A

Abalone

A large marine snail or gastropod of the mollusc family *Haliotidae*. More than 50 species have been identified. Abalone have a hard shell and a muscular foot. They inhabit rocky shorelines, from shallow water up to depths of approximately 40 m. Their shells are rounded or oval with a large dome towards one end. The shell has a row of respiratory pores. The muscular foot has strong suction power, permitting the abalone to clamp tightly to rocky surfaces. Abalone have succulent meaty bodies with a naturally salty and buttery flavour and chewy texture. Abalone meat is known for its texture and composition changes throughout the abalone's lifetime. Seasonal variations show that the **collagen** content in *Haliotis discus* is highest in winter and lowest in summer, affecting the texture of the flesh. They have been widely used by indigenous populations in Australia, New Zealand, East Asia and North America as an important subsistence food. Known in ancient times as 'elixir of life', abalones are believed to symbolize wealth and power and to have a unique flavour. Abalone are in high demand in China, Japan and other Asian countries. With capture fisheries in serious decline, abalone farming is expanding in Taiwan, South Korea, Chile, Iceland, Mexico, USA, Australia, Thailand and several countries in South-east Asia, in particular China (the world's largest producer and consumer of cultured abalone) with over 2000 farms that produced 163,169 t in 2018. In the natural environment abalone graze on benthic (bottom-growing) algae, but formulated diets from a combination of animal and plant **protein sources** have been developed for feeding farmed abalone.

(SPL; QS; DB)

Australian dried abalone. Photo courtesy of Avlxyz and Australia Fortune Company. Licensed under CC BY-SA 2.0.

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Abdominal fat

In most domesticated species, deposits of abdominal fat can be divided between peritoneal and inguinal regions; the exception is the duck, in which subcutaneous fat deposits, required for thermal insulation, comprise the largest single depot and are a special development in this species. The fat of the peritoneum is located within the abdominal cavity and extends ventrally over the visceral mass, being attached to the peritoneal membranes lining the abdominal wall. Inguinal fat lies along the interior femoral and tibiotarsal region and extends from the sartorius muscle to approximately two-thirds the length of the tibiotarsus. Consistency and appearance of fat in terms of its chemical and physical nature can vary between species, reflecting not only genetic traits but also diet. For example, abdominal deposits of fat in horses and certain Channel Island breeds of cattle are yellow while those of sheep are hard and white and those of pigs soft and greyish in colour. Body temperature is important, with fat being almost semi-fluid compared with that at cooler temperatures. **Brown adipose tissue** is not found in abdominal fat stores. (MMax)

Abomasum

The fourth compartment of the ruminant stomach. It communicates anteriorly with the **omasum** through the omaso-abomasal opening, and posteriorly with the **duodenum** via the pyloric orifice. The abomasum is analogous to the simple stomach of **monogastric** animals. Like the stomach of non-ruminants, it is lined with a glandular epithelium that secretes mucus, **hydrochloric acid** and enzymes, including pepsins and **lipase**. (RNBK; GMcLD)

Abortion

Abortion is defined relative to the stage of pregnancy when the embryo or fetus is lost. In cattle, early embryonic death refers to deaths occurring from the day of conception until about 42 days of gestation (the end of the embryonic period), which coincides with the end of differentiation. Embryos lost during this period may be either resorbed or aborted. A normal rate of early embryo **resorption** (0–45 days) is 9–12% and abortion or resorption after 45–60 days is usually rare (1–2%). Higher rates are attributed to disease. Bovine fetuses discharged from day 42 until approximately 260 days are generally called abortions, and from day 260 until normal term (281 ± 3 days), premature births.

Dietary causes of embryonic death, abortion or premature birth include poisonous plants, fungi and synthetic toxicants. Plants associated with abortion or premature birth include *Pinus* species (*P. ponderosa*, *P. radiata*, *P. taeda*, *P. cubensis*), *Juniperus communis*, cypress (*Cupressus macrocarpa*), snakeweeds (*Gutierrezia sarothrae* and *G. microcephala*), locoweeds (***Astragalus*** spp. and *Oxytropis* spp. containing swainsonine), hairy vetch (*Vicia villosa*), darling pea in Australia (*Swainsona* spp.) and **leucaena** (*Leucaena leucocephala*). **Mycotoxins** include **ergot** alkaloids from grains and grasses infected with *Claviceps* and *Balansia* spp., loline **alkaloid**s from endophyte-infected tall fescue, **trichothecene**s from *Fusarium* spp., grains and maize silage infected with *Aspergillus* and *Penicillium* spp., and hay, straw and mouldy sweet clover (**dicoumarol**) contaminated with *Stachybotrys* spp. Xenobiotics believed to contribute to embryo or fetal loss include nitrates and nitrites, high-protein diets (excess **urea**), carbon monoxide, oestrogenic compounds, **glucocorticoids**, lead, phenothiazines, **oxytocin**, chlorinated pesticides (DDT, dieldrin, heptachlor) and warfarin (coumarins). (KEP)

Absorption

The process by which nutrients are transported from the lumen of the **gastrointestinal tract** to the blood or lymphatic system. Absorption of most nutrients occurs predominantly in the **jejunum**. Absorption of intact macromolecules is very limited. Most are degraded into their constituents by digestive enzymes in the intestinal lumen: proteins to **amino acid**s and small **oligopeptide**s; **glycogen** to **maltose**, **isomaltose** and small **oligosaccharide**s; triglycerides to **fatty acid**s, 2-monoglycerides and **glycerol**. Further degradation of proteins and carbohydrates occurs at the **brush border** surface under the influence of a large number of specific enzymes for degradation to their mono-constituents, amino acids (small amounts of peptides may pass to the blood) and the hexoses **glucose**, **fructose** and **galactose**. Degradation products from **lipids** are emulsified by bile salts and **lecithin** and organized in micelles which diffuse through the unstirred water layer to the membrane of the brush border, where the nutrients are absorbed. In the distal **ileum**, about 95% of the bile is absorbed into the blood during one turn of the enterohepatic circulation.

Absorption of macromolecules can occur in specific instances; for example, absorption of immunoglobulins from colostrum in newborn mammals is performed by **pinocytosis**, mainly in the ileum.

Absorption of some minerals and of degradation products from microbial **fermentation**, such as **short-chain fatty acids** (SCFA), also takes place in the **large intestine**. In the horse, up to 70% of the absorbed **energy** is absorbed as SCFA in the **colon**. In ruminants, absorption of these products formed in the **rumen** or derived from diets mainly takes place in the fore-stomach.

Little water is absorbed from the stomach, but it moves across the **mucosa** via aquaporins in both directions in the **small intestine** and large intestine and generally the osmolality in the intestinal lumen is close to that of plasma. In the colon, sodium is pumped out and water moves passively with it. (SB; GW)
See also: Digestion; Intestinal absorption

Acceptability:
see Palatability

Acetaldehyde
An **aldehyde**, $CH_3{\cdot}CHO$. It can be produced chemically by **oxidation** of **ethanol** $CH_3{\cdot}CH_2OH$. In cellular **metabolism,** acetaldehyde is an intermediate produced in the conversion of ethanol to acetic acid. After activation in the cell, acetic acid can be used as a source of energy. Acetaldehyde can be toxic. (NJB)

Acetate
$CH_3{\cdot}COO^-$. Acetic acid, $CH_3{\cdot}COOH$, is one of the three (acetic, propionic, butyric) common short-chain **volatile fatty acid**s found in intestinal contents. This fatty acid accounts for a major proportion (more than half) of the **short-chain fatty acid**s produced by anaerobic fermentation in the **rumen** or in the **large intestine**. In cellular **metabolism,** acetate is converted to acetyl-**coenzyme** A (CoA) prior to being used in catabolic or anabolic processes. **Acetyl-CoA** is a major metabolic intermediate in the **catabolism** of fatty acids and carbohydrates to carbon dioxide and water and of **amino acid**s to carbon dioxide, water and nitrogen end-products in the production of cellular energy in the form of ATP. In cellular biosynthetic activities, acetate as acetyl-CoA is the precursor for all of the carbon in **long-chain fatty acid**s (16–18 carbons), **ketone**s and **cholesterol**. (NJB)

Acetic acid:
see Acetate

Acetoacetate
$CH_3{\cdot}CO{\cdot}CH_2{\cdot}COO^-$, one of the three **ketone** bodies (acetoacetate, β-**hydroxybutyrate** and **acetone**) produced in the incomplete **oxidation** of **fatty acid**s. In the liver, fatty acids, via their metabolism to acetyl-**coenzyme** A, can produce acetoacetyl coenzyme A which in turn can be converted to the other two ketone bodies. Acetoacetate and β-hydroxybutyrate can be taken up by other tissues and used for **energy**. (NJB)

Acetone
$CH_3{\cdot}CO{\cdot}CH_3$, one of the three **ketone** bodies (acetoacetate, β-**hydroxybutyrate** and acetone) produced in the incomplete **oxidation** of **fatty acids**. Because acetone is volatile and has a unique sweet odour, it can sometimes be detected in the breath of ketotic animals. Acetone is not further metabolized and is lost from the animal. (NJB)

Acetyl-CoA
Acetyl-coenzyme A, $CH_3{\cdot}CO{\cdot}SCoA$, the metabolically active form of **acetate**. It is produced in the metabolism of **carbohydrates**, **fatty acid**s and **amino acid**s. Free acetate is converted to acetyl-CoA in the cytoplasm of cells and utilizes **coenzyme** A and ATP in its production. (NJB)

Acetylcholine
A **neurotransmitter**, $(CH_3)_3N^+{\cdot}CH_2{\cdot}CH_2OOC{\cdot}CH_3$. It is formed in nerve endings by combining **acetyl-CoA** with **choline** and is found in synaptic vesicles. These vesicles are released into the synapse in response to nerve impulses and initiate a response in another nerve or muscle. (NJB)

Acid–base equilibrium
The balance between acids (elements or compounds that increase H^+ concentration) and bases (elements or compounds that decrease H^+ concentration). Neutrality (equal balance of acid and base) is at a pH of 7.0 (H^+ concentration = 1×10^{-7} mol l^{-1}). However, homeostatic mechanisms in living organisms tend to maintain an extracellular fluid pH between 7.35 and 7.45. Survival of the organism is not possible outside of the range of a pH between 7.0 and 7.7. Acidosis is defined as a blood pH < 7.35 and occurs with prolonged **starvation**, severe **diarrhoea**, asphyxia, **ketosis** and **lactic acidosis**. **Alkalosis** is defined as a blood pH > 7.45 and is associated with hyperventilation, vomiting of gastric acid and diuresis. Multiple systems within the body are primarily responsible for maintenance and regulation of acid–base equilibrium. These include the physiological buffers, the respiratory system and the renal system. These systems are interrelated and provide relatively rapid responses to shifts in acid–base equilibrium. The **gastrointestinal tract** also plays important roles in acid–base equilibrium but the responses are of greater consequence to long-term regulation and involve shifts in absorption and excretion of mineral ions.

Major physiological buffers include **bicarbonate**, phosphate and proteins. Bicarbonate ions (HCO_3^-) and hydrogen ions (H^+) are in equilibrium with carbonic acid (H_2CO_3), a weak acid. Carbonic acid is produced by enzymatic action of carbonic anhydrase from CO_2 and H_2O. The formation and end-products of bicarbonate can be easily eliminated via respiratory or renal systems without an effect on pH. Since mechanisms exist to maintain a constant extracellular concentration of bicarbonate ions (which are an excellent **buffer** for physiological fluids), the bicarbonate buffer does not provide a means for net elimination of acidic or basic loads imposed on the body. In terms of acid–base equilibrium, the bicarbonate buffer is considered a **futile cycle** since net elimination of bicarbonate as CO_2 via the lungs is eventually compensated for by renal synthesis of bicarbonate by the kidneys with no net change in H^+. Phosphate ions buffer H^+ in physiological fluids and contribute to the net equilibrium of acids and bases in the body. Within physiological pH ranges the concentration of dibasic (HPO_4^-) phosphate ions is approximately four times the concentration of monobasic ($H_2PO_4^-$), but the kidneys can concentrate H^+ in urine to a pH as low as 4.5. As urine pH decreases, the dibasic phosphate ions provide a buffer by accepting H^+ to form monobasic phosphate, thus providing net elimination of H^+ from the body.

Another major route for a net elimination of H^+ from the body involves renal production and secretion of ammonium ions from **glutamine** catabolism. Under acid loads, the expression of phosphate-activated glutaminase in renal mitochondria is increased, resulting in enhanced 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. The pH of the rumen is controlled through the actions of salivary phosphate and biocarbonate buffers, and absorption of the **volatile fatty acid**s produced by microbial fermentation. (TDC, GMcLD)

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 (see table).

Classification of forage fractions using the detergent fibre methods of Van Soest and Wine (1967).

Fraction	Components
Cell contents (soluble in neutral detergent)	Lipids Sugars, organic acids and water-soluble matter Pectin, starch Non-protein N Soluble protein
Cell wall constituents (fibre insoluble in neutral detergent) 1. Soluble in acid detergent 2. Acid-detergent fibre	Hemicelluloses Fibre-bound protein Cellulose Lignin Lignified N Silica

The determination of ADF involves the extraction of food (1 g) by boiling (1 h) in acid-detergent solution (100 ml; 2% cetyltrimethylammonium 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)

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

Acid treatment of feeds
Acids are generally applied to forages either to improve the degradability of poor-quality cereal crop residues or to enhance pH reduction during ensiling. They are also used as dietary supplements to help maintain blood pH. The addition of either hydrochloric or **sulphuric acid** to cereal straws reduces **hemicellulose** content but has little effect on either **cellulose** or **lignin**. However, **digestibility** and intake improve and so, like alkali treatment, acid treatment may hydrolyse the **ester** bonds between lignin and the other cell wall **polysaccharide**s. Again like alkali treatment, acid treatment improves degradability in the rumen, but sufficient dietary protein must be supplied to ensure that this potential can be realized. Animals consuming cereal straw treated with acid and **urea** have been shown to have both an enhanced flow of **microbial protein** to the **small intestine** and increased **nitrogen retention**. An additional benefit identified with this combined treatment is that acidification appears to enhance the degree of **ammoniation** of straw by the urea. When sulphuric acid is used, the **sulphur** content of the treated material increases, which may be beneficial as sulphur is a vital element in the production of microbial protein. It is generally recommended that where additional nitrogen is supplied, sulphur should be provided at a ratio of S:N of about 1:12. Short-term treatment of cereal straw with **organic acid**s such as **formic acid** has no effect on either digestibility or intake, with the acids being degraded in the rumen to **methane** and **carbon dioxide**.

The most common use of acids is their incorporation into the herbage mass to enhance the rate of pH reduction during ensiling. Successful preservation of plant material as **silage** depends on rapidly achieving a controlled fermentation under anaerobic conditions and the conversion of water-soluble carbohydrates to **lactic acid**. At pH 3.8 to 4.3, microbial activity is inhibited, resulting in well-preserved, stable silage. When the crop and conditions within the silo permit, no additives are needed; but where either these are inadequate or to minimize losses in fermentation, the desired pH can be partly achieved by direct acidification. This promotes a lactic acid fermentation and lowers the energy **cost** of fermentation. A.I. Virtanen of Finland first developed the use of acids in this way in the 1930s. In what became known as the AIV method, combinations of sulphuric and hydrochloric acids were added to forages at ensiling to encourage the rapid reduction of pH (< 4) so as to suppress proteolytic activity. A number of acid-based **silage additive**s are now available. For safety and to limit their corrosive effect, weaker organic acids such as formic acid are used, either alone or in combination with fermentation inhibitors such as formalin. The application of acids has been shown to increase animal performance, due to reduced losses of nutrients as well as improved **protein quality**, **palatability** and intake. (FLM)

Acidification
Acids are sometimes added to animal feed ingredients or diets to protect the material against microbial deterioration or to reduce the pH in the animal's stomach. **Propionic acid** can be added to hay or cereal grains to prevent the growth of moulds and the formation of **mycotoxin**s. This allows such feed materials to be stored safely with a higher moisture content than is normally recommended. Short-chain **organic acids** (e.g. formic, propionic, fumaric and citric) can be added to diets for newly weaned piglets to reduce digestive upsets. The young piglet has an immature gut, where enzymatic activity for the **digestion** of plant materials and **hydrochloric acid** secretion are not sufficiently developed; piglet feeds often have a high acid-binding capacity and are fed in relatively large meals. Organic acids reduce the incidence of **diarrhoea** in piglets post-weaning by their antimicrobial action on the feed itself, by reducing stomach pH and by acting as **energy sources**. **Lactic acid** can be added to **dried milk** powder for artificial rearing of calves. Lactic acid preserves reconstituted milk, allowing *ad libitum* feeding of cold milk; it also reduces the pH of the calf's **abomasum**, thereby assisting clot formation. (PCG)

Acidity of the gastrointestinal tract
The quality of being acid describes a solution with a pH less than 7.0. The contents of the stomach or **abomasum** are normally acid because of the secretion of 0.15 M hydrochloric acid by the **parietal cell**s in the gastric **mucosa**. This acid is bacteriocidal for many ingested organisms; it also provides the necessary pH for the conversion of pepsinogen to **pepsin** and for the latter to start the digestion of dietary protein. The gastric mucosa is protected from self-digestion by an unstirred layer of mucus, made alkaline with **bicarbonate**.

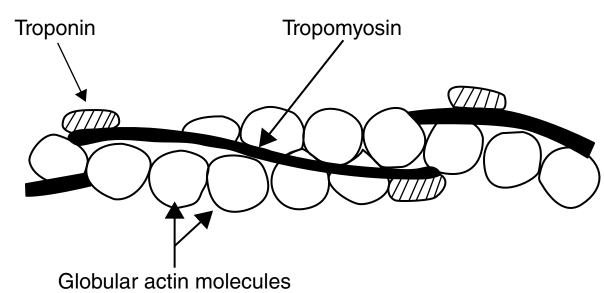
Because of its high content of bicarbonate, the **pancreatic juice** secreted into the **duodenum** is alkaline, e.g. pH 8.0. In addition, **bile** and intestinal juice both tend to be alkaline and so these three secretions soon neutralize the gastric contents entering the duodenum and raise the pH of the duodenal contents to 6.0–7.0. By the time the **chyme** reaches the **jejunum**, its reaction is neutral or may become alkaline, depending on the species. This has an important bearing on the solubility of **calcium phosphate** and the absorption of calcium ions from the upper part of the **small intestine** (*see* Hyperparathyroidism).

The pH of the contents of the **large intestine** is close to neutrality; however, in the horse, and other species in which there is a good deal of **cellulose** fermentation in the **caecum** and **colon** with the production of **volatile fatty acid**s, the pH of the gut contents in these regions is nearer 6.0 than 7.0. (ADC)

Acidosis:
see Lactic acidosis

Acorn
The fruit of the oak tree (*Quercus* spp.). Acorns can be dehulled but are more frequently fed whole, as, for example, to Iberian pigs in southern Europe to produce highly prized hams. These hams are considered to have special flavour due to the **tannins** and **fatty acid**s in the acorns. The tissues of pigs fed acorns have high concentrations of α-**tocopherol**, which reduces oxidative damage to the tissue. The **crude protein** of acorns is low (about 60 g kg^{-1}) and their **digestible energy** for pigs is 11–12 MJ kg^{-1}. Acorns contain hydrolysable tannins which degrade to produce pyrogallol. The consumption of acorns has been responsible for pyrogallol toxicity in cattle. (TA)

Actin
A water-soluble protein (molecular weight 43,000) containing 376 **amino acid**s. It is found in muscle and other tissues with motile function. It provides the thin filament backbone and combines with **myosin** to produce muscle contraction in the presence of **adenosine triphosphate** (ATP). Actin is the second most abundant protein in muscle, making up 10% of the total protein. (NJB)



The arrangement of actin, tropomyosin and troponin in the thin filament.

Activity, of enzymes:
see Enzyme activity

Activity, physical
Activity is brought about by muscular contractions in which chemical **energy** stores are converted into mechanical energy, which in turn is converted into heat as the work is performed. In this sense it is wasted energy but some activity is essential – for example, **foraging** by free-range animals, which involves further **energy expenditure**. This has led to the development of intensive production systems for egg layers and for growing chickens, pigs and calves, where activity is minimized.

Although chemical energy can be mobilized very quickly for vigorous work, this may not be reflected immediately in the animal's **oxygen consumption**, but the delay is only of short duration and the so-called oxygen debt is usually made up in a few minutes by increased respiration. Changes in oxygen consumption of an animal thus provide a good indication of the heat produced by activity. Even mild exercise can cause a considerable increase in oxygen consumption, and therefore in **heat production**, and at higher levels of activity increases of up to ten times the resting oxygen consumption can be sustained for prolonged periods, e.g. in draught animals, sheep being herded, racehorses and animals in flight from predators.

There have been few direct measurements of the metabolic cost of activity in farm animals. Most estimates take the form of comparisons of heat produced under different conditions, such as standing vs. lying, walking vs. standing still, walking uphill vs. walking on the level. These comparisons are surprisingly consistent, even between species. When cattle and sheep stand up, the effort involved in getting up causes increased oxygen consumption of some 30% over a few minutes, after which the standing:lying ratio is of the order of 1.12–1.20:1. The metabolic cost of continued standing over lying has been estimated as 0.07 to 0.14 watts kg^{-1} body weight (6–12 kJ kg^{-1} per day). In horses, which have the ability to sleep whilst standing, there is little difference in oxygen consumption between standing and lying.

The cost of movement on treadmills has been measured for animals and humans. The results for horses, cattle and sheep may be very crudely summarized as the increase in heat production per kg body weight in moving a distance of 1 m; it is 1.5–3 J kg^{-1} m^{-1} for horizontal movement and 25–35 J kg^{-1} m^{-1} for vertical upward movement. Speed of the movement has little effect on these estimates of total **energy cost**, because the effort of rapid movement has to be sustained for less time to cover the same distance. All these treadmill measurements may seriously underestimate the practical energy cost to animals of moving over soft or otherwise difficult ground. Experiments on animals dragging loads suggest that the mechanical work performed (i.e. force × distance) multiplied by three provides an approximate estimate of the extra heat produced by the animal. The metabolic cost of activities of humans, who are cooperative subjects, has been extensively studied and may provide a guide as to what may be expected in animals. (JAMcL)

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Acylglycerol

A form of **lipid** made up of one **glycerol** molecule combined with one to three individual (not necessarily identical) **fatty acid** molecules attached to the glycerol by **ester** bonds. Acylglycerols form part of the neutral lipid fraction. (NJB)

***Ad libitum* feeding**

Feeding at will. Unlimited access to feed allows animals to satisfy their **appetite**s at all times. Synonymous with full feeding. Their intake when feeding *ad libitum* is termed **voluntary food intake**. (MFF)

Adaptation

Term implying that there is some sort of norm from which the body or system deviates in response to changes in the normal environment. Within the normal population, a range of values is seen for any particular criterion that is examined, whether it be, say, activity of an enzyme, a blood parameter or body weight. Thus there is the statistical concept of the normal distribution. Adaptation implies a shift in the normal distribution or in the values for a particular individual. The former may be a long-term phenomenon in response to, for example, climatic change where those animals best suited genetically to the change will survive. Short-term adaptation implies that the physiological systems can respond to changes in external factors. These factors include **environmental temperature**, **light** cycle or intensity, stocking density, the physical environment and **nutrition** (particularly in relation to energy or protein intake). In general, the term can relate to a modification that lessens the negative impact of imposed change or takes advantage of an opportunity afforded.

One major aspect relates to changes in environmental temperature. Homeothermic animals tend to have a defined range of temperature – the thermoneutral zone – within which core body temperature remains constant without any change in **heat production**. The thermoneutral zone varies for different species and stages of development and may also be modified by adaptation of an animal to prolonged exposure to an environment that falls outside the thermoneutral zone. However, within the zone, different species have a wide range of mechanisms by which they can adapt to maintain **homeostasis**. For example, poultry can increase heat loss in warm environments by increasing **blood flow** to the comb, wattles and shanks and, conversely, can reduce heat loss by reducing blood flow, changing posture and piloerection, thus improving body insulation. Pigs, individually housed, alter posture to increase or decrease heat loss and, in groups, can significantly reduce heat loss by huddling together. Environmental temperatures below the thermoneutral zone result in shivering, which is a rapid noradrenaline-induced mechanism for increasing heat production. Prolonged exposure to low temperature results in an increase in basal **metabolic rate**, due to **non-shivering thermogenesis**. This adaptation takes several weeks to complete in response to a permanent reduction in environmental temperature.

Feed intake is increased at low temperatures and reduced at temperatures close to or above the upper limit of the thermoneutral zone. In the case of domestic fowl, food intake declines linearly across the normal range of environmental temperature (15–30°C). Stocking density and availability of trough space can also lead to marked changes in food intake. In pigs, for example, it has been observed that intakes are 10–15% higher with individually housed animals compared with those in groups. It is unclear whether this is a behavioural adaptation to boredom on the part of individual pigs or depression of intake due to **competition** in groups. However, there is a wide range of behavioural adaptations associated with changes in the physical environment, etc. For example, stereotypic behaviours such as bar-**biting** by sows tethered in stalls and reductions in tail-biting and aggression by pigs provided with the opportunity to root are negative and positive examples of such adaptations.

Of particular importance is the ability of the body systems to respond to changes in nutrition, especially in relation to energy and protein. One of the most extreme examples of response to **undernutrition** relates to studies by McCance and Mount (1960) on young pigs. These pigs were maintained for long periods on just sufficient quantities of a normal diet to maintain body weight. Whereas the **maintenance** requirement (MR) of normal piglets would be around 550 kJ kg^{-1} metabolic body weight ($W^{0.75}$), these undernourished pigs showed an MR of 250 kJ kg^{-1} $W^{0.75}$. The speed with which such changes occur in response to energy or protein deprivation was demonstrated by McCracken and McAllister (1984), who observed a reduction of approximately 25% in calculated maintenance requirement over a 3-week period. Changes in organ size relative to body weight have been observed during undernutrition of a wide variety of species, including poultry, pigs, cattle and sheep, and can be considered as contributing to the improved economy of the system. Conversely, increases in **energy intake** during **lactation** are associated with increased digestive organ capacity and increased metabolic rate. Similarly, offering a high-fibre (less digestible) diet to non-ruminants results in increased digestive organ size and weight, particularly in the hindgut, and increased energy supply from microbial **fermentation**.

In summary, the human or animal body has a wide range of mechanisms for coping with external stressors and a multitude of short-term and long-term adaptations have been reported, of which only a few examples have been discussed above. (KJMcC)

See also: Energy intake; Thermoregulation; Voluntary food intake

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Additives, feed

Feed additives are so numerous and heterogeneous that they almost defy precise definition. In general terms, however, a feed additive refers to low-inclusion products used in diet formulations for purposes of improving the nutritional quality of feed or the animal performance and health. A much broader description has been provided in EC regulation 1831/2003, wherein feed additives are defined as substances, microorganisms or preparations (other than feed material and pre-mixtures) which are intentionally added to feed or water to favourably influence *inter alia*: (i) the characteristics of feed or animal products; (ii) the environmental consequences of animal production; (iii) performance, health or welfare through their influence on gut microflora profile or feed **digestibility**; or (iv) to have a coccidiostatic or histomonostatic effect. Accordingly, feed additives are assigned to one or more of the following categories, depending on their functions and properties.

- Technological additives (e.g. antioxidants, emulsifiers, acidifiers)
- Sensory additives (e.g. flavours, pigments)
- Nutritional additives (e.g. vitamins, trace minerals, amino acids, non-protein N sources)
- Zootechnical additives (e.g. digestibility enhancers, gut flora stabilizers)
- Coccidiostats and histomonostats.

These additives have now become vital components in livestock and poultry diets. Lists of commonly used non-nutritional feed additives in poultry and ruminant diets are presented in Tables 1 and 2.

The use of feed additives in poultry feeds is expected to increase in the future and this will be driven by ongoing changes in world animal agriculture. In particular, three groups of additives, namely exogenous enzymes, replacements for antibiotic **growth promoter**s (AGP) and synthetic amino acids, are expected to play key roles.

The potential **nutritive value** of feedstuffs is often not realized at the animal level because of the limitations imposed by the presence of a range of anti-nutritional factors and the insufficiency (or lack) of digestive enzymes to break down specific chemical linkages. The need to improve nutrient utilization is the principal rationale behind the acceptance of feed enzymes. A wide range of feed enzymes, targeting different substrates in ingredients, is commercially available (see the Table 3). The poultry industry is now the largest user of feed enzymes.

Because of the AGP ban, the poultry industry has moved towards alternative strategies to prevent proliferation of pathogenic bacteria, thus maintaining health and performance status and optimizing digestion in poultry. A range of alternatives have been tested to directly affect microbial communities in the digestive tract. Although these additives all have been shown to 'mimic' the working effects of AGP on gut microbiome, none of the current generation of AGP alternatives, on their own, are capable of fully replacing them. Furthermore, the reproducibility of most AGP alternatives appears low and there is a lack of consistency in performance response. Available AGP alternatives are also costlier than conventional AGP programmes.

Table 1. Non-nutritional feed additives commonly used in poultry feeds

Additive	Examples	Reasons for use
Enzymes	Carbohydrases, phytase, protease	To overcome the anti-nutritional effects of arabinoxylans (in wheat and triticale), β-glucans (in barley) or phytate (in all plant feedstuffs) and to improve the overall nutrient availability and feed value.
Antibiotics[a]	Avilamycin, flavomycin, zinc bacitracin	To control Gram-positive, harmful bacterial species in the gut and to improve production efficiency; as a prophylactic measure against necrotic enteritis
Coccidiostats	Monensin, salinomycin, narasin	To prevent and control the clinical symptoms of coccidiosis
Pigmenting agents	Xanthophyll (natural and synthetic)	To improve the skin colour and appearance of carcasses
Antioxidants	Butylated hydroxy toluene (BHT), butylated hydroxy anisole (BHA), ethoxyquin	To prevent auto-oxidation of fats and oils in the diets
Antifungals		To control mould growth in feed; to bind and mitigate the negative effects of fungal toxins
Antibiotic replacers[b]		
i. Direct-fed microbials	Probiotics	Provision of beneficial species such as lactobacilli and streptococci
ii. Prebiotics	Fructo oligosaccharides (FOS), mannan oligosaccharides (MOS)	Binding of harmful bacteria
iii. Organic acids	Propionic acid, potassium diformate	Lowering of gut pH and prevention of the growth of harmful bacteria
iv. Botanicals	Herbs, spices, plant extracts, essential **oils**	Prevention of the growth of harmful bacteria
v. Antimicrobial proteins/ peptides	Lysozyme, lactoferrin, α-lactalbumin	Prevention of the growth of harmful bacteria

[a]The use of in-feed antibiotics is banned in the European Union and several other countries. Antibiotics are included in the above list because they are still in restricted use in other countries.
[b]A multitude of compounds (individually and in combination) are being used or tested as alternatives for antibiotic growth promoters (AGP).

Table 2. Additives used in ruminant animal feeds

Additive	Examples	Reasons for use
Non-protein N sources	Urea, biuret	Added to roughage feeds which have low rumen degradable protein contents as sources of ruminally available N to promote the growth and activity of rumen microorganisms
Minerals	Limestone, dicalcium phosphate, monoammonium phosphate	Improving the mineral content of feeds (often those based on cereal grains or low-quality roughages)
Surfactants	Poloxalene, vegetable oil	To reduce the foaming capacity of rumen contents and reduce the risk of frothy bloat
Protected nutrients	Formaldehyde-treated protein, Ca soaps	A way of protecting amino acids (e.g. methionine) and unsaturated fatty acids from microbial destruction in the rumen
Antibiotic	Virginiamycin	This antibiotic helps to protect the animal against acidosis and laminitis
Direct-fed microbials	Probiotics	Provision of beneficial species such as *Lactobacillus* spp., *Bacillus* spp., *Saccharomyces cerevisae*
Prebiotics	Fructo oligosaccharides, mannan oligosaccharides, yeasts	Nutrient sources for probiotic organisms

Protein is the second costliest item in animal diets, so maximizing the efficiency of protein and amino acid utilization is important. Geneticists have done their part in providing modern strains of poultry and pigs that can produce protein gain at greater efficiencies than ever before. The challenge to the nutritionists is to sustain these improvements in genetic potential by refining the amino acid nutrition. In this context, the commercial availability of synthetic amino acids has enabled

Table 3. Type of feed enzymes and target substrates

Enzyme	Target substrate	Target feedstuffs
β-Glucanases	β-Glucan	Barley, oats and rye
Xylanases	Arabinoxylans	Wheat, rye, triticale, barley, fibrous plant materials
α-Galactosidases	Oligosaccharides	Soybean meal, grain legumes
Phytases	Phytic acid	All plant-derived ingredients
Proteases	Proteins	All plant protein sources
Amylase	Starch	Cereal grains, grain legumes
Lipases	Lipids	Lipids in feed ingredients, lipid supplements
Mannanases, cellulases, hemicellulases, pectinases	Cell wall matrix (fibre components)	Plant-derived ingredients, fibrous plant materials

the nutritionists to meet more precisely the ideal amino acid profile and to sustain high performance levels. Currently four synthetic amino acids, namely DL-methionine, L-lysine HCl, L-threonine and L-tryptophan, are available at competitive prices. **Valine**, **leucine** and **isoleucine**, the next limiting amino acids in poultry diets, have recently become commercially available. (VR; GMcLD)

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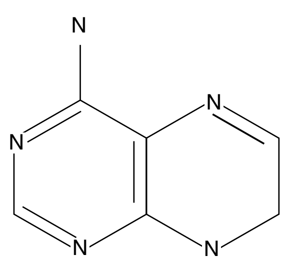
Adenine

6-Aminopurine $C_5H_5N_5$, one of the two **purine** (adenine, **guanine**) **nucleic acid** bases found in DNA and RNA. It is also part of molecules that are essential cofactors in **metabolism**, including ATP (**adenosine triphosphate**), ADP (adenosine diphosphate), NAD (**nicotinamide adenine dinucleotide**), NADP (nicotinamide adenine dinucleotide phosphate), FAD (flavine adenine dinucleotide) and CoA (**coenzyme** A). (NJB)



Adenosine diphosphate (ADP):
see Adenosine triphosphate

Adenosine monophosphate (AMP):
see Adenosine triphosphate

Adenosine triphosphate (ATP)

A water-soluble compound critical to cellular **metabolism**. It can store chemical **energy** for a short time (seconds to minutes) and then release that energy to support cellular processes (ATP → ADP + work + heat). The energy is derived from the electrons removed during the cellular **catabolism** of **carbohydrates**, **fatty acid**s and **amino acid**s. These electrons are used to reduce oxygen to water in the mitochondrial electron transport chain. In this process energy is stored in the terminal phosphate bond when adenosine diphosphate (ADP) is reconverted to ATP. (NJB)

Adenylate cyclase

A cytoplasmic enzyme involved in the production of the second messenger cyclic AMP (cAMP) from ATP. The cellular concentration of cAMP is increased or decreased by the action of hormones on adenylate cyclase activity. Cellular responses are modified by changes in the concentration of cAMP. (NJB)

Adhesion receptors

Receptors (which may have other functions) by which bacteria adhere to epithelial cells in the **gastrointestinal tract**. Adhesion is mediated by a specific **lectin** on either the receptor or the bacterium. (SB)

See also: Chemical probiosis; Gastrointestinal microflora; Probiotics

Adipocyte

A fat cell, a specialized cell in particular regions of the body in which neutral fats (**triacylglycerol**s) are stored. Adipocyte diameter can vary over threefold, depending on **lipid** content, which varies between the **adipose tissue** sites in the body. (NJB)

Adipose tissue

There are two types of adipose tissue: white and brown. White adipose tissue (WAT) is the main site of fat deposition in the animal body. Its main function is as an energy store, which accumulates in times of positive **energy balance** and is mobilized in times of negative energy balance. In addition, it protects certain internal organs against physical damage and provides thermal insulation.

The main WAT depots are subcutaneous, perinephric (perirenal), pericardial, abdominal (mesenteric and omental, sometimes also called gut and channel fat), intermuscular and intramuscular. In some **newborn animal**s there is very little WAT. It is a late-developing tissue that accumulates as animals approach their mature body size.

The main cell type found in adipose tissue is the **adipocyte**. Adipocytes range in size from 20 to 200 µm. The size and number of adipocytes vary between adipose tissue depots. Intermuscular adipose tissue contains a large number of small adipocytes whereas perinephric adipose tissue contains a small number of large adipocytes.

The main metabolic processes in adipose tissue are: (i) **fatty acid synthesis** and **triacylglycerol** synthesis, jointly known as **lipogenesis**; and (ii) **lipolysis**, the breakdown of triacylglycerols to yield **glycerol** and non-esterified fatty acids (NEFA). Adipose tissue is the major site of *de novo* fatty acid synthesis in ruminant species. In some non-ruminant mammals, fatty acid synthesis occurs in both adipose tissue and liver; whereas in avian species, adipose tissue is not an important site of fatty acid synthesis and triacylglycerols are synthesized from fatty acids of dietary origin or synthesized in the liver. In ruminant adipose tissue, **acetate** is the primary substrate for fatty acid synthesis. In non-ruminant mammals and birds, **glucose** is the major substrate.

Brown adipose tissue
(BAT) is a specialized form of adipose tissue. Its function is the generation of heat by the oxidation of fatty acids by the process of **non-shivering thermogenesis**. It is particularly important in neonatal animals. In some species (e.g. lambs) the ability to generate heat by non-shivering thermogenesis is lost within 2–3 days of birth; in others (e.g. rats) this property persists into adult life. Some species, such as the pig, do not have BAT and are particularly susceptible to cold immediately after birth. BAT is pale brown in appearance, due to the well-developed blood supply and to the presence of numerous mitochondria in adipocytes. It is found in a number of anatomical locations, for example in interscapular, axillary and perinephric regions. Its ability to generate heat is due to the 'uncoupling' from ATP synthesis of mitochondrial electron transport by uncoupling proteins (UCPs). These proteins cause the disruption of the proton gradient across the inner mitochondrial membrane. (JRS)

Adrenal
The adrenal gland is located above the anterior portion of the kidney. It is made up of two distinct anatomical and functional parts: the cortex and medulla. The cortex secretes three types of hormones: **glucocorticoids**, mineralocorticoids and androgens. The medulla produces and releases the catecholamine hormones, **dopamine**, **norepinephrine** and **epinephrine**. (NJB)

Adrenaline:
see Epinephrine

Adverse effects of food constituents
Any of the major food constituents (protein, carbohydrate, fat, mineral, vitamin, fibre, water) can induce adverse effects if they are not balanced for the requirements of the consumer. If the constituents are not balanced, the food may be avoided or, if it is the sole food available, intake will be low. One example is fibre which, being indigestible or only slowly digested (by microbes in the digestive tract), imposes physical work on the digestive tract as well as limiting the capacity to eat food. Other examples are specific plant toxins that interfere with **metabolism**, reducing the overall satisfaction the animal derives from each unit of food eaten. Many plants have evolved these to avoid being eaten. Another way in which food can have adverse effects is by the heat produced by its ingestion, **digestion** and metabolism, especially in a hot environment in which this extra heat is difficult to lose. A diet excessively high in protein can have such adverse effects due to the heat produced in the **deamination** of the excess **amino acid**s. Excessive concentrations of individual minerals, particularly in plants that accumulate the minerals as a means of protection, can induce specific toxicity symptoms or adverse effects by disturbing the mineral balance. Plants with a high water content, such as young herbage, may adversely affect the intake of dry matter, particularly if requirements are high and intake capacity is limited. (JMF)

Aerophagia
The consumption of excessive air during the eating of food. This may happen when food is eaten too quickly or the consumer vocalises while eating. (CJCP)

Aflatoxins
A family of bisfuranocoumarin **metabolite**s of toxigenic strains of *Aspergillus flavus* and *A. parasiticus*. The name derives from *Aspergillus* (a-), *flavus* (-fla-) and toxin. The major aflatoxins (AFs) are AFB1, B2, G1 and G2. The AFs are bioactivated by hepatic enzymes to toxic metabolites including AFB1-8,9-epoxide, and AFM1 (in milk). The AFs occur in the field in seeds (maize, cottonseed, groundnuts) and in storage of grains (maize, soybeans).

Biological effects are liver damage (acute and chronic) and liver cancer (chronic), reduced growth, impaired **lipid absorption**, with induced deficiencies of vitamins A, D and K, causing impaired blood coagulation, haemorrhage and bruises (poultry), and adverse reproductive effects. Differences in susceptibility between species of animals relate to the activity of hepatic **cytochrome** P450 enzymes, which bioactivate AF to the toxic metabolites. Rabbits, ducks and turkeys are highly susceptible to AF toxicity, while rats and sheep are less sensitive. Chronic AF intoxication is caused by 0.25 ppm (dietary) in ducks and turkeys, 1.5 ppm in broilers, 0.4 ppm in swine and 7–10 ppm in cattle. AF metabolites in liver cross-link DNA strands, impairing cell division and **protein synthesis**. AFB1 metabolites form DNA adducts, causing liver cancer. AF has immunosuppressive effects, impairing cell-mediated **immunity**. (PC)
See also: Mycotoxins

Age at weaning
This term is applied to young mammals, and it can be used in two ways: to mean either the age at which the young animal is separated from its mother, but may still be given milk or milk substitute; or the age at which any natural or artificial milk is withdrawn from the ration. (PJHB; GMcLD)

Agglutinins:
see Haemagglutinins

Agroforestry/silvopastoral system
A combination of trees with agricultural crops and livestock can have significant benefits for the environment and water use. When trees are combined with grazing in silvopastoral systems, this can provide benefits to parasite control in the animals, shade and diversification of feed resources. However, establishment of **legumes** and other **forage** for grazing can be hindered by low light levels under the canopy of the trees, particularly if it is almost closed. If properly managed, agroforestry can ensure good agricultural yields while maintaining biodiversity and promoting social equity. Agroforestry is seen as an alternative to large-scale conventional agriculture with the potential to deliver transformational agricultural practices.
(CJCP; DM)

Further reading
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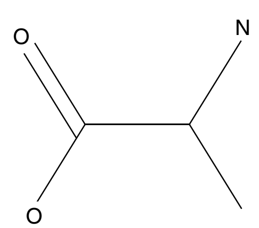
Alanine
An **amino acid** ($CH_3{\cdot}CH{\cdot}NH_2{\cdot}COOH$, molecular weight 89.1) found in protein. It can be synthesized in the body from **pyruvate** and an amino donor such as glutamic acid. Substantial quantities of alanine are synthesized in gut **mucosa** and muscle, and the alanine not used for **protein synthesis** is transported to the liver where the enzyme alanine **aminotransferase** converts alanine to pyruvate. Mitochondrial pyruvate in the liver can either be used in the **TCA cycle**, or it can be converted (carboxylated) to **oxaloacetate**, some of which is subsequently reduced to **malate**, some transaminated to aspartate, and some decarboxylated to phosphoenolpyruvate. All three of these compounds can escape the mitochondrion and enter the cytosol to be used for **gluconeogenesis**. Integration of these processes involving muscle and liver tissue is often referred to as the glucose–alanine cycle. (DHB)



See also: Gluconeogenesis; Pyruvate

Albumin
Originally classified as protein that was soluble in a 50% saturated solution of ammonium sulphate. Albumins (five separable proteins) account for approximately half of the protein in **blood plasma**. Plasma albumin plays an important role in regulation of osmotic pressure. Bilirubin, free **long-chain fatty acids** and a number of steroid hormones are found bound to albumin. (NJB)

Alcohols
Having a functional ·COH group. The group includes primary, secondary and tertiary alcohols, with one, two and three ·COH groups. Long-chain alcohols (up to 30 carbons) are found as esters with **palmitic acid**. **Glycerol** and **cholesterol** are alcohols. **Ethanol**, $CH_3{\cdot}CH_2OH$, is an alcohol produced by **fermentation** and can be used as a source of metabolic energy. It has a caloric value of 29.7 kJ g^{-1} or 23.4 kJ ml^{-1}. (NJB)

Aldehydes
Having a functional ·CHO group. Many six-carbon (e.g. **glucose**), five-carbon (e.g. ribose) or four-carbon **sugars** (e.g. erythrose) have a functional aldehydic carbon. Aldehydes are intermediates when a functional alcohol carbon is converted to an acid carbon. Aldehydes such as **formaldehyde** and **acetaldehyde** are highly toxic and react with tissues. (NJB)

Aldosterone
A 21-carbon steroid hormone synthesized in the **adrenal** cortex and classified as a mineralocorticoid. It plays a role in sodium retention and potassium excretion by the kidney. (NJB)

Aleurone
The single outer layer of living cells surrounding the **endosperm** of cereal grains. Rich in protein, these cells synthesize the enzyme α-**amylase**, which is responsible for the breakdown of the stored starch in the endosperm into **maltose** and **glucose** during **germination**. The aleurone layer remains attached to the bran during milling. (ED)
See also: Cereal grains

Alfalfa:
see Lucerne

Algae
Plant-like diverse aquatic photosynthetic, and nucleus-bearing organisms that lack the true roots, stems, leaves and specialized multicellular reproductive structures of plants. They possess **chlorophyll** in combination with accessory photosynthetic pigments and have minimal differentiation into defined

tissues or organs. They occur in a variety of forms and sizes and range from single microscopic cells (picoplankton that are between 0.2 to 2 micrometres in diameter) to among the tallest organisms known (giant kelps, c. 60 m in length) and are mainly aquatic, with some tolerating periodic or prolonged exposure to air. Algae are found in a range of aquatic habitats, both freshwater and saltwater, and they have potential as food and fuel in the future. Increasingly algae meal is used in aquatic animal feeds, for example in the diets of abalone, sea cucumber, marine shrimp, marine fish fry, etc., since it contains a high level of sticky algal **polysaccharide**s (Barsanti and Gualtieri, 2014) and a high level of protein (Li and Wu, 2020) in most single microscopic cells. The nutritional potential of algae additives in poultry nutrition includes improvement of the **antioxidant** activity of the blood, increase of immunoglobulins and strengthening of the immune system of the host, and use as a valuable phytogenic additive for partially replacing in-feed antibiotics (Tufarelli *et al.*, 2021; Feshanghchi *et al.*, 2022).

Some algae can reduce the output of **methane** from the rumen and hence greenhouse gases, without any negative effects on the productivity and health of ruminants. This could be one strategy to help prevent global climate change, but there is a need for more studies of suitable species of algae for commercialization and the determination of the optimal dosage in feeding domestic animal (McCauley *et al.*, 2020).

(CB; DB; QS; AS; BH-G; CJCP)

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Algal toxins

Toxins of algal origin (also called phycotoxins) are most often produced by unicellular marine flagellates, particularly dinoflagellates, but also by members of other major flagellate algal groups, such as raphidophytes, haptophytes and pelagophytes. A few species of the diatom genus *Pseudo-nitzschia* synthesize a potent neurotoxin, domoic acid. In fresh and brackish waters, cyanobacteria ('blue-green algae') are often implicated as toxic algal contaminants in drinking-water supplies for humans and livestock. In the **marine environment**, cyanobacterial toxins are responsible for 'net-pen **liver disease**' in caged salmonids. When present in high abundance or during periods of rapid growth ('blooms'), algae can cause water discolorations known as 'red tides', usually in fresh or coastal waters – these phenomena are not always associated with toxicity. Toxic events associated with algae may be divided into two types: (i) those caused by the production of specific toxic **metabolites**; and (ii) those resulting from secondary effects, such as post-bloom **hypoxia**, **ammonia** release, or other artefacts of decomposition on marine flora and fauna. Phycotoxins and their causative organisms are globally distributed in marine coastal environments, from the tropics to polar latitudes, and few areas are exempt from their effects, which may be expanding in geographical extent, severity and frequency on a global basis. In a few cases, this may be linked to eutrophication, but there is no general hypothesis to explain all such events.

Among the thousands of extant species of marine microalgae, only several dozen produce highly potent biotoxins that profoundly affect the health of marine ecosystems, as well as human and other animal consumers of seafood products (see table). As an operational category, certain toxic microalgae are often called 'fish-killers' because of their potent direct effects on fish, particularly in **aquaculture** systems. Such toxins are poorly characterized and the mechanism of action is often not well understood, although the toxic effects are typically mediated through the gills. In contrast, the toxins associated with human illnesses by consumption of contaminated finfish (e.g. ciguatera fish **poisoning**, clupeotoxicity) and paralytic, amnesic, neurotoxic and diarrhoeic shellfish poisoning (PSP, ASP, NSP and DSP, respectively) caused by ingestion of **shellfish** are much better known. The phycotoxins responsible for these syndromes constitute a heterogeneous group of compounds, affecting a variety of receptors and metabolic processes, acting as Na^+-channel blockers, Ca^{2+}-channel activators, **glutamate** agonists, phosphatase inhibitors, etc. These pharmacologically active compounds also include the emerging problems associated with 'fast-acting toxins' of poorly defined human health significance, such as gymnodimine and spirolides. Many of the phycotoxins can be propagated within marine food webs from **phytoplankton** through **zooplankton** (copepods, **krill**), then from ichthyoplankton to large carnivorous fish, and even marine birds and mammals. Toxin accumulation within fish stocks (e.g. anchovies) harvested for fish meal production may even be a risk for aquaculture of certain species. Except in bivalve shellfish, where oxidative and reductive transformations mediated by both enzymatic and non-enzymatic processes have been determined, and in the case of biotransformation within fish tissues of ciguatoxin precursors from dinoflagellates, metabolism of phycotoxins is poorly understood. (AC)

See also: Marine environment; Marine toxins

Acute toxicity (LD_{50}) of selected phycotoxins after intraperitoneal injection into mice. Only major toxin analogues found in shellfish or finfish, and/or the corresponding toxigenic microalgae, for which the pathology in mammals is known or highly suspected are included. Note that multiple derivatives of varying toxicity are common for most toxin groups. Data summarized from citations in Hallegraeff *et al*. (2002).

Toxin group	Analogue	Toxicity (μg kg^{-1})	Primary pathology
Azaspiracid	AZA	200	Gastrointestinal
	AZA2	110	Gastrointestinal
	AZA3	140	Gastrointestinal
	AZA4	470	Gastrointestinal
	AZA5	1000	Gastrointestinal
Brevetoxin	BTX-B1	50	Neurological
	BTX-B2	300	Neurological
	BTX-B3	> 300	Neurological
Ciguatoxin	CTX1	0.25	Neurological
	CTX2	2.3	Neurological
	CTX3	0.9	Neurological
Gambiertoxin	GTX-4B	4.0	Neurological
Maitotoxin	MTX1	0.05	Neurological
	MTX1	0.05	Neurological
	MTX2	0.08	Neurological
	MTX3	0.1	Neurological
Okadaic acid	OA	200	Gastrointestinal; tumour promotion
Dinophysistoxin	DTX1	160	Gastrointestinal
	DTX3	500	Gastrointestinal
Gymnodimine		96	Neurological(?)
Pectenotoxin	PTX1	250	Hepatotoxic
	PTX2	230	Hepatotoxic; gastrointestinal
Saxitoxin	STX	11	Neurological
	NeoSTX	12	Neurological
Gonyautoxin	GTX1	11	Neurological
	GTX2	32	Neurological
	GTX3	16	Neurological
	GTX4	13	Neurological
Spirolide	B	200	Neurological (?)
	des-methyl-C	40	Neurological (?)
Yessotoxin	YTX	100	Cardiotoxic

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Alimentary tract:
see Gastrointestinal tract

Alkali disease

A chronic form of selenosis, which occurs in cattle and horses after prolonged consumption of plants with high **selenium** concentrations. It is characterized by alopecia, hoof dystrophy, lack of vitality, emaciation, poor quality hair, sloughing of the hooves and stiff joints. Although not widespread, it is of major importance in some localized areas, such as parts of the Great Plains of North America. (CJCP)

Alkali treatment of feeds

A method of treating feeds to improve their **digestibility** and/or storage life. It is used with cereal grains, and with low-quality (i.e. highly lignified) forages such as cereal straws. The principle behind the treatment of fibrous materials with alkali is that it hydrolyses **ester** bonds between the cell wall **hemicellulose** and **lignin**, thus reducing the capacity of lignin to protect the cell wall **polysaccharide**s and rendering the material more susceptible to rumen microbial degradation.

Early techniques in the late 19th century were industrial processes requiring both heat and pressure. However, in the

Beckmann process, the first on-farm methodology, cereal straw was soaked for up to 2 days in a dilute (1.5%) sodium hydroxide solution, then washed to remove any excess alkali. This technique improved degradability but considerable soluble (i.e. potentially degradable) material was lost during the washing process. The use of more concentrated solutions, either sprayed on to chopped or shredded straw, or applied by dipping baled **straw** into vats which was then allowed to 'mature' for up to a week prior to feeding, reduced these losses. The delay ensured that residual sodium hydroxide had reacted with carbon dioxide, to form sodium carbonate.

The response to treatment varies inversely with the quality of the untreated straw. To realize the potential improvement in degradability, sufficient **ruminally available nitrogen** (RAN) and sulphur must also be provided when the treated straw is fed. Sodium hydroxide is the most commonly applied alkali, though potassium hydroxide (often as wood ash), calcium hydroxide, alkali **hydrogen peroxide** and calcium oxide (lime) have all been used. There are some disadvantages of this technique. Animals fed these treated materials increase their water consumption (a potential drawback in arid regions), leading to increased urine output, which generates a problem with quantity and disposal of bedding. The high urinary output of sodium may damage soil structure. Unreacted sodium hydroxide can cause ulceration around the mouth.

Alkalis applied to cereal grains disrupt the integrity of the seed coat, increasing the accessibility of the starch to the **rumen microorganisms** without the requirement for physical processing. Conventionally harvested grain is blended with sodium hydroxide, water is then added and the material mixed. This reaction produces considerable heat, following which the grain should be remixed prior to storage. The amount of sodium hydroxide required for optimum digestibility varies with the fibre content of the grain husk. About 25 kg t^{-1} is used with wheat and 40–45 kg t^{-1} for oats. Treated grain can be fed direct or after mixing with water, which causes the seed coat to swell and rupture. The slower release of starch relative to that from ground or rolled grain interferes less with fibre degradation, allowing higher intakes of **roughage** to be maintained. Residual alkali helps to maintain rumen pH, reducing the incidence of acidosis when high levels of grain are offered. An additional benefit is that sodium hydroxide treatment has a preservative effect on high-moisture grain, reducing both bacterial and fungal growth. Offered to cattle, treated grain maintains a higher rumen pH, tends to increase the acetic:propionic **propionic acid** ratio, and reduces the incidence of rumenitis in comparison with cattle fed conventionally processed material. Similarly, when high levels are offered to dairy cows, depressions in milk fat content are minimized and roughage intake is maintained. (FLM; GMcLD)

See also: Ammonia treatment

Alkaline phosphatase

An enzyme found in intestinal contents that catalyses the release of phosphate from a wide variety of phosphorylated cellular **metabolite**s and cofactors (e.g. sugar phosphates, **nucleotides**, ATP). It is also found in tissues such as liver, bone and kidney, which are sources of plasma alkaline phosphatase. In bone it is thought to contribute to crystal formation. (NJB)

Alkaloids

A class of **plant secondary compound**s generally characterized as containing at least one basic heterocyclic nitrogen atom and usually possessing some type of physiological activity. They are found in approximately 15% of all vascular plants. Alkaloids are a heterogeneous group of compounds, subdivided and further classified by a similar basic chemical structure containing the nitrogen atom. Alkaloids comprise several thousand different structures and possess a wide variety of physiological activities and potency. Some of the key sources of plant material containing alkaloids affecting animal **nutrition** are listed in the table. (DRG)

Key sources of plant alkaloids

Alkaloid class	Plant or organism	Physiological effect
Diterpene	*Delphinium*	Neurotoxic
Indole	*Claviceps*, *Peganum*, *Phalaris*	Neurotoxic, vascular
Indolizidine	*Swainsona*, *Astragalus*, *Physalia*	Glycosidase inhibitor, teratogenic
Piperidine	*Conium*, *Lupinus*, *Nicotiana*	Neurotoxic, teratogenic
Pyridine	*Nicotiana*	Neurotoxic
Pyrrolizidine	*Senecio*, *Crotalaria*, *Heliotropium*	Hepatotoxic, pneumotoxic, photosensitization
Quinolizidine	*Lupinus*, *Thermposis*, *Cytisus*, *Baptisia*	Teratogenic, myotoxic, neurotoxic
Steroidal	*Solanum*, *Veratrum*, *Zigadenus*	Teratogenic, cholinesterase inhibitor
Tropane	*Datura*, *Atropa*, *Hyoscyamus*	Neurotoxic, blindness

Alkalosis

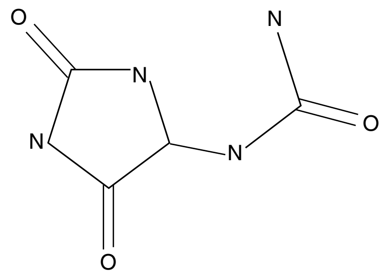
A pathological condition in which the arterial plasma pH rises above 7.4. The range of alkalosis that is compatible with life is 7.4–7.7. An example is metabolic alkalosis resulting from excessive loss of gastric acid during prolonged vomiting. This also involves considerable loss of potassium in the urine. Treatment is by intravenous infusion of isotonic saline containing supplementary **potassium chloride** to correct both the chloride and potassium deficits. The bicarbonate excess corrects itself. (ADC)

All-*trans* retinoic acid

A metabolic derivative of **vitamin A** (all-*trans* retinol) or β-carotene via the intermediate formation of all-*trans* retinol. Retinoic acid interacts with nuclear retinoic acid receptors (there are at least six) to affect appropriate genes, which results in cellular differentiation. (NJB)

Allantoin

$C_4H_6N_4O_3$, a degradation product of **purines**. It is an intermediate in the production of allantoic acid from uric acid that can be converted in part to urea except in birds and reptiles. (NJB)



Allowance nutrient requirements
The best estimates for the particular species, age and production system based on the available scientific evidence. The term 'allowance' takes account of the need to include a **safety factor** on top of 'requirements' to allow for variations in environmental conditions and individual variability in requirements. Allowances are usually set at 5–10% above requirements. (KJMcC)

Aloe (*Aloe vera*)
A plant with thick (fleshy) and long leaves, recognizable spots, blades at the end of the leaf, yellow-green flowers that grows in temperate and tropical conditions.

This plant contains a small amount of essential **oil** with a special smell belonging to aloes. It contains 12–13% resin. A special compound in aloe vera is called aloe emodine, with the molecular formula $C_{15}H_{10}O_5$, which is also known as frangula emodine, a methyltrioxyanthraquinone. The common name of the active compound of this plant is aloin (Zargari, 1997). This plant is one of the oldest medicinal plants, but in the 1990s the industrial use of this plant led to the expansion of its production, so that in 2018 the trade value of this plant in the world was estimated at US$1.6 billion. The presence of more than 75 bioactive compounds such as **polysaccharides** (the most important of which is acemannan), **phenolic compounds**, anthraquinones and phytosterols indicate the value of this plant (Thakare , 2020; Martínez-Burgos *et al*., 2022). The application of aloe vera is wide; it can be mentioned in cosmetic moisturizers, toothpaste, food flavouring, compounds and preservatives of medical products. The properties of this plant include wound healing, anti-inflammatory, immunogenic, anti-diabetic, natural antioxidant, laxative, antibacterial, antifungal, antiviral and anti-tumour effects (Martínez-Burgos *et al*., 2022). A review of scientific literature shows that supplementing poultry diets with aloe vera (0.1–1%) can increase body weight by 7–25%, improve and strengthen the immune system by 10–50%, and reduce the number of intestinal bacteria by 24% and 30%, while increasing the population of beneficial bacteria in the gut. These results indicate the usefulness of aloe vera extracts as a natural supplement without side effects to maximize poultry productivity (Ebrahim *et al*., 2020). (AS, BH-G, CJCP)

Aloe vera as a cultivated crop. Photo courtesy of Mathias Isenberg. Licensed under CC BY-ND 2.0.

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Alpaca meat, effects of nutrition:

see South American camelids, effects of nutrition on meat quality

Aluminium

The most abundant metal in the earth's crust. Its low solubility ensures that the concentration in most plant and animal tissues remains low. The only evidence of toxicity in farm animals comes from its interaction with essential nutrients, in particular phosphorus and magnesium in ruminants and iron in poultry, possibly leading to deficiencies in those elements in range livestock. Neurobehavioural disorders have been demonstrated at high aluminium intakes in laboratory animals by those seeking to determine the role of aluminium in the development of Alzheimer's disease in humans. (CJCP)

Amadori products

Intermediates in the reaction of phenylhydrazine with monosaccharides (e.g. glucose) to form glucose phenylosazones. Amadori products are undefined intermediates in Amadori rearrangement in the production of, for example, **glucose** phenylosazone from glucose phenylhydrazone. (NJB)

Amaranth

There are 75 species in the *Amaranthus* genus. According to the report of the Food and Agriculture Organization (FAO), amaranth could contribute significantly to meeting human nutritional requirements (Li *et al*., 2018). The World Health Organization (WHO) considers amaranth a neglected and underutilized species (NUS), which could improve food security and contribute to climate change mitigation (FAO, 2018).

Cultivated crop of *Amaranth opopopeo*. Photo courtesy of Photofarmer.

Several species have edible leaves, such as *Amaranthus tricolor*, *A. dubius* and *A. lividus*. In addition to leaves, some species have valuable edible grain, such as *A. hybridus*, *A. cruentus*, *A. caudatus*, and *A. hypochondriacus* (Cai *et al*., 2004). The amaranth grain has a high protein content relative to many other plant-sourced foods and has a **metabolizable energy** value similar to that of cereals (Hosseintabar-Ghasemabad *et al*., 2020). Amaranth grain protein consists mainly of albumin (48.9–65%) and glutelin (22.4–42.3%), **globulin** (13.7–18.1%) and prolamin (1–2.3%). It is a good source of some **amino acids** such as **lysine**, **methionine** and **arginine** in animal nutrition (Cai *et al*., 2004). In recent years, the diversity and abundance of amaranth's bioactive compounds have attracted the attention of researchers and the health benefits of amaranth have been investigated (Tang and Tsao, 2017). Due to the challenges of providing squalene from marine sources (whales and ocean sharks), amaranth is of interest as a rich source of squalene in plants. Squalene has significant roles in medicine, as well as in chemical (in the formulation of lubricants) and pharmaceutical industries (in the formulation of cosmetics and corona vaccines). Amaranth is **gluten**-free, which makes it useful for coeliac patients. It is also recommended in the formulation of baby food and for high-risk communities affected by AIDS, hepatitis and malaria (Cai *et al*., 2004; Tang and Tsao, 2017). The anti-cancer properties of the amaranth grain are attributed to the presence of compounds such as lunasin, amaranthine, isoamaranthine, some **tocopherol**s and **tocotrienol**s, squalene, **lectin**, **resistant starch** (RS) and phytasmic compounds. The leaves contain **carotenoids**, such as **lutein** and beta-carotene with anti-cancer properties. Anti-obesity properties and reduction of **cholesterol** and atherogenic index (LDL/HDL) are attributed to the fibre, squalene, **vitamin E** and B **isomers** and isoprenoids in amaranth (Paśko *et al*., 2011; Tsao and Tang, 2017). Anti-diabetic properties of amaranth are thought to be due to the presence of dipeptidyl **aminopeptidase** IV (DPP IV) and 20-hydroxyecdysone (20HE) (O'Harte *et al*., 1999; Tsao and Tang, 2017). In 1975, the National Academies of Science, Engineering and Medicine of the USA listed amaranth as a feed ingredient in animal nutrition, supported by research on poultry (broilers, laying hens, turkeys and quails), ruminants and **aquaculture** (Peiretti, 2018). (AS, BH-G, CJCP)

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Amide

A compound with the specific carbon–nitrogen linkage R·CON·R. The peptide bond between amino acids in proteins is an amide linkage. Familiar amides are the amino acids **asparagine** and **glutamine** in which an **amino nitrogen** ($\cdot NH_2$) is linked to a carboxyl-carbon, e.g. asparagine, $NH_2CO\cdot CH_2\cdot CH(NH_2)\cdot COOH$. (NJB)

Amine

A compound with the specific carbon–nitrogen linkage $R\cdot CNH_2$. The simplest amine is **methylamine** ($CH_3\cdot NH_2$) in which one of the hydrogens of ammonia has been replaced by a methyl ($CH_3\cdot$) group. Free **amino acid**s can be considered as amines. Some amines produced by **decarboxylation** of amino acids or modified amino acids are precursors of active substancees (e.g. **histidine** to **histamine**, 5-hydroxy-**tryptophan** to **serotonin** etc.). (NJB)

Amino acid

Organic substance containing both amino and acid groups. All amino acids consist of the elements C, H, N and O, and some have the elements S, P, I and Se. An acid group in a natural amino acid can be the carboxyl (-COOH; e.g. **alanine**), sulfonic acid ($-SO_3H$; e.g. **taurine**), phosphoric acid ($-PO_4H_2$; e.g. phosphoethanolamine), or phosphonic acid ($-PO_3H_2$; e.g. 2-aminoethylphosphonte) group. Amino acids are readily ionizable in an aqueous solution to form a structure known as a dipolar ion or zwitterion, with both positive and negative electrical charges. The different carbon atoms of amino acids are named in sequence according to the Greek alphabet. If the amino group is linked to the ß-, γ-, δ-, or ε-carbon, the amino acid is designated a ß-, γ-, δ-, or ε-amino acid, respectively. Examples of natural α-, ß-, γ-, δ-, or ε-amino acids are **alanine**, β-alanine, γ-**aminobutyric acid**, 5-aminovaleric acid and 6-aminocaproic acid, respectively. (GW)

See also: individual amino acids

Amino acid metabolism

Although there are hundreds of naturally occurring amino acids, only 20 are normally found as constituents of protein.

Other amino acids not found in protein are products (e.g. **taurine**) or intermediates (e.g. **ornithine** or **citrulline**) in essential metabolic processes. Proteinogenic amino acids have the general formula $R{\cdot}CH(NH_2){\cdot}COOH$. In solution they are 'zwitterions', meaning that the $\cdot COO^-$ is negatively charged and the $\cdot NH3^+$ is positively charged. The metabolism of amino acids involves their incorporation into a wide variety of proteins, their release from protein during **protein turnover**, their use in the production of essential peptides (e.g. **glutathione**) as precursors of other amino acids and essential **metabolite**s, and as a source of energy via **gluconeogenesis** or ketogenesis. In the body approximately 1% of all amino acids are found as free amino acids, while 99% are integrated into protein, with a small fraction found as polymers such as peptides and **hormone**s.

The main source of amino acids for animals is the **diet**, though in some animals (especially ruminants) amino acids are also produced by gut microflora from dietary amino acids (i.e. one amino acid is metabolized to a different amino acid by the microbes) and non-amino acid precursors during fermentative **digestion**. In **foregut** fermenters, the microbially synthesized protein continues through the digestive tract, and is subject to digestion and the amino acids absorbed in the same manner as dietary protein. In hindgut fermenters, **microbial protein** synthesis takes place after the gastric **stomach**, and therefore microbial protein digestion and amino acid utilization by the animal is limited. Some animal species (e.g. rabbits, hamsters and guinea pigs, among others) engage in caecotrophy to further extract the amino acids from microbial protein and other nutrients (*see* Coprophagy). Amino acids are absorbed from the **small intestine** as free amino acids or as di- and tripeptides and released into the **blood** mostly as free amino acids but some peptides. Cellular uptake of amino acids is dependent on both **sodium**-dependent and sodium-independent transporters.

For non-ruminant animals, dietary amino acids are classified as being dispensable (or nutritionally non-essential; i.e. can be synthesized at rates sufficient to meet the metabolic need), conditionally indispensable (i.e. can be made from the basic carbon skeleton with **amino nitrogen** provided by reactions such as **transamination**) or indispensable (or nutritionally essential; i.e. the carbon skeleton cannot be synthesized by the animal and must normally be supplied fully formed in the diet). The dispensable amino acids are **alanine** and aspartate, because their precursor carbon skeletons are unlikely to be limiting under normal metabolic conditions. The conditionally indispensable amino acids are **arginine** (indispensable for birds, fish and young mammals), **aspartate, glutamine**, **glutamate**, **glycine**, **proline,** and **serine**. The indispensable amino acids are **histidine**, **isoleucine**, **leucine**, **lysine**, **methionine**, **phenylalanine**, threonine, **tryptophan** and **valine**. Often included in this category are the semi-indispensable amino acids, **cysteine** and **tyrosine**, which can be synthesized by animals from methionine and phenylalanine, respectively. For **ruminant animal**s, the same classification applies but a large proportion of the amino acids required can be derived from microbial synthesis in the rumen.

The limitation to synthesis of indispensable amino acids is the ability to synthesize the carbon skeleton, or to transaminate the alpha-**keto acid**. Within the body, glutamate is synthesized by the reaction of α-ketoglutarate with ammonium or an existing amino group from another amino acid. The general process of synthesis of some (but not all) dispensable amino acids begins with transamination or amidation reactions. An amino group is transferred from an existing amino acid to an alpha-keto acid arising from metabolic pathways within the body to produce a new amino acid.

There is no long-term storage of free amino acids in the body. Rather, individual amino acids in excess of the requirement for **protein synthesis** or use for the formation of non-protein metabolites are catabolized.

The carbon skeleton of the glucogenic amino acids (alanine, arginine, **aspartic acid**, **cysteine**, glutamic acid, glycine, histidine, methionine, **proline**, serine, threonine and valine) provides precursors for the production of **glucose** via the **citric acid** cycle (*see* Gluconeogenesis). In many species, both the liver and kidneys are involved in the production of glucose from amino acids and from three-carbon intermediates (**pyruvate** and **lactate**) from glucose **catabolism**. The ketogenic amino acids (leucine and lysine) provide (acetyl-CoA) that is the precursor of **ketone** bodies or give rise to them directly (acetoacetate). Depending on the metabolic pathways used, some amino acids can give rise to either type of intermediate and are thus both glucogenic and ketogenic (isoleucine, phenylalanine, tryptophan and tyrosine).

The nitrogen from amino acid catabolism in mammals is excreted in urine as **urea** (CN_2H_4O) and ammonium ion (NH_4^+). The production of urea occurs primarily in the liver and involves five enzymes, two of which are in the mitochondrial matrix. This subcellular division in the site of urea production requires transporters (ornithine/citrulline, **malate**, aspartate, **glutamate**) located in the membrane of the mitochondrion and gives rise to the potential for transporter control of urea synthesis. Other nitrogen-containing compounds found in urine (e.g. **creatinine**) are not part of a dedicated nitrogen excretion pathway. Birds lack carbamoyl-phosphate synthetase I and other enzymes, and therefore lack a functional **urea cycle**. In birds, the main end-product of nitrogen excretion is uric acid ($C_5H_4N_4O_3$). Production of uric acid requires the transfer of two single-carbon units via **tetrahydrofolate** and thus competes with other systems requiring one-carbon units as part of their **metabolism**. Fish primarily excrete ammonia, but under certain conditions may excrete some nitrogenous waste as urea.

The main site of catabolism of most amino acids is the liver but the catabolism of the transaminated **branched-chain amino acids** may involve both muscle and liver. On a whole-body basis, the capacity for **transamination** with subsequent production of the branched-chain alpha-ketoacids is higher in muscle while the capacity to catabolize the branched-chain alpha-ketoacids via a branched-chain alpha-ketoacid **dehydrogenase** is greater in the liver. Another example of inter-organ cooperation is seen in the transport of nitrogen from amino acid catabolism in muscle to the liver via the 'alanine cycle'. Nitrogen from the branched-chain amino acids and other sources is combined with pyruvate to produce alanine, which is transported to the liver; the nitrogen can then be incorporated into aspartate and glutamate and then into urea.

A number of amino acids are precursors of such essential products as haem, **purine**, **pyrimidine**, hormones and **neurotransmitters**. Arginine reacts with glycine and, following a reaction involving *S*-adenosyl methionine, gives rise to **creatine**, which is involved in **adenosine triphosphate** recycling. Lysine in proteins can be methylated by ***S*-adenosylmethionine** in a reaction catalysed by specific methyltransferases to **trimethyllysine** which, after the protein is broken down, becomes part of **carnitine**, which is involved in transport of **long-chain fatty acids** into the mitochondrion and other functions. Histidine gives rise to **histamine**, which plays a role in local immune responses and neurotransmission. Histidine bound in certain proteins (e.g. **actin** and **myosin**) is methylated by *S*-adenosylmethionine to form 3-**methylhistidine** which, upon **protein degradation**, is released but cannot be reused for protein synthesis. Because it is quantitatively excreted in the rat and human, it has been used to estimate muscle protein catabolism. Histidine, with β-alanine, forms the dipeptide **carnosine**, which has **antioxidant** and other functions. The dipeptide anserine (a potential neuroprotectant) contains β-alanine and 1-methylhistidine, and is formed by the **methylation** of carnosine. Phenylalanine is a precursor of tyrosine, which provides the basic structure for L-3,4-dihydroxyphenylalanine (DOPA), the precursor for the neurotransmitters **dopamine**, **epinephrine** and **norepinephrine**. Tryptophan is converted into the vitamin **niacin** in many species; after conversion to 5-hydroxytryptophan, it can be metabolized to the neurotransmitter **serotonin**. Methionine, via its conversion to *S*-adenosylmethionine, is a source of methyl carbons for numerous **methylations**. Additionally, via conversion to *S*-adenosylmethionine, methionine provides **sulphur** for the biosynthesis of cysteine (the carbon comes from serine), and the $-(CH_2)_3-NH_3^+$ group for the biosynthesis of spermidine and spermine. (DRK)

See also: Protein metabolism

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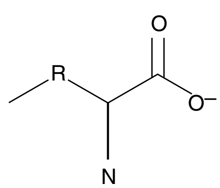
Amino nitrogen

The amine nitrogen ($-NH_2$) attached to the α-carbon and, in some cases, the terminal carbon of an **amino acid**. The reaction of ninhydrin with α-amino nitrogen of free amino acids was an early basis for quantifying amino acids. (NJB)



Amino sugars

Monosaccharides (simple sugars) in which a single hydroxyl group (-OH) is replaced by an amino group ($-NH_2$). Glucosamine, **galactosamine** and mannosamine are examples. Glucosamine is a component of heparin, while the *N*-acetyl derivative is found in hyaluronic acid. Galactosamine, as the *N*-acetyl derivative, is a component of chondroitin. Mannosamine, as the *N*-acetyl derivative, is a component of sialic acid. (NJB)

Amino-oligopeptidase:
see Aminopeptidase

Aminobutyric acid

Can be found in two forms. α-Aminobutyric acid ($HOOC{\cdot}CH_2{\cdot}CHNH_2{\cdot}COOH$) is produced by **transamination** of α-ketobutyric acid produced in the **catabolism** of threonine and **methionine**. γ-Aminobutyrate ($H_2NCH_2{\cdot}CH_2{\cdot}CH_2{\cdot}COO^-$) is a **neurotransmitter** formed by the **decarboxylation** of **glutamate**. (NJB)

Aminopeptidase

A **peptidase** that cleaves **peptide** bonds from the N-terminal of peptides, e.g. **leucine** amino peptidase (EC 3.4.11.1), which is attached to epithelial cells of the **small intestine**. (SB)

See also: Protein digestion

Aminotransferases

Enzymes that are involved in transfer of an α-**amino nitrogen** from one **amino acid** to the ketoacid precursor of another amino acid. Aminotransferases can be found in many tissues and in the cytosolic as well as mitochondrial fractions of cells. The accepted vitamin co-factors for **transamination** reactions are **pyridoxine** 5′-phosphate (removal of $-NH_2$) and pyridoxamine 5′-phosphate (addition of $-NH_2$). (NJB)

Ammonia

Ammonia (NH_3) is a gas at normal ambient temperatures. It is produced industrially and used as a fertilizer for crops by injection into the soil. It is toxic, even fatally, and is an irritant to membranes exposed to it. It reacts with water to become ammonium hydroxide (NH_4OH). In **amino acid metabolism** it can be released as ammonium (NH_4^+) from the amino acid **glutamine** by the enzyme glutaminase or from the amino acid

glutamate by the enzyme **glutamate dehydrogenase**. Because ammonium can be incorporated into glutamate by the enzyme glutamate dehydrogenase or into glutamine by glutamine synthetase, ammonium nitrogen (NH_4^+) in the form of ammonium citrate ($C_6H_{14}N_2O_7$) can be used as a source of nitrogen for the biosynthesis of dispensable amino acids in non-ruminants. In the rumen, bacteria convert **urea**-N into ammonium-N which is then incorporated into microbial amino acids and protein, which are later digested and become available to the host in the form of absorbed amino acids. (NJB)

Ammonia treatment of straws

The requirement for supplemental **ruminally available nitrogen** (RAN) and the observation that alkalis other than sodium hydroxide also improved **digestibility**, led to the development of systems using either gaseous (NH_3) or aqueous (NH_4OH) ammonia to treat low-quality **roughages** such as barley, oat and wheat straws. **Urea**, or even **urine**, can be used as the ammonia source, as these release ammonia when acted on by **urease** enzymes present in bacteria in the straw. Urease levels have been enhanced by the addition of **jackbean**s to the straw prior to treatment.

Ammonia treatment, at a rate of about 4% of the straw dry matter, increases **organic matter digestibility** (by about 10% units, from about 45%), nitrogen content (from 0.8 to 1.4% of dry matter) and intake (by about 30%). An added advantage is that ammonia treatment inhibits spoilage organisms, especially moulds, thereby increasing the storage properties of damp straw.

Ammonia, either as anhydrous ammonia (NH_3) gas or as an ammonium hydroxide (NH_4OH) solution, is injected into straw stacks or large bales sealed with plastic sheeting or film. Under temperate summer temperatures the process is generally complete in 4–6 weeks. In tropical conditions, treatment of straw (rice, barley, maize or sorghum) is achieved in 2–3 weeks. For ammonia retention to be effective, the treated straw must contain at least 10% moisture, and retention increases as the straw moisture content increases. For this reason it is recommended that treatment should occur as soon as possible after the grain harvest, before the straw has lost too much moisture. Forty to 60% of the added ammonia-N is lost when the treated stack is opened and aired. This loss can be reduced by treating the ammoniated straw with sulphur dioxide gas, although this has to be done carefully to avoid possible H_2S toxicity.

Treatment with gas can also be undertaken in 'ovens'. Oven treatment takes only 24 h and enables straw to be treated during periods of cold weather or under winter conditions.

Toxicity symptoms may arise if high quality forages (e.g. grass or **lucerne** hay) are ammoniated and offered to ruminants. This takes the form of a hyper-excitability, commonly referred to as 'crazy **cow** syndrome', which is totally unconnected with **bovine spongiform encephalopathy** (BSE). **Roughages** with a high carbohydrate content prior to ammoniation are particularly implicated, with the compound generally associated with this effect, 4-methylimidazole, being formed by the interaction of **sugars** with ammonia in the rumen. (EO, FLM, GMcLD)

See also: Alkali treatment

Reference and further reading

Dryden, G. McL. and Leng, R.A. (1986) Treatment of barley straw with ammonia and sulphur dioxide gases under laboratory conditions. *Animal Feed Science and Technology* 14(1-2), 41–54.

Sundstol, F. and Owen, E. (1984) *Straw and Other Fibrous By-products as Feed*. Elsevier, Amsterdam, 604 pp.

Ammoniated feeds:
see Ammonia treatment

Ammonium:
see Ammonia

Amylase

An enzyme (α-amylase; 1,4-α-D-glucan-glucanohydrolase; EC 3.2.1.1) secreted in the saliva of omnivorous animals and from the **pancreas**. The enzyme hydrolyses **starch** and **glycogen** and produces the disaccharides **maltose** and **isomaltose**, and also **maltotriose** and α-limit dextrins. Preparations of α-amylase (EC 3.2.1.2) have been isolated from various sources, such as bacteria, barley malt and **sweet potato**, and are used for structural investigations of **polysaccharide**s. (SB)

Amyloglucosidase

An enzyme (EC 3.2.1.3) that acts on terminal units of α(1→4)-linked **glucans** from the non-reducing end, releasing **glucose**. (SB)

Amylopectin

A branched polymer of **glucose** which has a role as a storage form of carbohydrate. **Starch** (from plants) and **glycogen** (from animals) consist of **amylose**, with linear chains of α(1→4) glycosidic bonds, together with amylopectin, in which linear chains of glucose are interspersed with branches due to α(1→6) glycosidic bonds. (NJB)

Amylose

A linear polymer of **glucose** which has a role as a storage form of carbohydrate (energy reserve) found in both plants and animals. Found in **starch** (from plants) and **glycogen** (from animals), amylose consists of linear chains of glucose units with α(1→4) glycosidic bonds. (NJB)

Anabolic steroids

Steroid **hormone**s (often synthetic) that stimulate anabolic processes, in particular **protein synthesis** from **amino acid**s, whilst inhibiting **catabolism** and in this respect act antagonistically to **glucocorticoids**. These agents promote retention of nitrogen, potassium and phosphate. The effect is to promote weight gain, provided that nutritional status is adequate. May act by influencing the transfer of amino acids from tRNA to ribosomes. Often derived from testosterone esters or

17α-methyl dihydro-testosterone, although oestradiol and its derivatives may also be effective. Typical examples used to promote growth in farm animals, particularly in beef cattle, are stilboestrol, trenbolone **acetate**, boldenone, nor-ethandrolone and ethylestrenol. The use of these agents in food-producing animals is banned throughout the European Union, and enforcement and monitoring are achieved by routine testing for residues and **metabolites** in meat and in animal tissue, faeces and **body fluid** samples. However, they are still widely used in other parts of the world. (MMit)

See also: Glucocorticoids; Growth; Muscle

Anaemia

A deficiency in quality or reduction in the number of circulating functional red blood cells (erythrocytes) or in the **haemoglobin** content of circulating red blood cells. Anaemia is classified as regenerative (usually caused by haemorrhage or haemolysis) or non-regenerative (caused by decreased erythropoietin or an abnormality in the bone marrow). Symptoms include pale mucous membranes, increased heart and respiratory rate, poor growth rates and exercise intolerance. It is potentially fatal. Causes include:

- Chronic or acute haemorrhage, either external or internal, due to trauma, vascular damage, endo- or ectoparasites, warfarin **poisoning**, platelet deficiency (e.g. in thrombocytopaenic pupura in piglets) etc.
- Excess erythrocyte destruction (haemolytic anaemia), initiated for example by infections such as babesiosis (red-water), *Clostridium oedematiens* (bacillary haemoglobinurea), or copper poisoning.
- Insufficient synthesis of either haemoglobin or red blood cells, caused by dietary deficiencies, e.g. iron in piglets, copper, vitamin B_{12} or **cobalt**, or by conditions affecting bone marrow, e.g. chronic bracken poisoning, radiation, certain drugs, leucoses.
- Poisoning, or dietary excesses, e.g. **molybdenum**, excess feeding of kale and other brassicas, chronic lead poisoning.

Vaccination is available against some of the infectious diseases that cause anaemia. Treatment may be specifically for the primary cause or symptomatic therapy. For acute anaemia, blood transfusion may be appropriate. Correction or **supplementation** of the diet is essential. (EM; DB)

See also: Blood; Haemoglobin; Iron deficiency anaemia

Reference

Marks, S.L. and Kendall, A. (2019) Anemia in animals. *MSD Veterinary Manual*. Available at https://www.msdvetmanual.com/circulatory-system/anemia/anemia-in-animals (accessed 13 August, 2022).

Anaerobic digestion:

see Fermentation; Rumen digestion

Analogues of amino acids

Carbon skeletons that are immediate precursors of **amino acids**. To function nutritionally, analogues must be converted to the amino acid at rates consistent with need. Hydroxymethionine is a synthetic source of **methionine** used extensively in the poultry industry. It supports growth roughly equivalent to that obtained with methionine. Most D-amino acids may be considered analogues of the physiological L-amino acids since all but **lysine** and threonine can be converted to the L-amino acid. The **keto acids** of all amino acids except lysine and threonine may be considered analogues since when used singly they can support growth approaching that with the amino acid. (NJB)

Analytical methods:

see Chromatography; Gas–liquid chromatography; Mass spectrometry; Near infrared spectroscopy; Neutron activation analysis; Nuclear magnetic resonance; Proximate analysis of foods; Weende analysis; *see also* individual constituents

Anchovy

A small, schooling, pelagic fish found mainly inshore in bays and estuaries, but not in the open ocean. More than 130 species of anchovies are distributed in many parts of the world. They are important human food and animal feedstuffs (fish meal and oil). Anchovies swim through the water with their large mouths open and strain out small organisms (plankton) with fine, sieve-like structures called gill rakers. The main nutrients in dried anchovies are protein (59.4%) and lipid (16.0%), with plenty of minerals and vitamins. (SPL; QS)

Reference

FAO (2018) *The State of World Fisheries and Aquaculture – Meeting the Sustainable Development Goals*. FAO, Rome. Available at: http://www.fao.org/3/i9540en/I9540EN.pdf (accessed 17 August, 2022)

Angora goats

Goats named after the Turkish province, now known as Ankara, in which they originated. Like other breeds of domesticated goat (*Capra hircus*) they are thought to be descended from the bezoar or wild goat (*Capra aegagrus*). The distribution of Angora goats was, for many centuries, restricted to Turkey. In the mid-19th century they spread, firstly, to South Africa and shortly afterwards to the USA. Today they are found principally in the Middle East, southern Africa and Texas, with smaller numbers in other US states and in Argentina. In recent decades Angora goat populations have been established in a number of European states and in Australasia.

Angora goats, kept predominantly for wool production. Photo courtesy of Christine McIntosh. Licensed under CC BY-ND 2.0.

Mature female Angora goats (does) weigh about 40–45 kg and males (bucks) around 60–65 kg. They are farmed for their fibre, mohair (not to be confused with angora fibre, which comes from rabbits). Unlike all other goat breeds, which have coats comprising a mixture of coarse and fine fibres, Angora goats are single-coated: the mohair fleece is composed of only one fibre type and contains, or ideally should contain, no coarse hairs. In practice most mohair fleeces contain a small proportion of coarse hairy fibres known as kemps. These have a different morphology from the true mohair fibres and are regarded as a fault, because they cause problems in the manufacture of mohair garments and fabrics. Most Angora goats are white but some breeders specialize in the production of black or brown mohair. The typical mohair fleece is white, long and lustrous with wavy locks or staples. Mohair grows rapidly, at a rate of 2–2.5 cm per month, and the animals are generally shorn every 6 months to provide a fibre that meets the requirements of the processors (staple length up to 15 cm) and to prevent excessive soiling caused by the fleece trailing on the ground.

The average annual mohair production of adult does is between 2.5 and 6 kg of greasy fibre. The yield (i.e. the weight of the clean fleece, after scouring, as a percentage of the greasy weight) is typically around 75%, though this varies between different strains within the breed. Mohair fibre diameter increases with age, from less than 25 microns (μm) at the first shearing at 6 months of age to 35 μm or more at about 4 years old. It is now known that both fleece weight and fibre quality (fineness) are influenced by nutrition. High levels of feeding, particularly of high-protein diets, lead to the production of heavier fleeces with coarser (thicker) fibres, i.e. there is an inverse relationship between quantity and quality.

Like other domesticated breeds, Angora goats are seasonally polyoestrous. Does come into heat at 21-day intervals during the breeding season which, in the northern hemisphere, extends from about August to February, and in the southern hemisphere during autumn (March to May). Gestation length averages about 150 days.

The principal mohair-producing countries have dry climates and in these conditions the goats can be kept outdoors throughout the year. In other countries Angora goats are housed during winter or in the **wet season**. Their main nutritional requirements are met outdoors from grazing and indoors from conserved **forage**. Some supplementary concentrates are generally supplied during late pregnancy and in early **lactation**. (AJFR)

Animal fat

The **lipids** isolated from animal fat depots contain many fractions, most importantly **triacylglycerol**s, but also **phospholipid**s, **cholesterol**s, cholesterol esters and **free fatty acid**s. Fat rendered commercially from carcasses of cattle (*Bos taurus*) and sheep (*Ovis aries*) is commonly called tallow. Fat produced from pigs (*Sus scrofa*) is termed **lard** and rendered pork fat. Fat obtained from the tissues in the commercial processes of **rendering** or extracting during the slaughter of poultry, mainly chickens (*Gallus gallus*), is known as poultry fat. The major fat depots of mammalian animals are subcutaneous, intermuscular, abdominal and intramuscular. The distribution of the fat varies with animal species, breed, gender, age at slaughter and nutritional background. Suet is a term used for the raw fat of beef or mutton located around the loins and kidneys. Animals may also store fats in other sites or locations in the body such as the tail in sheep and hump in camels (*Camelus dromedarius*) and cattle (*Bos indicus)*. Tail fat in sheep comes from specific breeds, and it weighs up to 30% of carcass weight. The hump of camels contains a white fat, which is used as storage energy (food) for survival during **drought** or long trekking in deserts. Tallow and suet are hard and solid at room temperature (24°C). Lard and poultry fat are softer than tallow and are semi-solid at room temperature.

The expression of **fatty acid** (FA) concentrations in foods is vital because in recent years nutrient-based guidelines have been introduced by government authorities around the world, which include guidance on fatty acid intakes. These guidelines also aim to maintain the daily intake of energy, protein and other nutrients of each person to avoid **metabolic disorder**s associated with an imbalance of dietary intake or overconsumption. Previous research has reported the fatty acid composition in animal-based foods in two main ways. One is providing the fatty acid concentration in animal-based foods (e.g. meat) in mg FA per 100 g of fat (or lipid) within the food itself. The other is providing the fatty acid concentration in foods in mg FA per 100 g of the food itself or mg FA per meal portion. The latter way has been followed by many health professionals, nutritionists, dieticians, researchers and food regulatory bodies. The fatty acid composition of animal fat is determined by many factors, including nutritional background, feeding systems, animal species, breed, gender and age at slaughter. In general, ruminant fats are more saturated (e.g. with increased **stearic acid**) than non-ruminant fats. Ruminant fats have a very diverse fatty acid composition, due to the active microbial community in the rumen. As a percentage of total fatty acids, tallow typically contains 2–5% myristic, 20–26% palmitic, 7–17% stearic, 30–45% oleic, 0.5–2% linoleic and 2–4% ***trans*-fatty acid**s. Mutton tallow contains 5–10% more stearic acid than beef tallow, due to greater bio-hydrogenation in the rumen of sheep. Fat collected from fat-tail sheep contains 10% more **unsaturated fatty acid**s than visceral fat. Camel hump fat contains 10% myristic, 34% palmitic, 10% stearic and 28.2% **oleic acid**s, respectively. The fatty acid composition of lipid or fat from **monogastric** species (e.g. pigs, poultry) reflects the dietary lipids. Thus lard and poultry fat have a greater content of unsaturated fatty acids as compared with tallow. Lard typically contains 23–28% palmitic, 12–24% stearic, 30–45% oleic, 8–13% linoleic and 1–1.5% *trans* fatty acids. Chicken fat contains 50% more **linoleic acid** and 50% less stearic acid than lard.

Animal fat is largely used in the production of butter, cheese, yoghurt, shortening and compound fat. Industrial and non-food uses of animal fats include the production of soaps, pharmaceuticals, lubricants and feedstuffs. Since the occurrence of **bovine spongiform encephalopathy** (BSE, commonly known as mad **cow** disease), tallow from ruminant species has not been used in the formulation of animal feeds, but has been replaced by alternative vegetable fats with similar physical properties (e.g. palm oil). Inedible animal fat is suitable for the production of biodiesel and pharmaceuticals.

The quantity and fatty acid composition of animal fat are significantly influenced by animal nutrition. Feeding a concentrate-based diet increases carcass fatness, comprising mainly oleic and linoleic acid concentrations, while pasture and forage feeding increases the **polyunsaturated fatty acid**s, such as omega-3 and conjugated linoleic acids (CLAs) in animal fat. The inclusion of vegetable oils (e.g. flaxseed oil, canola oil) has been an effective nutritional strategy in modifying the fatty acid composition of fat in favour of a healthier fatty acid composition; for example, long-chain omega-3 fatty acids. Animal fat with increased levels of polyunsaturated fatty acids is vulnerable to **oxidation** of the double bonds, **lipolysis** by contaminating microbes, and formation of off-flavours or odours (e.g. greasy or rancid flavour). Tallow and lard respond well to the addition of **antioxidant**s (e.g. **vitamin E**). Appropriate applications of antioxidants (natural or artificial) and **polyphenol** compounds in feeds have been used to alleviate the development of abnormal flavours from lipid oxidation in animal fat or foods containing animal fat. (AK, ENP)

Further reading

Richards, M.P., Olson, J.M. and Haas, M.J. (2021) Animal fats. In: Shahidi, F. (ed.) *Bailey's Industrial Oil and Fat Products* No. 5. Wiley Online Library, pp. 1–49. doi:10.1002/047167849X.bio028.pub2

Toldrá-Reig, F., Mora, L. and Toldrá, F. (2020) Trends in biodiesel production from animal fat waste. *Applied Sciences* 10(10), 3644. doi:10.3390/app10103644

Animal plasma:
see Spray-dried animal plasma

Animal production level (APL)
The amount of **metabolizable energy** (ME) (the **net energy** remaining after faecal and urinary energy loss) required to support the productive state of the animal, relative to its requirement for **maintenance**. For ruminants it is the ratio between the total net energy needed and that used for maintenance: APL = (total ME requirement)/(ME for maintenance). (JMW; DB)
See also: Plane of nutrition

Animal protein
Protein from animal sources. The term includes products derived from milk, eggs, meat and fish and derived proteins e.g., **casein**, **whey protein**, gelatine, egg proteins, and fibroin (in

silk). As dietary protein made from varied type of amino acids, these products are distinguished from plant protein by generally containing complete nutrients. In general, animal **protein sources** have higher concentrations of essential amino acids, especially **lysine** and the **sulphur** amino acids, than most plant protein sources, but the plants can synthesize all of the 20 different amino acids. In excessive amounts, animal proteins are considered detrimental for human health and for developing non-communicable diseases. (MFF; DB)

Anions
Anions can be inorganic or organic. They carry a negative charge. The major anions in **blood plasma** are **bicarbonate** (HCO_3^-), **chloride** (Cl^-), phosphate (PO_4^{2-}), **sulphate** (SO_4^{2-}) and **organic acids** ($R{\cdot}COO^-$). To maintain anion/cation balance, the anions are balanced by an equivalent charge in the form of cations (positive ions) such as **potassium** (K^+) and **sodium** (Na^+). (NJB)
See also: Acid–base equilibrium

Anoestrus
A period of infertility, ovarian inactivity or sexual quiescence which may be seasonal (in sheep, goats, horses etc.) or induced by nutritional imbalances, stresses (such as heat, cold, confinement, poor management), disease, **lactation** or old age. Nutritional causes of anoestrus include inadequate intake of energy, **micronutrient** imbalances and toxicoses. Xenobiotics that contribute to infertility include **oestrogen**-like compounds, phyto-oestrogens from some clovers, zearalenone from *Fusarium* moulds, ergot **alkaloids**, locoweeds (swainsonine), ***Leucaena*** (**mimosine**), **mustard** family (**glucosinolates**) and **selenium** deficiencies or toxicoses. (KEP)

Anorexia
General lack of appetite, markedly low **voluntary food intake** or complete abstinence from food. There are numerous causes, including infectious or non-infectious disease, unavailability of acceptable, nutritious feed and certain mental disorders. Severe stress can induce anorexia, as in the case of sheep travelling long distances by ship. Removal of affected sheep from overcrowded pens and placing them in individual pens with a variety of feeds can restore the appetite of affected sheep. Seasonal **inappetence** seen in winter in many species should not be regarded as anorexia. True anorexia is rare in non-human animals as there is natural selection against it. Humans suffering from anorexia voluntarily restrict their food intake, resulting in chronic **starvation**, **malnutrition**, a severe loss of body weight, and, if untreated, even death. This **eating disorder** is a serious mental illness and usually develops during **puberty** and young adulthood, primarily in females. In Western countries, up to 4% females and 0.3% males are anorexic. Affected individuals have an intense fear of body weight gain or abnormal body shape and a strong desire to be thin. The causes of anorexia in people are unknown but may include genetic, environmental, psychological and social factors. (JMF; CJCP; GW)

Reference
van Eeden, A.E., van Hoeken, D., and Hoek, H.W. (2021) Incidence, prevalence and mortality of anorexia nervosa and bulimia nervosa. *Current Opinion in Psychiatry* 34, 515–524.

Anorexia, pathogen-induced
A voluntary reduction in the food intake of animals and humans, which occurs during infection with pathogens. It is observed across mammalian and avian species, infected with either macro-parasites, such as worms, or micro-parasites, such as bacteria and viruses. Very frequently, it is the only, early symptom seen during such infections and its extent can vary from a small reduction in food intake (10–20%) to complete cessation of eating for a period of time. Therefore, it is considered largely responsible for the consequences of infection on growth, reproduction and the overall biological fitness of an organism.

Currently, there are hypotheses to account for both the functional (i.e. why it happens) and causal (i.e. how it happens) basis of anorexia. Kyriazakis *et al.* (1998) suggested that anorexia developed to allow animal and human hosts to cope with infection, since its persistence appears to confer advantages to the affected hosts. Infected hosts that show anorexia appear to suffer to a lesser degree from the consequences of infection and recover at a faster rate. The causal basis is linked to the host immune response to infection, as anorexia is seen mainly in hosts that have not yet developed **immunity** to a pathogen, or in hosts whose immunity breaks down due to stressful events in their life cycle, such as pregnancy.

By definition, the occurrence and characteristics of anorexia (its duration, extent, and the rate of recovery from it) depend on the characteristics of the pathogen and the ability of the host to eventually overcome the consequences of the infection. Anorexia may last for several weeks in infections with parasitic worms in sheep and cattle, or for a few days in bacterial infections of pigs. Nevertheless, anorexia constitutes a paradox, because it occurs at life stages when the **nutrient requirements** of the infected host are increased, due to the nutritional demands of the pathogen on the host, including the need to repair the damage caused to the host's body by the pathogens or the need to develop an immune response to overcome the pathogen. Currently it is unclear whether diet composition plays a role in the occurrence and characteristics of anorexia, although it is known that infected animals on poor-quality diets seem to show anorexia for a longer period of time and recover more slowly from it. This is consistent with the view that links anorexia with the development of the immunity to a pathogen. The interaction between diet composition, anorexia and response to infection is an area of research that merits greater attention. Understanding how host nutrition affects pathogen-induced anorexia will shed light on how infected animals, and even humans, should be fed during the critical stages of an infection. (IK)

Reference

Kyriazakis, I., Tolkamp, B.J. and Hutchings, M.R. (1998) Towards a functional explanation for the occurrence of anorexia during parasitic infections. *Animal Behaviour* 56, 265–274.

Antagonism
A negative interaction between a nutrient and other nutrients, or between nutrients and non-nutrients. The interaction may be related to uptake or to use. An example is **branched-chain amino acid** antagonism in which three- to fourfold increases in dietary **leucine** in a low-protein diet result in decreases in food intake and weight gain and in the blood and tissue concentrations of the other branched-chain amino acids, **valine** and **isoleucine**, and their **keto acid**s. Another amino acid example is the **lysine–arginine** antagonism in which two- to threefold increases in dietary lysine result in an increase in the need for arginine. Antagonisms can be found in mineral interactions in which one mineral affects the rate and extent of uptake of another mineral such that more of the other mineral is required in the diet. Examples are zinc–copper, zinc–iron, calcium–zinc, calcium–iron, calcium–phosphorus, iron–copper and many more. (NJB)

Key reference

Shinneck, F.L. and Harper, A.E. (1977) Effects of branched-chain amino acid antagonism in the rat on tissue amino acid and keto acid concentrations. *Journal of Nutrition* 107, 887–895.

Antagonist
A compound that blocks the physiological action of another compound. For example, **acetylcholine** released by parasympathetic nerves binds intestinal muscarinic receptors to stimulate **motility**. Atropine also binds these receptors but does not increase motility. Thus, atropine can act as an antagonist by outcompeting acetylcholine for these receptors, effectively blocking acetylcholine actions. (JPG)

Anthocyanins
These plant pigments are **glycoside**s containing a nucleus (aglycone) called an anthocyanidin. Anthocyanidins are flavonoids, or water-soluble phenolic derivatives. They are generally red, crimson, blue, purple or yellow. They tend to be metabolically inert in animals but some have **antioxidant** activity. They form dimers (procyanidin) which can polymerize to form condensed **tannins** (proanthocyanidins). (PC)

Antibiotics in animal feed
Antimicrobial pharmaceuticals, usually of plant or fungal origin. Antibiotics have been included as a **growth promoter** in the feed of chickens, pigs and cattle since the industries intensified in the 1950s. The industrialized animal production systems are susceptible to pathogen growth and antibiotic inclusion in feed was seen as a means to prevent the spread of disease organisms. Antibiotics may be routinely administered to livestock at increased risk of disease. Low-level, routine antibiotic inclusion also improves the **efficiency of feed conversion** (FCE) by controlling microorganism growth in the **gastrointestinal tract**. Thus, although the primary use of antibiotics was originally in the treatment of infections, certain antibiotics came to be used as **feed additives** in order to improve growth and feed conversion efficiency. The modes of action of antibiotics used as growth promoters include reduction in sub-clinical disease, thinning of the wall of the intestine and, in ruminants, a change in the microflora and fauna in the rumen. For example, in chickens the popular antibiotic Flavomycin stops microorganisms from reproducing by preventing the synthesis of murein, an essential component of cell walls. This causes cell lysis in ***Escherichia coli*** and salmonella, but lactobacilli and bifidobacteria are not affected; indeed they competitively inhibit pathogenic bacteria. In addition, **villi** and crypts are shorter when antibiotics are fed, reducing the mass of the intestines.

In 2006, antibiotics previously licensed in the European Union for use as growth promoters were banned because of fears that their use might encourage the development of antibiotic resistance and prejudice the treatment of human disease.

Flavophospholipol is used for promotion of growth and improvement of feed efficiency in pigs, domestic fowl, turkeys, rabbits, calves, growing and fattening cattle and fur animals. It is a phosphoglycolipid, and is not absorbed from the digestive tract, so is not metabolized by the animal. It changes the pattern of **rumen microorganism**s by inhibiting some Gram-positive bacteria and by reducing the formation of **peptidoglycan**. Another antibiotic, avilomycin, has been used in pigs, broiler chickens and turkeys. Salinomycin is an **ionophore** available for use in pigs and also used to prevent **coccidiosis** in broiler chickens.

Monensin is still used for growth promotion in non-lactating cattle. It has had fatal effects when fed to horses, and when fed to cattle within 7 days before or after being treated with tiamulin. Monensin is an ionophore, and is poorly absorbed from the digestive tract, about two-thirds being lost unaltered in faeces. Ionophores facilitate the movement of ions across membranes by forming hydrophobic complexes with ions such as potassium and sodium, and in so doing disrupt bacterial cell walls, and possibly the cell walls of **protozoa**. They thereby change the pattern of rumen microorganisms, reducing the production of **acetate**, **butyrate** and **methane**, and increasing the proportion of **propionate**. Since methane is a waste product, the efficiency of rumen activity is improved. Ionophores also reduce the total mass of bacteria and thereby decrease the amount of dietary protein degraded.

Inclusion of antibiotics in the feed of farm animals confers resistance in pathogenic bacteria, which have a survival advantage. These may transmit from meat products or the environment of the meat-producing farms and factories to humans, who are then susceptible to the resistant pathogenic bacteria. In 2021, the EU banned the use of monensin sodium, salinomycin sodium, avilamycin and flavophospholipol as growth promoters in animal feed.

Consumer resistance to inclusion of antibiotics in animal feed is strong, and alternatives, mainly in the form of **probiotics**, prebiotics, synbiotics, vaccines, **organic acid**s, enzymes and medicinal plants (or phytobiotics), such as garlic and ginger, are starting to replace the antibiotics in animal feed. Replacements are more useful for growth promotion and improving **feed conversion** efficiency than for treatment of disease or prophylactic use. In this respect, pro- and prebiotics both improve gut health, whereas vaccines have to be administered well before any potential infection, and bacteriophages and antimicrobial peptides have to be administered at the time of initial infection.

All antibiotics must be used with care and the current data sheet should be consulted for dosage, contraindications and other precautions. Some are incorporated into **feed block**s or used as top-dressing of feeds such as **silage**. (WRW; CJCP)
See also: Additive, feed; Growth promoters

Reference

PEW (2017) *Alternatives to Antibiotics in Animal Agriculture*. PEW Charitable Trusts, Philadelphia, Pennsylvania. Available at : https://www.pewtrusts.org/-/media/assets/2017/07/alternatives_to_antibiotics_in_animal_agriculture.pdf (accessed 17 August, 2022).

Antibodies
Long-chain **globulin** proteins produced by plasma cells in response to the presence of an **antigen** (foreign protein) as part of the body's defence system. Antibodies are made of two light and two heavy **peptide** chains. Constant regions are common to all antibodies; variable regions are specific to the antigen that stimulated their production, and can form a site that binds with that specific antigen to form an antigen–antibody complex. This aids the elimination or destruction of that antigen.

Antibodies are produced in five different classes, depending on the structure of the constant regions, and this determines the site in the body at which they have their action (*see* Immunoglobulin). Antigens that stimulate the production of antibodies can be from the environment, food, infection or vaccination.

Plasma cells in the **mammary gland** produce antibodies (IgA) shortly before parturition, which are concentrated in the colostrum and are also present in declining amounts in early **lactation**. Circulating antibodies (IgG) are also transported and concentrated in the colostrum. They provide the potential source of passive **immunity** to most of the domestic species. The relative importance of IgG and IgA varies with species. The greater the number of antigens the dam has been exposed to, the more antibodies there are likely to be in the colostrum, assuming adequate health and nutrition. (EM)
See also: Antigen; Colostrum; Immunity

Antigen
Any substance that stimulates an immune response. Many different substances can act as antigens, but most are proteins of more than 20 **amino acids**. **Microorganisms** act as antigens but their complex structure provides many antigenic sites or epitopes. Large protein molecules may also have many epitopes. (EM)
See also: Antibodies; Immunity

Anti-infective agents
Anti-infective agents in feedstuffs include natural phytochemicals and **feed additives** (e.g. antibiotics). Phytochemicals with anti-infective activity, especially against **protozoa**, include **phenolic compounds** and **saponins**. They cause lysis of protozoal cell membranes. Anti-infective phytochemicals in herbal products may become more important if use of antibiotics as feed additives is restricted. (PC)

Antimicrobial activity
The ability to kill or impair the growth of bacteria or **protozoa**. Many natural toxins have antimicrobial action and most antimicrobial pharmaceuticals used today are of plant or fungal origin. Although many antimicrobials are used to treat infections, others impair the digestion of feed, especially in ruminants. Plants such as broom snakeweed (*Gutierrezia* spp.), pine needles and sage brush (*Artemesia* spp.) contain toxins that inhibit rumen fermentation and reduce animal production. (BLS)

Antinutritional factors (ANFs)
Feed components that have negative effects on the intake or utilization of feeds, or that may be inherently toxic when ingested. Many common feeds, such as **legume** seeds, contain ANFs; many **rangeland** plants contain phytochemicals or toxins. The most important ANFs are **alkaloids**, **haemagglutinins** (**lectins**), phenolics, **phytates**, phytooestrogens, **saponins**, **tannins** and **trypsin inhibitors**.

Alkaloids are cyclic **organic compound**s containing nitrogen. When ingested they may cause feed refusal, **abortion**, birth defects, wasting diseases, agalactia and death. There are marked animal species differences in reactions to alkaloids, which may be due to differences in rumen microbial metabolism or in the **absorption**, metabolism or excretion of alkaloids, or may be directly related to alkaloid affinity to target tissues such as binding at receptor sites. Alkaloids constitute the largest class of **plant secondary compound**s, occurring in 20–30% of perennial herbaceous species in North America. Major categories of toxic alkaloids include pyrrolizidine (e.g. *Senecio*), quinolizidine (e.g. *Lupinus*), indolizidine (e.g. *Astragalus*), diterpenoid (e.g. *Delphinium*), piperidine (e.g. *Conium*), pyridine (e.g. *Nicotiana*) and steroidal (*Veratrum*-type) alkaloids. Management schemes to prevent losses are usually based on recognizing the particular toxic plant, knowing the mechanism of toxicity, and understanding the temporal dynamics of plant alkaloid concentration and consumption by livestock. Once these are understood, losses may be reduced by maintaining optimal forage conditions, adjusting grazing pressure and the timing of grazing, strategic **supplementation**, changing livestock species and herbicidal control.

Phenolic compounds are produced by a wide range of plants. Low molecular-weight (MW) plant phenolics are often converted to **tannins** when plants mature. When ingested, phenolics reduce feed intake and weight gain. After ingestion, phenolics are absorbed, producing negative effects on physiological functions. Conversely, hydrolysable tannins may be converted to low-MW phenolics in the **gastrointestinal tract** of ruminants and may be toxic (*see* Tannins).

Phytates are divalent mineral ions complexed with organic phosphorus in seeds. Phytate phosphorus is poorly available to non-ruminant livestock. Most (50–70%) of the phosphorus in cereal grains is in the form of phytic acid. Phytates may be soluble (e.g. sodium or potassium) or insoluble (e.g. calcium). Phytates readily complex with phytic acid and **inositol** in cereal grains, and these **chelate**s then bind much of the phosphorus and zinc in grains, while complexing to a lesser extent with copper, cobalt, magnesium and calcium. Phosphorus deficiency is characterized by distorted appetite, reduced weight gain and impaired reproduction. Zinc deficiency is manifested by reduced weight gain and skin lesions. Through microbial fermentation in the rumen, ruminants are capable of cleaving **phosphorus** from phytates, making it available to the animal. Phytates are particularly high in maize and in wheat by-products, and are also present in most other cereal grains. Adding the industrial enzyme **phytase** to pig and poultry rations may be economically feasible, because phosphorus is relatively expensive to supplement; it also reduces phosphorus elimination in faeces.

Phyto-oestrogens are **plant oestrogen**s that affect reproduction. Phyto-oestrogens inhibit release of reproductive hormones and compete with oestrogen at cellular receptors. Hence, livestock consuming forages containing phyto-oestrogens exhibit reductions in fertility, including abnormal **oestrous cycle**s and ovulation, and defective development of reproductive organs and genitalia. Forages that typically contain phyto-oestrogens include **lucerne** and clover (*Trifolium* spp.). Cattle are much less sensitive to phyto-oestrogens than are sheep, which appear to activate phyto-oestrogens in the rumen to more potent compounds and may also have more sensitive oestrogen receptors. Poultry may also be affected by phyto-oestrogens; there is some evidence that quail are adversely affected by phyto-oestrogens in range plants.

Saponins are steroidal or triterpenoid **glycoside**s that have considerable biological activity. Saponins have a bitter taste, reducing the palatability of feeds. They may also reduce the digestion and absorption of nutrients, including minerals. These effects occur primarily in non-ruminant livestock. Nevertheless, saponins in some range plants from the Caryophyllaceae (pink) family (e.g. *Drymaria*, *Agrostemma*, *Saponaria*) or in snakeweed (*Gutierrezia* spp.) can have toxic effects in ruminants, including loss of appetite, weight loss, diarrhoea, abortion and photosensitization. The primary livestock feed with significant amounts of saponins is lucerne (*Medicago sativa*), which causes frothy **bloat**. The concentration of saponins in lucerne changes seasonally, with the highest amounts in midsummer.

Tannins are high-MW phenolic compounds that bind strongly with proteins and other macromolecules such as starch, cellulose or minerals. Two major classes of tannins are hydrolysable and proanthocyanidins (condensed tannins). Tannins reduce feed intake because of astringency (i.e. reduced acceptability) and reduce digestibility by the formation of largely indigestible complexes in the digestive tract. Deleterious effects vary depending on the type of tannin and the tolerance of the animal, but concentrations above 10–20% may be toxic to ruminants. Clinically affected ruminants may show signs of kidney failure and elevated serum **urea** nitrogen. Non-ruminant animals may have reduced growth rates with low (< 5%) concentrations; higher concentrations may be fatal. Tannins are common in plants, occurring in both gymnosperms and angiosperms. Woody species and broadleaf plants are more likely to contain tannins than are **Gramineae**. Compounds such as polyethylene glycol (PEG) may be added to feed and water to bind and inactivate tannins, allowing high-tannin feeds to be used for grazing or pen-fed livestock. For ruminants, tannins may have some positive effects through complexing with high-quality protein (allowing it to bypass rumen degradation) or through increased **nitrogen recycling** to the rumen.

Trypsin inhibitors are plant proteins that inhibit the pancreatic enzyme trypsin, which is partly responsible for **protein digestion**. Trypsin (and other protease) inhibitors bind tightly to trypsin and **chymotrypsin**, inhibiting their proteolytic activity. Trypsin inhibitors occur primarily in legume seeds, particularly soybeans, but are also found in low concentrations in cereal grains such as wheat, oats, buckwheat, barley and maize. There are two classes of trypsin inhibitors: the low-MW Bowman–Birk inhibitor and the larger Kunitz inhibitor. The anti-tryptic activity is destroyed by moderate heat, which may be applied during the processing of plant materials. The Bowman–Birk inhibitors are more heat-stable than the Kunitz type. Excessive heating may reduce **protein quality** through non-enzymatic **browning** reactions. Ruminant livestock are less affected than non-ruminants, because most trypsin inhibitors are degraded slowly in the rumen, though some may escape the rumen and enter the **small intestine**. In poultry, trypsin inhibitors cause pancreatic enlargement and reduce feed efficiency and growth rates; in pigs and calves, growth rates are depressed from reduced protein digestibility without accompanying pancreatic enlargement. Trypsin inhibitors from soybeans may be added to bovine colostrum, resulting in increased immunoglobulin **absorption** in calves. (JAP)

See also: Alkaloids; Haemagglutinins; Lectins

Antioxidant

Natural or synthetic compounds in origin that delay or inhibit the **oxidation** of molecules in cells or tissue compartments of biological systems. Oxidative processes in biological systems are essential to produce energy to drive the metabolic events that take place in organisms. The utilization of oxygen by the cellular systems provides animals with the benefit of metabolizing fats, proteins and carbohydrates for energy. The oxidation process also serves as a medium for the production of reactive oxygen species (ROS) and cellular defence action for the maintenance of life, for example improving immune function.

However, ROS also have negative consequences in organelles when produced at high levels. The production of ROS in the cell at a high level can cause damage to DNA and proteins and induce membrane damage through **lipid peroxidation**. Antioxidants present in biological systems reduce the formation and actual number of **free radical**s by directly scavenging ROS such as **hydrogen peroxide** (H_2O_2) or **chelate** the metal ions serving as an oxidative base such as Fe^{2+}. Both actions, in turn, minimize the overproduction of free radicals in biological systems.

Synthetic antioxidants include butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), propyl gallate (PG) and tertiary-butyl hydroquinone (TBHQ). Natural antioxidants mostly derive from plant materials, such as fruit, vegetables, **yams**, herbs and spices. The antioxidants that are available to the cells either originate from ingested foods or can be synthesized endogenously, and they are classified as enzymatic and non-enzymatic. The non-enzymatic antioxidants include vitamins (A, C and E), minerals (**selenium**, **zinc**, **manganese**), **carotenoid**s (β-carotene, **lycopene**, **lutein**, zeaxanthin), organo-sulphur components (lipoic acid, alliums, allyl sulphide, **indole**s), **polyphenol**s, **glutathione** and uric acid. The enzymatic antioxidants, synthesized endogenously, are **superoxide** dismutase (SOD), catalase (CAT), **glutathione peroxidase** (GPx) and glutathione reductase. Alternatively, antioxidants can be grouped as membrane antioxidants, soluble antioxidants and antioxidant enzymes. Membrane antioxidants are lipophilic; mostly **tocopherol**s, but also ubiquinones and carotenoids. Soluble antioxidants are NADPH, NADH, **ascorbic acid**, reduced glutathione and other thiols, uric acid, thioredoxin, bilirubin, polyphenols, and several metal-binding proteins (**copper**: ceruloplasmin, **metallothionein** and **albumin**; **iron**: **transferrin**, **ferritin** and myoglobin). SOD is a **metalloenzyme** present in the mitochondria (contains manganese) and in the cytosol (contains both copper and zinc). GPx has four isoforms, containing selenium (Se). GPx regenerates the reduced glutathione (GSH) from its oxidized glutathione form (GSSG). Thioredoxin reductase is also a selenoprotein. Catalase has iron and its distribution is almost exclusively limited to the peroxisomes/lysosomes. All endogenously synthesized (e.g. antioxidant enzymes, GSH) and exogenously supplied (**vitamin E**, carotenoids, etc.) antioxidants work cooperatively to maintain optimal redox (reduction/oxidation) balance in the cell or body. For example, in the cellular systems, SOD enzyme converts two superoxide radicals to one oxygen molecule and one hydrogen peroxide and then CAT and GPx further decompose the hydrogen **peroxide** molecules to water.

Free radicals are produced in cells by normal aerobic cellular metabolism and also in response to environmental radiation and pollutants. Oxygen is a highly reactive atom that is capable of becoming incorporated into potentially damaging free radical molecules. The main free radicals are ROS and reactive nitrogen species (RNS), derived from oxygen and nitrogen, respectively. The production of ROS in cells is linked to the use of oxygen as a primary electron acceptor for generating energy through the respiratory chain. The ROS compounds includes superoxide anion ($O_2^{-\bullet}$), H_2O_2, hydroxyl radical ($^\bullet OH$), alkoxyl radical ($RO^\bullet$) and peroxyl radical ($ROO^\bullet$). The RNS compounds are **nitric oxide** ($NO^\bullet$), peroxy **nitrite** ($ONOO^-$), peroxynitrous acid (ONOOH) and nitrogen dioxide (NO_2). Although free radicals at low to moderate concentrations play key roles in immune function and essential metabolic functions, as signalling molecules, their overproduction in biological systems can damage cells. This can trigger the oxidation of lipids, DNA and proteins and produce adverse modifications. For example, the peroxyl radical ($ROO^\bullet$), which is produced from the long-chain **unsaturated fatty acid**s (PUFA) of cellular membranes, initiates a chain reaction that can lead to compromised cell membranes, loss of membrane permeability and tissue integrity, and eventually cell/tissue death.

The main function of antioxidants in biological systems is to protect animal and plant tissues against damage due to free radicals. In the antioxidant defence system, natural antioxidants of exogenous origin, such as vitamin E, scavenges radicals within the membrane, where it blocks initiation and interrupts the propagation of lipid peroxidation. Enzymes produced endogenously, such as SOD, GPx, and CAT, also collectively block the initiation of peroxidation from within the soluble phase of the cell. The processes are the conversion of $O_2^{-\bullet}$ to H_2O_2 by SOD; further reduction of H_2O_2 to H_2O by catalase and GPx. The aggregate effect of this enzymatic system is to clear $O_2^{-\bullet}$ by reducing it fully to H_2O, thus preventing the generation of highly active ROS [e.g., $^\bullet OH$, and singlet oxygen ($^1O_2$)]. GPx can also reduce fatty acyl hydroperoxides to the corresponding fatty alcohols, thus serving to interrupt the propagation of lipid peroxidation in the cellular compartments of biological systems. Lipid hydroperoxides are naturally found in all food containing fats and oils. Removal of hydrogen and lipid peroxides from biological tissues of living organisms is critical to prevent oxidative damage and ultimately the preservation of their products, in particular milk and meat.

Vitamin E is the commonly used antioxidant in animal feed and human food formulations. Vitamin E consists of four tocopherols (α-, β-, γ- and δ-) and four **tocotrienols** (α-, β-, γ- and δ-), which are all naturally occurring lipophilic compounds. Vitamin E can therefore be seen as a generic name for all tocopherols and tocotrienol derivatives that exhibit the activity of α-tocopherol (trimethylated tocopherol). The chemical antioxidant activity of natural α-tocopherol is about 200-fold that of the commonly used artificial food antioxidant BHT. The main sources of vitamin E are green plants, vegetable oils, seeds and cereal grains. Animal tissues tend to contain low amounts of α-tocopherol, the highest levels occurring in fatty tissues. In most non-adipose cells or tissues, vitamin E (mostly α-tocopherol) is localized almost exclusively in membranes. The average tocopherol concentration in membranes is one α-tocopherol molecule per 500–1000 **phospholipid** molecules. Vitamin E can scavenge lipid peroxyl radicals from the tissue systems. This is because vitamin E has a chromanol nucleus with a hydroxyl group at position C-6 (phenolic hydrogen) with the ability to accommodate an unpaired electron. The chromanol hydroxyl group gives α-tocopherol the ability to accept one or two electrons, thus converting it into α-tocopheroxyl radical and α-tocopheryl **quinone**s, respectively. The α-tocopheryl quinones are non-radical products. Therefore, vitamin E inhibits chain reactions initiated by peroxyl radicals when exposed to PUFA.

A by-product of lipid peroxidation is malondialdehyde (MDA), which can be determined by the thiobarbituric acid reactive substances (TBARS) assay. The accumulation of MDA in biological systems is used as an indicator of oxidative damage to membrane lipids. The chain reaction producing MDA is terminated when a peroxyl radical (ROO$^{\bullet}$) reacts with α-tocopherol to produce an α-tocopherol radical intermediate (α-tocopheroxyl radical) that reacts with another peroxyl radical to produce a non-radical product (α-tocopheryl quinones). Because α-tocopherol can compete for peroxyl radicals much faster than PUFAs, small amounts of the vitamin E present in biological membranes are adequate to neutralize large amounts of peroxyl radicals in the system; the relative molar ratio of vitamin E to PUFA in biological membranes is very low (1:850). To be effective, the tissue vitamin E concentration must be above a critical threshold. When the tissue vitamin E concentration is below the threshold, peroxyl radicals can propagate extensively and deplete α-tocopherol, but when the vitamin E concentration is above the threshold, the activity of peroxyl radicals is suppressed by the adequate α-tocopherol reserve. Fortunately, in biological systems, most vitamin E is recycled by the reduction of α-tocopheroxyl radical back to α-tocopherol.

Vitamin C (L-**ascorbic acid**) contributes to the prevention of oxidative damage to lipids, proteins and DNA in cells. Vitamin C is the major water-soluble antioxidant in plasma and soluble phases of cells. As a strong reducing agent, ascorbic acid is oxidized to dehydroascorbic acid in two successive losses of single electrons. The first monovalent oxidation results in the formation of the ascorbyl free radical (monodehydroascorbic acid). The partially reduced form can establish a reversible electrochemical couple with ascorbate, or it can be further oxidized to dehydroascorbic acid. Vitamin C reduces the superoxide radical ($O_2^{\bullet-}$) to H_2O_2. Ascorbate peroxidase enzyme reduces H_2O_2 to water by using vitamin C as an electron donor. Ascorbate undergoes oxidation by reaction with tocopheroxyl radical and regenerates the metabolically active form of vitamin E. The antioxidant efficiency of vitamin C is significant at physiological concentrations of 20–90 μM.

Reduced **glutathione** (GSH) is another water-soluble antioxidant. The GSH is made in the liver, kidneys and intestine from three amino acids (glutamyl-cysteinyl-glycine). The SH in GSH refers to the **cysteine** portion of the molecule, which is involved in oxidation/reduction reactions. In its role as an antioxidant, two molecules of GSH (2GSH) are oxidized into glutathione disulphide (GSSG) coupling with reduction of the α-tocopherol radical into α-tocopherol. The enzyme glutathione reductase is involved in the interconversion of GSSG to GSH (i.e. GSSG → 2GSH). The reducing equivalents required to convert GSSG into GSH come from glucose-6-phosphate via the production of NADPH. When GSSG is reduced to 2GSH an equivalent of NADPH is oxidized to $NADP^+$. The direct use of glutathione in protection against ROS depends on GPx. GPx is a cystolic **enzyme** that catalyses the reduction of H_2O_2 and lipid peroxides (ROOH). In the presence of GPx, 2GSH reacts with H_2O_2 and produces $2H_2O$ and GSSG. When H_2O_2 is not catabolized by GPx, it can produce the hydroxyl radical ($^{\bullet}OH$), in the presence of ferrous iron (Fe^{2+}), which is the most powerful ROS involved in tissue damage (such as the production of MDA from PUFA).

Lipoic acid (1,2-dithiolane-3-pentanoic acid), known as **thioctic acid**, acts as an antioxidant. It is synthesized in the mitochondria from PUFA and cysteine. Lipoic acid contains two vicinal sulphur atoms that are subject to oxidation/reduction; the reduced form of lipoic acid (dihydrolipoic acid) has two thiols. Lipoic acid functions as an amphipathic antioxidant capable of quenching free radicals, regenerating other cellular antioxidants. Lipoic acid is involved in cellular antioxidant protection through both direct and indirect functions. Dihydrolipoic acid is able to reduce oxidized forms of other cellular antioxidants, including glutathione, α-tocopherol and ascorbic acid, as well as quenching ROS and RNS. Several studies have reported that dietary supplementation of lipoic acid enhances antioxidant capability and shelf life of ruminant and poultry meat and meat products.

Carotenoids, well known as pigments, are effective fat-soluble antioxidants protecting cells against oxidative damage. Carotenoids most efficiently react with peroxyl radicals (ROO$^{\bullet}$). β-Carotene, α-carotene, lycopene and lutein are the main carotenoids with antioxidant activity. Lycopene is the most potent carotenoid antioxidant, being twice as effective as β-carotene in quenching singlet **oxygen** ($^1O_2$) and ten times as effective as α-tocopherol. It is found in significant amounts in red-coloured foods such as tomatoes, watermelon, pink grapefruit and guava. Lutein and zeaxanthin found in corn represent major sources of pigmentation for poultry diets. The **xanthophyll**, **astaxanthin**, is the source of the pink colouration of salmon.

Polyphenol compounds in plants, a subclass of phytochemicals, have antioxidant properties. They have a large diversity of structures, from simple molecules to complex polyphenols, grouped as phenolic acids (e.g. rosmarinic acids, caffeic acids and gallic acid), phenolic diterpenes (e.g. carnosol and carnosic acid), flavonoids (e.g. quercetin and catechin) and essential volatile oils (e.g. carvacrol, thymol, eugenol and menthol). Tannins and flavonoids can scavenge free radicals, rendering them inactive; they are widely found in agricultural by-products. For example, grape pomace, olive pomace and pomegranate fruit are rich sources of polyphenol compounds. Although antioxidant activity for some flavonoids (e.g. quercetin, catechin, anthocyanins, gallic and ellagic acid) has been shown *in vitro,* not many studies have been conducted *in vivo* to validate their antioxidant functions in biological systems, and this area has the potential for future research.

By maintaining and/or increasing the intake of natural antioxidants or antioxidant enzymes as feeds (foods) and supplements, the development of free radicals in the animal body can be minimized. This in turn will reduce animal health issues (e.g. by alleviation of oxidative stress), improve livestock performance on-farm and ultimately product quality, through its effects on the preservation of meat and milk. For example, supplementation of animal diets with high levels of vitamin E inhibits the development of off-flavours in meat and meat products by lipid peroxidation (oxidative **rancidity** of lipids) and colour deterioration (**haemoglobin** oxidation). A vitamin E concentration of 3.0–3.5 mg kg^{-1} of **meat** is sufficient to maintain the retail colour stability of beef and sheep meat under simulated commercial retail conditions. Similarly, polyphenols improve oxidative stability, retard the development of off-flavours, and improve the colour stability of meat. Phytochemical supplementation in the diets of farm animals has shown enhanced antioxidant activity in milk and dairy products. (ENP, AK)

Further reading

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Antiparasitic agents

Parasites may colonize either the internal or external medium of animals, or occasionally both, but are present in greatest numbers outside their host animal vector. Currently treatment of infected animals is usually based on anthelmintic agents but resistance is increasing, particularly in nematode worms. Attention is turning to prophylactic measures, such as the provision of uninfected pasture, and biological control, in particular by treatment of the parasite with fungi in its native pasture environment. (CJCP)

Antiprotozoal agents

Protozoa are single-celled organisms that are often present in soil and may be transmitted to farm animals when feeding or by insect vectors. Many infect the digestive tract; others penetrate vital organs. A variety of drugs are available to treat protozoal diseases but they can be difficult to eradicate. Some antibacterial and anti-fungal agents have a limited effectiveness in treating protozoal infections. Chemoresistance is also emerging and new drugs must be targeted for effective chemotherapy. (CJCP)

Apo-enzyme

An enzyme form that requires a co-factor in order to function. The intact enzyme protein without the enzyme cofactor bound to it is called the apo-enzyme. When the enzyme co-factor is bound to the enzyme protein this combination is called the holo-enzyme. An example is the red blood cell enzyme transketolase. The vitamin co-factor **thiamine** diphosphate binds to the enzyme and aids in the reaction but is not permanently changed by the reaction. This relationship is different from that of other vitamin-dependent co-substrates such as NAD or NADP, which are changed to NADH and NADPH, respectively, as a result of the **enzyme** reaction. (NJB)

Apolipoproteins

Proteins that are essential components of the lipid transport system in the body, which involves **chylomicron**s and the **lipoprotein**s HDL, LDL, IDL and VLDL (high-density, low-density, intermediate-density and **very low-density lipoprotein**s). Two general types of lipoproteins are identified: those that are integral (e.g. apo B-100), which cannot be removed and are critical to structure and function; and those that can be exchanged (e.g. apo A, apo C etc.). Apolipoproteins also act as enzyme co-factors and as ligands for lipoprotein receptors on cell surfaces. (NJB)

Apparent digestibility

Digestibility determined simply from the difference between the amount of a nutrient consumed (I) and the amount excreted in the faeces (F), expressed as a proportion of the intake. Thus, apparent digestibility = (I – F)/I. It is also determined at the terminal **ileum** by measuring the loss of the nutrient in ileal **digesta** (D); thus apparent digestibility at the terminal ileum = (I – D)/I. Unlike **true digestibility** or **real digestibility**, apparent digestibility ignores losses of endogenous origin which increase faecal excretion and give a lower digestibility value. (SB)

See also: Digestibility

Appetite

An instinctive desire for food or drink, or any other instinctive desire necessary to maintain life. Regarding feeding, appetite is an object or objective, such as obtaining a food or foodstuff. For example, during a meal, the appetitive phase is the goal-directed behaviour focusing on acquiring food, while the consummatory phase is the act of ingestion. During the consummatory phase, mechanisms are initiated that help to terminate the meal. The degree of disposition towards obtaining food may vary greatly, so that the appetite may be a subtle or overwhelming compulsion.

Hunger is often used synonymously with appetite, but differs in several aspects. Hunger may be viewed as the ‘stimulus to eat’ that arises from internal cues which provide information about energy or essential nutrient status. Hunger may be considered the motive to eat, in the same way that thirst is considered to be the motive to drink. Appetite may arise from the same internal cues that are responsible for hunger, as well as from the sight or smell of food, or from psychological desires or cravings. Appetite often implies a greater selectivity towards the food(s) consumed than hunger.

In contrast to food intake, which can be quantified in terms of the amount of food consumed per unit time, appetite is difficult to quantify and so the mechanisms controlling appetite are not differentiated from the mechanisms that control food intake. Food intake is controlled, both on a long-term, day-to-day and within-meal basis. On a long-term basis, adult animals will adjust their food intake to maintain a relatively stable body weight. On a day-to-day basis, animals will eat a relatively constant amount of energy each day and will correct for daily perturbations in **energy intake**. Circadian, diurnal or specific daily feeding patterns also contribute to how and when food is consumed within a day – these patterns can vary greatly between species. Within a meal, there are mechanisms that initiate the meal, sustain the meal and terminate the meal. Stimuli arising from within the body (internal) as well as from environmental (external) stimuli may be involved in initiating a meal.

Very little is known about the internal stimuli that initiate a meal. Nonetheless, these stimuli are probably **energy metabolite**s in nature, and signal information regarding energy or essential nutrient (e.g. **glucose**) stores. The internal stimulus responsible for initiating the meal probably gives rise to the feeling of appetite or hunger. External stimuli that may be involved in initiating a meal can include social eating habits, the sight or smell of food, or other environmental factors. Signals from long-term energy stores such as **adipose tissue** also influence feeding, as low levels of **insulin** or **leptin** enhance feeding.

The appetite for food is controlled by the central nervous system (CNS), but is also responsive to metabolic, humoral and vagal signals originating from the periphery. Metabolic modulators include small transient drops in blood glucose that precede a meal, as well as hepatic glucose and fatty acid metabolism. Hormonal signals include factors such as amylin, **apolipoprotein** AIV, enterostatin, **oestrogen**, leptin, **glucagon**, **glucocorticoids**, insulin and somatostatin. The vagus nerve transmits information to the brain regarding gastric or rumen distension and the release of gastrointestinal peptides during a meal.

While it is generally thought that animals eat to meet their energy demands, there are numerous circumstances when this is not true. Highly palatable diets often cause animals to overeat and become obese, while extremely unpalatable diets will cause animals to undereat. A diet extremely deficient in an essential nutrient will cause **anorexia** if it is the only diet available. At the same time, animals fed mildly protein-deficient diets may overconsume the diet in an attempt to obtain more protein. Appetite is also suppressed during infection and cancer. **Cytokines** such as tumour necrosis factor-α, interleukin-1 and interleukin-6 appear to be the primary cytokines responsible for infection- and cancer-induced anorexia.

Neurotransmitters such as **norepinephrine**, **serotonin**, **dopamine**, **histamine** and GABA have all been shown to be involved in the control of feeding. Neuropeptides or peripheral peptides that act at CNS sites to affect food intake include agouti-related protein, amylin, α-melanocyte-stimulating hormone, bombesin, cocaine and amphetamine-related transcript (CART), corticotropin-releasing factor, enterostatin, galanin, glucagon, glucagon-like **peptide**, insulin, melanin-concentrating hormone, opioids, orexin (hypocretin), neuropeptide Y, somatostatin, thyrotropin-releasing hormone and urocortin. Differences in the role and importance of these neurotransmitters and neuropeptides vary with species.

Numerous brain areas are involved in the control of appetite. The **hypothalamus** plays a critical role, particularly the arcuate nucleus, paraventricular nucleus, lateral hypothalamus, ventromedial hypothalamic nucleus and the dorsomedial nucleus. The caudal brainstem also plays an important role in feeding, as it contains the motor neurones that function as the central pattern generator for the rhythmic and stereotyped movements of ingestion (e.g. **mastication**, licking, lapping). The caudal brainstem also receives afferent fibres from the mouth, stomach and small intestine. Higher cortical brain areas are involved in multiple aspects of food intake, including making food associations, such as learned preferences and learned aversions, controlling motor movements necessary for finding or catching food, or making appropriate food choices.

Specific appetites arise from the animal's attempts to maintain an adequate intake or prevent a deficiency of dietary essential nutrients such as protein, vitamins and minerals. For example, animals maintain a level of protein intake above their requirement when allowed to select between different foods – this is often considered a specific appetite for protein. Animals deficient in a specific essential nutrient will select foodstuffs or diets containing the deficient nutrient over foodstuffs lacking the needed nutrient – this is also considered a specific appetite and serves to restore **homeostasis** in deficient animals. All specific appetites except sodium appetite appear to require post-absorptive feedback and learning before an animal will display a specific appetite for a given food. That is, the animal must first consume and absorb a specific food that contains adequate quantities of the needed nutrient. The brain then senses some event associated with the repletion of the limiting nutrient or the restoration of homeostasis. This 'positive post-absorptive event' is then associated with some aspect of the consumed food (usually taste) and will direct the animal toward obtaining and consuming this specific food during subsequent meals. In contrast, sodium appetite is innate and does not require post-absorptive feedback or learning. Animals deficient in sodium will immediately recognize foods containing this nutrient.

Perverted appetites or pica involve the intake of inedible or non-nutritive material such as earth, hair, bone, etc. The purpose of pica is unknown, but under some circumstances pica may occur during expression of a learned taste aversion or during states of **nutrient deficiency**. (NJB)

Appetite disorders

Appetite disorders may be secondary effects of diseases, most of which cause a reduction in food intake, or they may be diseases themselves, such as **anorexia**. Many diseases cause a fever, with elevated body temperature. A reduction in food intake occurs, which is presumed to derive from a direct effect of the elevated temperature on the brain. Diseases involving abdominal discomfort (e.g. ovarian cancer) also depress intake: the reduction in intake should alleviate the discomfort, particularly if the food was the source of the problem. Other diseases are metabolic, i.e. in the body as distinct from the digestive tract, and again a reduction in intake is an innate response to metabolic imbalance or discomfort. In a normal animal, this is most likely to be due to the food but, even if it is not, intake will still be reduced. On the other hand, there are certain metabolic abnormalities that lead to an increased intake; for example, insufficient **insulin** secretion, as in **diabetes**, does not allow normal cellular uptake of **glucose**, with the result that certain cells (liver, hind-brain) signal their shortage of energy to the intake-controlling circuits of the brain. Appetite disorders are not likely to be transmitted genetically as they cause infertility and premature death. (JMF)

See also: Anorexia

Appetite stimulant

A single compound or group of compounds that flavours a feed to increase the appetite. These include yeasts, mixtures of herbal extracts, distillery or brewing **by-product**s and simple

sugars. Appetite refers to the desire of an animal or bird for food or water, but is generally used to refer to a long-term effect. A number of compounds have been reported to be effective in the diets of young pigs but the literature is somewhat conflicting. Poultry have < 1% of the taste buds found in humans or other farm animals and these stimulants are ineffective (Chiy and Phillips, 1999). (SPR)

See also: Flavour compounds

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Apple

The juice of apples (*Malus* spp.) is extracted for apple juice or cider, leaving a residue of apple pomace that contains the remaining tissue, skins, pips and stalks. Pomace may be fed directly to livestock, dried, or sold moist. Some pomace has absorbents (e.g. wood shavings) added to aid juice extraction, which increase the fibre content and reduce the nutrient concentrations. Apple pomace is palatable and suitable for feeding to adult ruminants but it is low in protein (*c.* 5%) and in minerals. It is also low in **dry matter** (DM) and has only the moderate energy level of ~10 MJ ME kg^{-1} DM for cattle. Moist apple pomace can be stored for up to 6 months covered in clamps and its **bulk density** when moist is < 150 kg m^{-3} and when dried < 350 kg m^{-3}. The pectin and **pentosan** contents make it unsuitable for young ruminants, piglets and poultry. Maximum DM inclusion rates as a percentage of diet are 20% for dairy and beef cattle, 10% for lambs and 5% for ewes, sows and finishers. (JKM)

Aquaculture

The cultivation of **aquatic organisms** (fish, crustaceans, molluscs, unicellular algae, macroalgae and higher plants), using extensive or intensive methods in order to increase the production or yield per unit area or unit volume to a level above that obtained naturally in a particular **aquatic environment** (Hall and Holby, 1986). The term does not apply to the impoundment of aquatic organisms for direct sales in markets; nor does it include the culture of essentially terrestrial organisms (e.g. terrestrial plants grown hydroponically).

Aquaculture includes ponds, raceways, cages, pens, rafts, paddy fields, intertidal zone and greenhouse culture. Marine (as opposed to freshwater) aquaculture has been termed ‘mariculture’. Aquaculture encompasses the culture of aquatic organisms for stock enhancement, ocean ranching and ornamental purposes. The objectives of aquaculture are to increase production above levels occurring in natural ecosystems and to provide a more stable temporal supply of food organisms of consistently higher food quality under greater human control than can be supplied through the natural fisheries. These objectives are realized through selection of species or strains with higher feed conversion efficiencies, higher growth rates, later maturity and greater resistance to disease.

Commercial aquaculture is an ancient practice, though large-scale farming is relatively recent. The earliest known treatise on aquaculture is the *Classic of Fish Culture* in 500 BC by Fan Lei, a Chinese politician turned fish culturist who attributed his accumulation of wealth to pond production of carp. However, in reality the first practical aquaculture probably was the integrated fish farming in paddy rice fields in Hemudu Site in Qiantang River, China, in approximately 5000 BC, as evidenced by the discovery of large quantities of carbonized rice and fish together at that site. Oyster culture is known to have been practised in Japan and Greece *c.* 2000 years ago. **Seaweed** culture is much more recent, the earliest known text being published in 1952 in Japan. Fish farming in Europe was first carried out by the Etruscans, in approximately 500 BC.

World aquaculture production attained a record high of 114.5 million tonnes in liveweight in 2018, with a total farmgate sale value of US$ 263.6 billion. This comprised 82.1 million tonnes of aquatic animals, 32.4 million tonnes of aquatic algae and 26,000 t of ornamental seashells and pearls. The farming of aquatic animals in 2018 was dominated by finfish (54.3 million tonnes). Fed aquaculture production (57 million tonnes) has outpaced that of the non-fed subsector in world aquaculture. World aquaculture production of farmed aquatic animals grew on average at 5.3% per year in the period 2001–2018, although it slowed towards the end, 4% in 2017 and 3.2% in 2018. The recent low growth rate was caused by a slowdown in China, the largest producer (FAO, 2020)

In 2018, inland aquaculture produced 51.3 million tonnes of aquatic animals, accounting for 62.5% of the world’s farmed food fish production, an increase from 57.9% in 2000. Mariculture and coastal aquaculture collectively produced 30.8 million tonnes of aquatic animals in 2018. Major aquatic organisms currently under culture include several species of carp, catfish, tilapia, oyster, scallop, clam, mussel, prawn, marine shrimp, salmon, trout, grouper, sea bass and sea bream. Despite technological developments in marine finfish aquaculture, marine and coastal aquaculture produce many more molluscs than finfish and crustaceans (FAO, 2020).

World aquaculture production of farmed aquatic animals has been dominated by Asia, with an 89% share in the past two decades or so. Among major producing countries, PR China, Egypt, Chile, India, Indonesia, Vietnam, Bangladesh and Norway have consolidated their share of world production over the past two decades (FAO, 2020).

The contribution of world aquaculture to global fish production reached 46.0% in 2018, up from 25.7% in 2000. At a regional level, aquaculture accounted for 17.9% of total fish production in Africa, 17.0% in Europe, 15.7% in the Americas and 12.7% in Oceania. The share of aquaculture in Asian fish production outside of China reached 42.0% in 2018, up from 19.3% in 2000. Inland aquaculture produced most farmed fish (51.3 million tonnes, or 62.5% of the world total), mainly in fresh water, compared with 57.7% in 2000. The share of finfish production decreased gradually from 97.2% in 2000 to 91.5% (47 million tonnes) in 2018, while production of other species groups increased, particularly through freshwater crustacean farming in Asia, including that of shrimps, crayfish and crabs (FAO, 2020). (RHP; QS)

Coastal net pens off the coast of Maine. Photograph courtesy of NOAA National Centers for Coastal Ocean Science

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Aquatic environment

Aquatic environments encompass both freshwater (lakes, rivers, wetlands) and saline (oceans, estuaries, salt lakes and sloughs) conditions. They display a wide range of thermal regimes, pH, salinity and other chemical characters, clarity, and degree of movement, all of which determine the type of organisms that occupy them. A stagnant pond, for example, is a very different aquatic environment from a fast-flowing river or exposed ocean coast. Although aquatic habitat is usually judged to be physically more stable than the aerial or terrestrial environment, it is nonetheless subject to periodic changes. In temperate latitudes, seasonal thermal changes may be considerable, from freezing to 30°C or more. Water levels rise and fall seasonally, or more frequently in the case of tides, periodically exposing some inhabitants to air. Estuarine habitats may experience large fluctuations in salinity within hours. The organisms that live in these environments influence the physical properties to some extent, as in trapping or producing sediment, obscuring clarity of the water, or changing the content of oxygen and other chemical constituents. (CB)

Aquatic organisms

Organisms living in fresh, brackish and **sea water** are generally divided into plankton, nekton, benthos and neuston (invertebrates, fish, mammals, etc.). Most fish and aquatic invertebrates are poikilotherms (body temperature conforms to external environment) with their **metabolic rate** increasing as the **water temperature** increases. Marine invertebrates are osmoconformers; **marine fish**, however, maintain their plasma hypotonic to that of the seawater medium by drinking, reducing urinary water loss and excreting salt through the gills. **Freshwater fish** osmoregulate by pumping out water while retaining the salts. External respiratory surfaces (gills) must be kept moist for gas exchange.

In the **marine environment**, many small free-floating eggs are often released and externally fertilized. The larvae are widely dispersed and feed on plankton, thus reducing the need for a large **yolk sac** within the egg. High mortality rates are associated with these planktonic larvae. In a freshwater environment, generally eggs are either retained by the parent or associated with the bottom and contain a large yolk sac, which produces more highly developed larvae or juveniles at hatch. Aquatic animals usually excrete nitrogenous wastes in the form of **ammonia**, a soluble toxic substance requiring large amounts of water for its removal. (DN)

Aquatic plants

Vegetation that has adapted to living in saltwater or freshwater **aquatic environment**s. It is normally associated in nature with standing water, either permanently or at least for prolonged periods during the year. The plants may be wholly submerged, or with photosynthetically active parts entirely or partly submerged. In the broad sense of the term 'plants', they are represented by flowering plants, ferns, bryophytes, algae and fungi. As **marine plant**s are generally categorized separately, the term 'aquatic' is often applied to only the freshwater species. The distinction between true aquatic plants and those that inhabit wet soils is unclear and ultimately relies on whether the plant requires some degree of submersion or merely tolerates it. Some intrinsically terrestrial plants can be relegated to aquatic habitats by poor competitive ability on drier soils, for example *Taxodium* (bald cypress). Herbaceous vascular plants dominate the aquatics, spanning a large number of families and ranging in size and habit from minute floating species, for example *Lemna* and *Wolffia* (duckweeds), to tall emergent forms such as *Oryza* (rice) and *Typha* (cattails). Freshwater algae comprise at least 15,000 species but are mostly microscopic and inconspicuous. Fungi are small filamentous species.

Aquatic plants are important in stabilizing shorelines and purifying water. They exhibit capacity to remove **arsenic** (As) from the water and soil sediments. Ironically, where water movement is minimal, they often contribute to the destruction of their aquatic habitat by accruing sediment, towards hydrarch succession to terrestrial conditions. Aggressively growing and invasive macrophytes can be nuisances, clogging waterways, altering food webs, reducing dissolved oxygen concentrations and producing anoxic conditions after death. The large biomass of such plants means that it may be used as a supplement to silage and other livestock feed; for example, *Eichhornia crassipes* (water hyacinth), one of the well-known aquatic invaders, has sometimes been used for this purpose.

As a result of human activities some aquatic plants are expected to undergo radical changes because of increased **bicarbonate** concentrations in lakes due to acidification, deforestation and use of nitrogen fertilizers. (CB; DB)

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Arabinogalactans

Branched heteropolysaccharides with molecular weight 16,000–100,000, having varying proportions of D- or L-**arabinose**, and D-**galactose**; arabinose may be present in the **furanose** or **pyranose** ring form, galactose in the pyranose form. The backbone frequently consists of galactose residues. Arabinogalactans are usually water soluble and they may be covalently linked with protein. They may contain small amounts of **rhamnose** and **uronic acid**s. They are the major **hemicellulose**s in plants. (JAM)

See also: Arabinose; Dietary fibre; Galactose; Hemicelluloses

Arabinose

A five-carbon **sugar**, $C_5H_{10}O_5$, molecular weight 150, in L- or D-form and as a **pyranose** or **furanose** ring. Does not occur free in nature. A major component of plant **polysaccharides**. Absorbed in the **small intestine** by passive **diffusion**. (JAM)

Arabinoxylans

Branched heteropolysaccharides with molecular weight 6000–30,000, having varying proportions of **arabinose** (usually in L-form and as the **furanose** ring) and **xylose** (in D-form and as the **pyranose** ring). Arabinoxylans frequently contain linear chains of xylose residues and may include small amounts of **uronic acid**s. They are water soluble and are the major constituents of plant cell walls, particularly in cereals and grasses. (JAM)

See also: Arabinose; Carbohydrates; Dietary fibre; Hemicelluloses; Structural polysaccharides; Xylose

Arachidic acid

Eicosanoic acid, a saturated **long-chain fatty acid**, $CH_3{\cdot}(CH_2)_{18}{\cdot}COOH$, shorthand designation 20:0. It is found in **groundnut** oil, **rape** oil, butter and **lard**. (NJB)

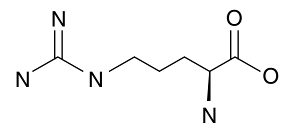
Arachidonic acid

5,8,11,14-Eicosatetraenoic acid, molecular structure $CH_3{\cdot}(CH_2)_4(CH{=}CH{\cdot}CH_2)_4{\cdot}(CH_2)_2{\cdot}COOH$, a long-chain **unsaturated fatty acid**, shorthand designation 20:4, found in fish and groundnut **oils**. It is an **essential fatty acid** for the cat family, but can be produced from **linoleic acid** in many animals. This makes linoleic acid an essential fatty acid and without it a deficiency of arachidonic acid is expected. Arachidonic acid is found in high concentration in membranes as part of the **phospholipid** fraction. Metabolically it is a precursor of the **prostaglandins**, thromboxanes and **leukotrienes**. (NJB)

Arctic char (*Salvelinus alpinus* (L.))
The most northerly adapted of the **salmonid** fish, with a circumpolar natural range. There are both anadromous and strictly freshwater forms. Eggs should be incubated at less than 8°C, and the optimum temperature range for growth is 10–13°C. Iceland is the major producer of cultured Arctic char. A major problem for culture to date has been highly variable growth rates. (RHP)

Arginase
This enzyme catalyses the **hydrolysis** of L-**arginine** into **urea** and L-**ornithine**. There are two isoforms of arginase in animals. Type-I arginase is present in the cytosol of hepatocytes and many other cell types, whereas type-II arginase occurs in the mitochondria of extrahepatic tissues and cells. Arginase is also found in some tissues (e.g. the kidneys) of birds, which excrete **nitrogen** mainly as uric acid. Arginase activity in avian cells is much less than that in most mammalian tissues. In ureotelic animals, the highest activity of arginase is found in the liver but this protein is also expressed in other tissues such as the kidney, small intestine, brain, mammary gland, macrophages and red blood cells. Arginase plays important roles in **ammonia detoxification** in all mammals, as well as in the synthesis of **proline** and **polyamines** in all animals. (GW; NJB)

Arginine
An **amino acid** ($NH_2{\cdot}NH{\cdot}C{\cdot}NH{\cdot}(CH_2)_3{\cdot}CH{\cdot}NH_2{\cdot}COOH$, molecular weight 174.2) found in protein and physiological fluids. Arginine is synthesized from **citrulline**, which is generated from **glutamine**, **glutamate** and **proline** in the **enterocytes** of most mammals, including humans, pigs, cattle, sheep and rats. Although arginine is formed via the **urea cycle** in mammalian hepatocytes, there is no net synthesis of this amino acid by the liver due to an exceedingly high activity of **arginase**. In neonatal mammals, the **small intestine** is the primary site for arginine synthesis from glutamine, glutamate and proline. In post-weaning mammals, the kidneys become the major site for the conversion of the small intestine-derived citrulline into arginine. Most of young mammals (e.g. humans, pigs, rats, cattle, sheep and dogs) can synthesize sufficient arginine to achieve growth rates that are about 50% of maximal and, therefore, require this amino acid for maximum growth and optimum health. Most adult mammals do not require arginine in the diet for maintaining **nitrogen balance**, but they do need dietary arginine to meet physiological needs such as **nitric oxide** synthesis, **blood flow**, spermatogenesis, embryonic survival, wound healing and maximum **lactation**. Feline species, however, have a limited ability to synthesize arginine and therefore require arginine in their diets. (GW; DHB)



See also: Citrulline; Urea cycle

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Arsanilic acid
Formerly used as a feed additive, as a coccidiostat in broilers and as a **growth promoter** in pigs and broilers, which makes use of its antibacterial properties. Feed efficiency is increased but residues of **arsenic** occur in meat and offal. (JMF)

Arsenic
A mineral element (As) with an atomic mass of 74.92. It is found naturally in small amounts in **sea water** and rocks. Soils contain from 1 to 40 mg kg^{-1} but can accumulate more where **arsenical pesticides** and herbicides are used. Vegetables and grains contain < 0.5 mg kg^{-1}; **freshwater fish** contain an average of 0.75 mg kg^{-1} and seawater **shellfish** may contain much higher concentrations. Arsenic compounds can leach into ground water and contaminate well water. This has prompted some regulatory agencies to suggest a limit of 10 μg As l^{-1} drinking water for human consumption.

Arsenic as arsenate or arsenite is readily absorbed from the intestine and some of the As is converted to the methylated form in the liver before being excreted in the **urine**. There is no known metabolic function for As and it is generally considered to be a toxic substance. However, some investigators have found evidence, though weak, that As might have limited nutritional benefit in certain animal species, especially ruminants. The phenylarsenic compounds are the least toxic and are used as feed additives in the diets of pigs and poultry as a growth stimulant, whereas the water-soluble inorganic compounds are the most toxic, resulting in their use as **pesticides**. Although the element is also considered a **carcinogen**, its trioxide form has been used to induce remission of acute promyelocytic leukaemia in humans. Low concentrations of **selenium** and As have been shown to induce hypomethylation of DNA in isolated intestinal cell models. This mechanism is thought to give selenium its anti-carcinogenic properties. Whether As has similar properties is not known. Natural **antagonists** to **intestinal absorption** and organ accumulation of As are other dietary minerals such as **selenium**.

Although the inorganic forms of As are more toxic than the organic forms, it has been reported that cattle and sheep can tolerate various inorganic As compounds in dietary concentrations up to 280 mg kg^{-1} for 60 days or more without ill effects. Pigs also tolerate rather high amounts of dietary arsenic, but they have reduced food intake at concentrations > 500 mg kg^{-1}. (PGR, CJCP)
See also: Selenium

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Arsenicals

Arsenic-based compounds used as **pesticide**s in crops and livestock, especially for tick control. Arsenical pesticides present significant hazards to animal health, causing gastroenteritis and a rapid drop in blood pressure. (CJCP)

Artemisia

Artemisia annua, from the Compositae family, is widespread and diverse.

A. annua is an annual plant with relatively bitter and aromatic leaves due to the presence of the high content of terpenoids and lactone-**terpene**. It is abundantly found in temperate regions. Its main effective ingredient is artemisinin, which is distributed throughout the plant (Al-Khayri *et al*., 2022). The WHO believes that this plant has valuable nutritional and medicinal properties (WHO, 2006). With the support of the United Nations, the *A. annua* plant has been used in the treatment of malaria (Soni *et al*., 2022). Artemisinin in *A. annua* can be effective against various cancer cells, such as leukaemia and **colon** cancer (Baldi and Dixit, 2008), and in the treatment of AIDS, hepatitis and corona virus. A hydroalcoholic extract of *A. annua* causes the destruction of the cyst stage of *Giardia lamblia* parasite (Bahman *et al*., 2012). Ethanolic and chloroform extracts of this plant can prevent the growth of ***Escherichia coli***. Artemisinin can strengthen the host's immune system, and, as an immune stimulant, it can be considered as an alternative to in-feed antibiotics. Also, due to the antiparasitic effects of the compounds of artemisinin and the high **antioxidant** capacity of crude extracts of this plant, its use as a dietary supplement for humans and domestic animals (ruminants and poultry) is expanding. In animals (sheep and goats), *Artemisia* spp. have antiparasitic activity, for example against *Fasciola*, *Eimeria*, *Trichostrongylus* and *Haemonchus*. It also has positive effects on the performance and health of broiler chickens and laying hens (improvement of atherogenic index, antioxidant status and the reduction of **coccidiosis**) (Cherian *et al*., 2013; Baghban-Kanani *et al*., 2019). (AS, BH-G, CJCP)

Artemesia tridentata ssp. *Wyomingensis* (Wyoming big sagebrush), with seed stalks. This plant is of value in the nutrition of livestock and wildlfe. Photo courtesy of USFWS Mountain Prairie.

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Artificial drying

Artificial drying of crops ('parching' over fire) dates back to biblical times. Green crop drying is normally associated with artificially drying with hot air. This method allows green crops to be preserved independent of weather conditions, at high nutritive quality with low conservation losses (as low as 3% of the dry matter). While dried grass accounted for 200,000 t in 1972 in the UK, this process declined in popularity during the 1980s due to the high cost of fossil fuels. Almost 300 l of oil is required to dry 1 t of dried grass from a crop of 80% moisture content. Composition of leafy dried grass can be dry matter (DM) 90%, **crude protein** 18.7% DM, **metabolizable energy** 10.6 MJ kg^{-1} DM. Barn drying provides a method of blowing cold air through a stack of cured hay bales to ensure that the moisture content of the dried hay is < 12%. Hay preservatives and drying agents allow for increased flexibility in haymaking systems. Under certain conditions, they can greatly increase the efficiency of nutrient preservation. The most common preservatives are **organic acid**-based formulations. Drying agents available are usually carbonate-based products, which may also contain **fatty acid** esters. (RJ)

Artificial rearing of mammals

The process of substituting intensive technology for the normal care and nutrition provided by the dam in neonatal life. The most extreme need applies when offspring have been removed directly from the womb by hysterectomy to establish minimal-disease flocks or herds. It also has a function for neonates deprived of maternal care by an accident, a breakdown in maternal health or because of failure of the dam to lactate. The boundary between artificial rearing and very **early weaning** is not exact. Very early weaning following a very short **lactation** may facilitate the breaking of the disease chain from parent to offspring, particularly if this is accompanied by intensive medication of the offspring. Some success is claimed for reducing the incidence of some pig diseases such as porcine respiratory and reproductive syndrome and enzootic pneumonias.

For successful artificial rearing, the complex physiological needs must be met. The environment must be controlled so that the nutritional, social and physical environment provided by the dam can be simulated in the essential aspects. The immune system of the neonate at birth is naive. Rearing is greatly facilitated if the neonate can receive passive **immunity** via colostrum or by an equivalent dose of relevant **immunoglobulins** extracted from blood. At birth the gut is permeable to proteins and the globulins can be absorbed directly into the bloodstream. The benefits may be sustained well towards adult life. Offspring that are totally deprived of colostrum need 'hospital quality' care. This should include protection from air- and food-borne pathogens, a stable temperature and isolation from other livestock. The process of normalization of the environment needs to be very gradual and in step with the development of active immunity.

Nutrition during artificial rearing is critical to its success. The closer the artificial diet is to the composition of the natural milk of the species, the better the outlook. Growth rates tend to be more normal if the artificial diet is offered in a liquid rather than a solid form. Liquid feeding requires particularly diligent hygiene. In ruminants, **liquid diet**s carry an additional benefit because they stimulate the reflex closure of the oesophageal groove and allow the food to bypass a non-functioning rumen. The reflex is assisted by a husbandry routine that raises the expectation of being fed. The **protein source** in the artificial diet is critical. The **casein** in milk has clotting properties in the presence of the stomach enzyme **rennin**, and this attribute aids **digestion**. Proteins other than those of milk are often less suitable partly because they do not clot and are usually less soluble. Those of vegetable origin tend to be difficult to digest, because the molecules are larger than those of the milk proteins and they may provoke an immune reaction. Milk fats are easily digested, particularly if emulsified, but in dry diets **lipids** rich in **medium-chain fatty acid**s tend to be the most readily digested. **Lactose** not only supplies energy but is also readily fermented in the gut, encouraging the development of a friendly, lactobacillus-based flora. (VRF)

Artificial rumen

A vessel in which rumen contents can be incubated under conditions resembling those of the rumen *in vivo*. It may be a closed or open system operating batchwise or a continuous-flow stirred tank reactor (CFSTR) or chemostat that will achieve a steady state. Such systems allow study of the products of rumen fermentation, the population dynamics of rumen microflora or studies of the degradation kinetics of components of forage and feeds, **methanogenesis** etc. The most complex of these continuous fermenters involve dialysis of the products to mimic **absorption** and gaseous exchange. Temperature, pH and redox potential may be monitored or controlled. The system may be used to study isolated pure cultures or mixed microbial and **protozoa**n ecosystems. Artificial rumen systems allow study of the time course of change of **substrates**, gases and organisms. They are usually kept anaerobic using hydrogen and reducing agents. Simple batch systems are more easily managed. The semi-continuous rumen simulation technique (RUSITEC) designed by Czerkawski and Breckenridge (1977) is a widely used artificial rumen system.

Artificial rumens do not exactly parallel conditions in the rumen and give typically different results, for example lower total **volatile fatty acid** and **acetate** concentrations, reduced or absent **protozoa**l populations, and lower **organic matter** and neutral detergent fibre digestibilities (Hristov *et al*., 2012). When comparing results from different laboratories, it is important to understand the effects that differing sources of rumen liquor, **feed particle size**s and flow rate are likely to have on the results (Hristov *et al*., 2012). (IM, GMcLD)

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Artificial sweeteners:
see Attractants; Flavour compounds

Ascites (or hydroperitoneum)

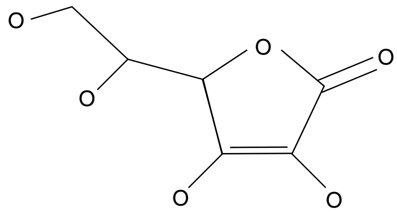
A non-inflammatory peritoneal effusion, seen as an accumulation of serous fluid in the abdominal cavity. Though ascites can be part of generalized vascular oedema (vascular **hypertension** or hypoproteinaemia), more typically it results from chronic passive congestion of the portal venous system of the liver, often as a sequel to hepatic diseases such as **cirrhosis** or veno-occlusive disease. Other traumatic, neoplastic or vascular diseases that obstruct venous or lymphatic draining can also cause ascites but are relatively rare. Ascites must be differentiated from other accumulation of fluid in the peritoneal space, including exudates from inflammatory diseases or urine from a damaged urinary system.

There are nutritional, infectious, immunological and toxic diseases that result in **liver disease** and ultimately cirrhosis. As cirrhosis is a non-specific change, definitively identifying the inciting cause is often a diagnostic challenge. Toxins that are commonly associated with liver disease in livestock include copper (sheep are most susceptible), **gossypol**, pitch (clay pigeons), cocklebur, lantana, sacahuista, lechugilla, some vetches, blue-green **algae**, **aflatoxin**s and pyrrolizidine-containing plants (*Senecio*, *Crotolaria*, *Amsinkia*, *Cynoglossum*, *Echium*, *Symphytum* and *Heliotropium* spp.). One of the common lesions of pyrrolizidine **alkaloid** intoxication is fibrosis and obliteration of the hepatic central vein (veno-occlusive disease).

Avian ascites or broiler pulmonary hypertension syndrome is a disease of rapidly growing broilers. Birds 3–4 weeks old are the most commonly affected and flock mortality can be nearly 20%. Ascites syndrome worldwide costs about US$1 billion, with an average incidence of 4.7% in broiler flocks. Affected birds are stunted and lethargic, with abdominal enlargement and lack of appetite. Post-mortem changes include marked right ventricular dilation and hypertrophy, arterial hypertrophy, ascites (serous fluid distension of the abdomen), pulmonary congestion and oedema. Although the aetiology of ascites syndrome is not completely known, it is closely associated with right congestive heart failure. Other proposed contributing factors include chronic oxygen deficits (housing at elevations of 3000 m), poor ventilation, high-energy diets and salt, monensin or furazolidone **supplement**s. Of all these aetiologies, those that contribute to rapid growth appear to be most closely linked to broiler ascites. A likely pathogenesis is that rapid growth and increased oxygen requirements lead to cellular oxygen deficits, pulmonary arterial **hypertension**, right heart failure, passive congestion of the abdominal organs and ascites. A comparable syndrome with similar nutritional and genetic contributing factors is seen in turkeys (round heart disease). Other toxins have also been shown to cause ascites in birds. Severe ascites and oedema were reported in the 1960s when thousands of birds were poisoned with polychlorinated dibenzo-*p*-dioxin 'chick oedema factor'. Poisoned birds developed extensive hepatic necrosis and cholangiolar hyperplasia and portal hypertension. Heart failure is common in ascites produced in birds poisoned with high-salt diets or furazolidone. Ducklings and turkeys appear to be most susceptible to furazolidone toxicosis. (BLS)

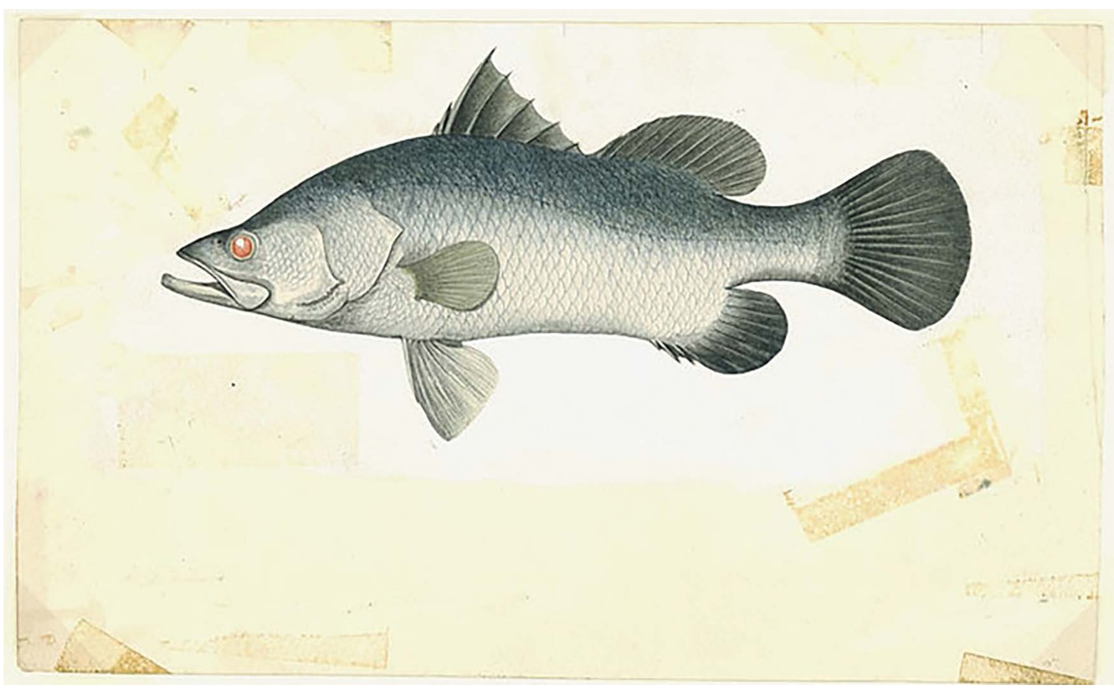
Ascorbic acid

L-Ascorbic acid is **vitamin C**, $C_6H_8O_6$. It is required in the diet of primates, guinea pigs and some bats and birds. In humans a dietary deficiency results in the classical symptoms of scurvy in which wound healing is impaired and subcutaneous haemorrhages are seen as well as muscle weakness, swollen gums and loose teeth. L-Ascorbic acid is a major water-soluble **antioxidant** involved in **oxidation**/reduction reactions in the body (ascorbic acid ⇌ dehydroascorbic acid + 2H). It participates in many processes, including **collagen** synthesis, in **epinephrine** synthesis from **tyrosine** and absorption of iron. (NJB)



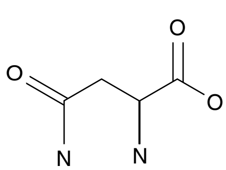
Ash
The mineral elements in a feed, or in biological tissue, measured by burning off ('ashing') the **organic matter** and weighing the residue (the ash). During ashing the organic matter in the material under test is oxidized and minerals present in organic combination are changed to inorganic form. The measurement does not provide any information on the specific elements present and ash may include carbon from organic matter as carbonate when base-forming minerals are present in excess. As with the measurement of any feed component, it is important that a representative **sample** of the feed be used. The sample should be ground so that it will all pass through a sieve with 1 mm diameter openings; the sample should then be thoroughly mixed. A portion (2–3 g) is then dried to constant weight at 103°C and the moisture content determined. A portion (approximately 2 g) of the dried feed is weighed into a crucible (nickel or porcelain) and placed in a muffle furnace. The temperature is raised, stepwise, to 600°C. Ashing is allowed to proceed overnight (18 h), after which the crucible is transferred directly to a dessicator, cooled and weighed and the ash content of the sample determined as the weight remaining. (CBC)

Asian sea bass (*Lates calcarifer*)
A commercially important fish species farmed in several Asian countries and northern Australia. It belongs to the family Centropomidae and is commonly known as barramundi, bhetki or giant sea perch. Asian sea bass are widely distributed in tropical and subtropical areas of the Indo-Pacific region inhabiting a wide variety of freshwater, brackish and marine habitats, including streams, lakes, estuaries and coastal waters, but **spawning** only in inshore marine waters. These predatory fish feed initially on small crustaceans and later switch to fish. Juvenile sea bass may be cannibalistic. (RMG)

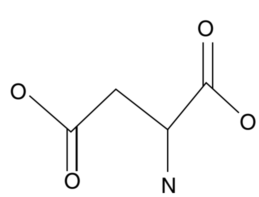


Giant Perch, otherwise known as Palmer or Barramundi, Photo courtesy of Queensland State Archives. Licensed under Public Domain Mark 1.0.

Asparagine
An **amino acid** ($NH_2 \cdot CO \cdot CH_2 \cdot CH \cdot NH_2 \cdot COOH$, molecular weight 132.1) found in protein. It contains both an amino and an **amide** group. It can be synthesized in the body from **aspartic acid**. (DHB)



Aspartic acid
A dicarboxylic **amino acid** ($COOH \cdot CH_2 \cdot CH \cdot NH_2 \cdot COOH$, molecular weight 133.1) found in protein. It can be synthesized in the body from **oxaloacetate** and an amino group donor. (DHB)



Aspergillosis

A fungal infection (mycosis) caused by a number of *Aspergillus* spp. It is primarily a respiratory infection, especially in birds, but can affect the digestive and reproductive tracts. Clinical findings include dyspnoea, gasping and polypnoea, with microscopic evidence of fungal growth in affected tissues. Mastitis and **abortion** may occur in ruminants. (PC)

Associative effects of foods

The effect of one food on the utilization of another given with it; for example, the change in **digestibility** of feed A attributable to the presence of food B. Thus, a diet of equal parts of dry matter (DM) from coarse **forage** (DM digestibility 0.45) and a concentrate mix (DM digestibility 0.75) will not necessarily have a DM digestibility of 0.6. This means that the **metabolizable energy** value attributed to an individual feed is not necessarily its value when used as a dietary component.

Although associative effects occur in all species, they are most important in ruminants given concentrates and **roughages** together. Ruminants, through their **rumen microorganisms**, have a unique capacity to digest plant cell wall constituents (especially **cellulose** and **hemicellulose**), which allows them to utilize poor-quality forages, such as crop residues. However, to meet production targets for milk and meat, the poorer the quality of the forage the more necessary will be supplementary starch-rich and/or protein-rich feeds. **Starch** is rapidly fermented in the rumen, causing a fall in the pH of the rumen liquor which, in turn, inhibits the cellulose-fermenting enzymes. This depresses the breakdown of the cellulose contained in the forage component of the diet. The effects will be greater when large amounts of concentrate are added and the forage component includes mature grasses or crop residues. Feeding concentrates that supply **ruminally available nitrogen** may enhance the activity of rumen microorganisms and thus improve cell wall **digestion**.

Adding concentrates to an all-roughage diet can either reduce or increase roughage intake, thus giving a 'substitution' or 'replacement rate', defined as the change in roughage DM intake per unit change in supplement DM intake.

True associative effects of foods are not easy to estimate, especially when mature forage or crop residues are a major dietary component. Such feeds are also generally deficient in protein, thereby restricting the growth of cellulolytic bacteria and limiting the rate and extent of fibre digestion. To maximize rumen efficiency from widely divergent foods, a combination of rapid and slowly degradable proteins is needed. The overall effect of combining forages and concentrates depends on the amount of each in the diet and on the quality of the forage (which is influenced by species composition and season) (Galyean and Goetsch, 1993; Stockdale 2000).

Many feeds are subjected to some form of physical processing. For grains, this is usually either rolling or hammer-milling. Breaking the grain exposes the starch-rich **endosperm**, which allows the rumen microbes easier contact with the grain contents, potentially resulting in an increase in the extent and rate of digestion. With roughage, **milling** reduces the **particle size** and allows for more complete mixing with other feed ingredients. This reduces the ability of the animal to select the more nutritious plant components. It can also make the feeds more dusty and, therefore, less palatable.

Positive associative effects of foods can also be described as synergy, when the effect of the combination in the diet is greater than when either food is fed alone. Benefits can be measured either as increased intake or as digestibility, or a combination of both. (TS; GMcLD)

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Astaxanthin

Many plants and animals contain a variety of natural pigments that impart yellow, orange and red colours to the flesh, skin and eggs of **fish**. One of the most important groups of natural pigments in the plant and animal kingdom is the **carotenoids**. In salmonids, two oxycarotenoids, **astaxanthin** (3,3′-dihydroxy-4,4′-diketo-β-carotene) and canthaxanthin (4-4′-diketo-β-carotene) are responsible for the red to orange colouring of the flesh, skin and fins. Astaxanthin is the main carotenoid pigment of wild salmonids and is derived mainly from **zooplankton**. Astaxanthin is the principal pigment for **rainbow trout** (Storebakken and No, 1992), **Atlantic salmon** (Christiansen *et al*., 1995), Atlantic charr (Olsen and Mortensen, 1997), Australian snapper (Doolan *et al*., 2009) and tiger shrimp (Okada *et al*., 1994).

Carotenoids have been shown to have several physiological functions, including: (i) accessory pigment in photosynthesis; (ii) protective pigment against photosensitization; (iii) provitamin A source; and (iv) communication in aquatic animals. Responses to physiological or pharmacological administration of carotenoids are normally classified as actions. Potential mechanisms associated with carotenoid actions include **antioxidant** and singlet **oxygen** quenching, provitamin A activity, upregulating of DNA expression, co-oxidation, and enhancement of immune functions associated with increased tumour **immunity** and modulation of macrophage and lymphocyte activation (Bendich, 1993).

It was found that supplementing diets with astaxanthin can increase growth of Atlantic salmon (Torrissen, 1984; Christiansen *et al*., 1994). Similar results were found for Nile **tilapia** (Boonyaratpalin and Unprasert, 1989) and Kuruma **shrimp** (Chien and Jeng, 1992). Consequently, astaxanthin can be considered a vitamin for fish and shrimp

(Torrissen and Christiansen, 1995). Astaxanthin **supplementation** has improved egg quality and larval production in Atlantic cod (Sawanboonchun *et al*., 2008) and **spawning** and fecundity in tiger shrimp broodstock (Pangantihon-Kühlmann *et al*., 1998; Huang *et al*., 2008). Antioxidation capacity and survival after thermal and osmotic stress can be enhanced in tiger shrimp by including astaxanthin in their diet (Chien *et al*., 2003). Astaxanthin incorporation in feed (Kumar et al., 2009) or by injection (Angeles *et al*., 2009) improves immune responses and disease resistance of giant river prawn (NRC, 2011).

However, not all researchers have obtained such positive results: Christiansen and Torrissen (1997) reported that astaxanthin is not essential for fertilization and egg survival in Atlantic salmon. Choubert *et al*. (1998) found that frequency of maturing females or the date of maturation in rainbow trout was not improved by supplementing astaxanthin in the diet. More information is needed on the essentiality of astaxanthin in diets for fish and shrimp, not only qualitatively but also quantitatively (i.e. dose–response relationship). Evidence of deficiency symptoms associated with absence of the compound is also needed (NRC, 2011). (QS)

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Astragalus

A member of the Leguminosae family with more than 3000 species, usually existing in montane environments (Maassoumi, 1989; Li *et al*., 2014). Astragalus is believed to strengthen the immune system of humans and domestic animals, due to the presence of bioactive compounds. It has **polysaccharide**s that modulate the immune system, increasing the activity of macrophages, natural killer cells, dendritic cells, T lymphocytes, B lymphocytes and microglia and causing gene expression of various **cytokines** and chemokines. The immunomodulatory effects of the astragalus polysaccharide suggests that its use for the treatment of some diseases, including cancer, infections, type 1 **diabetes**, asthma and autoimmune diseases, may be successful (Zheng *et al*., 2020; Li *et al*., 2022). Poultry research reveals that the astragalus extract can enhance the effectiveness of vaccines and can potentially be an alternative to in-feed antibiotics (Farag and Alagawany, 2019; Shan *et al*., 2019). In addition to astragalus polysaccharides, the presence of more than 200 bioactive compounds, such as **flavonoid** and **saponin**s, may be beneficial for improving the health of animals (Shan *et al*., 2019; Zheng *et al*., 2020; Li *et al*., 2022).

(AS, BH-G, CJCP)

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Ataxia

A **gait disorder** in which the movement of the animal is uncoordinated, typified by a swaying gait. It occurs in young lambs and goat kids suffering from swayback, which is caused by **copper** deficiency. (WRW)

Atherosclerosis

A condition in which atheromas, consisting of fatty material, occur in the wall of arteries. It is not normally a problem in farm animals. (WRW)

Atlantic salmon (*Salmo salar* (L.))

A typically anadromous **salmonid** fish of the North Atlantic, ranging from the Arctic circle to Portugal in the eastern Atlantic and from Iceland and Greenland to Connecticut in the western Atlantic. Eggs are spawned in late autumn in freshwater streams. The fry hatch the next spring and migrate to sea as smolts after 1–8 years, depending upon latitude. Landlocked forms, living the full life cycle in **fresh water**, also occur. Over 98% of Atlantic salmon production worldwide is cultured.

In cultivated salmon systems, feed provision has to provide adequate nutrients, minimize water pollution and maximize **welfare**. Competition between fish at feeding time can lead to unequal distribution of feed and divergent weights (Santurtun *et al*., 2018).

Efficient feeding systems have not only to meet the salmons' **nutrient requirement**s and minimize water pollution but also need to result in good salmon welfare. Factors such as **appetite**, number and size distribution of fish and feed distribution influence pellet concentration in a sea cage and hence discarded pellets. Agonistic behaviour at feeding times not only adversely affects fish welfare but also increases **feed intake** by dominant individuals and hence causes size divergence within the group, making a uniform product at a single point in time unattainable. Such an effect could lead to a positive feedback situation in which agonistic behaviour causes size disparity and this further increases agonistic behaviour. This is complicated by the fact that at least at low stocking densities Atlantic salmon show territorial behaviour and are able to defend an area within their tank or enclosure, preventing others from accessing pellets that arrive there. Atlantic salmon are often fed with a pelleted diet through **automatic feeding** services which can deposit pellets either at a pre-determined rate or at a rate that increases or decreases according to fish activity ('on demand'). They are normally fed in sea cages using a pneumatic conveying system with a rotor spreader. On-**demand feeding** systems have been developed to replace imposed regime systems in order that agonistic behaviour and competition are reduced and growth is more uniform within the group of salmon. In salmon parr, the on-demand system reduces dorsal fin injuries, competition and overfed fish, leading to more efficient food conversion. Offering a single daily meal increases conspecific aggression, even though the fish are fed to satiation.

Pneumatic conveying systems have raised some concerns, as pellets colliding with the pipe wall may break and not be uniformly distributed or go outside the cage and cause water pollution. Therefore aspects such as the revolutions per minute of the air blower, **particle size** and spreader arrangements should be considered in the development of an efficient feeding system. Spatial distribution of pellets within an enclosure can influence food intake and water pollution with **ammonia**, with the type and intensity of the water current playing important roles. Circular water tanks with current at the edge produce a more uniform feed distribution over the entire water body, compared with water tanks without such currents. Hence the latter are not used in salmon production, as they lead to aggression, lower growth rates and more individual and group food intake variability.

Modifying **fish feeding behaviour** represents a useful tool to determine feeding regime efficiency, with information on swimming patterns and spatial distribution of the fish contributing to improved feeding systems, providing that they can be accurately measured. Salmon show fast swimming in a vertical orientation towards pellets during high intensity feeds, disrupting their natural schooling behaviour. Depth transmitters have revealed that fish approach the surface zone during feeding (1–2 m) and later swim to deeper areas (8–9 m).

Salmon feed in a synchronized manner and feeding rhythms have to be considered when implementing feeding systems, as they can influence appetite, consumption, uniformity of growth, feed wastage and water pollution. Natural feeding rhythms are primarily circadian and seasonal, but tidal and lunar rhythms are also reported. Salmon are preferentially diurnal feeders but at certain stages in their life cycle they can seasonally change to nocturnal feeding under natural feeding conditions. Thus season has to be considered when attempting to feed the fish at their most active time of day. Salmon parr also have natural feeding rhythms that vary with season, including a morning peak in late summer and a midday feeding during spring. Attempts to maintain their natural behaviour, and hence welfare, should take this into account. The daily ration is also affected by seasonal and environmental factors, correlated with temperature variations and day length in on-demand feeding systems. Highest intake is at about 14°C and lowest at about both 18°C and 6°C in Atlantic salmon smolts.

The predictability of the feeding time can influence feed intake and stress levels in the fish. There is increased frequency and severity of dorsal fin damage when there is unpredictable feeding of 1+ salmon parr. However, aggression and attacks can also occur with predictable feeding, probably because of food anticipatory activity. When food is distributed consistently at the same time and place, dominant fish eat first at the surface and the subordinate ones later, with the latter using different strategies such as eating in the middle or bottom of the sea cage. Some fish may receive no food at all. In other farmed animals, feeding systems that seriously disadvantage subordinate animals are either not recommended or not permitted. Feeding systems that result in **starvation** (a severe deficiency in the intake of nutrients necessary for the maintenance of life) and severely damaged fins for a significant number of salmon would clearly be unacceptable to most consumers. As the fish that consume most have less variation in day-to-day intake, unpredictable feeding times make intake more even across fish. However, this might lead to more fin damage. With an unpredictable feeding time, initiators of aggressive interactions are heavier and longer and have less fin damage in comparison with receivers. The solution would seem to be to find better feeding systems. The range of size in fish groups is normally recommended to be kept to a minimum but some scientists suggest the use of older fish (1+ parr) within a younger group (0+ parr) to reduce agonistic behaviours. The older fish should not be of a size where they might eat the younger fish, as this might be difficult to manage. (RHP; CJCP)

See also: Salmon culture

Further reading

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Attractants

Animals have innate preferences and aversions that can be used to make feeds attractive or repellent. Sweet flavours are commonly added to foods for young animals, especially weaned piglets and calves, as most animals have an innate preference for sweetness. This flavour normally indicates the presence of sugars which are readily available sources of energy. Even in the absence of such sugars, sweet flavours can induce animals to prefer foods containing them, as long as they do not also have **antinutritional factor**s such as high fibre, toxins, or nutritional imbalances. There is a belief (or hope) that the inclusion of **palatability** agents in a food will increase **feed intake** but this has rarely been demonstrated to last for more than a few days. However, improving the attractiveness of one food when it is offered as a choice with one or more other foods may increase the short- and long-term preference for the flavoured food, depending on the relative nutritional value of all the foods on offer. (JMF)

Atwater factors

These factors describe the **metabolizable energy** per gram of protein, fat and carbohydrate (4, 9 and 4 kcal, respectively). They are used in relation to human diets but are not commonly used in animal nutrition. (JAMcL)

Automatic feeding

Mechanical methods of providing feed to animals without human intervention. For poultry, the most common form is the chain feeder, in which **compound feed**, as **mash** or crumbled pellets, is conveyed round the house in an open-topped metal duct. The feeder is controlled by a time clock so that animals can be fed at fixed times, even when the stockman is not available. This system allows equal access to feed by all the birds and is normally used for breeding birds in lay and for layers during rearing. Spin feeders distribute pellets over the floor of the house. These are only suitable for birds on restricted intake, such as **broiler breeder**s during rearing, to ensure maximum distribution in the minimum time. With pan feeders a central auger conveys feed into a number of suspended feeding dishes known as pans. These can be adjusted to hold a given quantity of feed to ensure that all the pans receive the same amount of feed. As the last pan empties, it triggers the drive mechanism to refill the pans. Pans are the preferred system for *ad libitum* feeding, as in broiler houses.

For pigs, the most usual system for *ad libitum* feeding is similar to pan feeders, having an overhead conveyor that replenishes self-feeders, which are hoppers in which the feed flows by gravity into a trough to which the pigs have continuous access. For restricted feeding, predetermined amounts of meal or pellets are released into troughs, or on to the floor of the pen. Liquid feeding systems are also easily automated for both *ad libitum* and restricted feeding. Electronic systems can be used to control the intake of loose-housed animals such as dry **sows**: each animal has an electronic tag which identifies it and triggers the release of a predetermined amount of food when the animal enters the feeding station, but also denies it access if it has already eaten all its allotted food.

A similar system is commonly used for dairy cows, which are fed a predetermined ration when they enter the milking stall. Calves may be automatically fed reconstituted milk powder in single or group pens. Fully automatic systems are less common for other farm animals, though self-feeding and controlled grazing are widely used for cattle and sheep, and many systems of feeding are mechanized. (KF; CJCP)

Availability

'Availability' and '**bioavailability**' are terms used to describe the percentage of a nutrient in a feed ingredient that is digested, absorbed and metabolically utilized so that it is available for growth, maintenance, reproduction or production (milk, eggs, work). 'Relative bioavailability' refers to how well a nutrient in a feed ingredient is used relative to a known standard. For example, a growth assay might be used to compare the utilization of threonine in **soybean** meal to that of threonine fed as pure L-threonine, which is completely available. This is commonly a slope ratio assay, which involves feeding at least three doses of L-threonine in the linear area of the growth response curve (usually between 40% and 70% of the requirement). A criterion of response such as weight gain or protein accretion is then related to supplemental threonine intake to generate a standard slope. Graded doses of soybean supplying similar amounts of threonine are also fed and again the response is related to threonine intake. The slope for soybean meal threonine is divided by the slope for standard L-threonine to provide an estimate of relative bioavailability. A similar procedure can be used with a single level of soybean meal. In this assay, the resulting weight gain is inserted into the regression for free threonine to give the bioavailable threonine intake. This value is then divided by the actual measured threonine intake to arrive at an estimate of relative bioavailability.

With **amino acid**s, relative availability determined by growth assay should be similar to **true digestibility** measured directly. However, growth assays do not work well for many nutrients, such as phosphorus, iron, manganese and **vitamin A**. For such nutrients, response criteria are needed that respond linearly to graded doses of the nutrient in question, such as bone ash, **haemoglobin**, bone manganese concentration and liver accumulation of vitamin A, respectively.

The term 'available' is used in a more restricted sense in connection with **lysine**, to describe the percentage of lysine in a feed ingredient that is not chemically conjugated in ways that make it unusable in **metabolism**. 'Available lysine' used in this sense does not include any measure of its **digestibility**.

(DHB)

See also: Nutrient bioavailability

Avidin

A natural glycoprotein found in egg white. It tightly binds **biotin** and has been shown to induce biotin deficiency in chicks and rats when fed raw. There are also anecdotal reports of avidin-induced biotin deficiency in other livestock. As avidin is easily denatured by heat, cooking or biotin, **supplementation** is recommended when animals are fed raw egg whites. (BLS)

Ayu (*Plecoglossus altivelis*)

Also known as 'sweet fish' or 'pond smelt', a member of the salmon family, native to East Asia. This anadromous **fish** spawns in **fresh water** and after a year it returns to the sea, where it feeds on benthic organisms such as diatoms and blue-green **algae**. Ayu are cultured in either freshwater or seawater ponds and their optimum **water temperature** range is 15–25°C. Larvae hatched in captivity require acclimation to **sea water** before being fed live food organisms such as **rotifers** and artemia. The average market size is 50–150 g. (SPL)