The Encyclopedia of Farm Animal Nutrition

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their enzyme systems for the digestion of solid food than their slower-growing contemporaries that have been forced to augment their mother's milk with solid food. (JJR)

Weende analysis Analysis of carbohydrates was, for many decades, accomplished by proximate analysis procedures developed at the Weende Experiment Station in Germany over 100 years ago and hence frequently referred to as Weende analysis. The procedure divided carbohydrates into soluble (nitrogen-free extract) and insoluble (crude fibre) fractions, the former being the digestible portion and the latter the less digestible portion. Crude fibre was determined by boiling the sample in weak acid and then in weak alkali. The residue so obtained was dried and the loss from it, upon ignition, was the crude fibre. Nitrogen-free extract was determined by difference, being the weight of material remaining after subtracting from the weight of starting material the values previously obtained for crude fibre, crude protein, ether extract and ash. Consequently, Weende analysis entailed a proximate analysis of the sample under test. Weende analysis served nutritionists well for over a century in that it enabled feeds to be separated into broad categories such as roughages with high crude fibre and concentrates with low crude fibre. However, the digestibility of crude fibre may sometimes be higher than that of nitrogen-free extract. Consequently, crude fibre does not separate carbohydrates into readily digestible and less readily digestible portions. A more recent method uses detergent extraction to separate carbohydrate fractions. (CBC)

See also: Acid detergent fibre; Crude fibre; Neutral-detergent fibre; Nitrogen-free extractives; Proximate analysis of foods

Weir formula A formula for calculating heat production from respiratory exchange

Wet season In many parts of the world, especially in the tropics and subtropics, defined wet and dry seasons are normal. In most regions wet seasons occur in the warmer months, resulting in optimum conditions for plant growth. In equatorial regions two rainy seasons per year are not uncommon.

In the wet season, where grazing is available livestock generally have sufficient natural vegetation, which is high in protein and low in fibre, for their current needs and recovery from dry-season underfeeding. Where grazing is not available, animals are often stall-fed or tethered during the rains, to protect cropping areas. Because demands for labour are high at this time, cut-and-carry is often inadequate. For animals in these conditions, wet-season feeding stress is possible. The start of the rains is followed by ploughing and planting. Where land pressure is high and rainfall adequate, two arable crops are needed every year (e.g. wheat; rice). In the arid and semi-arid regions rainfall tends to be variable, in both amount and pattern of distribution, often threatening production of stable foods. When available, irrigation expands the growing season. (TS)

See also: Rainy season

Wheat Wheat is one of the oldest and most important members of the *Gramineae* (grass) family cultivated for its grain. On a worldwide basis, a greater area is devoted to growing wheat than to any other food crop. The world's largest producer is China, with an estimated annual yield of almost 100 million tonnes. Other leading producers include the USA, Russia, India, Ukraine, France, Canada, Kazakhstan and Turkey.

The wheat plant has long, slender leaves, generally hollow stems and heads with varying numbers of flowers, ranging from 20 to 100. The flowers are grouped together in spikelets, each having two to six flowers. In most

Creatinine The anhydride of creatine and the end-product of creatine breakdown (by loss of H_2O and P_i) in muscle followed by total excretion by the kidney. Creatinine excretion is related to muscle mass and thought to be constant over 24 h. For this reason it is used in clinical settings as a basis to calculate total 24 h urine excretion from a single urine sample. (NJB)

Creep feeding The feeding of supplementary diet to suckling animals, most commonly applied to piglets. This practice allows piglets to compensate for any deficiencies in sow milk production and become gradually accustomed to eating solid food; it also induces development of the digestive enzymes necessary for breakdown of complex carbohydrates on which they will be dependent for energy after weaning. Because of the high nutritional quality of sow milk, piglets generally consume very little solid food before 3 weeks of age. However, if weaned later than this, creep feed will be consumed increasingly as milk supply declines and becomes inadequate. Thus, whilst creep feeding of piglets weaned at 3 weeks of age or younger is generally of little benefit, piglets weaned at later ages will show increased growth rate both before and after weaning.

There are large and unexplained differences, both within and between litters, in the quantity of creep feed consumed. To achieve good intake, it is necessary to feed a highly digestible and palatable diet containing a high proportion of milk products. Intake is further encouraged by freshness of feed, achieved by feeding little and often, and by presentation in a feeder in which the diet is easily visible and accessible. (SAE)

See also: Piglets

Crop Synonymous with ingluvies, a thin-walled extension of the oesophagus of birds, located to the right side of the neck. When full of food, the crop is easily palpated. Its function is to store ingested food when the gizzard is full. Movement of its muscular walls allows the food to soften and swell before chemical digestion in the proventriculus. The crops of well-fed birds are rarely empty. (MMax)

Crop fractionation: see Fractionation, green-crop

Crop residues: see Stover; Straw; Wine-making residues. *See also:* individual crop

Cruciferae **Cabbage** (*Brassica*) family, consisting of some 300 genera and 3000 species, including cabbage, sea cabbage, **kale**, Brussels sprouts, **cauliflower**, broccoli, **kohlrabi**, **oilseed rape**, **mustard**, radish, **crambe** and related weeds and herbs. (JKM)

Crude fibre A collective term for complex carbohydrates, mainly celluloses and lignin, that are insoluble in water, dilute acid and dilute alkali. There are various ways of estimating fibre, each of which defines a somewhat different fraction. In the proximate analysis of foods (the Weende system) crude fibre is measured by digesting a feed sample successively with dilute acid (1.25% sulphuric acid) and dilute alkali (1.25% sodium hydroxide). Soluble components such as sugars, starch, fat and protein are thereby removed, leaving an insoluble residue. The weight loss on ignition of this dried residue represents crude fibre. Other methods for examining complex, insoluble carbohydrate in feeds have involved the use of a neutral detergent that removes soluble material and leaves behind cellulose, hemicellulose and lignin (neutral detergent fibre). Subsequent boiling with an acid detergent hydrolyses the hemicellulose, leaving behind cellulose and lignin (acid detergent fibre). Oxidation of lignin with potassium permanganate leaves cellulose and ash. Ignition of this residue gives a value for cellulose. (CBC)

Crude protein The crude protein content of a feed, or other biological material, is defined as its N content multiplied by the factor 6.25. The value of this factor is based on the observation that N occurs in different proteins in a fairly constant proportion, 16% on average. In determining the crude protein content of a material its N content is measured, usually by a Kjeldahl procedure. Crude protein is not an exact measure of the protein content of a material, because different proteins have different proportions of amino acids and their N content may thus vary a little from 16%, and also because not all the N present in biological materials is in the form of protein. Compounds, other than protein, that contain N are generally classed as non-protein N. These compounds are diverse in structure and function; they include free amino acids, amines, amides, purines, pyrimidines and nitrogenous lipids. The level of non-protein N in most animal feeds and tissues is very small compared with the level of protein N. In addition, much of the non-protein N in feeds may be utilized by animals for the synthesis of non-essential amino acids or, in the case of ruminants especially, for the synthesis of microbial protein. Although the use of an average conversion factor of 6.25 does not lead to an exact value, the protein content of feeds and the protein requirements of farm animals are invariably expressed in this way. (CBC)

See also: Kjeldahl; True protein

Crushing Crushing usually refers to the pressing of oilseeds in order to extract their oil. Oil-rich vegetable seeds, such as **soybean** (20% oil), **oilseed rape** (46%) and **linseed** (39%), are first dehulled and then crushed between rollers or in a screw press. The resultant oil is collected, further purified and used for other purposes. The remaining meal is known as expeller or cake and still contains approximately 10% oil. This can either be used as an animal feed or, more commonly, it undergoes further chemical treatment to extract the remaining oil.

Crushing can also refer to rolling, especially of cereals such as oats and barley, to prepare them for feeding. This is also known as 'bruising'. (MG)

Crustacean feeding Fisheries biologists have always had some interest in the type of food needed by large crustaceans such as lobster, shrimp or prawn. These animals were known to thrive on a variety of molluscs, worms and other invertebrates found in aquatic environments. Aquaculturists interested in culturing crustaceans used this knowledge to maintain crustaceans in the laboratory and, in the case of shrimp and the prawn, to produce limited numbers in ponds where abundant supplies of natural feeds were present. However, in the 1970s as culturists became interested in intensifying the production of crustaceans, natural feeds quickly became a limiting factor. The lack of suitable formulated feeds and, more importantly, the paucity of information on what was needed to make formulated diets for crustaceans, stimulated research interests in aquaculture centres throughout the world.

The initial flurry of nutritional research encompassed a fairly diverse group of crustaceans, including lobster, shrimp, the freshwater prawn and crayfish but today this has narrowed to focus primarily on marine shrimp. Commercial pond production of marine shrimp grew exponentially during the 1980s to become a significant industry in a number of tropical countries. Early culturists almost always used an extensive approach that depended on enriching the natural productivity of the pond ecosystems to provide food for the shrimp. However, intensification in response to continuing market demand necessitated the direct addition of feeds to increase production per pond area. As a consequence, crustacean nutritional studies became centred on providing information applicable to marine shrimp and the need to formulate artificial feeds for their culture.

Culturing of marine shrimp and many other crustaceans is made more difficult by the fact that they have complicated life cycles, with each stage requiring a distinct type of feed.

Such a life cycle is not unusual for crustaceans of aquaculture interest. The nauplius sustains itself on stored yolk but the rest of the hatchery (sub-juvenile) stages have distinctive requirements. Protozoea feed exclusively on algae or other similar-sized microscopic feedstuffs. Increasingly, specific species of algae are cultured to provide an optimum feed for the protozoea stage. After a few days the protozoea stage moults into a mysis stage that requires zooplankton rather than phytoplankton for continuing growth. The shrimp industry is heavily dependent on feeding brine-shrimp nauplii that have been freshly hatched from cysts to support mysis production. Finally, as the mysis stage moults into the megalopa (or post-larva as the industry refers to it) larger types of zooplankton are needed. It is only at this last stage that formulated rations are exclusively used.

human and animal food. The cereals most commonly cultivated are barley (*Hordeum sativum*), maize (*Zea mays*), oats (*Avena sativa*), wheat (*Triticum aestivum*), rice (*Oryza sativa*), rye (*Secale cereale*), triticale (hybrid of wheat and rye) and sorghum (*Sorghum bicolor*). Most of the proteins of cereal grains are found in the endosperm (e.g. 72% in wheat) and their overall content is influenced by a range of factors, including species, variety, fertilizer application, soil fertility and climate. Protein concentrations are typically 97–160 g kg^{-1} dry matter (DM) for barley and wheat but lower for maize and oats. Cereal proteins are generally deficient in essential amino acids, especially lysine. In all cereal species the starch-rich endosperm is the most important fraction, both nutritionally and economically. The starch comprises amylose and amylopectin and their ratio determines the quality of the starch. The cell wall content (as NDF) ranges from about 124 for wheat to 310 g kg^{-1} DM for oats. The animal feed industry represents a major market for cereal grains, which contribute a large proportion of the energy supply to pigs, poultry and young ruminants. Generally cereals make a lower contribution to the diets of ruminants. Cereal by-products arise from a number of industries, including milling, brewing, distilling and starch manufacture. Cereal by-products play an important role in the diets of ruminants owing to their greater capacity to degrade fibre. (ED)

Further reading

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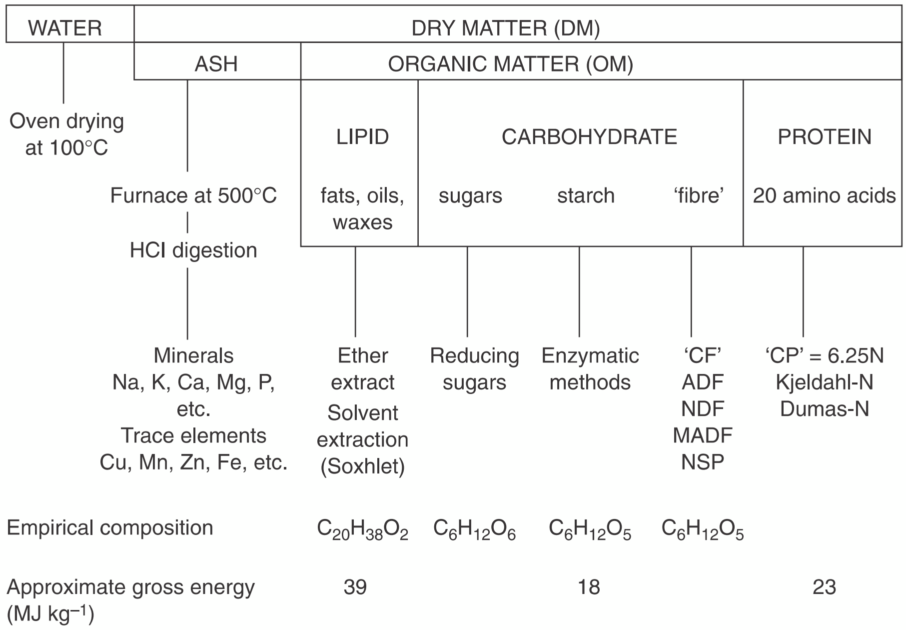
Ceruloplasmin The US spelling of **caeruloplasmin**.

Cetoleic acid *cis*-11-Docosenoic acid, $CH_3{\cdot}(CH_2)_9{\cdot}HC{=}CH{\cdot}(CH_2)_9{\cdot}COOH$, molecular weight 338.6, shorthand designation 22:1 n-11, a long-chain 22-carbon monounsaturated fatty acid found in the oils of cetaceans (whale and dolphins) and fish. (NJB)

Chelate An association of two or more independently existing molecules or ionic species to form a heterocyclic ring compound. The new compound formed by this association exhibits chemical and physical characteristics distinct from those of either parent compound or element. In biological systems chelates typically involve a metal cation such as iron, cobalt, copper, magnesium or zinc bound to an organic compound via oxygen, nitrogen or sulphur elements. Examples include chelates such as haemoglobin, chlorophyll and vitamin B_{12}. Ligand bonds vary from relatively stable covalent bonds to very unstable, highly ionic bonds between molecules. In animal nutrition, chelating compounds are used to sequester or stabilize metal ions. A common chelating agent is ethylenediaminetetraacetic acid (EDTA). (TDC)

Chemical composition Descriptions of the chemical composition of foods (and of plant and animal tissues) are largely based on the proximate analysis scheme introduced by Henneberg and Stohman at the Weende Institute in Germany in about 1840. In this scheme (see figure) food is considered to be composed of water and dry matter. The dry matter consists of an inorganic fraction (minerals and trace elements), represented practically as ash, and an organic matter fraction represented by the mass lost on combustion. The organic matter in turn is composed of three classes of chemical compounds: lipids, carbohydrates and proteins.

The lipid consists of fats, oils and waxes, which are mainly long-hydrocarbon-chain glycerol triesters $(\text{-}CH_2\text{-})_n$. They are hydrophobic and insoluble in water but soluble in non-polar organic solvents. Total lipid can be determined by a percolating extraction with solvent in a Soxhlet extractor. Originally, diethyl ether was used and total lipid was therefore described as ether extract (EE). The lipid components can be further characterized by determining individual fatty acids from gas chromatography of their methyl esters (FAME-GC: fatty acid methyl esters) or by high-pressure liquid chromatography (HPLC) of intact triglycerides.



The proximate analysis scheme for plant and animal tissues.

The protein content of foods can be estimated from the nitrogen content. Proteins contain, on average, 160 g N kg^{-1}; hence crude protein (CP) is defined as N × 6.25. Total nitrogen has traditionally been determined by the Kjeldahl procedure (1883) but the Dumas method is also used. Methods of estimating protein from nitrogen determination do not distinguish between protein and non-protein nitrogen (NPN). Amino acid composition can be determined on hydrolysates by ion exchange or HPLC methods.

The carbohydrate fraction of foods consists of soluble sugars (mainly monosaccharides and disaccharides), starch and non-starch polysaccharides (NSP), imperfectly described as 'fibre'. In the Weendes system the carbohydrate fraction was considered to consist of crude fibre and nitrogen-free extractives (mainly starch and simple sugars). The term 'fibre' is used for a complex range of plant cell wall constituents that may or may not include lignin, which is not a carbohydrate but a complex aromatic polymer of phenylpropane subunits. Many methods for determining and characterizing fibre have been developed from the original much-criticized acid–alkali crude fibre (CF) method. In forages the Van Soest scheme (acid detergent fibre, ADF; and neutral detergent fibre, NDF) has been developed to better characterize fibrous cell wall constituents fed to ruminants. In starchy foods the Englyst non-starch polysaccharide (NSP) enzymatic procedure is more appropriate for non-ruminant animals and humans. Enzymatic or chromatographic methods can be used to measure individual monosaccharides, disaccharides and starch.

Major minerals (Na, K, Ca, Mg, P) and trace elements (Fe, Cu, Mn, Zn, Co, Mo, etc.) can be determined by flame emission spectroscopy (FES), atomic absorption spectroscopy (AAS), or inductively coupled plasma spectroscopy (ICP) conducted on hydrochloric acid solutions of the ash from feeds. Modern ICP spectrometers can measure as many as 26 elements simultaneously on one ash solution.

The gross energy (GE) value of foods is determined by combustion in an adiabatic bomb calorimeter. It may also be approximated from the lipid, nitrogen and carbohydrate determination, using average heats of combustion of those components. It will be appreciated that a full characterization of the chemical composition of a food is a lengthy, complex and costly procedure that can never be complete. Gross composition is 'operationally defined' and overlap between the classes of lipid, carbohydrate and protein (e.g. glycolipids, lipoproteins) means that measured constituents may not sum to 100% in any given food.

Because of the many costly analyses required to determine the composition of foods, a newer method of analysis, near infrared spectroscopy (NIRS), attempts to characterize the composition of food from its spectral signature in the near infrared. Instrumental methods of food analysis have now largely replaced extractive wet chemical methods for food analysis. (IM)

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Chemical probiosis The control of the **gastrointestinal microflora**, especially of bacterial pathogens, by dietary substances that interfere with microbial adhesion. Many bacterial pathogens adhere to the gut surface by the binding of their fimbriae to sugar moieties on the epithelial surface. The fimbriae contain specific **lectins** called adhesins: this binding mechanism is essential for adhesion and infection by many pathogenic bacteria that need to resist peristalsis in the intestine in order to colonize it.

Lectins are proteins capable of specific and reversible binding to sugar moieties. Suitable lectins for inhibition of bacterial adhesion can be isolated from bacteria, e.g. from those pathogenic bacteria that cause infections. Certain plant lectins have similar affinities to those of the specific bacterial lectins involved in adhesion of the bacteria to intestinal epithelial cells and these can also be isolated and used to inhibit bacterial adhesion. On the other hand, lectins themselves may have a major influence on the turnover of the intestinal cells and the effect of lectins in relation to infection by pathogenic bacteria depends on the specificity of the lectin as well as its concentration. Thus, dietary lectins can both enhance and reduce colonization by pathogenic bacteria.

In an alternative form of chemical probiosis, bacterial adhesion is inhibited by feeding simple or complex carbohydrates that have a terminal structure that closely mimics the carbohydrate side chains of the bacterial receptors on the gut wall. While dietary lectins actually occupy the same sites as the bacterial adhesins, the complementary saccharides act by competing with them.

Chemical probiosis is an alternative to probiosis by the addition of live bacteria (called probiotics) which also function by a competitive exclusion of pathogenic bacteria. Thus, both methods may help to maintain normal commensal flora (the resident non-pathogenic flora). (SB)

See also: Prebiotic; Probiotics

Chemical score An evaluation system used to assess the relative value of a single protein or mixture of proteins (and amino acids) to be used in a diet. A value is obtained by assessing the amino acid pattern (usually mg amino acid g^{-1} N) of the protein(s) in relation to an established reference amino acid pattern. This pattern may be developed from the estimated amino acid requirements of the animal in question, or from the pattern of high quality protein, such as egg protein. The value of a protein is not constant, because amino acid requirements vary with species and with purpose (maintenance, growth, milk or egg production). The score is calculated by dividing the amount of each indispensable amino acid in the diet by the amount of the same amino acid in the reference pattern: the score is the lowest of these ratios. For example, if the lowest score is for lysine (making it the first limiting amino acid) and the amount of lysine (mg g^{-1} N) in the diet is 80% of that in the reference pattern, the chemical score is 80%. This protein evaluation scheme assumes accurate estimates of the amino acid content of the proteins involved and that dispensable amino acid nitrogen is not limiting. (NJB) concentration of non-casein proteins, leading to poor clotting in the abomasum and thus reduced digestibility. The use of excessive amounts of carbohydrates and proteins that are not derived from milk also predisposes to diarrhoea in calves, as does the inclusion of too much protein from soybean or fish. The proteases in the digestive tract of pre-ruminant calves and lambs cannot denature the soluble antigenic constituents of soybean protein and so a hypersensitive reaction may develop in the tract of such animals. Similarly, milk replacers made from components of bovine origin may lead to diarrhoea when fed to lambs, piglets or foals.

Dietary diarrhoea can be induced in all species by a sudden change in diet, particularly at the time of weaning. This is particularly important in the early-weaned pig. The cause is probably related to the fact that changes in gut enzyme activity, necessary for the digestion of a new diet, take some time, so that gradual exposure to the new diet is advisable to maintain proper digestion.

Treatment of dietary diarrhoea in the neonate involves cessation of milk-feeding for 24 h and its replacement by oral electrolyte solutions. Milk of the correct composition is then gradually reintroduced. Treatment with an antibiotic may be necessary if secondary infection is suspected, along with oral kaolin or pectin to protect damaged intestinal mucosa. (ADC)

Diastase An obsolete synonym for **amylase**. (SB)

Dicalcium phosphate Dibasic calcium phosphate is usually available in anhydrous ($CaHPO_4$) or dihydrate ($CaHPO_4.2H_2O$) forms. The phosphorus (P) occurs in the highly available *ortho* (PO_4^{3-}) form. The crystalline product is usually prepared by the treatment of rock phosphate with hydrochloric acid. Acid treatment of bones or heat defluorination of rock phosphate are alternative methods of production. Pure anhydrous dicalcium phosphate contains 22.8% P by weight but, depending on the origin and method of production, the actual level is usually between 18% and 20.5%. The corresponding value for the dihydrate is 17% to 18%. (CRL)
See also: Rock phosphate

Dicarboxylic acids Organic acids containing two ·COOH groups. Examples in metabolism are oxalate ($^{-}OOC{\cdot}COO^{-}$), succinate ($^{-}OOC{\cdot}CH_2{\cdot}CH_2{\cdot}COO^{-}$), fumarate ($^{-}OOC{\cdot}CH{=}CH{\cdot}COO^{-}$) and oxaloacetate ($^{-}OOC{\cdot}CH_2{\cdot}C{=}O{\cdot}COO^{-}$). Aspartate ($^{-}OOC{\cdot}CH_2{\cdot}CHNH_3{\cdot}COO^{-}$) and glutamate ($^{-}OOC{\cdot}H_2{\cdot}CH_2{\cdot}CHNH_3{\cdot}COO^{-}$) are dicarboxylic amino acids. (NJB)

Dicoumarol (coumarin) White and yellow sweet clover (*Melilotus albus* and *M. officinalis*) are biennial legumes that grow throughout much of the USA. The plant's pleasant odour is due to coumarin, a non-toxic substance that is converted to the anticoagulant dicoumarol when moulds grow on clover hay or silage. Dicoumarol is a vitamin K antagonist and animals poisoned by it lack the critical proteins needed for blood coagulation. Affected animals bruise easily and bleed excessively. Some may bleed to death from a relatively small injury or surgery such as castration, dehorning, or vaccination. Prevention lies in avoiding mouldy feeds or limiting the dose by intermittently feeding only small amounts of affected clover hay or silage. (LFJ)

Diet All food consumed over a specified period. The term includes any material that enters the digestive tract, regardless of whether or not it is nutritionally available. It can be applied to a single feed or a combination of feeds, e.g. roughage and concentrate fed to ruminant animals. (SPR)

Diet-induced thermogenesis: *see* Heat increment of feeding

Dietary fibre Dietary fibre is the name given to the polysaccharides of plants that cannot be hydrolysed by the digestive enzymes of higher animals. It includes cellulose, hemicelluloses, pectic substances, fructans and β-glucans. Lignin, a group of complex polyphenolic compounds, is usually also included. The dietary fibre complex is the major source of energy via fermentation in ruminants and a minor source in non-ruminant species. Fermentation yields short-chain fatty acids, acetate, propionate, butyrate and lactic acid, carbon dioxide, methane and hydrogen. An estimated 400–600 different bacterial strains produce enzymes that degrade these carbohydrates. Typically, 60–80% of the energy and two-thirds of the amino acids needed daily by adult ruminants are produced by the microbial fermentation. If starch is present in the diet of the ruminant, it is typically fermented in the rumen, whereas in non-ruminants it is digested in the stomach and small intestine. Variable amounts of starch, particularly in legumes and severely treated grains, are not susceptible to endogenous enzymes in non-ruminants: this fraction of starch is termed resistant starch. It passes into the large intestine where it is rapidly and completely fermented.

The rate and extent of fermentation of the dietary fibre polysaccharides are determined by physical and biochemical characteristics of the plant material. If there is extensive lignification, microbial action is hindered and fermentation of the material is incomplete before it leaves the rumen. The extent of silicification and cutinization also affects microbial fibre degradation. Tannins, essential oils and polyphenols, if present, inhibit cellulases and proteases and slow rumen digestion. Solubility also determines fermentation rate. Soluble dietary fibre in forages includes unlignified pectic substances and hemicelluloses, β-glucans and fructans. Soluble carbohydrates are rapidly and completely fermented both in the rumen and in the large intestine of non-ruminants. Structural carbohydrates in plants include cellulose, hemicelluloses and pectins. They may be associated with lignin. These components are generally more extensively fermented in the rumen than in the large intestine of non-ruminants. For example, wood and newsprint are not degraded in non-ruminants, whereas in the rumen 0–40% of wood and about a quarter of newsprint is fermented. Straw, cottonseed hulls and tropical grasses are either not fermented or poorly fermented in the large intestine of non-ruminants, but one-third to two-thirds of them is fermented in the rumen.

Dietary fibre is analysed essentially by removing all of the non-fibre components from the plant material. However, many methods of fibre analysis either do not remove non-fibre components adequately or fail to recover completely material that is a part of the dietary fibre complex. The neutral detergent fibre (NDF) procedure (Van Soest and Wine, 1967) is a gravimetric method that is widely applied to animal feeds. It was designed to recover plant cell wall material and does not recover storage or soluble fibre components, though a modification of the NDF method allows recovery of a soluble fibre fraction (Mongeau and Brassard, 1993). The NDF method measures all cellulose, variable amounts of the hemicelluloses and essentially no pectins or β-glucans. Enzymatic treatment with amylase is necessary to remove starch from the NDF residue (Robertson and Van Soest, 1981). Nitrogen also is incompletely removed by conventional NDF analysis. In the Association of Official Analytical Chemists (AOAC) method, a dry sample is defatted (if it contains more than 5% by weight of fat), treated with proteases and amylases, dried and weighed. Then one aliquot of the remaining fibre residue is ashed; Kjeldahl nitrogen is measured in the duplicate aliquot and converted to crude protein (× 6.25). The weights of ash and crude protein are subtracted from the residue weight to give total fibre. The AOAC method is not without potential error – firstly because starch is not always removed completely and secondly because, during the ethanol precipitation step, simple sugars co-precipitate with the fibre residue when they are present in high concentrations, such as in fruits or feeds containing sugar products. Both sources of error produce an inflated dietary fibre value. The most accurate method of measuring dietary fibre is to obtain a residue free of simple sugars and starch, acid-hydrolyse it with sulphuric acid to generate the constituent monosaccharides and individually quantitate these, usually by either HPLC or GLC. Colorimetric quantitation of these mixtures of monosaccharides is not accurate because the mixture contains essentially unknown amounts of different monosaccharides which absorb at different wavelengths. All fibre analysis methods are labour intensive and require considerable analytical expertise to obtain accurate or even reproducible results on a variety of samples. (JAM)

See also: Carbohydrates; Gums; Hemicelluloses; Oligosaccharides; Pectic substances; Pentosans; Storage polysaccharides; Structural polysaccharides

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Net protein utilization (NPU) One of the systems used to evaluate the quality of protein(s) for use in human and animal diets. It is defined as the percentage of the dietary protein retained. The value of dietary protein (therefore, not a single protein) is estimated by use of an animal growth trial. This method involves measuring total body nitrogen in a group of experimental animals (groups of 4 or more rats) which have consumed a protein-free diet and another group fed a similar diet containing the test protein. After the animals have consumed the diets for the desired time (10 or more days) the value of the protein is estimated using the formula for NPU:

NPU = 100 × ((Body N of test group) – (Body N of protein-free group))/(Nitrogen consumed) (NJB)

Key reference

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Neurotransmitter A chemical that functions at the junctions (synapses) between two nerve cells (axon to dendrite) or between a nerve cell and a cell of another type such as muscle (neuromuscular junction) or a gland. The presynaptic neuron has at its termination synaptic vesicles containing neurotransmitters (e.g. acetylcholine, serotonin). In response to an impulse the synaptic vesicles release the neurotransmitter into the synaptic cleft, where it migrates 20–40 nm across the junction to affect the nerve or muscle, etc. The term neurotransmitter applies to individual chemicals such as acetylcholine or to classes of chemicals such as amines, excitatory or inhibitory amino acids, polypeptides, purines, gases or lipids. (NJB)

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Neutral-detergent fibre (NDF) An insoluble matrix prepared by the extraction of food plants and mixed feeds in a solution of sodium dodecyl sulphate (SDS) and ethylenediamine tetraacetic acid (EDTA) in a phosphate buffer at pH 7. NDF is an estimate of the cell wall fraction of forages and mixed feeds. Cell wall polysaccharides (with the exception of pectin), lignin and cutin are the major components of NDF from forages. Proteins, lipids, non-structural polysaccharides and other cytoplasmic constituents are removed by the extraction. NDF is used to measure the amount of cell wall in foods and to determine fibre digestibility. Within the context of the detergent system of forage analysis, NDF separates completely available food components that are nutritionally uniform from those feed components that are only partially available or completely unavailable for digestion. The detergent system of forage analysis was developed by Van Soest to replace the fibre analysis of the Weende system with a more rational and easily applied system. Digestibility of a forage is estimated by analysis of NDF and an estimate of the degradability of NDF by lignin analysis, *in vitro* degradability of NDF or enzymatic degradability with fungal cellulases. (JDR)

Neutron activation analysis (NAA) An extremely sensitive, non-destructive technique used for the determination of about 69 elements. The technique involves the bombardment of the sample with neutrons to convert stable elements to radionuclides, which are subsequently measured by the radioactivity they emit as they decay. The method allows trace multi-element analyses with minimal sample preparation in various matrices such as food, fuel, drugs, fertilizers, minerals and water. (JEM)

Newborn animals The first needs of newborn animals are for food and warmth. Because they have a high ratio of surface area to body weight, and because they are wet, newborn mammals and newly hatched birds are susceptible to hypothermia, which then limits their ability to find shelter and food. The first nutritional need of newborn mammals is for **colostrum** to provide passive immunity against infections, particularly of the gastrointestinal tract. The capacity to absorb immunoglobulins intact is short-lived and aniporter in renal mitochondria is inhibited, resulting in additional degradation of glutamine and excretion of H^+ as ammonium (NH_4^+).

The strong ion difference (SID), which is the sum of all strong cations (mol l^{-1}) minus the sum of all strong anions (mol l^{-1}), also impacts on the regulation of acid–base equilibrium. The SID affects the partial pressure of blood CO_2 and renal electrolyte excretion. Shifts in SID impact renal compensation by changes in the relative amounts of ammonium and phosphate ion excretion. (TDC)

Acid-detergent fibre (ADF) The detergent fibre analysis scheme was introduced to overcome inadequacies in the use of the traditional acid–alkali crude fibre estimation when applied to fibrous forage feeds for ruminants (Van Soest, 1970; see table).

The determination of ADF involves the extraction of food (1 g) by boiling (1 h) in acid-detergent solution (100 ml; 2% cetyltrimethyl-ammonium bromide (CTAB) in 0.5 M H_2SO_4). The insoluble residue is filtered, washed with acetone, dried (8 h, 100°C) and weighed. This residue, which includes cellulose, lignin and some inorganic elements such as silica, is described as ADF. The residue can be used for subsequent measurement of cellulose after oxidation of lignin by saturated potassium permanganate solution and removal of manganese dioxide by oxalic acid (Van Soest and Wine, 1968). (IM)

References and further reading

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Acid-detergent fibre nitrogen (ADFN) The amount of nitrogen retained in the acid-detergent fibre residue. Also called acid-detergent insoluble nitrogen (ADIN), it has been used to determine heat damage to proteins in feedstuffs. Excessive heating of foods containing protein and carbohydrate leads to Maillard reactions which cause the formation of covalent bonds between aldehyde groups in carbohydrate and free amino group residues on protein, especially lysine. ADFN is an indicator of these heating effects, which decrease the digestibility of the protein. (IM)

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Diffusion A process of molecular mixing of gases or liquids when pure substances are either poured together or are separated by a semipermeable membrane and allowed to mix. In a cellular setting gases and substrates diffuse down electrochemical gradients across membranes by either simple diffusion (no carrier) or facilitated diffusion, where a carrier protein is involved. (NJB)

Digesta The contents of the digestive tract, synonymous with chyme. Digesta consist of undigested feed mixed with secretions, desquamated mucosal cells and microorganisms. (SB)

Digestibility A measure of the degree of net absorption in the digestive tract of dietary nutrients. Macromolecules such as starch and proteins need to be degraded to absorbable units, i.e. monosaccharides and amino acids. This is done by the digestive enzymes of the animal as well as those of **gastrointestinal microflora**. In carnivores and omnivores, the animal's own enzymes predominate, whereas in non-ruminant herbivores microbial activity usually predominates. Microbial activity in the rumen converts food nutrients into microbial matter and volatile fatty acids, both of which are then utilized by the host animal.

Digestibility is influenced by a number of factors relating to treatments of the foodstuffs and complete diets, e.g. milling and processing. Processing can improve digestibility; for example, heat can destroy antinutritional factors such as protease inhibitors in legume seeds and thereby reduce endogenous protein losses; chemicals such as sodium hydroxide can make lignified cellulose more available for microbial enzymes in ruminants; addition of feed enzymes, such as glucanase and arabinoxylase, can reduce viscosity in the small intestine of poultry and piglets. All these treatments improve digestibility. Food processing may have a negative influence, in particular on the digestibility of proteins. Heat causes the formation of inter- and intramolecular covalent bonds that are resistant to enzymatic digestion. In the presence of reducing sugars (e.g. fructose) and amino acids, the **Maillard reaction** leads to the formation of complex adducts between the sugar and amino acids, especially lysine. The Maillard reaction can also occur during storage of dried foods and make lysine unavailable for absorption.

Starch is generally made more available by heat processing but this can also convert available starch into a form that is unavailable for enzymatic degradation. **Resistant starch** is produced by rearrangements in the molecular structure of amylose, which constitutes about 20% of starch and is generally less available than amylopectin.

The digestibility of a nutrient is not a constant value, like a chemical analysis of the nutrient in a particular sample of feed. Feeding conditions (e.g. method and level of feeding) and the particular animal (its species, sex, age and physiological stage) influence digestibility.

The digestibility of a nutrient after passing through the entire digestive tract can be determined by total collection of faeces over a suitable period. Digestibility measured directly from the difference between the intake (I) and output in digesta or faeces (O) of the nutrient is called the apparent or net digestibility (AD):

$$AD = (I - O) / I$$

However, the excreted matter also includes the endogenous loss of the particular nutrient, which has been digested and absorbed but has then re-entered the gut in the form of endogenous secretions. After correction for this loss (E), the true digestibility (TD) of the dietary nutrient can be calculated:

$$TD = (I - O + E) / I$$

The endogenous losses of a nutrient were traditionally estimated by measurements of the losses in animals given diets devoid of that nutrient. However, for some nutrients at least, endogenous secretions may be modified by the diet and these estimates may not represent what occurs under normal circumstances, when the animal eats a complete diet. For this reason, other corrections are used. Undigested food and unreabsorbed endogenous secretions may, furthermore, be metabolized by the microflora, being either degraded or converted to microbial matter. In non-ruminants, microbial metabolism occurs predominantly in the large intestine. The digestibility of protein and amino acids is particularly influenced by microbial metabolism. Most of the protein in faeces is microbial, and because the microflora can synthesize amino acids there may be little relation between the amino acid composition of the undigested food and that of the faeces. This in turn means that digestibility of amino acids measured over the entire digestive tract may be very misleading. Lipids are less metabolized by the intestinal microflora but fatty acids can be elongated and unsaturated fatty acids may be partly hydrogenated by the microbial metabolism in the large intestine. Carbohydrates not available for digestion in the small intestine, due to either physical inaccessibility or chemical structures not hydrolysed by the mammalian enzymes (in dietary fibre), are the main energy sources for the microflora. The end-products of microbial fermentation, i.e. the short-chain fatty acids, are absorbed by the host animal and contribute to the energy supply.

A complete characterization of nutrient availability in the animal therefore includes measurements of digestibility in the different compartments of the gastrointestinal tract, i.e. in non-ruminants, of digesta at both the ileal and faecal level, respectively. In ruminants, measurements of degradation in the rumen are of particular importance, due to a relatively predictable and constant composition of the outflow from the rumen. In animals with a less significant microbial activity, e.g. carnivores such as mink, ileal sampling is of less importance for a proper characterization of digestibility.

Sampling of digesta for measurements of digestibility in different compartments requires a **cannula**. If only a fraction of digesta is collected, an indigestible **marker** must be added to the diet so that the proportion of the whole flow that is collected can be calculated. For a correct measurement of the digestibility of a nutrient, the flow rate of the marker needs to be the same as that of the nutrient. Furthermore, an ideal marker must not be absorbed and affected by the digestive tract or the microbial population in the tract and it should be closely associated with or physically similar to the undigested nutrient in question. No existing marker totally satisfies all these requirements. The combined use of internal and external markers can improve the measurements, e.g. insoluble ash can be used as an internal marker together with chromic oxide, one of the most commonly used external markers.

To determine the digestibility of nutrients that are modified in the large intestine, especially amino acids, digesta are sampled at the terminal ileum to determine 'ileal digestibility'. The simplest method of obtaining samples of digesta from the terminal ileum is to sacrifice the animals, taking the samples under terminal anaesthesia. For repeated sampling, various kinds of cannula may be used. A simple T-cannula allows only partial sampling and needs the inclusion in the diet of an indigestible marker. The cannula is relatively small and may give unrepresentative samples with coarse or fibre-rich feeds. A more advanced technique, the post-valvular ileocaecal cannula, involves a large cannula placed in the caecum opposite the ileocaecal valve. It can be steered with a nylon cord in such a way that, during the collection, digesta are directed into the cannula, so that, during the sampling period, all the digesta leaving the ileum are collected. An alternative surgical approach, which avoids the use of a cannula, is to bypass the large intestine by ileorectal anastomosis.

In fish, digestibility is measured by several methods for faeces collection, including dissection, stripping (i.e. pressing digesta out of the rectum with the fingers) or anal suction of the individual fish, or alternatively, immediate pipetting, continuous filtration, or decanting of tank water.

By the use of marker technique, the determination of digestibility is based on the increase of the marker in relation to the nutrient in the digesta or faeces. AD is calculated from analyses of the concentrations (g kg^{-1}) of nutrient (N) and marker (M) in the experimental diet and in samples of digesta (or faeces), n and m, respectively.

$$AD = (N - n.(M/m)) / N$$

Other approaches to determining digestibility are based on: (i) the rate of appearance of the nutrient in the body by measuring the difference in the arteriovenous concentration across the portal-drained viscera together with the portal blood flow; this approach may underestimate absorption due to uptake of the nutrient by the tissue of the gut; (ii) isotopic techniques, e.g. labelling the experimental animal with ^{15}N so as to distinguish (labelled) endogenous protein from (unlabelled) dietary protein; this gives a direct measure of the real digestibility of dietary protein, uninfluenced by endogenous protein loss; however, there may be some recycling of (unlabelled) nutrient from the diet into endogenous secretions during the feeding period; and (iii) chemical modification of the dietary protein, e.g. treatment with *o*-methyl-isourea in order to guanidinate lysine to homoarginine and then to determine lysine digestibility; this method assumes that the chemical reaction is distributed equally between digestible and indigestible lysine, that the treatment does not influence the general digestibility of the protein, and that homoarginine is digested and absorbed to the same extent as lysine.

Other methods include predictions from: (i) *in situ* digestibility based on incubations in bags (*in sacco*) in the digestive tract, e.g. after incubation in the rumen or throughout the intestine (mobile nylon bag) with collection at the end of the ileum through a cannula, or in the faeces; (ii) *in vitro* digestibility based on incubation with enzymes similar to those occurring in the digestive tract; (iii) chemical composition; and (iv) physical methods based on **near infrared**, NIT, **nuclear magnetic resonance** or other methods, alone or in combination with chemical analyses.

Availability is often used as a synonym for digestibility but also has a different meaning (*see* **Availability**). (SB)

See also: Markers; Protein digestibility

Further reading

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Digestible energy That part of the gross energy of a food substance or complete ration which is not expelled as the gross energy of faeces. It is widely used to express both the energy value of a diet and the energy requirements of animals. (JAMcL)

See also: Energy balance

Digestible organic matter: *see* D value

Digestion The process of breaking down dietary components to make them available for absorption from the gastrointestinal lumen by epithelial cells. Food particles are reduced in size by mechanical and chemical means. The mechanical breakdown is performed by chewing in the mouth and by contractions of the muscular walls of the gastrointestinal tract. Chemical breakdown is mainly effected by enzymes secreted in digestive juices. Food constituents of large molecular weight, such as proteins, starch and lipids, have to be broken down to low-molecular-weight compounds before they can be absorbed. A large number of specific enzymes are involved in their breakdown, some from the animal and some from colonizing microorganisms in the digestive tract.

Most digestive enzymes are found in all species. However, their activity varies with age and responds to variations in the diet. The digestion of the food may be initiated in the mouth, where it may be disintegrated by chewing. Although birds have no teeth, they may use their beaks to reduce the size of food components. During the process of mastication, saliva is added. In the saliva of many animals an α-amylase initiates the enzymatic degradation of starch. In very young pigs, salivary amylase is low; it increases slightly between 2 and 3 weeks of age and then falls to very low levels. In young (suckling) animals, a lipase initiates the degradation of milk lipids. The saliva provides a source of N (from urea and mucoproteins), P and K, which in ruminants are essential for the microorganisms in the rumen.

Some species have a forestomach: birds have a **crop** which serves as a storage organ in which microbial fermentation may occur together with a continued action of salivary amylase on starch degradation; in ruminants the **rumen**, together with the reticulum and omasum, are considered as forestomachs to the abomasum, which corresponds to the true (gastric) stomach of non-ruminants.

Protein digestion begins in the stomach, where pepsins cleave some of the peptide link-

Stimulation of the humoral or cell-mediated immune systems, either by natural infection or by vaccination, produces active immunity, which may provide protection to the specific antigen for months or years. This property is used in vaccination, where antigen, from inactivated pathogens or toxins, attenuated organisms, related mild strains, or genetically engineered forms, is used to stimulate an immune response with the intention of providing long-term specific protection. Vaccines may contain an adjuvant to improve the immune response. More than one dose of vaccine may be required in an initial course to provide satisfactory protection, particularly where the antigen is not a live replicating organism. The initial dose will produce a small primary antibody response, and the second a secondary or amnestic response (Fig. 2). Satisfactory establishment of a memory cell population may also need an initial course of vaccination. Booster doses of vaccine may be used to prolong the protection or to raise circulating antibody levels.

Passive immunity does not require exposure to an antigen: the antibody is given to the animal either in colostrum or in antiserum. Protection is limited to a few weeks as the protein immunoglobulin is broken down over time. Passive immunity does not aid the production of protective antibodies in the animal, as exposure to the antigen is needed. The presence of passive immunity may interfere with the immune response to a vaccine and this should be taken into consideration when a vaccine programme is drawn up. (EM)
See also: Colostral immunity

Immunoglobulin: *see* Immunity

In sacco Literally 'in a bag'. Methods of measuring the digestion or microbial degradation of feeds in a bag within the gastrointestinal tract are called *in sacco* techniques. To measure the degradation of feeds within the rumen, samples of feed are sealed in bags of woven plastic (e.g. nylon or Dacron) that has pores small enough to retain the feed particles but large enough to allow microbes to enter and the end-products of digestion to leave. The bags are suspended in the rumen via a fistula in the rumen wall; they are retrieved at intervals and analysed to determine how much of the original material has been lost. The same approach can be used to measure digestion in the stomach and a 'mobile nylon bag' technique is also used to measure digestion in the intestine. The bags are usually introduced via a cannula and recovered either through another cannula further down the intestine, or from faeces, according to which part of the digestive process is being studied. (MFF)

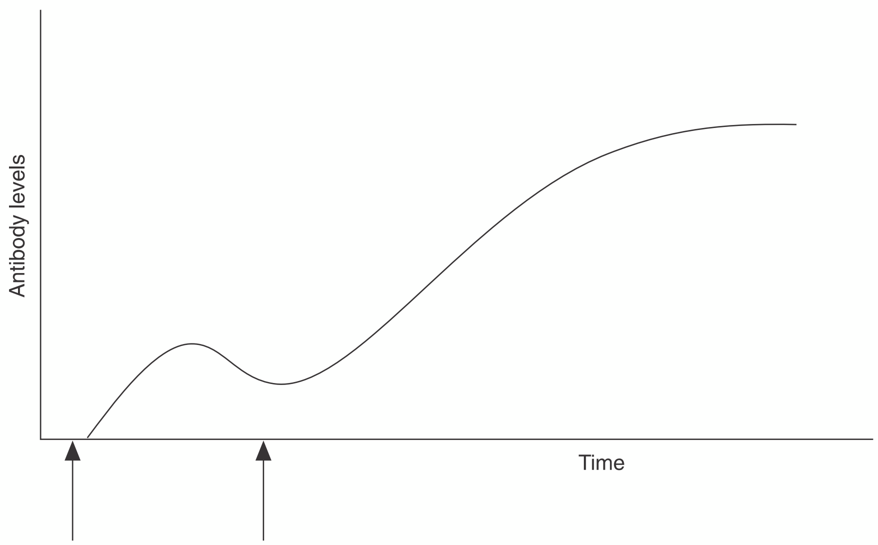

Fig. 2. Antibody response to two doses of vaccine (indicated by ↑).

***In vitro* digestibility** Digestibility determined in the laboratory by simulating the *in vivo* digestion. Commercial enzyme preparations or appropriate inocula (e.g. digesta or rumen liquor) are used in controlled incubations. To derive reliable predictions of *in vivo* digestibility from *in vitro* assays requires equations describing the relationship between *in vivo* and *in vitro* digestibility values obtained with identical feed samples. (SB)
See also: Digestibility

Further reading

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Inborn errors of metabolism Inborn errors of metabolism (IEMs) are congenital abnormalities of metabolic pathways. Most are due to enzyme deficiencies or defects in metabolic transport. In the human population there are over 300 identified IEMs but far fewer are known in farm animals. Because farm animals are bred from a smaller gene pool than humans, there are probably fewer IEMs but they may individually be more prevalent because of the high level of inbreeding. Most are inherited through the monogenic recessive mode and may go undetected in farm livestock because farmers accept a high level of neonatal mortality. Examples in cattle include carbonic anhydrase deficiency syndrome, citrullinaemia, an inborn error of urea-cycle metabolism characterized by deficiency of argininosuccinate synthetase and consequent life-threatening hyperammonaemia, and deficiency of uridine monophosphate synthase. In sheep there is an inherited lysosomal storage disease that involves deficiencies of β-galactosidase and α-neuraminidase. There are also copper storage diseases and depressed biliary transport of conjugated sulphobromophthalein (SBP) compounds. Glycogen storage diseases have been recognized in cattle, quail and laboratory animals and are among the most widespread of IEMs. (CJCP)

Incubation The time taken for the embryo to develop *in ovo* and then hatch varies from species to species, but there is a trend for the time required for incubation to increase as the size of the hatchling increases (see table).

Typical incubation times for different species.

Species	Incubation time (days)
Chicken (standard)	21
Chicken (bantam)	20
Duck (except Muscovy)	28
Muscovy duck	33–35
Goose, small (e.g. Chinese, Canada)	30
Goose, large (e.g. Emden, Toulouse)	33–35
Guinea fowl	28
Japanese quail	17
Ostrich	42
Partridge	23
Pheasant	24
Pigeon	17
Turkey	28

The times shown are intended as a guide only. For example, when incubating chickens under commercial conditions, the incubation period may be extended by 12 or more hours to allow time for the hatching process to be completed and the hatchlings to dry off. Similarly, extra time will be required if the eggs have been stored for more than 1 week, for example, or come from older parent stock or are incubated at a suboptimal temperature. (NS)

Indicator A substance that shows a change in chemical conditions (e.g. pH), often by a change in colour. In nutrition, indicators are simple measures that change with more complex or deep-seated alterations in metabolism. Examples are the use of blood urea concentration as an indicator of protein utilization and the activity in plasma of the enzyme glutathione reductase as an indicator of riboflavin status. A method of estimating the requirement for an amino acid also uses the oxidation of a non-limiting ('indicator') amino acid: with increasing intake of the limiting amino acid the oxidation of the excess indicator amino acid decreases up to the point at which the requirement of the test amino acid is met. (MFF)