. In short, energy is the capacity to do work. Work, as commonly defined, is only one of several uses of energy in the biological sense. Unlike plants, animals cannot derive energy from the sun and are thus dependent on molecular energy. Therefore, nutritionists deal with the conversion of chemical energy stored in food molecules into kinetic energy through chemical reactions of metabolism, work and heat. In animals, feeding energy is particularly important because in diets containing adequate amounts of all required nutrients, the efficiency of food utilisation depends on the energy content of the diet.

All energy in an animal's body is derived via the Krebs cycle or c*itric acid cycle*. The Krebs cycle is part of a metabolic pathway involved in the chemical conversion of carbohydrates, fats and proteins into carbon dioxide and water to generate a form of usable energy. It is central to many paths of biosynthesis, which suggests that it was one of the earliest formed parts of the cellular metabolic processes. The reactions of the cycle take place in the mitochondria of cells. The energy created is in the form adenosine triphosphate (ATP), which is a multifunctional nucleotide used in cells as a coenzyme. It is often called the 'molecular unit of currency' of intracellular energy transfer – metabolic processes that use ATP as an energy source convert it back into its precursors. Animals, such as birds and mammals, are homoeothermic, which means that they maintain a relatively constant deep body temperature. Energy plays an important role in the maintenance of body temperature and production: it is also important for growth and egg production. Traditionally, there are two categories of energy cost to the animal: those associated with maintenance and those with production:

Maintenance requirements

- Basal metabolism
- Adaptive thermogenesis
- Dietary thermogenesis
- Physical activity

Production requirements

- Energy within products
- Thermogenesis associated with their synthesis

This is perhaps an oversimplification of events and probably does not correspond to the true biological situation, particularly concerning the growing animal, as there is no one level of energy supply capable of maintaining a constant body composition (Labier ***et al.***, 1994).

Partitioning of energy

Apart from the radiant energy gained from the sun, or from hot surfaces in the environment, the energy requirements of farm animals are met entirely by the chemical energy contained in their food. Energy is the most important feed constituent and makes up the largest proportion of total feed costs. Due to the importance of the dietary energy content all nutrient concentrations are related to the energy content of the feed. The fate of the ***gross energy*** (GE), which is the total amount of energy contained in the food, is illustrated in Figure 3.1. GE is simply the amount of heat produced when the food is burned completely to produce water, carbon dioxide and nitrogen, whereas d***igestible energy*** (DE) is the amount of GE minus the energy in the faeces. The indigestible energy contained in the faeces may range from very little to about 30%, but is typically about 15%. Losses from the intestine also include those of urinary origin, which range from 5% to 15%. These losses are particularly important when considering the metabolites of protein. The collective intestinal losses are deducted from the GE, giving what is known as ***apparent metabolisable energy (***AME***)***. Some of the energy contained in the faeces and urine is endogenous (from within the bird) and this needs to be accounted for: this adjustment gives rise to t***rue metabolisable energy*** (TME).

Not all of the metabolised energy is available to the animal. The absorption of energy from the gut is followed by an increase in heat production by the animal, which is referred to as the ***heat increment*** of the diet. After deducting the latter, the remainder is the ***net energy*** (NE) of maintenance and of production. This represents the amount of energy that the animal actually has available to perform work. The heat increment (also known as the specific dynamic effect) is associated with the digestion and absorption of the food. Heat may be used to help maintain body temperature in cold environments, but animals generally have difficulty in dissipating heat and preventing an increase in body temperature. The heat increment of a diet as a percentage of the metabolisable energy depends largely on the composition of the diet: the ingestion of excess protein causes a heat increment equivalent to 30% of the metabolisable energy of the protein; carbohydrate produces 10–15%; and fats may produce only a 0–5%.

Amino acids

Fact
Protein contains 16.5% nitrogen. The crude protein content of feed is calculated as nitrogen % x 6.25.

Chapter 3 discussed energy and energy metabolism at some length. Although energy makes up the largest proportion of any diet, protein is by far the second largest component of the feed. Protein is of special significance to most nutritionists both because of its high cost and the fact that meat and egg production revolves around the conversion of feed protein to animal protein. In addition, most tissues of the body are made up almost entirely of protein; structural protein is also found in bone, muscle and skin. Proteins also play a regulatory role in the body as most enzymes are proteins. In poultry, one-fifth to one-quarter of the fat-free body of birds is protein, of which as much as 20–30% may be found in the feathers.

Although all proteins are made up of amino acids, the combinations and sequential arrangements of the amino acids, which are found in the multitude of proteins that exist in nature, differ considerably. These differences have specific influences on the property of each individual protein. The job of a nutritionist is to ensure the provision of an adequate level of available nitrogen and essential amino acids necessary for optimum protein anabolism (synthesis) in the individual, at each stage of production. This involves determining the exact combinations of the various proteins to be obtained from the available raw materials and then meeting the bird's requirement from those components.

Quantitatively, the requirement for amino acids is driven by the sum of three process: (i) the rate at which amino acids are needed for functional purposes, such as protein accretion, or as precursors for other metabolites; (ii) the rate of endogenous losses of protein and amino acids, which occur mostly from the digestive tract; and (iii) the rate at which amino acids are lost to oxidation or other metabolic pathways. To be able to apply knowledge of protein nutrition correctly the properties of proteins, protein structure and the assimilation of proteins by animals must be fully understood.

Amino acid metabolism

As discussed in Chapter 1, protein is usually expressed as crude protein (CP) and it is determined by multiplying the percentage of nitrogen in the feed by a factor of 6.25. It, therefore, includes not only true protein but also nitrogen present as NPN. True proteins, in which we are interested, are composed of amino acids, which are compounds containing carbon, hydrogen and nitrogen; some also contain sulphur and/or phosphorus. There are only 22 known amino acids and they have been described as the letters of the alphabet that nature uses to construct words and sentences. All proteins, whether feathers, muscle or enzymes, are built up from a complex combination of these amino acids and so avian nutrition is concerned only with the amino acid composition of the diet and not with its CP content *per se*.

Free amino acids and small peptides, either circulating or within tissues, constitute the amino acid pools within the animal. Concentrations within pools are based on the balance between losses and gains. The amino acids have two origins, either dietary or metabolic and they are used predominantly for the synthesis of proteins. They also act to maintain the osmolarity of body fluids, buffer pH, and serve as neurotransmitters, antioxidants and shuttles in intermediary metabolism. In addition, they can be metabolised in to a wide range of metabolically important molecules. Proteins of dietary or endogenous origin (enzymes, proteins within desquamated epithelial cells and those of bacterial origin) are hydrolysed prior to absorption). Within the animal, tissue proteins are being renewed constantly with the liberation of endogenous amino acids. Moreover, there are a number of metabolic reactions during which metabolites are converted into nonessential amino acids. The metabolic utilisation of amino acids is equally diverse. Whereas protein synthesis allows the manufacture of new proteins, degradation leads on the one hand to nitrogen excretion and on the other to the production of carbon skeleton molecules (for glycogenesis and lipogenesis), carbon dioxide and the release of energy (Figure 4.1).

Classification of amino acids

It is customary to classify amino acids as ***essential*** and ***non-essential***. Although all amino acids are normally found in biological tissues and are biologically essential, this classification pertains to their dietary necessity. ***Essential*** amino acids are those that cannot be synthesised by the animals themselves and must, therefore, be supplied in the diet. Those that can be synthesised by the animal are termed ***non-essential*** amino acids. Of these, a few cannot be synthesised at a rate fast enough for maximum growth and should, therefore, be included in the diet as well. The essential amino acids can be classified into one of three categories, dependent upon the animal's ability to achieve limited synthesis or not:

- Lysine and threonine have no intermediary precursors, and so 100% must be supplied in the diet.
- Leucine, isoleucine and valine can be synthesised from precursor intermediary metabolites. However, the production is very limited and may only supply 2–5% of requirement.
- Arginine and histidine can also be synthesised from intermediates, and under normal circumstances this will yield 5–8% of requirement.

The major non-essential amino acid found in animal tissue and in feedstuffs

Vitamins

Fact
Fat soluble vitamins can be stored by the animal in fat depots.

From Chapter 1 you will remember that vitamins were classified as organic compounds. Broadly speaking, a vitamin may be defined as an essential dietary factor that is required by an organism in small amounts and whose absence results in deficiency disease. They are not usually synthesised by the body cells, but are necessary for maintenance, growth and reproduction. While experimental diets deficient in each of the known vitamins have been fed to chickens and the deficiency signs studied, many of them can be looked upon as scientific curiosities as far as diets compounded from natural materials are concerned. Only those vitamins whose requirements are so great and the sources of supply so low that deficiency symptoms are likely to be seen in practice will be dealt with here.

There are 13 vitamins usually listed as being necessary for the animal; they occur in feedstuffs in varying quantities and in different combinations. Some vitamins are produced by micro-organisms of the intestinal tract, one by irradiation at the area of the animal's skin, while others are manufactured synthetically. As vitamins are definite chemical compounds, commercially produced vitamins are as valuable as those found in natural feedstuffs. There are two groups of vitamins: fat-soluble and water-soluble; all of them require some body fat for their metabolism. They are often present in plants as pro-vitamins, which are quickly converted to the true vitamins in the body of the animal. They are easily stored in fat cells and any excesses are excreted through the faeces. The *fat-soluble vitamins* include the following:

Vitamin A (Retinol)	Vitamin E
Vitamin D	Vitamin K

The *water-soluble vitamins* are mainly needed for normal energy metabolism, although we are becoming increasingly aware that they also play a role in protein metabolism. Animals require all the water-soluble vitamins in their diet except Vitamin C. When a feed contains excess levels of the water-soluble vitamins they are excreted in the urine. Apart from vitamin B_{12} birds are not able to store any of the water-soluble vitamins. When a feed contains excess levels of the water-soluble vitamins they are excreted in the urine. For this reason, it is important that birds receive the correct level of these vitamins on a daily basis. A single large dose once a week will only end up on the floor. It is precisely for this reason that humans are advised to take a vitamin tablet every day. The important vitamins in the water-soluble group are:

Vitamin C (Ascorbic acid)	Pyridoxine (B_6)
Thiamine (B_1)	Riboflavin (B_2)
Biotin	Pantothenic Acid
Folic Acid	Niacin
Vitamin B_{12}	Choline

The significance of the difference between the classes of vitamins is very clearly illustrated by work published by Leeson *et al.* (2003) (Table 11.12). Single vitamins were removed from the diet of breeding hens and were then reintroduced 15 weeks later. It is important to note, first, just how dramatic an effect the deletion of a single vitamin can be, particularly the water-soluble vitamins. Secondly, it is of interest that fertility returned to normal after 4 weeks, implying that no permanent damage was done.

Fat-soluble vitamins

Vitamin A

True vitamin A exists only in the animal kingdom. Its precursor, carotene, is found in the vegetable kingdom, largely in green leafy plants, lucerne meal and yellow maize. Carotene is converted via pro-vitamin A into vitamin A, which can be stored in the body, mainly in the liver. Young birds are less efficient at this, therefore, they have a higher dietary requirement. Vitamin A activity is expressed as IU (international units), and the recommended level in the diet ranges from 6,000 IU/kg for mature birds to 15,000 IU/kg for young chicks. Vitamin A is required for the normal development and repair of epithelial tissue and,as a result, it is one of the first lines of defence in disease. If a feed is deficient in vitamin A, symptoms will begin to appear at about 20 days of age: growth rate is reduced, and the birds are weak and emaciated with a ruffled plumage and an unsteady gait. As the condition progresses, the eyes become inflamed (xerophthalmia) and a nasal discharge occurs. This latter condition is known as nutritional croup in adult birds, seen as discharges from the eyes and nostrils. In marginally deficient cases, the symptoms take up to 6 weeks to develop, and nervous symptoms are common. Adult birds tend to show reduced egg production and hatchability. On post-mortem examination, pustules in the mouth, pharynx and oesophagus are seen and urate crystals are present in the kidneys and urethras. The latter more so in young growing birds. These urate crystals are often found on the serosal surfaces of the heart, liver and spleen, as well as in the folds of the Bursa of Fabricius.

The nervous symptoms observed are as a result of the degenerative changes in the central and peripheral nervous system, whereas the other symptoms are as a

Minerals

Fact
The ash content of the diet gives little or no indication of the essential mineral content of the diet.

Minerals, which comprise the ash content of feed, are the inorganic component of the diet. Out of the 109 known elements, 26 are considered essential for animals (Vieira, 2008). They make up only a relatively small part of the diet of any animal but are nevertheless vital and must always be taken into consideration. Minerals form an integral and essential part of all body tissues, but their distribution throughout the body is not uniform; the skeleton contains most of the calcium (Ca) and phosphorus (P), potassium (K) is found mainly in muscle, iron (Fe) in the blood and silicone (Si) in feathers. It is possible to generalise their primary function as catalysts of enzymatic cell systems with a broad range of functions. In these systems minerals are frequently associated with proteins in a fixed proportion as metalloenzymes in which interactions between minerals and protein improve catalytic activities but also reduce protein turnover.

Mineral sources

Minerals are supplied either as supplements or in the ingredients used in the diet; so metals reach the animal either as inorganic salts or organometallic compounds, some of which occur as soluble chelates. The concentrations of some of the microminerals in the usual feed ingredients are shown in Table 6.1. The availability of minerals varies considerably in feed ingredients, but are generally below 30%. This is primarily due to the formation or presence of poorly soluble complexes in both plant material and in the GIT of the bird. Selenium often occurs as soluble salts or organic compounds and its digestibility is, therefore, higher. Most of the microminerals supplied in the diet occur in the supplement. The biological availability of these minerals in the different classes of salt varies considerably and it is important that it is specified only salt with a high bioavailability is used in premixes. As a general rule, the carbonates are the most available, followed by the sulphates: the oxides of most minerals are very poorly available but, unfortunately, they are also the cheapest form.

Mineral absorption

Absorption of microminerals occurs mainly in the proximal small intestine, although uptake from the stomach has been reported in some cases. The mechanism of uptake differs for the different microminerals. Mucosal uptake of copper (Cu) and zinc (Zn) is mediated by metallothionine and cystine-rich intestinal protein. Chromium (Cr) and selenium (Se) show saturation characteristics, which indicate facilitated diffusion. Any study of mineral nutrition and metabolism is complicated by the manner in which the functions of the various elements and other feed components interact with one another. From Figure 6.1 it can be seen just how complex these interactions are. In the case of Zn and Cu and to a lesser extent Fe, availability is reduced by high concentrations of macrominerals such as Ca and P, as well as by the presence of materials such as phytate and tannins caused by the formation of insoluble complexes. Protein, amino acids and ethylenediaminetetraacetic acid (EDTA) often form more soluble complexes, thus facilitating the uptake of the mineral. Other forms of interaction may take place at the mucosal level. Cadmium and copper decrease assimilation due to competition for the same metallothionine. Vitamin C has been found to have a negative effect on Cu absorption but increases the uptake of Fe and Zn. Increasing the intake of microminerals does not result in a linear increase in absolute absorption.

Table 6.1 Mineral concentrations in some feed ingredients (after Batal *et al.*, 2011)

Origin	Ca (g/kg)	P (g/kg)	Na (g/kg)	Cu (ppm)	Fe (ppm)	Mn (ppm)	Se (ppm)	Zn (ppm)
Maize	0.1	2.3	0.2	2.9	25	4.5	0.08	20
Wheat	0.5	4.1	0.6	10.6	50	40	0.2	34
Soyabean meal	3.1	6.7	0.4	15.3	171	41	0.1	48.5
Sunflower meal	3	12.5	2	15	50	34	0.15	50–80
Wheat bran	1.4	11.7	0.6	10.3	170	100	0.8	95
Fish meal	40	28.5	8.8	9	226	9	2.7	100

Balance

Fact
Animals respond to increasing intake of a balanced diet in a typical manner.

In preceding chapters we have discussed the nutrients that make up the diet and their importance to the animal itself. Although mention has been made of the fact that a finite quantity of protein or energy is required for normal growth and or production, little mention has been made as to proportions of each nutrient that are required in the feed. In this chapter the concept of balance will be discussed.

The concept of balance

A balanced diet is one in which all of the required nutrients, together with sufficient energy, are supplied to the animal on a daily basis. Obviously, no deficiencies may exist, but it is equally important to ensure that excessive levels of any nutrient have not been included. The objective of feeding a balanced diet is to allow the animal to achieve maximum productivity. This would include such factors as growth, liveability and reproduction. In the generalised diagram (Figure 7.1) it can be seen that the animal reacts to a range of different nutrient levels. The diets fed to animals will differ with species, age and season but there are certain conditions that must be met if the final diet is to be balanced.

Ratio of digestible to indigestible organic matter

The digestive systems of poultry are not adapted for the utilisation of large quantities of fibrous foods and, as a general rule, diets should contain a large proportion of low fibre, readily digestible ingredients. Birds are tolerant of a fairly high level of indigestible matter in their diet: ducks and, especially geese, have an improved ability to digest fibre and, from the age of 5 weeks, geese can be expected to obtain all of their food from good quality grazing. Ostriches are unique in that they are able to utilise fibre in much the same way as ungulates do. For all species, a certain amount of indigestible organic matter is necessary to maintain the tone of the gut. Young animals require about 13% indigestible material while adult animals require up to 15%. Below these levels, the faeces become watery and scouring may occur. High levels (above 15%) are known to result in a decreased growth rate in young birds.

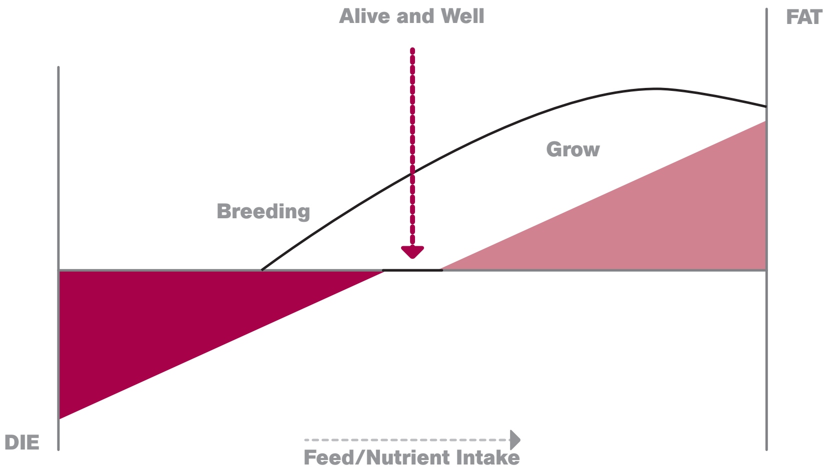

Figure 7.1 The productivity gradient experienced by all animals

Ratio of protein to energy

Protein (and amino acids) is only utilised efficiently when the ratio of protein to energy is correct. This ratio varies with species, age and the animal's productive state. The protein to energy ratio is usually assessed in terms of amino acid (lysine) to metabolisable energy. The determination of the correct protein to energy ratio is probably the most crucial exercise in the feeding of any animal. To summarise what was covered in Chapter 3, the factors that may influence an animal's requirements for energy, are as follows:

- size
- temperature and feather insulation
- growth rate
- reproductive state
- feeding

The factors that affect the protein requirement are similar but, as protein is not required to maintain body temperature or to perform work, total protein requirement is less variable. Unlike vitamins, a deficiency of protein or energy does not usually result in clinical symptoms. A complete description of the effects of protein and energy deprivation has been entered into already. However, it is essential that protein and energy be examined together and not singly.

In an instance where energy intake is insufficient to meet the animal's needs, a number of physiological steps are taken to overcome the problem. The first step is to increase feed consumption in order to consume more energy. Failing this, the animal will catabolise – break down to energy and uric acid – any additional protein and utilise it as an energy source. This is not a particularly efficient process as it is an expensive energy source both

Anatomy, digestion and absorption

Fact
The chicken does not have any teeth & does not chew it's food - rather it coats it with mucus & swallows it whole.

It is clear from previous chapters that foods are made up of a diversity of organic constituents, many in the form of large insoluble molecules. These must be degraded to simple molecular compounds before they can cross the intestinal mucosa and enter the general circulation for delivery to specific sites within the body. The process of degradation is termed ***digestion*** and the passage across the intestinal mucosa absorption. A diet with an ideal nutrient profile is of little nutritional benefit if it cannot be broken down and assimilated following consumption.

Digestion involves a combination of mechanical, chemical and microbial activities, which contribute to the sequential degradation of food components. Mastication and alimentary muscular contractions diminish the size of ingested food particles mechanically. Enzyme-rich digestive juices secreted into the digesta in the stomach and small intestine instigates chemical degradation. Bacteria in the terminal section of the alimentary canal also produce enzymes capable of chemical digestion. This chapter takes a systematic approach to digestion, tracing the route of food ingested by the mouth, travelling through the oesophagus to the stomach, the small and large intestine and finally, excretion of the undigested residue. First, there is a short section on anatomy.

Anatomy of digestive tract

Mouth

The term gastrointestinal tract (GIT) is used to describe the digestive tract: more commonly known as the gut (Figure 8.1). The oral cavity or mouth of a chicken consists of a beak with a palate and a choanal slit on the dorsal palate: there are no lips or teeth. Included on the dorsal palate are ridges and papillae. The maxillary and palatine glands open into the area of the dorsal palate at the base of the papillae. In the angle of the mouth where the dorsal and ventral palate meets, the salivary glands open into an area known as the lateral cheeks. The tongue is on the floor of the oral cavity and at the base of the tongue are the sub-mandibular glands, which open into the oral cavity where the tongue is attached to the caudal part of the oral cavity. The next area of the oral cavity is known as the pharynx.

Pharynx

The roof of the pharynx contains more salivary glands. The actual bony structure of the tongue is fixed at the base of the pharynx. Included in this area, at the base, are structures, which are very similar to taste buds. A feature of the wall of the mouth and the pharynx is that it is virtually continuously supplied by salivary glands, which are extremely well developed. They secrete mainly mucus, however, a small amount of amylase is also secreted. The mucus is made up of muco-proteins and a muco-polysaccharide, which may be non-sulphated or sulphated. The mechanism of swallowing by a bird is that the beak seizes the feed, the tongue vigorously moves the food to the roof of the oral cavity and mixes it with the mucus, forming a sticky bolus. The tongue is aided by the papillae or the projections found in the palate and the bolus is moved caudally where it accumulates until peristalsis moves it down the oesophagus.

Oesophagus

The next part of the digestive tract is known as the oesophagus, which is made up of a cranial or cervical part. This is followed by a diverticulum or swelling in the oesophagus, commonly called the crop, and then the caudal part or thoracic area of the oesophagus, which ends at the junction to the proventriculus. The lining of the oesophagus contains numerous mucosal glands. Another feature is tonsillar or lymphoid tissue at the junction of the oesophagus to the proventriculus.

Proventriculus

This is known as the glandular stomach and it joins to the muscular stomach via a narrowing known as the isthmus. The lining of the proventriculus contains papillae and multi-lobular glands, which secrete both acid in the form of hydrochloric acid and proteolytic enzymes in the form of pepsin.

Gizzard

The gizzard or muscular stomach, which occurs after the isthmus, is covered internally by a tough membrane, the structure of which is such that it a matrix of glandular secretions forms a carbohydrate protein matrix. The membrane is folded longitudinally. Near the caudal area of the muscular stomach (that is the area at which the duodenum is attached), are the villi and mucus glands. The sphincter resembles the mammalian pyloric sphincter. The external layer of this muscular stomach is made up of smooth muscle.

Small intestine

The small intestine consists of a cranial duodenal loop and then a caudal portion, known as the jejunum, followed by the ileum. The duodenum itself consists of a descending and an ascending loop, encompassing the pancreas, with pancreatic and bile ducts opening into the ascending loop. The duodenum is lined by long villi. The jejunum is the coiled part of the small intestine. Meckel's diverticulum, which is the remnant of the yolk sack, is halfway down its length. The mucus membrane is very similar to that of the duodenum, however, villi are shorter and the wall contains large amounts of lymphoid tissue. A peculiarity of the jejunum is a sphincter found at the jejunal–rectal junction.

Layer nutrition

Fact
Physiological goals need to be achieved when feeding laying hens.

Hens used for commercial egg production are of two main genotypes, namely the Leghorn (white-shelled eggs) and the Rhode Island Red (brown shells). A combination of these two genotypes gives us 'tinted' birds. Consumer preference dictates egg-shell colour. White eggs predominate in the USA whereas brown eggs are more popular in Europe and Africa. Leghorns tend to be lighter than brown layers and produce slightly smaller eggs. A comparison between the two strains is shown in Table 9.1. Needless to say, brown birds are preferred in countries where there is a significant market for spent (cull) hens. In addition to differences in genotype, there are considerable differences brought about by housing and management, which has an impact on the ways in which these birds are fed. Any recommendations concerning 'ideal specifications' would be both short-sighted and misleading: the information in this chapter should be used as a guideline only.

The difference in preference for white and brown birds affects has implications for nutrition. The NRC (1994) makes scant mention of the requirements for brown eggs layers. Nutritionists are, therefore, obliged follow the European guidelines in this regard. Although the feeding of laying stock can broadly be split into two components, namely, the growing stock (rearing) phase and the mature (egg-producing) phase, it is essential that the feeding and rearing of laying hens be considered as a continuum.

Table 9.1 Genetic traits of brown (Hy-Line Brown) and white (Hy-Line W 98) layers (Hy-Line, 2011)

Trait	White layers	Brown layers
Live weight at 17 week (g)	1230*	1400
Live weight at 70 weeks (g)	1670	1970
Eggs per hen housed (60 weeks)	250	255
Egg weight 70 weeks (g)	65.6	64.1
Feed intake 0–17 weeks (kg)	5.05*	5.62
Feed intake 18–80 weeks (g)	98	107.0
Mortality (%)	3	3%

Note: *The figures for the W 98 are given to 16 weeks of age.

There are a number of important nutritional goals in feeding the laying hen:

- Organ development must be achieved by 5–6 weeks of age.
- Frame size must be achieved by 12–4 weeks of age. Most (90%) of the frame is developed at this stage and so the 'size' of the pullet is then fixed. It almost impossible to modify body weight without a change in frame size.
- The bird must reach sexual maturity at the correct weight and body composition. It is well-established that body weight is important for normal, early production but there is still insufficient evidence regarding optimum body and composition. It is probable that birds that have some energy reserve (fat) as they approach peak egg production are less prone to subsequent problems.
- Flock uniformity is important and this is achieved by managing the birds in a suitable and constant environment.
- Layers must be in a positive energy balance at peak production. The establishment of an energy reserve occurs during the rearing phase and has a significant effect on the bird's body composition at point of lay.
- We must strive to maintain a 'steady state' throughout the egg production period.
- In some countries the attainment of an optimum 60-week weight is also be important is it has an impact on the value of the spent hen.

In order to ensure that we achieve these goals, it is important to measure the process. This is not always possible, as many of the traits we need to measure would involve sacrificing the bird. However, we can measure body weight (and uniformity) as well as egg quality and production levels.

Broiler nutrition

Fact
Broilers can consume about 10% of their bodyweight in dry matter on a daily basis.

The broiler industry has been characterised by steady growth and it is anticipated that this will continue . Figure 10.1 clearly shows how the production of broilers has increased. Most of the major companies are 'integrated' to some extent although the structure may differ between companies.

The secret of successful broiler nutrition is to adopt the correct feeding strategy, which means feeding the correct feed on each day of the production cycle to optimise the use of available feed ingredients and to maximise profits. In order to compete, feed ingredient prices and other costs should be equitable when compared to the world's two most efficient producers, namely Brazil and the USA. In this chapter the underlying principles of broiler nutrition and the strategies that can be adopted to maximise profits will be discussed. First, it is interesting to take a look at the broiler's body composition (Figure 10.2) and conversion of nutrients (Table 10.1).

Factors influencing broiler nutrition

Broiler nutrition is complicated by a number of interrelated factors that need to be considered before any detailed discussion about nutrition.

Feeding behaviour

As discussed in Chapter 1, feed palatability may be of little consequence to chickens and much of their feeding behaviour is dictated by particle selection. In the case of broilers, it is usually assumed that all birds within a flock eat similar quantities and that feed intake is controlled by appetite (Leeson, 2010): nothing could be further from the truth. Broilers consume about 10% of their bodyweight in dry matter on a daily basis. In human terms, this would be equivalent to eating a 10 kg bag of rice each day. Generally, if birds have adequate access to feed, they are capable of maintaining normal energy intakes over a wide range

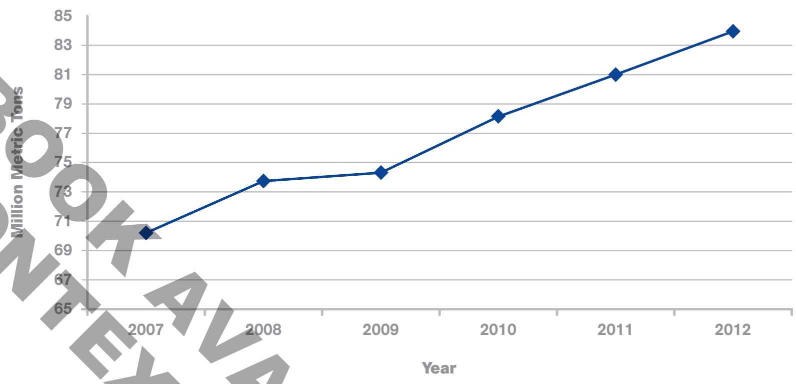

Figure 10.1 World broiler production (USDA, 2011)

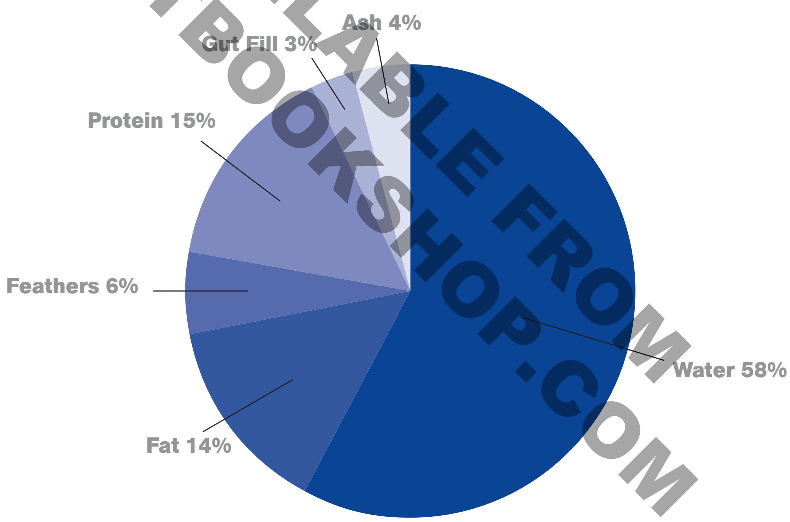

Figure 10.2 Body composition of a typical broiler

of different dietary energy levels (Table 10.6). Young birds do have a problem maintaining nutrient and energy intake when fed low-density diets. Broilers are meal eaters and, when unrestricted, they will eat for about 8 minutes each hour, preferably as one meal although this is often interspersed with voluntary pauses. After about 28 days of age, or when a density of about 30 kg of chicken per m^2 is reached, birds rarely have the luxury of finishing a meal at a single sitting as competition for feeder space intensifies (Table 10.43).

Differences between sexes

In most cases, broilers are raised 'as hatched'. In terms of their growth potential and hence the nutrient requirements, male and female broilers are vastly different animals. They differ in their mass gain, feed intake, carcass composition

Rearing

Fact
Ad libitum fed birds become obese, lay poorly and have high mortality. Hence feed restriction needs to be applied to control weights.

The management and nutrition of broiler breeders is, perhaps, the most complex aspect of poultry production. As broiler marketers adapt their products to changing consumer needs, primary breeder companies follow suit with new genetic products of their own. In essence this has meant faster growing, leaner birds (more breast meat) on an ever changing basis. With broiler breeders, what worked yesterday may not work today.

Many aspects and concepts of broiler breeder nutrition are identical to laying hen nutrition, yet the feeding of broiler breeders is fundamentally different. The utilisation of protein, energy and other nutrients remains the same but growth rate and reproductive performance are antagonistic and breeding stock cannot be allowed to express its genetic potential for growth if reasonable reproductive performance is expected. *Ad libitum fed birds become obese, produce fewer eggs and suffer from high levels of mortality.* Normally, the amount of feed allocated to any flock of broiler breeders is controlled (restricted): this improves bird health and performance but if the feed is severely restricted birds become chronically hungry and suffer from frustration of their feeding motivation. Despite these problems, breeder management and performance have been successfully improved (Table 11.1).

Feed restriction means that broiler breeder nutrition is a function of both feed specification and daily feed allocation and even although the nutritionist formulates diets to the *nth* decimal point, It still depends on whether the farm manager is allocating the feed the correctly.

World-wide only a few strains of breeders predominate. These are the birds produced by Cobb-Vantress (Cobb and Avian) and those produced by Aviagen (Ross, Arbor Acre and Indian River), the Hubbard and the Hybro. The recommendations and approaches of the different companies differ slightly but, ultimately, the same broad guidelines need to be applied together with good stockmanship. Fisher (1998) believes that any improvements in broiler breeder nutrition in the future are likely to be made through improving feeding programmes rather than through changed or improved dietary specifications.

Rearing

The prime objective of rearing breeders is to produce uniform flocks at the correct weight for age with the correct body composition. Each commercial strain has an optimum weight at time of approaching sexual maturity. For most strains this is around 2.4 kg at 22 weeks (Ross 2.54; Cobb 2.44 kg). In general, slightly overweight flocks tend to perform better, regardless of strain. In a study reported by Robinson *et al.* (1995), breeder pullets that had been reared in floor pens to 20 weeks of age were divided into five weight groups (96–105% of average 20-week weight) (Table 11.2). Fifteen hens from each group were placed in individual laying cages and fed on an identical restricted feeding program to 58 weeks of age.

Age at first egg was similar and so was mean egg weight. Fertility and chicks per breeder were significantly lower for those birds that were the lightest at 20 weeks. The heavier weight breeders at 20 weeks, especially the 105% group, resulted in superior reproductive performance. Although the results were variable, due in part to the small number of birds employed, the data clearly demonstrate there is a difference in reproductive performance of breeder pullets based on 20 week body weight. Since all birds were fed the same feed allotment from 20 weeks on, the smaller birds would probably would have been fed in excess of their metabolic requirements. Hence, excess protein and energy intake would be converted into body fat deposits. Heavy birds, with the same feed allocation, will have been fed close to their optimum metabolic nutrient requirement to maximise production.

The target body weights and the expected feed intakes, together with a graph of the growth curve for each strain, are published by the primary breeding companies: they are similar. The first 6 weeks of life are crucial for both skeletal and feather development, and feed restriction during this phase should not be too severe. From 6 to 16 weeks of age the growth needs to be held back a significant amount. From 16 weeks of age, the rate of growth is accelerated through to point of lay (Figure 11.1). Aviagen tends to make very specific recommendations concerning ideal feed allocations whereas Cobb Vantress state quite clearly that the only important part of their recommendation is the body weight curve itself. Feed allocation will vary with

Table 11.1 Expected performance taken from breeder guides intended to be representative of the top 25% performance of current flocks (Laughlin, 2009)

	Total eggs/ hen housed	Hatching eggs/ hen housed	Cumulative hatchability (%)	Total chicks/ hen housed
1976	154.6	144.8	80.4	116.4
2001	167.7	159.1	85.6	136.1
2007	173.2	166.6	85.2	141.7

Nutrition and health

Fact
How birds are fed affects nutritional pathology, gut health, immune system stimulation & metabolic disease.

Nutritionists will increasingly be required to be involved in all aspects of poultry health. The areas of specific importance include nutritional pathology, the management of gut health, immune system stimulation and metabolic diseases. Vets are adept at diagnosing the diseases, but as they cannot prescribe medication or use vaccines to solve the problem, they are limited in what they can do little to solve the problem. Nutritionists tend to accept that many metabolic diseases are a function (genetic) of the rapidly growing bird and so it will require a co-operative effort from both professions and the primary breeders to face these challenges.

Pathology is defined as 'the branch of medicine concerned with the cause, origin, and nature of disease, including the changes occurring as the results of disease'. Nutritional pathology, therefore, could be defined as the study of pathology that arises from feeding or nutritional causes, such as simple deficiencies of feed and/or nutrients, illness arising from harmful substances contained in the feed, and complex metabolic disease arising through the interaction between the bird and its diet, which in many instances are complex and the underlying mechanisms not fully understood.

Nutritional deficiency

Nutritional deficiencies may be seen as either simple or complex, depending on whether the total feed consumed is adequate or if one or more essential nutrients is limiting: a deficiency can be further defined as marginal or severe. In the case of a marginal deficiency, symptoms are extremely difficult to identify to a specific cause as, normally, growth rates, feed utilisation and other production parameters are marginally affected and difficult to measure. In the case of a severe deficiency the symptoms are more marked as production virtually ceases and death can occur, which indicates the development of a true deficiency disease or a pathological nutritional deficiency.

In the physiology of bodily function, no single nutrient – vitamin, mineral or amino acid – is solely involved rather functions are governed by a number of essential and non-essential nutrients. In deficiency pathology, there is the possibility that any number of nutrients may cause a similar syndrome. Conversely, a single nutrient may result in several symptoms. To diagnose a condition a complete history of the diet fed, the water and the environment must be obtained. This must be coupled to the clinical symptoms and the *post-mortem* evaluation to find the most likely cause.

A chronic, low-grade deficiency is extremely difficult to diagnose and may have disastrous effects on production because of the time involved in recognising this. Diseases, e.g. viral, parasitic or bacterial – as well as environmental conditions and management – may affect nutrient availability, nutrient requirements, nutrient stability and, perhaps, most importantly, the bird's ability to eat.

Feed or water deficiency

The most common nutrient deficiency is the shortage of, or the complete absence of, feed and/or water. This is often as a direct result of poor management on the farm (no feed or too few feeders, etc.). In adult birds, a feed deficiency will usually result in body weight loss or a reduction in egg production;. in broilers, a reduced growth rate will be seen. In severe cases, specific deficiency symptoms may be present; and in young birds, a shortage of feed results in a condition called *starve out*.

Protein amino acid deficiencies

A deficiency of an individual amino acid is in essence a protein deficiency, which results in a reduction of growth with a reciprocal increase in fat deposition. A gradual decline in egg size and/or production may be recorded. The degree of severity is linked to the level of amino acid deficiency. Importantly, protein or amino acid deficiency causes a depression in feed intake. Of the amino acids, lysine plays an important role in growth and together with methionine they are the two first limiting amino acids. Lysine is also an integral part of melanin formation and deficiencies result in colour deviations in feathers. Leucine and isoleucine, together with phenylalanine, when deficient, will cause tongue deformities. Cystine is involved in feather formation, and a deficiency results in retarded or slow feather growth.

Energy deficiency

Birds require energy for every biochemical reaction in the body, and if energy intake is insufficient the rate of growth is immediately reduced. A more complete discussion of energy deprivation is given in Chapter 2.

Phosphorus deficiency

Phosphorus deficiencies are not common: in the case of laying hens, very little supplementary phosphorus is required under normal conditions. However, under heat stress, a deficiency of dietary phosphorus causes an increase in mortality and a drop in production. If no mineral phosphorus is added to broiler diets (if the wrong ingredient is added, for example), broilers will exhibit anorexia and, therefore, poor growth and performance. Marginal deficiencies will result in weak bones and rickets.

Calcium deficiency

Calcium deficiencies may occur if it is omitted from the diet, or it may be induced. There is an interaction between calcium, phosphorus, the phytase enzyme

Feed ingredients and additives

Fact
Grain is the principle ingredient of most poultry diets. This needs to be a source of consistency in the diet.

A wide range of primary and secondary products is used in animal feed. Many have features and characteristics that make them unique or limit their inclusion in the diet in some way. In addition, there are a number of ingredients that fall into the category of additives. Under commercial conditions, the choice of feed ingredients is often based on economic considerations but quality considerations still play an important role. There are two important parameters that should be used when selecting feed ingredients: these are the physical nature of the ingredient itself and the nutrient content of that ingredient. Table 13.14 gives an overview of the correct levels for each ingredient; Ewing (1997) and INRA (2003) provides more details and Batal et al., (2011) have compiled a table of feedstuff nutrients which is published in Feedstuffs annually.

Cereal grain makes up a high proportion of poultry diets: There is large variation across cereal species, cultivars, individual grain samples and animal types in the amount of energy made available to animals from grains. Similarly, oilseed meals are used to satisfy requirements for essential amino acids and total nitrogen. Variation in processing methods and temperatures applied to oilseeds during the oil extraction process can markedly affect the availability for animals of essential amino acids, particularly lysine. This variation can have marked effects on both the efficiency of production, and the cost of the ingredients.

Current methods of assessing the energy value of cereal grains (mean book values, test weight (kg/hl), per cent screenings and calculated values) do not represent either their available energy content (MJ/kg) or the impact that they will have on the animals energy intake when included in the diet. Similarly, laboratory methods for assessing the availability of amino acids, particularly lysine, are complex and time consuming. Near infra-red (NIR) represents an exciting new methodology for the feed industry (Black et al., 2011). There has been a large range in AME values (MJ/kg DM) for Australian sourced grains: 11.9–15.3 for wheat, 10.9–13.6 for barley, 12.1–14.5 for triticale and 15.3–16.7 for sorghum. It was also shown that there was no relationship between the AME content of a diet (MJ/kg) and the amount of the diet consumed by broiler chickens ($R^2 = 0.003$). This suggests that different characteristics of the grain determine digestibility compared with intake. In addition, there were significant differences ($P < 0.05$) within grain types in the intake (g/day) by broilers when grain samples were incorporated into diets. For example, the intake of wheat based diets by broilers varied by 20%, depending on the particular wheat sample incorporated at a constant proportion into the diet. The daily intake of AME (MJ/d) by broilers varied by approximately 34% across the wheat based diets. Lastly, broiler growth rate was more closely related to AME intake (MJ/d) than to the AME content of the diet (MJ/kg).

Most nutritionists build up a table of nutrient values for each of the materials that are to be used in animal feed, usually referred to as the ‘matrix’, which should be built up from the results of laboratory analysis of the feed ingredients., However, tables such as those published by Batal et al. (2012) are often used. In general, accurate results can be obtained for the more common components of the feed such as nitrogen,fibre and fat.. It should be borne in mind that the organic constituents of feeds (protein and carbohydrate) can vary by as much as 15%, the mineral constituents by 30% and the energy values by at least 10%. Formulations will only be as good as your ingredient matrix used.

Grains

Maize

Maize is the most important grain and usually presents few problems when included in the diet. It has generally low protein levels and is particularly low in lysine but is an excellent source of carbohydrate energy. It also contains significant quantities of xanthophyll or natural yellow pigment. Aflatoxins, which are toxins produced by moulds, may be a problem if maize is grown in humid conditions, is insect damaged or is stored wet. In countries where grain dries naturally, aflatoxins rarely prove to be a problem. However, when grain is field dried, wet conditions can cause Fusarium sp to occur. These are responsible for the production of fumonosins, DON and T_2 toxins, which can be problematic.

NIR work has been carried out on maize by Addisseo, who were able to show that the TME_n value of maize can be in the range 12.81–16.05 MJ/kg, with a mean of 14.2 MJ/kg with a CV 3% (Relandeau, 2010).

Stack burnt maize is maize that has been discoloured due to post-harvest drying or storage under tropical conditions. On analysis, the protein content of the stack burnt material appeared to be unaffected. Detectable amino acids showed decreases of 52% for lysine, 35% for arginine and 15% for glycine concentration in some of the most severely discoloured samples. There was a decrease in digestibility with an increase in discolouration. Samples were fed to broiler chickens at a level of 60% in the diet in a growth trial. Weight gain, the efficiency of feed utilisation and the ME value of the diets were significantly affected by the degree of discolouration.

Researchers in Brazil have developed an equation that estimates the loss in ME as

Enzymes in poultry nutrition

Fact
Enzymes eliminate encapsulating cell walls and break up large indigestible molecules.

There is little doubt that the addition of exogenous enzymes to poultry diets represents one of the greatest opportunities available to nutritionists to improve the effectiveness of poultry feeding. They lead to an improvement in the utilisation of the nutrient and energy contents of the diet, a reduction of the environmental impact of animal production and an improvement of intestinal health and gut function and, at the same time, an improvement in litter quality and bird welfare. Commercial nutritionists need, therefore, to understand which classes of enzymes are available, what their mode of action is and how they interact with each other and the other ingredients or additives used in the diet.

There are a wide range of different enzymes but they fall into two broad categories: those products that supply phytase to the diet, and a second group containing enzymes that aid or enhance the digestion of the various feed components of the diet that supply protein and energy to the birds, including xylanase and glucanase, protease, amylase, mannanase and lipase. This distinction has been based on the site of activity within the gastro-intestinal tract of the chicken. Commercially available products may contain single enzymes, a blend of several enzymes or a cocktail of enzymes that contain guaranteed levels of certain enzymes, and a range of other enzymes with supplementary activities.

The global enzyme market is currently about US$500 to 600/year, with phytase making up about 60% of this market (Adeola ***et al.***, 2011). More than 70% of the world's enzymes are produced and sold by four key players: BASF, DSM/ Novozymes, Addisseo and Danisco Animal Nutrition. Other suppliers include AB Vista, Chemgen, Alltech, Novus and Kemin (Barletta, 2011).

This chapter will discuss the general principles of enzyme activity in poultry diets, the roles of phytase and other enzymes that are used and, finally, give some practical recommendations and methodologies.

General considerations

Mode of action

The principle mode of action of enzymes is to enhance the digestibility of dietary components. Some achieve this by eliminating the encapsulating effect of the cell walls and improving access of the digestive enzymes to the feed components. The digestion of minerals, starch, fat and amino acids is incomplete in the alimentary tract of the chicken. Most of the digestive activity in the chicken gut occurs in the crop, gizzard, proventriculus and ileum, with varying amounts of material passing on undigested into the caecum. The undigested material represents inefficiency to the animal and provides a nutrient source to both the harmful and beneficial micro-biota in the gastrointestinal tract by the release of oligosaccharides from the cell walls of plant material.

Although some digestion may take place in the caecum, there is very little nutrient uptake from this organ, particularly in the case of young birds such as broilers where it is undeveloped. For this reason, as far as enzymes are concerned it is ileal digestibility (ID) that is important. There is an indirect effect of enzyme addition to the diet: it has been shown that they alter the digestive physiology of the animal by altering parameters such as the intestinal mass and absorptive capacity of the gut. Measuring the small changes in the bird's physiological status is difficult, and nutritional experiments need to go beyond the measurement of growth and mortality rates as the only indicator of bird and gut health if any real progress in this field is to be made. Lastly, enzymes may also be responsible for the removal of anti-nutrients from the diet, such as phytic acid the effects of which can largely be overcome by the addition of phytase. It has also been reported that proteases will reduce the levels of trypsin inhibitor in soya bean meal (Barletta, 2011).

Site of activity

Clearly enzymes are required to act within the gastrointestinal tract of the bird, and conditions in many parts of this tract are amenable to the activity of exogenous enzymes. Retention time in the anterior digestive tract appears to be the limiting factor for enzyme activity in poultry. This could be increased by meal feeding (the crop is then used as a storage organ) or through increasing the feeding of structural components (whole grain and hard fibre) in the diet, which leads to an improved development of the gizzard including an increase in size and retention time (Svihus, 2011).

The phytases used commercially act in a largely acid environment (pH 4–5), which means that they are active in the upper digestive tract (mainly the crop, gizzard and proventriculus), with the crop being reported as the primary site of phytase activity. Other plant sourced phytases do act in an alkaline environment but these are not used commercially. The other enzymes used commercially (carbohydrases and proteases) require the alkaline environment of the lower digestive tract to be effective (pH of 6.5–7.5). This means that phytase will in all probability be active before any other enzyme, and should probably be the starting point when considering multiple enzymes, which may explain why researchers feel that phytase is the predominate enzyme when enzyme mixtures are used.

Experimental design

Fact
Most scientific progress begins with simple observation and questioning.

'There is nothing so tragic as a beautiful theory destroyed by an ugly fact.'

(Thomas Huxley, 1825–1895)

It is important to remember that nutrition and poultry production are based on scientific principles. This chapter will deal with what the scientific process is and, perhaps more importantly, how comparative data needs to be dealt with, whether from a scientific experiment, an advertisement or indeed farming operations. Science is a tool: it is a logical, objective process for testing ideas and reaching a conclusion. It moves ahead by gradually emergent themes and theories, supported by a raft of evidence from a number of different disciplines on a number of different explanatory levels (Goldacre, 2008). Scientific method has 'value' because it represents a systematic approach but it is valuable only because the alternatives can be very misleading. Scientific truths cannot be decided by a public opinion – rather a formal process is required. It more important than ever that we develop an understanding of the scientific process (Figure 15.1).

Observation and hypothesis

Nearly all improvements in nutrition or science in general are made through astute observation. For example, we observe how an animal grows, that food intake increases in cold weather or that certain ingredients lead to better performance. In addition, by reading the scientific and popular press, many observations are made, which leads us to make assumptions, form ideas or even develop theories. These theories need to be tested, and an hypothesis is then formed to test the 'logical or empirical consequences' of them. From a practical perspective, it is important not to confuse evidence with an hypothesis. Sadly, this is the basis upon which many products are marketed.

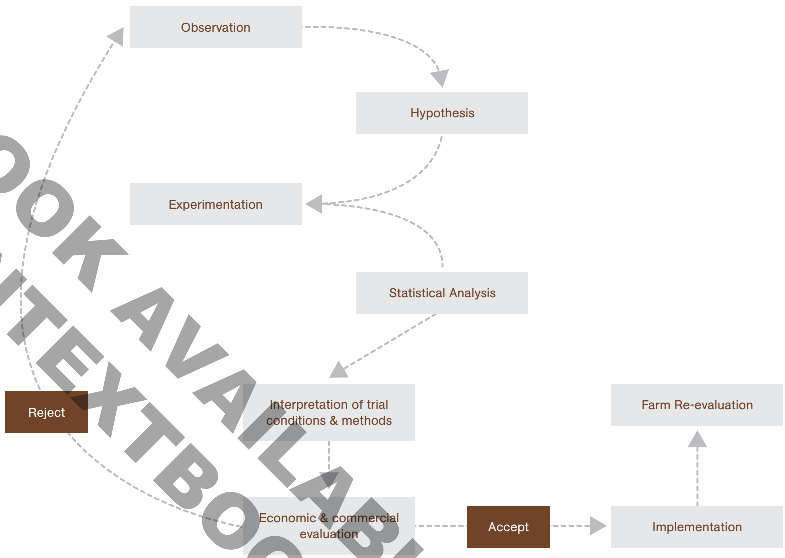

Figure 15.1 An outline of the scientific process

Experimental design

It is at this point that the active process of experimentation begins: it is necessary to intervene and manipulate a system in a methodical manner and compare the outcome with a control that lacks the applied treatment (Dawkins, 2009), for example, by feeding different levels of an ingredient in the diet or using a range of different feed additives. In order to generate valid trial data an experiment needs to be properly designed and there are a number of basic rules that need to be followed in order to do this:

- Each treatment should be replicated (in a pen or a house) several times to increase reliability. The number of replications required differs depending on the experimental layout but should seldom be less than five or six replicates per treatment – depending on what it is that is being tested.
- Replicates need be randomised by reducing experimental bias, for example, it would avoid all of the birds in one treatment from being placed on the cool side of a house.
- In larger experiments blocks are used: one would be a plot or pen of each variable being tested. Within blocks the experimental pens are randomised – leading to what a randomised block design (RBD).
- It is essential that correct control treatments are used because it has to be possible to make a valid comparison with whatever is being tested, and so a positive control is used. When testing an ingredient, a negative control should be included as well: it is not unreasonable to expect the negative control to be what is the current practice
- An adequate number of animals per treatment are required. Using uniform individuals, such as chicks hatched from a single parent flock, increases the probability of finding real differences when they exist.

Effective feed formulation

Fact
Commercial considerations often override what are known to be best practices.

Feed formulation is the means by which nutritionists apply their nutritional knowledge in practice: it is based on a relatively simple mathematical technique called linear programming (LP). The complex set of interacting factors that need to be considered when formulating diets mean that considerable experience needs to be built up if the formulations that are produced are to be optimal (Figure 16.1).

Nutrient requirements and feed specifications

Understanding of the concept of a requirement can vary: in clinical terms it is used to describe the minimum amount of a nutrient that is required to prevent a feed related disease from occurring. Many nutritionists consider the figures produced in the familiar tables as 'ideal requirements' and it is assumed that they embody some underlying biological truths about the intrinsic need of the animal. In fact, the values that are provided by such tables are not really estimates of requirements at all but recommended feed specifications. There is a need to distinguish between the specific requirements of the animal to maintain a certain rate of a particular metabolic activity and the amounts we suggest should be given to the animal in practice. For example, it has already been shown that an animal's energy requirement for growth is determined in a factorial manner (Equation 3.10).

The next step is to determine the expected or desired growth rate and, therefore, a daily allocation for each nutrient. The recommended dietary allowances may be derived from estimates of specific requirements, empirical experiment, traditional practice, accumulated experience or prejudice (Fuller and Wang; 1989), and so it is important that they are translated into practical terms. This is made possible by the concept of a feed specification, which is defined as the amount of a particular nutrient that needs to be included in a feed in order for the animal to consume the recommended daily allowance.

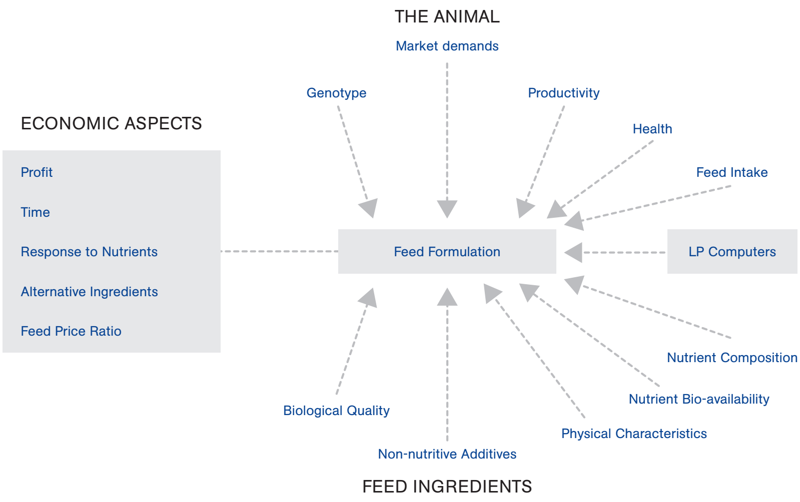

Figure 16.1 Factors that need to be considered in the development of optimal diets for animals

Economics

The determination of the exact nutrient requirements for farm animals has been a goal that has been pursued avidly for many years. These values are determined so the animals can achieve optimum biological efficiency but they are generally insufficient to satisfy the objectives of the entrepreneur, whose aim is to find the level of inputs that will maximise the difference between the value of the output and the cost of the input. The task of translating a requirement into a recommended daily allowance is further complicated by the fact that animals do not have an unlimited capacity to consume feed. This capacity is influenced by many factors, including the nature of the feed itself, the animal's size, level of production and physiological state at any given time. Determining feed intake is perhaps the most difficult aspect of feeding any animal. Rapidly growing animals will generally eat as much as is physically/environmentally possible, while most mature animals will adjust their feed intakes almost perfectly to meet the requirement for the first limiting nutrient.

Expected nutrient requirements, recommended allowances and, ultimately, feed specifications are available from many sources, both locally and internationally. These include the sets of tables published by the American NRC and the British ARC: increasingly, commercial companies such as Aviagen and Cobb are also publishing values. The publication of tables of nutrient requirements is perhaps an unfortunate trend as even though they are derived by factorial methods they fail to present working and logical sequences of quantified steps for creating a practicable scheme for calculating allowances for farm animals that are unique to a particular set of circumstances (Whittemore, 1983; Crabtree, 1985). Very simply, the question is not what are the requirements

Quality assurance and poultry feed

Fact
In order for a QA program to be successful it should be driven by senior management.

The maintenance of feed quality is vital for any poultry company not only from a performance perspective but also for economic reasons. In addition, feed and poultry producers realise that their industries are a vital part of the human food chain and food safety issues have become extremely important. AFMA in South Africa has adopted the slogan 'Safe Feed for Safe Food', which demonstrates just how seriously the feed industry takes this responsibility.

Senior management are required to put a quality assurance programme (QA) in place in their organisations to give a framework within which the mill should operate. Indeed, experience has shown that unless senior management drive the QA process it is unlikely to be effective. QA is not a passive process, and inertia quickly sets in if the process is not driven and controlled in much the same way that cash flow needs to be managed. QA is the process of verifying or determining whether products or services meet or exceed customer expectations: it considers design, development, production, and service. A popular tool used to determine it is the Shewhart Cycle, developed by Dr W. Edwards Deming: it consists of four steps: ***plan***, **d**o, **c**heck and **act** (PDCA):

- *Plan*: establish objectives and processes required to deliver the desired results.
- *Do*: implement the process developed.
- *Check*: monitor and evaluate the implemented process by testing the results against the predetermined objectives
- *Act*: apply actions necessary for improvement if the results require changes.

PDCA is an effective method for monitoring QA because it analyses existing conditions and methods used to provide the product or service to customers. The goal is to ensure that excellence is inherent in every component of the process. QA also helps determine whether the steps used to provide the product or service are appropriate for the time and conditions: the quality control (QC) programmes are the individual systems that are applied to the various parts of the feed manufacturing process to ensure that the directives of the QA programme are met.

The manufacture of quality feed means providing customers with efficiently manufactured products that are correctly delivered to their facilities on schedule. They should be consistent and contain the available nutrients required by animals for optimal performance. The tools needed by feed manufacturers to accomplish this are:

- Materials (feed ingredients, fuels, power, etc.).
- Machinery (feed delivery systems, feed storage equipment, feed milling equipment, etc.).
- People.
- Procedures

Quality programmes must make us of these tools in such a way as to always provide optimal diets while minimizing the content of unwanted or toxic substances. A good feed quality programme is made up of seven major components:

- Ingredient quality.
- Feed formulation.
- Process control.
- Finished feed quality.
- Control of toxic substances, including pathogenic micro-organisms.
- Admiration includes record keeping, debtors and creditors.
- Monitoring customer feedback.

QC programs are in the key elements of any QA system, which should be applied to each part of the feed manufacturing processes. A QA program needs to specify, monitor and trace all aspects of the feed manufacturing process, as well as all failures of the system (Table 17.1).

There are many goals of a QA programme and they can be summarised as follows:

- The correct feed must be delivered to the correct farm at the correct time with the correct documentation to maximise returns.
- Ingredients need to conform to the chemical, biological and physical standards that we have set (see Chapter 14).
- No contaminants or toxin should be included in the feed.
- Feed must be correctly formulated and manufactured according to this formula.
- The feed that is manufactured should have the correct physical structure.
- Feed needs to be correctly mixed and there should be little or no separation or segregation between the mixer and the farm.
- Feed should contain no substances that are harmful to the animals or to humans who consume the animal products, including toxins, drugs and microbial contamination.

Measuring performance

Fact
Feed problems may be dramatic but typically they are insidious and difficult to identify

Lack of performance can be explained by: the bird itself, the environment (management), and health and/or nutrition. Although each class of bird has unique parameters that need to be assessed, in terms of nutrition the important matter is the measurement of feed quality and consistency.

If a claim for damages arises there are two clearly defined conditions that must be met: first, it must be shown that the feed supplied to the farm was in some way defective, and that a potential feed problem was the most likely cause for loss of performance and, secondly, it is the farmer's task to quantify the losses incurred in a transparent and verifiable way.

Feed impact on performance

A number of feed-related factors have a direct impact on bird performance, some of which can be controlled if sensible measures are taken:

Feed disorders

There are very few feed (nutritional) disorders that will cause an acute loss in production and/or an increase in mortality: generally, a deficiency is characterised by a general and gradual tail off in performance. If feed (or water) is absent entirely, the performance will drop sharply and immediately: this is most noticeable in laying hens. Surprisingly, production can return to normal levels fairly quickly. Always look for patterns when considering feed problems: did the problem coincide with a feed delivery and are other house/farms similarly affected? Any form of nutrient deficiency will result in a production slump because a deficiency of any nutrient cannot be tolerated for any length of time. The production curve shown in Figure 18.1 illustrates typical deviations seen in laying flocks.

As far as broiler feed problems are concerned the situation is more complex. A gross error in the feed (10 times the ionophore level, for example) will cause an immediate drop in feed intake and growth, and an increase in mortality. The latter are usually easy to diagnose and remedy but the loss of production is more of a problem. From the response data for both protein and energy carried in Chapter 10, it can be seen that relatively large differences in feed specifications cause relatively small differences in performance – so it not always possible to know if any production drops seen are because of the feed, or some other factor. Some factors which will cause immediate production problems are:

- *Salt*: if high levels of salt are included in the diet there will be an increase in water consumption and the litter will become wet and slimy. The secondary effects of high salt intake can cause mortality and reach alarming proportions in a short space of time. When the feed is corrected, the mortality usually stops but growth and production do not return to their normal levels. When salt levels are too low, other symptoms develop: the flock becomes nervous (agitation and a distressed vocalisation), scratching as if looking for something, pecking is increased, and feathers are found in the digestive tract and the house.

- *Limestone*: if the limestone (calcium) is left out of a layer or broiler diet there is a dramatic increase in small, soft shelled eggs and after a few days, production drops sharply. There may also be increased mortality from calcium depletion (cage layer fatigue). By hand feeding oyster shell or limestone grit, the problem can be rectified reasonably quickly. In broiler rickets, soft keel bones and rubbery beaks may be seen: in this instance too much calcium is as likely to be the problem as too little (see Chapter 12).

- *Phosphorus*: too little phosphorus in the diet causes a dramatic drop in feed intake. A surplus of calcium may complicate the issue. Ensure that the correct Ca:P ratio is achieved (Chapter 10).

- *Protein*: if protein levels are too low (only grain fed for, example), there will be an increase in nervousness, peck outs, poor albumin quality and low protein level from feed analysis. In broilers there may be ruffled and broken feathers: primary feathers on the wings stick out in a characteristic manner, which is why they are sometimes termed helicopter chicks.

- *Fat*: persistently low fat levels (not in the short term) result in low body weight gains, a drop in egg size and low fat in feed analysis. Rancid fat, on the other hand, causes immediate and dramatic feed refusal – one of the few things that has this effect.

- *Additives*: almost all of the feed additives used in the feed mill will cause irretrievable damage if fed at high levels. Usually, high levels of feed additives cause feed refusal, and birds show similar signs to those observed with a sodium or protein deficiency as feed intake drops. Nicarbazin causes shell-less eggs, loss of pigment of brown eggs, lowered hatch of fertile eggs, and a positive assay of feed for nicarbazin. Monensin causes reduced feed consumption, the birds lack co-ordination and show signs of paralysis and a positive feed assay for monensin.

- *Feed Ingredients*: substandard fishmeal or other protein sources can cause a fairly dramatic drop in growth and or production but

Appendix

Vitamin and Mineral Levels

Recommended vitamin and trace mineral levels of poultry as used by SPESFEED (2012) (active per kg of feed)

		Layer	Breeder layer	Broiler starter	Broiler grower	Chick starter	Chick grower
Vitamin A	IU	8000	13000	12000	10000	10000	7500
Vitamin D_3	IU	3500	4500	3500	2000	3000	2000
Vitamin E	mg	20	40–80	40–80	30	20	10
Vitamin K	mg	3	4	4	2	2	2
Vitamin B_1	mg	0.5	3	2	2	2	2
Vitamin B_2	mg	3	8	6	5	5	5
Vitamin B_6	mg	2	4	4	3	3	3
Vitamin B_{12}	mg	0.02	0.03	0.02	0.01	0.015	0.01
Folic acid	mg	0.5	2	2.5	2	0.8	0.5
Niacin	mg	20	40	40	30	20	20
Pantothenic	mg	4	12	15	12	10	10
Choline (60%)	mg	250	600	600	500	400	250
Biotin	mg	0.05	0.25	0.075	0.05	0.05	0.05
Vitamin C	mg	0	100	0	0	0	0
Mn	mg	100	120	100	100	100	100
Zn	mg	80	100	100	100	100	100
Cu	mg	8	8	8	8	8	6
Fe	mg	70	70	70	70	70	70
I	mg	1	1	1	1	1	1
Se	mg	0.25	0.35	0.35	0.25	0.25	0.25
Co	mg	0.5	0.5	0.5	0.5	0.5	0.5

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