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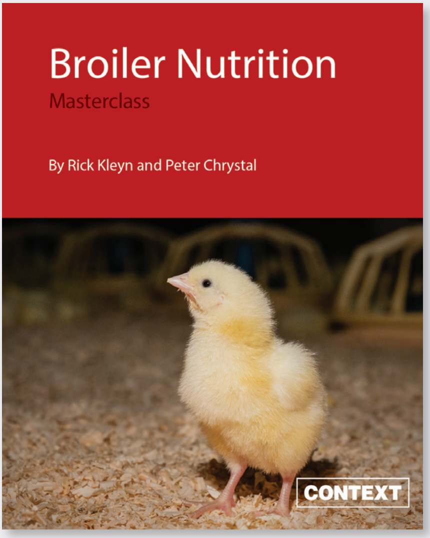



# BROILER NUTRITION: MASTERCLASS

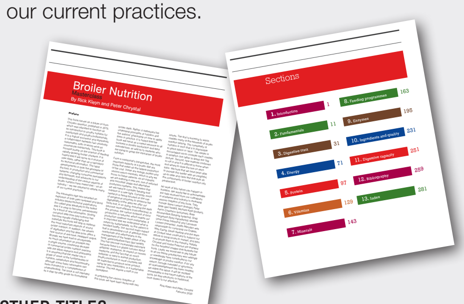
By Rick Kleyn and Peter Chrystal

**£45.00**

This title addresses the underlying principles of broiler nutrition and the authors' philosophy on how to apply them in practice.

Broiler Nutrition serves as a follow on from Chicken Nutrition, published in 2013, which was intended to function as an introduction to poultry nutrition for nutritionists and poultry professionals. It is a logical successor and represents a collaboration between two university classmates, Rick Kleyn & Peter Chrystal, both of whom work as commercial nutritionists.

This book is focused purely on the science of feeding rapidly-growing broiler chickens. The rapid developments in both the genotype of the bird; in production and commercial systems; changing consumer perceptions and demands; and advances in our understanding of the various aspects of broiler nutrition have meant that – as an industry – we are required to rethink many of our current practices.

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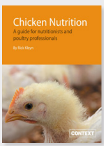
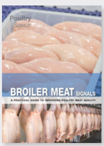
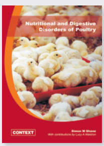
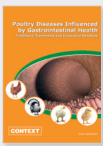
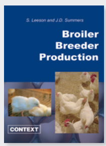
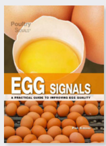


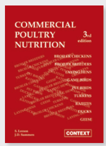



# Broiler Nutrition

## Masterclass

By Rick Kleyn and Peter Chrystal

CONTEXT PUBLICATIONS

# Broiler Nutrition

## Masterclass

By Rick Kleyn and Peter Chrystal

**Preface**

This book serves as a follow on from *Chicken Nutrition*, published in 2013, which was intended to function as an introduction to poultry nutrition for nutritionists and poultry professionals. It is a logical successor and represents a collaboration between two university classmates, both of whom work as commercial nutritionists. This book is focused purely on the science of feeding rapidly-growing broiler chickens. It is hoped that it will serve as a source of new ideas, rather than as a repository for technical information. The rapid developments in both the genotype of the bird; in production and commercial systems; changing consumer perceptions and demands; and advances in our understanding of the various aspects of broiler nutrition have meant that – as an industry – we are required to rethink many of our current practices.

The information age has heralded an explosion of both peer-reviewed and good industry-based technical publications (so-called grey literature) to the extent that it is easy to become overwhelmed by a flood of new information. Sorting out good data from bad science has become equally challenging and hopefully this book will help to address the most important aspects of sound broiler nutrition. In addition, the advent of digitisation and big data tools offers a new source of real-time, intelligent output. Broadly, we have tried to encapsulate as much information as possible into a single volume, combining decades of commercial broiler nutrition practice with the latest research and philosophy. It is assumed that the reader has a grasp of some of the fundamentals of nutrition, metabolism and biochemistry, although some basic information has been included for a completeness of understanding. The book is not intended as a step-by-step guide for formulating broiler diets. Rather, it addresses the underlying principles of nutrition and the authors' philosophy on how to apply them in practice. It is hoped that the book will serve as a useful resource to all involved in poultry production and feed manufacture, as well as to students who are trying to grasp the intricacies of broiler nutrition.

From a nutritionist's perspective, the most important aspects of a broiler diet are those that make up the largest proportion of the cost. These are energy, protein and various macro-minerals, which is why we focus on these aspects. As an industry, we are entering a new era, one of reduced anti-microbial usage and alternative production systems. This means that we will need to consider feeding and nutrition in a new light. Currently, much research is being focused on the use of exogenous enzymes to enhance the digestibility of the diets we offer our birds and, in so doing, ensuring the diets become more efficient (cost effective). In the process, the carbon footprint of food production is reduced, which makes our production systems more sustainable. It is important that we understand what is meant by sustainability, so this aspect is handled briefly. The second major aspect that is demanding a lot of attention from nutritionists and veterinarians is the management of the health status of the birds' gastrointestinal tract (gut health). This has become increasingly important because there is a global concern about antibiotic resistance, its impact on human medicine, and the fact that so much antibiotic is used in animal production. Poultry producers in most countries will be expected to produce more product, using far less medication, in a sustainable manner. This will require a shift in our paradigms.

In preparing the various chapters of this book, we have been faced with two issues. The first is knowing to which chapter many of the elements of broiler nutrition belong. The complexity of nutrition is such that it is impossible to place topics in 'silos'. The reader is encouraged not to consider each chapter in isolation, but rather to grasp the 'big picture'. Second, new material continues to roll in and it is difficult to know when and where to draw the line on each topic. We trust that we have been able to provide the reader with an insightful, up-to-date and clear text that puts all the components of broiler nutrition into perspective.

No work of this nature can happen in isolation. We would like to acknowledge the help received from our colleagues in academia and industry in reviewing various chapters of this book. They include Steve Leeson (energy), Peter Selle (gut health), Michael Kidd (protein), Aaron Cowieson (enzymes), Brett Roosendaal (feeding systems), Greg Hargreave (feed ingredients), Murtala Umar-Faruk (vitamins) and Leonardo Linares (minerals). Judith Marsden was responsible for correcting our English. Wes Ewing, Sarah Keeling and the team at Context have continued to support our efforts to bring books to market, and then to promote them to the industry. Natalie Chrystal and Andre Pretorius are thanked for the excellent images that illustrate the book. Lastly, we would like to pay tribute to all our fellow practitioners who wittingly or unwittingly have contributed to our knowledge of poultry nutrition. If for any reason, through oversight or ignorance, an acknowledgement has been omitted, we regret this lapse. It will be rectified immediately in any future editions of the book, be they electronic or traditional, once drawn to our attention.

Rick Kleyn and Peter Chrystal
February 2020

# Sections

# Gut function

**Fact**
Large, insoluble molecules of dietary origin are degraded into simple molecular components which can be absorbed by the bird.



## The digestive tract and ensuring its health

An understanding of the gastrointestinal tract (GIT) or gut, as it is commonly known, is imperative for the nutritionist. Maintaining a healthy GIT tract is one of the core issues in broiler nutrition as it impacts on bird health, field performance (nutrient utilisation), bird welfare and ultimately profitability. Not only is the gut responsible for assimilating the various dietary components and ensuring their absorption, it is also the most important route of entry for antigens such as food proteins, natural toxins and invading pathogens. The gut-associated lymphoid tissue (GALT) is the largest lymphoid organ in the body. Klassing (2016) states that the "anatomy and function of the gut is brought about by the need to compromise between food digestion and absorption and protection against pathogens", which perfectly describes the complexity of the issue.

Large, insoluble molecules contained in the diet 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 is termed absorption. The coalition of these processes is central to the theme of nutrition – a diet with an ideal nutrient profile and optimal palatability is of no nutritional benefit if it cannot be broken down and assimilated.

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 instigate chemical degradation. The gut microbiota plays a role in the maintenance of homeostasis in its contribution to digestion and absorption (it produces enzymes). It also modulates the immune system by preventing mucosal infections and contributes to energy metabolism (Celi, 2018). Bacteria resident in the GIT produce enzymes capable of chemical digestion, which form an important part of the digestive system. Rather than being a luminal event, digestion occurs largely at the intestinal surface near the sites of absorption (Moughan *et al.*, 2018).

Various interacting components impact on gut health and nutrient uptake. Importantly, gut health begins at the cellular level (enterocytes and microbiota) – cellular interactions influence tissue structure and physiology (Iseri, 2016). The first and most obvious of these components is the structure of the GIT itself. Avian species have a relatively short digestive tract, which is believed to be an adaptation for flight. Granivores, such as chickens (*Gallus gallus*), have special adaptations for a grain-based diet (Klassing, 1998). The second component that impacts on gut function is the physical environment that exists within the lumen. This environment can include temperature (although it remains fairly constant), pH, the ionic balance and viscosity. The makeup and status of the microbiota (which will be discussed extensively below) form the third component of gut function. Lastly, the diet – in terms of its texture, nutrient and ingredient content – impacts on gut function. In the majority of cases, the interaction among these components is synergistic, but antagonisms do occur, often with an undesirable outcome.

## The structure of the GIT

The wall of the bird's GIT comprises four distinct layers that are common throughout the gut – the mucosa, a submucosa, a muscular layer and the serosa. Although a single entity, the GIT differs in form and function from the mouth (proximal end) to the cloaca (distal end). From a nutritional perspective, we need to concern ourselves with both the macrostructure and microstructure of the GIT. It is not the intention to describe the anatomy and physiology of the gut here, as these aspects are well described elsewhere. Table 3.1 carries an overview of gut form and function, while Table 3.2 gives a summary of the fate of the various feed components as they pass through the GIT. From gut health and nutrient absorptive points of view, the most important aspects at the macro levels are those of gizzard form and function and the length of the intestine. From a micro perspective, we need to focus on the well-being of the gut lining.

In order to function optimally, the avian gut exhibits a unique feature: vigorous gut refluxes (reverse peristalsis), which are regarded as normal and an adaptation to compensate for a short intestine.

# The macrostructure of the gut

**Fact**
The gizzard is regarded as the pacemaker of the gut. A healthy, well-developed gizzard is central to good gut health.

These refluxes serve to re-expose the digesta to gastric secretions, mix the digesta with enzymes, enhance nutrient absorption and discourage microbial proliferation. Reflux occurs in three regions of the gut (Ferket *et al.*, 2002):

- The gastric reflux moves digesta from the gizzard back into the proventriculus, allowing ingested feed to be ground repeatedly and exposed to the enzymes and acid of the proventriculus. Once fine enough (< 1 mm), the feed leaves the gizzard.
- The second reflux moves chime from the duodenum and jejunum back into the gastric area, about three times every hour. This process increases as the fat content of the diet rises and decreases with a higher fibre content. The characteristic yellow colour of the gizzard lining is due to the bile contained in the chime.
- A nearly continuous reflux between the cloaca and the caecal tonsils also occurs. Water is resorbed in the caeca, and some of the waste material in the chime is converted into either microbial biomass or volatile fatty acids by the caecal microflora.

The bird's unique ability to carry out reflux or reverse peristalsis may have negative consequences. If fasting (a reduction in normal access to feed) should take place for any reason, reflux will occur at higher than normal levels. This has a twofold effect. First, waste nitrogen (uric acid) is moved from the cloaca back to the caecum, where it may be used as a N source by the proteolytic and other bacteria that reside there. Second, microorganisms are transferred from the caeca to the ileum, where they have the potential to cause dysbacteriosis and inhibit nutrient uptake (Leeson, 2018). Many normal aspects of broiler management lead to fasting. The most obvious is a feed outage, but other causes are often overlooked. These include the pressure brought to bear on feed intakes through the use of high stocking densities; changes to the feed shape, hardness or colour (neophobia); using long dark periods during the production cycle; and feed withdrawal during thinning or prior to processing.

### The macrostructure of the GIT

While there are major differences between avian species in terms of GIT form and function (Klassing, 1998), the areas of importance for the poultry nutritionist are the length of the digestive tract and the health, size and functional integrity of the gizzard. The gizzard or muscular stomach of grain-eaters is characterised by massive muscular development and a lining with a thick corrugated layer of horny material (keratinoid-like). In species that eat soft food, it is less muscular and may be long, saccular and distensible. The main function of the gizzard is to grind the grain (seeds) into a fine paste and, through rhythmic contractions, pass it into the duodenum. The muscles of the gizzard effect both rotary and crushing movement on contraction, and these contractions occur four or five times per minute. On contraction, fine particles move into the duodenum (< 1. 5 mm), while coarse particles move back to the proventriculus. Some particles move from the duodenum back to the gizzard (reflux) when the muscles are relaxed at the end of a contraction. Interestingly, the sizes of particles leaving the gizzard are smaller (finer) when diets that contain large amounts of structural component are fed (see below).

The gizzard is regarded as the 'pacemaker' of normal gut motility, particularly in terms of gut refluxes. The way in which the gizzard develops and functions is important since this governs many of the physiological aspects of the GIT (Mateos *et al.*, 2012). These include the following:

- the regulation of GIT motility
- the control of digesta flow and gastroduodenal refluxes
- the enhancement of digestive secretions, including hydrochloric acid (HCl), bile acid and endogenous enzymes
- the synchronisation of the digestive and absorptive processes.

It is presumed that the consequences of a larger gizzard are an increase in the retention time of the digesta in the gizzard and an increase in the passage rate through the entire GIT. When structural components, such as whole or coarsely-ground cereals, and fibrous materials, such as oat hulls, sunflower hulls, wood shavings and sugarcane bagasse, are added to the diet, the pH of the gizzard contents decreases by between 0.2 and 1.2 units. Svihus (2018) suggests a simple test to assess if a fibre

# Energy

**Fact**
**Energy is 'partitioned' to aid our understanding of energy utilisation, although this is likely an oversimplification.**

### Energy and broiler nutrition

Feed makes up 70% of the cost of broiler production and the energy component of feed represents about 60% of the total feed cost. Thus, the energy provided in the diet of a broiler chicken represents about 40% of the cost of production, making feed energy the single largest input. This section starts with a basic discussion on energy and energy systems and ends with the practical application of these systems in broiler production. Energy forms the cornerstone of feed formulation and hence applied poultry nutrition. The accurate measurement of energy values for ingredients is vital for formulation systems in poultry (Wu *et al.*, 2019).

Energy is often described as the 'fire of life'. In the physical sciences, energy is designated as work or anything that can be converted into work. Nutritionists deal with the conversion of chemical energy stored in food molecules into kinetic energy through the chemical reactions of metabolism, work and heat. In broilers, feed energy is particularly important because, in diets that contain adequate amounts of all required nutrients, the efficiency of food utilisation is greatly influenced by the energy content of the diet.

All energy in a bird's body evolves via the Krebs cycle (also known as the *citric acid cycle*). This is the metabolic pathway involved in the chemical conversion of carbohydrates, fats and proteins into carbon dioxide and water in order to generate a form of usable energy. 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. When the energy-rich chemical bonds of ATP split, energy is transferred to other molecules, creating the less energy rich molecule adenosine diphosphate (ADP). ATP can later be regenerated from ADP, again via the Krebs's cycle. In order to construct biomass, the bird first converts energy from a fuel source such as glucose into the chemical energy of ATP. It then uses this chemical energy to build, step by step, the chemical bonds of the biomass, making ATP the crucial middleman in energy transfer (Wagner, 2014).

Birds are homoiothermic, which means that they maintain a relatively constant deep body temperature. Energy plays a role in the maintenance of body temperature as well as in 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 the synthesis of products

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 that is capable of maintaining a constant body composition (Labier *et al.*, 1994).

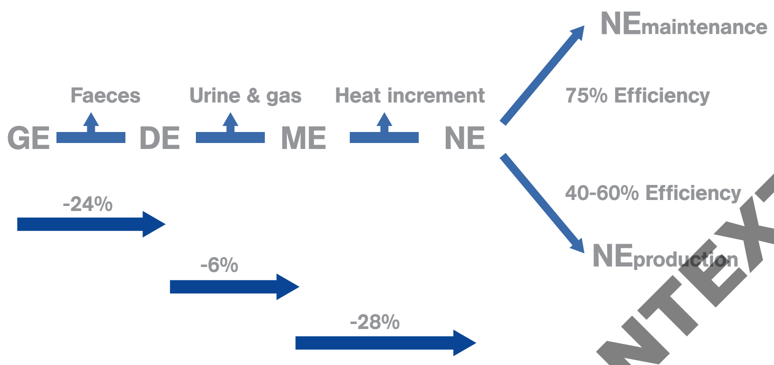
### Partitioning of energy

The energy consumed by the bird can be partitioned into different categories of use. As mentioned above, this thinking may not correspond to the true biological situation; however, it is a widely-used model that has allowed us to advance our understanding of energy metabolism.

The most simplistic measurement of energy is known as *gross energy* (GE), which is the total amount of energy contained within food, as illustrated in Figure 4.1. GE is simply the amount of heat produced when food is burned completely, yielding water, carbon dioxide and nitrogen, whereas *digestible 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 in the bird's excreta also include those of urinary origin, which range from 5–15%. 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 *metabolisable energy* (ME). Some of the energy contained in the faeces

# Partitioning of energy

**Fact**
To better quantify true dietary energy, losses in faeces, urine and from heat given off must be considered.




**Note:** Estimates of energy losses and efficiencies from Labier et al., 1994 and Chocht, 2017.

**Figure 4.1** Scheme of the partition and flux of dietary energy in birds

and urine is endogenous (from within the bird), and it needs to be accounted for – this adjustment gives rise to *true metabolisable energy* (TME). The most common system in use commercially, in poultry, is the $AME_n$ system. This is simply apparent metabolisable energy (AME) adjusted for zero nitrogen retention. Confusingly, these terms are often considered to be synonymous, and the values derived are used interchangeably. The TME system is theoretically a more accurate measure of ME (see the explanation later in this chapter), but it is determined using individual birds and variances may be large. The reason for this is twofold: first, there are comprehensive tables as well as equations to determine $AME_n$ and second, most research in broilers has made use of the $AME_n$ system.

Not all the ME is available for the bird to use. The uptake of energy from the gut is followed by an increase in heat production by the bird, referred to as the heat increment (HI) of the diet. The HI is associated with the digestion and absorption of food. After deducting the HI from the ME, the remainder is the *net energy* (NE) which is utilised more efficiently for the purpose of maintenance rather than production. NE represents the amount of energy that the bird actually has available to perform work. The HI, as a percentage of the dietary ME, depends largely on the composition of the feed: the ingestion of excess protein causes a HI equivalent to 30% of the ME of the protein; carbohydrates produce 10–15% and fats may produce only 2–5%. Under low temperatures, the HI may in part meet the energy costs of adaptive thermogenesis. Under normal conditions, however, birds generally have difficulty in dissipating heat, thereby preventing an increase in body temperature. This is particularly true for rapidly growing broilers.

A number of feed characteristics (physico-chemical composition) or technological factors such as particle size, pelleting and the addition of feed enzymes have an impact on the energy content of the diet. In addition, specific factors related to birds affect the energy contribution of any diet. These include:

- The bodyweight of the bird and its relative rate of growth.
- The bird's physiological stage, for example sexual maturity, or indeed sex for that matter.
- Genotype, in as far as it relates to carcass composition (fat: lean).
- The feed intake that is achieved in practice.
- Gut development, as influenced by feed structure and ingredient content.

The energy content of feed is usually measured in calories, a calorie being the amount of heat necessary to raise the temperature of 1 g of water by 1°C. Under the SI system, the joule (normally expressed as megajoule or MJ) is used rather than the calorie (normally expressed as kilocalorie or kcal). In this book, it was decided that all data would be shown in kcal. The following conversion factors are used:

Equation 4.1 Conversion of joules to calories

$$1\text{ MJ} = 1000\text{ kJ} = 1\ 000\ 000\text{ J} = 239\ 000\text{ cal} = 239.0\text{ kcal}$$

$$1\text{ kcal} = 4184\text{ J} = 4.184\text{ kJ} = 0.004184\text{ MJ}$$

### Practical energy systems

Scientific nutrition is only possible when the nutritionist knows the energy

# Crude protein

**Fact**
All protein contains nitrogen, but not all nitrogen is derived from protein. Crude protein is only a measure of the N content.

**Protein and broiler nutrition**

Protein is of special significance to most nutritionists because of both its high cost and the fact that meat and egg production revolve around the conversion of feed protein into animal protein. In addition, most tissues throughout the body are made up almost entirely of protein; – structural protein is found in bone, muscle and skin. Protein also plays a regulatory role in metabolism as most enzymes are proteins. In poultry, one-fifth to one-quarter of the fat-free body of birds is protein, of which a fair proportion can be found in the feathers. Breast muscles represent approximately 7% of the total body protein and are responsive to dietary amino acid (AA) concentrations, particularly lysine (Cemin *et al.*, 2017).

Proteins consist of long chains of AA joined in a definite and characteristic manner. The linkages within these chains are called peptide bonds, which are strong covalent bonds. The simplicity of protein lies in the fact that it comprises chains of AA. Protein folds into intricate three-dimensional shapes (most exist as an alpha helix or in spiral forms) that wobble and vibrate. To appreciate their exact nature, both their AA sequence and physical form and properties need to be understood. We have yet to comprehend or be able to predict the form and movement of proteins from the underlying AA strings, so complex and subtle are the rules guiding these aspects. Our understanding is further complicated because proteins rarely function on their own; rather, they operate like the workers in a swarm of bees (Wagner, 2014).

Proteins are grouped according to their solubility, structure and function. AA in the bird are deposited in fixed ratios into body tissue; there is a requirement for the constituent AA rather than for protein *per se* (Alhotan & Pesti, 2016). The task of the nutritionist is to ensure the provision of adequate levels of available nitrogen and AA. These are necessary for optimum protein anabolism (synthesis) in the individual at each stage of production. This involves determining the exact combinations of the various AA to be obtained from the feed ingredients and then meeting the bird's requirements from those components.

Protein is usually expressed as crude protein (CP). This value is determined by multiplying the percentage of nitrogen (N) in the feed by a factor of 6.25 (protein comprises 16% N), which has been in use for over 150 years. The proximate analysis for the routine description of animal feedstuffs was devised by Henneberg and Stohmann of the Weende Experiment Station in Germany in 1860. It is often referred to as the Weende System. While it was principally devised to separate carbohydrates into two broad classifications of crude fibre and nitrogen-free extract, it also included the crude protein calculation from N analysis. In 1883, Kjeldahl published the method he had developed for analysing N while working as the head of chemistry for Carlsberg Brewery. This method is still widely in use today. Crude protein includes not only protein but also nitrogen, present in a non-protein form. The measurement of N is comparatively simple – hence, crude protein is a widely used measure and forms the basis of most quality control programmes. The true conversion factors of some common feed and food ingredients are shown in Table 5.1 (McDonald *et al.*, 2010). Although fundamentally unsound, the use of an average conversion factor of 6.25 for all food proteins is justified in practice. The reason is that the protein requirements of farm animals, expressed in terms of N x 6.25, are the actual requirements for N and not for protein *per se* (McDonald *et al.*, 2010). However, the use of crude protein as a variable in the calculation of energy (see Chapter 4) should perhaps be reconsidered.

Therefore, it is the true protein in which we are interested. True protein is composed only of AA, which are compounds that contain carbon, hydrogen and nitrogen; some also contain sulphur and/or phosphorus. There are 22 known AA, which have been described as the letters of the alphabet used by nature to construct words and sentences. More detail is covered later in the chapter under AA and crude protein which shows slightly different values compared to those in Table 5.1 (Alhotan & Pesti, 2016). All proteins, whether feathers, muscles or enzymes, comprise a complex combination of these AA.

Any improvements in the efficiency of protein accretion, with a concomitant reduction in nitrogen excretion into the environment, will only be achieved by more closely matching the available AA content of the diet with the bird's AA requirements for maintenance and production. In order

# Nutritional strategy

**Fact**
Regardless of the energy and nutrient content of a broiler diet, achieving high feed intakes is the core of successful production.

Our objective as commercial nutritionists is to implement feeding strategies that allow for the consumption of nutrients and energy throughout the production cycle. Clearly, there are differences between production systems, including the availability and cost of ingredients, the housing system used, and the product required (the marketing mix). Added to this are practicalities such as feed mill design, logistics and commercial pressures. The primary breeding companies publish recommendations for each of their genotypes. While performance using these recommendations will be adequate, the recommendations may not always be optimal. It is unrealistic to expect a single recommendation to suit all countries, or indeed, all companies.

The cornerstone of good broiler performance is the achievement of good feed intakes. As nutritionists and producers, we have come to realise that a sound start leads to a flock with good uniformity, a well-developed gastrointestinal tract (GIT) and good musculature, all of which have an impact on the field performance of the birds. The management of feeding programmes on farm is important. We strive to balance the bird's absolute requirements with practicality. The bottom line, however, is that all good feeding programmes should be as simple as possible, but no simpler (to paraphrase Albert Einstein). They should also generate maximum returns. This chapter will deal with these aspects, as well as stocking density and litter management which are closely linked to nutrition.

## Feed texture and feed intake

Feed form is the link between the nutritionist and the farm. The texture of the diet plays a critical role in determining feed intake and ultimate field performance. The manner in which ingredients are ground and the coarseness of that grind impact on bird physiology and change the efficiency of utilisation. Pelleting contributes the equivalent of 187 kcal/kg of $AME_n$ to the diet when pellet quality is perfect (100%), but this effect declines in a curvilinear manner when pellet quality falls (McKinney & Teeter, 2004). As a rule of thumb, each 1% fat added at the mixer results in a 10% increase in the level of fines. For every 10% of fines in the diet, AME is reduced by 20 kcal/kg (Leeson, 2018). In addition, the energy and nutrient content of the diet may impact on feed intake. All these aspects will be discussed in this chapter.

Feed texture comprises two elements: microstructure, which describes particle size and uniformity; and macrostructure, which describes pellet size, hardness and quality. These aspects are linked because all feed components are first reduced to particles before being pelleted. In broilers, feed is not retained in the gizzard for any significant period. The gizzard acts as a 'transit' rather than a grinding organ, thereby reducing exposure to the digestive enzymes of the proventriculus. Nutrient digestibility decreases when small particles are fed because they cause gizzard atrophy and discrete intestinal hypertrophy (caused by bacterial fermentation). An anomaly exists in that the finer feed particles are, the less efficient the gizzard becomes (see Chapter 3); thus, larger particles pass into the proximal small intestine, retarding digestion. The role of poorly digested feed particles in the upper intestinal tract is unknown; however, they may play a role in aberrant bacterial populations such as *E. coli.*

Naderinejad *et al.* (2015) illustrated many of these aspects (Table 8.1). When mash is fed, fine milling reduces gizzard size and possibly feed intake (but not significantly). Pelleted diets improve growth and FCR, but gizzard size is reduced. Pelleting decreases the apparent ileal nitrogen digestibility but increases fat digestibility. Increasing the mash particle size improves starch digestibility and AME in pelleted diets, while it has no effect in mash diets. Coarse grinding of maize, even in pelleted diets, enhances the energy utilisation of the diet. Broadly, coarse grinding boosts gizzard development and functionality, which benefits nutrient and energy utilisation.

## The microstructure of the diet

Particle size is commonly reduced using hammer and roller mills. Hammer mills impact on slow-moving ingredients with a set of hammers operating at high speed, generally producing spherical-shaped particles with a polished surface. Size distribution varies widely around the geometric mean, with some large-sized and many small-sized particles occurring. Roller mills reduce size through a compression force between rotating roll pairs, producing more uniform particle size distribution with a low proportion of fine materials (Koch, 1996). Peisker (2011) reports

# Enzyme structure

**Fact**
**All enzymes are complex 3D protein molecules whose structure (shape) is more important than their AA makeup.**

The effective use of exogenous enzymes in poultry diets represents a significant technology in poultry feeding. Exogenous enzymes lead to an improvement in the utilisation of the nutrient and energy contents of the diet, a reduction in the environmental impact of animal production, and an improvement in intestinal health and gut function. On farm, their use may lead to improvements in litter quality and bird welfare. Much foundational knowledge of enzymes (spearheaded by work on phytase) has been generated during the last two or three decades (Cowieson & Roos, 2016). This helps commercial nutritionists to understand the different classes of enzymes available, their mode of action, how they interact with each other, and the other ingredients or additives used in the diet.

Chemically, enzymes are proteins with a complex three-dimensional molecular structure. They are highly effective biological catalysts, capable of accelerating chemical reactions millions of times over and then reverting to their original state. Enzymes have a high substrate-specificity. They break down substrates at specific reaction sites, determined by the shape of the molecules involved, their charge (remember, similar charges repel each other), and the fact that they vibrate and shake in a specific manner. The degree of vibration is temperature-dependent. If the temperature is too low, then the vibrations are inadequate for the catalytic function to occur. At high temperatures the protein molecules unravel, and the all-important shape is lost. Interestingly, enzymes with similar folds, catalysing the same reaction, may share less than 20% of their amino acids (Wagner, 2014). The ‘lock and key’ analogy is often used to explain how enzymes function. It is possible for a number of enzymes to catabolise a single substrate, or even for a specific enzyme to catabolise several substrates (protease, for example can break down a wide range of substrates), but mostly each substrate requires a specific enzyme.

The bulk of digestive activity in the chicken gut occurs in the crop, gizzard, proventriculus and small intestine, with varying amounts of material passing on undigested into the caecum. The endogenous nutrient flow in the intestine represents an important part of the inefficiency of digestion. 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 (GIT). This occurs largely through the release of oligosaccharides from the cell walls of plant material, but undigested protein fractions cannot be ignored. 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 in which the caecum is undeveloped. For this reason, in relation to enzymes, the measurement of ileal digestibility (ID) is important.

It is essential to appreciate that metabolism involves a complex web of complementary steps, rather than a few simple chemical reactions. Each of these steps requires a catalyst (enzyme) to take place. These enzymes are mostly produced endogenously by the bird itself, but many of the processes of digestion are performed by enzymes synthesised by the gut microflora. The enzymes that we add to the diet exogenously only form a small part of the overall process.

Clearly, enzymes need to be chosen on the basis of the substrates that occur in particular poultry diets and on their ability to survive in the harsh environment of the GIT. Several conditions need to be met for an enzyme to act. These include sufficient moisture and suitable temperature, pH, enzyme concentration and substrate concentration (Ravindran, 2013). Moisture is essential for the mobility of the enzyme and the solubility of the substrate and enzyme. In general, enzyme activity increases up to 40°C and then sharply declines due to the loss of structure (denaturing) of the protein molecule, rendering the enzyme inactive. Most enzymes are denatured in low and/or high-pH environments, with the optimum being at around pH 4–6. The reaction rate of enzymes increases with raised concentrations because there are more chemically active sites available. This will continue until no more enzyme substrate complexes can be formed. The rate of reaction also increases with elevated substrate concentration.

For any enzyme to be effective, it requires a substrate to act on that should be in a specific physical and/or chemical form. Birds are not fed substrates, but rather ingredients with substrates contained within complex matrices (the cell wall). Undigested substrate, passing through the digestive tract, becomes the target