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)

Further reading

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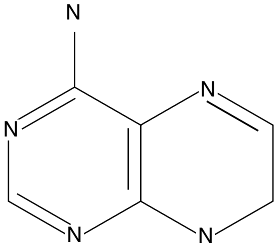
Adenine

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 (**triacylglycerols**) 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 acids**. 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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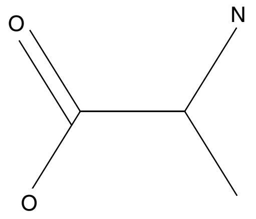
Alanine

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 ($\mu g\ kg^{-1}$)	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 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

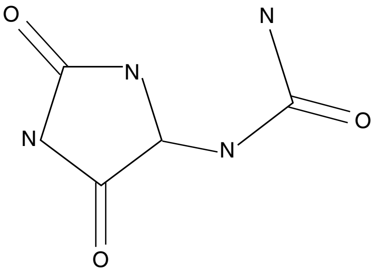
A pathological condition in which the arterial plasma pH rises above 7.4. The range of alkalosis that is compatible with life is 7.4–7.7. An example is metabolic alkalosis resulting from excessive loss of gastric acid during prolonged vomiting. This also involves considerable loss of potassium in the 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. Licensed under CC BY 2.0.

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 **tocopherols** and **tocotrienols**, 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 acids** 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 acid**s 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 **methylation**s. 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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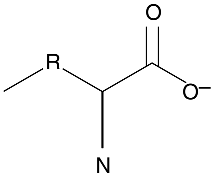
Amino nitrogen

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