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Essential amino acid

An **essential amino acid**, or **indispensable amino acid**, is an amino acid that cannot be synthesized from scratch by the organism fast enough to supply its demand, and must therefore come from the diet. Of the 21 amino acids common to all life forms, the nine amino acids humans cannot synthesize are phenylalanine, valine, threonine, tryptophan, methionine, leucine, isoleucine, lysine, and histidine.[1][2]

Six other amino acids are considered **conditionally essential** in the human diet, meaning their synthesis can be limited under special pathophysiological conditions, such as prematurity in the infant or individuals in severe catabolic distress.[2] These six are arginine, cysteine, glycine, glutamine, proline, and tyrosine. Six amino acids are non-essential (**dispensable**) in humans, meaning they can be synthesized in sufficient quantities in the body. These six are alanine, aspartic acid, asparagine, glutamic acid, serine,[2] and selenocysteine (considered the 21st amino acid). Pyrrolysine, which is proteinogenic only in certain microorganisms, is not used by and therefore non-essential for most organisms, including humans.

The **limiting amino acid** is the essential amino acid found in the smallest quantity in the foodstuff. This concept is important when calculating animal feeds.

Contents

Essentiality in humans

Essential	Conditionally essential[3][4]	Non-essential
Histidine (H)	Arginine (R)	Alanine (A)
Isoleucine (I)	Cysteine (C)	Aspartic acid (D)
Leucine (L)	Glutamine (Q)	Asparagine (N)
Lysine (K)	Glycine (G)	Glutamic acid (E)
Methionine (M)	Proline (P)	Serine (S)
Phenylalanine (F)	Tyrosine (Y)	Selenocysteine (U)
Threonine (T)		Pyrrolysine* (O)
Tryptophan (W)		
Valine (V)		

(*) Pyrrolysine, sometimes considered the "22nd amino acid", is not used by humans.[5]

Eukaryotes can synthesize some of the amino acids from other substrates. Consequently, only a subset of the amino acids used in protein synthesis are essential nutrients.

Recommended daily intake

Estimating the daily requirement for the indispensable amino acids has proven to be difficult; these numbers have undergone considerable revision over the last 20 years. The following table lists the WHO and United States recommended daily amounts currently in use for essential amino acids in **adult humans**, together with their standard one-letter abbreviations.[6][7]

Amino acid(s)	mg per kg body weight	
	WHO	USA
H Histidine	10	14
I Isoleucine	20	19
L Leucine	39	42
K Lysine	30	38
M Methionine + **C** Cysteine	10.4 + 4.1 (15 total)	19 total
F Phenylalanine + **Y** Tyrosine	25 (total)	33 total
T Threonine	15	20
W Tryptophan	4	5
V Valine	26	24

The recommended daily intakes for children aged three years and older is 10% to 20% higher than adult levels and those for infants can be as much as 150% higher in the first year of life. Cysteine (or sulfur-containing amino acids), tyrosine (or aromatic amino acids), and arginine are always required by infants and growing children.[6][8]

Relative amino acid composition of protein sources

Foodstuffs that lack essential amino acids are poor sources of protein equivalents, as the body tends to deaminate the amino acids obtained, converting proteins into fats and carbohydrates. Therefore, a balance of essential amino acids is necessary for a high degree of net protein utilization, which is the mass ratio of amino acids converted to proteins to amino acids supplied.[9]

Complete proteins contain a balanced set of essential amino acids for humans. Whole foods plant and natural animal sources provide all of the essential amino acids.[10] Near-complete proteins are also found in some plant sources such as quinoa.[11]

The net protein utilization is profoundly affected by the **limiting amino acid** content (the essential amino acid found in the smallest quantity in the foodstuff), and somewhat affected by salvage of essential amino acids in the body. It is therefore a good idea to mix foodstuffs that have different weaknesses in their essential amino acid distributions. This limits the loss of nitrogen through deamination and increases overall net protein utilization.[9]

Protein source	Limiting amino acid
Wheat	lysine
Rice	lysine
Maize	lysine and tryptophan
Legumes	methionine/cysteine pair and tryptophan
Egg, chicken, milk	none; egg is the reference for complete protein

The amino acid distribution profile is less optimal in plant foods than in animal foods.[12][13] but it is not necessary to consume plant foods containing complete proteins as long as a reasonably varied diet is maintained.[14] Numerous pairs of different plant foods can provide a complete protein profile. Certain traditional combinations of foods, such as corn and beans, or beans and rice, contain the essential amino acids necessary for humans in adequate amounts.[15] The official position of the Academy of Nutrition and Dietetics is that protein from an appropriate planned combination of a variety of plant foods eaten during the course of a day can be nutritionally adequate when caloric requirements are met.[14]

Protein quality

Various attempts have been made to express the "quality" or "value" of various kinds of protein. Measures include the biological value, net protein utilization, protein efficiency ratio, protein digestibility-corrected amino acid score and complete proteins concept. These concepts are important in the livestock industry, because the relative lack of one or more of the essential amino acids in animal feeds would have a limiting effect on growth and thus on feed conversion ratio. Thus, various feedstuffs may be fed in combination to increase net protein utilization, or a supplement of an individual amino acid (methionine, lysine, threonine, or tryptophan) can be added to the feed.

Protein per calorie

Protein content in foods is often measured in protein per serving rather than protein per calorie. For instance, the USDA lists 6 grams of protein per large whole egg (a 50-gram serving) rather than 84 mg of protein per calorie (71 calories total).[16] For comparison, there are 2.8 grams of protein in a serving of raw broccoli (100 grams) or 82 mg of protein per calorie (34 calories total), or the Daily Value of 47.67g of protein after eating 1,690g of raw broccoli a day at 574 cal.[17] An egg contains 12.5g of protein per 100g, but 4 mg more protein per calorie, or the protein DV after 381g of egg, which is 545 cal.[18] The ratio of essential amino acids (the quality of protein) is not taken into account, one would actually need to eat more than 3 kg of broccoli a day to have a healthy protein profile, and almost 6 kg to get enough calories.[17] It is recommended that adult humans obtain between 10–35% of their 2000 calories a day as protein.[19]

Complete proteins in non-human animals

Scientists had known since the early 20th century that rats could not survive on a diet whose only protein source was zein, which comes from maize (corn), but recovered if they were fed casein from cow's milk. This led William Cumming Rose to the discovery of the essential amino acid threonine.[20] Through manipulation of rodent diets, Rose was able to show that ten amino acids are essential for rats: lysine, tryptophan, histidine, phenylalanine, leucine, isoleucine, methionine, valine, and arginine, in addition to threonine. Rose's later work showed that eight amino acids are essential for adult human beings, with histidine also being essential for infants. Longer-term studies established histidine as also essential for adult humans.[21]

Interchangeability

The distinction between essential and non-essential amino acids is somewhat unclear, as some amino acids can be produced from others. The sulfur-containing amino acids, methionine and homocysteine, can be converted into each other but neither can be synthesized *de novo* in humans. Likewise, cysteine can be made from homocysteine but cannot be synthesized on its own. So, for convenience, sulfur-containing amino acids are sometimes considered a single pool of nutritionally equivalent amino acids as are the aromatic amino acid pair, phenylalanine and tyrosine. Likewise arginine, ornithine, and citrulline, which are interconvertible by the urea cycle, are considered a single group.

Effects of deficiency

If one of the essential amino acids is not available in the required quantities, protein synthesis will be inhibited, irrespective of the availability of the other amino acids.[2] Protein deficiency has been shown to affect all of the body's organs and many of its systems, for example affecting brain development in infants and young children; inhibiting upkeep of the immune system, increasing risk of infection; affecting gut mucosal function and permeability, thereby reducing absorption and increasing vulnerability to systemic disease; and impacting kidney function.[2] The physical signs of protein deficiency include edema, failure to thrive in infants and children, poor musculature, dull skin, and thin and fragile hair. Biochemical changes reflecting protein deficiency include low serum albumin and low serum transferrin.[2]

The amino acids that are essential in the human diet were established in a series of experiments led by William Cumming Rose. The experiments involved elemental diets to healthy male graduate students. These diets consisted of cornstarch, sucrose, butterfat without protein, corn oil, inorganic salts, the known vitamins, a large brown "candy" made of liver extract flavored with peppermint oil (to supply any unknown vitamins), and mixtures of highly purified individual amino acids. The main outcome measure was nitrogen balance. Rose noted that the symptoms of nervousness, exhaustion, and dizziness were encountered to a greater or lesser extent whenever human subjects were deprived of an essential amino acid.[22]

Essential amino acid deficiency should be distinguished from protein-energy malnutrition, which can manifest as marasmus or kwashiorkor. Kwashiorkor was once attributed to pure protein deficiency in individuals who were consuming enough calories ("sugar baby syndrome"). However, this theory has been challenged by the finding that there is no difference in the diets of children developing marasmus as opposed to kwashiorkor.[23] Still, for instance in Dietary Reference Intakes (DRI) maintained by the USDA, lack of one or more of the essential amino acids is described as protein-energy malnutrition.[2]

See also

- Biological Value (BV)
- Essential fatty acid
- Essential genes
- List of standard amino acids
- Low-protein diet
- Orthomolecular medicine
- Protein Digestibility Corrected Amino Acid Score
- Ketogenic amino acid
- Glucogenic amino acid

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External links

- Amino acid content of some vegetarian foods (http://www.veganhealth.org/articles/protein) at veganhealth.org.
- Amino Acid Profiles of Some Common Feeds (https://web.archive.org/web/20050319163510/http://www.dasc.vt.edu/extension/nutritioncc/9729.html) at Virginia Tech.
- Molecular Expressions: The Amino Acid Collection (http://micro.magnet.fsu.edu/aminoacids/index.html) at Florida State University. Features detailed information and crystal photographs of each amino acid.
- vProtein (https://web.archive.org/web/20120202075048/http://foodwiki.com/vprotein), an online software tool to analyze the essential amino acid profiles of single and pairs of plant based foods based on human requirements.