Protein quality

No. 2023/19A3e, The Hague, 13 December 2023

Background document to:
A healthy protein transition
No. 2023/19e, The Hague, 13 December 2023

Health Council of the Netherlands

Contents

1.1 Dietary reference values for protein and underlying principles

Proteins are made up of amino acids, of which nitrogen is an important component. Nitrogen balance studies are used to determine how much protein an average individual needs to consume per kilogram of body weight to maintain bodily functions (the average requirement). These studies measure nitrogen intake (in the diet) and nitrogen loss (largely in urine and faeces). They determine the level at which nitrogen intake is in balance with nitrogen loss.[1] They also generate information about the efficiency of the body in converting dietary protein into body protein. This efficiency factor, which is estimated at 47%,[2] is called the 'net protein utilisation' (NPU). The NPU is determined by the extent to which the body digests and absorbs protein (in other words: the extent to which consumed protein becomes biologically available) and the extent to which the protein in the diet of an individual supplies the amino acids that the body needs.[3] An NPU of 47% means that, on average, the body uses 47 grams of every 100 grams of consumed protein intake for protein synthesis. The NPU is used as a factor to estimate the amount of protein to be consumed to meet protein and amino acid requirements – in other words: to determine the dietary reference values for protein.[1]

Dietary reference values

There are various dietary reference values. The average requirement is the intake level that would meet the individual requirement of half of the population but not the other half of the population.
The average requirement is used to estimate whether the intake of a population is adequate. The individual requirements are not known, which is why also dietary reference values are derived that are considered sufficient for almost all individuals in the group in question (the 'population reference intake' or 'adequate intake').

The average protein requirement for adults has been set at 0.66 grams of protein per kilogram of body weight and the population reference intake at 0.83 grams of protein per kilogram of body weight. The dietary reference values for protein assume that the protein quality of a diet is 'good' or 'optimal'. [1]

Protein quality indicates the extent to which a particular food, meal or diet provides the essential amino acids the body needs. This depends on both the digestibility of the protein and the amino acid profile of the digested proteins. The Protein Digestibility-Corrected Amino Acid Score (PDCAAS) is often used to evaluate protein quality.
This method calculates protein digestibility (PD) and the amino acid profile (AAS).

A PDCAAS value of <100% means that at least one of the essential amino acids in an amino acid profile of a particular food, meal or diet is limiting.[4] However, a lower protein quality can be compensated by a higher protein intake, provided all essential amino acids are present. In other words: even products with a low protein quality can provide the amount of essential amino acids required if enough of the product in question is consumed. If the amount of essential amino acids is sufficient, the PDCAAS will have a value of 100% or more. The excess amino acids will not be used for the synthesis of body proteins, but as a source of energy.

A varied (omnivorous) diet usually provides a good protein quality.[5] Animal-based foods generally have a higher protein quality score than plant-based foods do.
NB: the protein quality of isolates and concentrates may be different from that of the products from which they are derived.[6]

In 2001, the Health Council of the Netherlands used the PDCAAS to calculate the conversion factors necessary to estimate the protein requirements of vegetarians and vegans. The population reference intake of protein was then adjusted (in other words: increased) for these dietary patterns.[7] The current advisory report by the Health Council of the Netherlands reevaluated the conversion factor for vegetarians. See Paragraph 1.5 of this background document for the findings on this subject.

1.2 Amino acid requirements and the reference pattern for amino acids

The reference pattern estimates the requirements for the essential amino acids. It does this based on the amino acid composition required to maintain body tissue and, for children up to the age of 18, for growth as well. In every age group the same amino acid pattern is used to estimate amino acid needs for body maintenance and age-specific additional needs for growth are added where appropriate. The reference pattern is determined by dividing the age-dependent requirement for individual essential amino acids by the age-dependent protein requirement (average requirement). Different reference patterns apply per age category (see the copy of Table 3 from the 2013 FAO report).[3,8] The reference pattern is used to calculate protein quality.[3,4]

Although experts have asked for attention to be given to the quality of the reference pattern data and are of the view that the requirement for (certain) essential amino acids could actually be higher (see references [9,10,11], for example), international calculations have been based on the 2013 FAO reference patterns for the time being.[4]
The FAO advises using the reference pattern for 3–10-year-olds to calculate the protein quality score for everyone from the age of three onwards. Separate reference

pattern are advised for infants and younger children (see the copy of Table 5 from the 2013 FAO report).[3,4] A detailed description of the background of the reference patterns is given in a publication by Millward.[8] The PDCAAS calculations used in the current advice of the Health Council of the Netherlands are based on the reference pattern for 3–10-year-olds, as advised.

The amino acid present in the lowest concentration in relation to the amino-acid requirement (based on the reference pattern) in an individual food, or a combination of foods (meal or diet), is known as the ‘limiting amino acid’.[4] For example, lysine is generally the limiting amino acid in grain products, while the limiting amino acids in legumes are generally sulfur-containing amino acids (methionine and/or cysteine).

In their 2013 report, the experts consulted by the FAO also asked for attention to be given to the availability of lysine, which can change when products are prepared. Because lysine is often a limiting amino acid,[4,12] it is important to follow developments in this field to be able to estimate the extent to which they have consequences for protein quality calculations.

TABLE 3.
Amino acid scoring patterns for toddlers, children, adolescents and adults (amended values from the 2007 WHO/FAO/UNU report)

			His	Ile	Leu	Lys	SAA	AAA	Thr	Trp	Val
Tissue amino acid pattern (mg/g protein)[1]			27	35	75	73	35	73	42	12	49
Maintenance amino acid pattern (mg/g protein)[2]			15	30	59	45	22	38	23	6	39
	Protein requirements (g/kg/d)										
Age (yr)	**Maintenance**	**Growth[3]**	*amino acid requirements (mg/kg/d)[4]*								
0.5	0.66	0.46	22	36	73	63	31	59	35	9.5	48
1-2	0.66	0.20	15	27	54	44	22	40	24	6	36
3-10	0.66	0.07	12	22	44	35	17	30	18	4.8	29
11-14	0.66	0.07	12	22	44	35	17	30	18	4.8	29
15-18	0.66	0.04	11	21	42	33	16	28	17	4.4	28
>18	0.66	0.00	10	20	39	30	15	25	15	4.0	26
			scoring pattern mg/g protein requirement[5]								
0.5			20	32	66	57	27	52	31	8.5	43
1-2			18	31	63	52	25	46	27	7	41
3-10			16	30	61	48	23	41	25	6.6	40
11-14			16	30	61	48	23	41	25	6.6	40
15-18			16	30	60	47	23	40	24	6.3	40
>18			15	30	59	45	22	38	23	6.0	39

His, histidine; Ile, isoleucine; Leu, leucine; SAA, sulphur amino acids; AAA, aromatic amino acids, Thr, threonine, Trp, tryptophan; Val, valine

1 Amino acid composition of whole-body protein.

2 Adult maintenance pattern.

3 Calculated as average values for the age range: growth adjusted for protein utilization of 58%.

4 Sum of amino acids contained in the dietary requirement for maintenance (maintenance protein x the adult scoring pattern) and growth (tissue deposition adjusted for a 58% dietary efficiency of utilization x the tissue pattern).

5 Amino acid requirements/protein requirements for the selected age groups. Note that these values, some of which are slightly amended from the 2007 report, are the correctly calculated values. In the published report, the value for the SAA requirement for children aged 3-10 is incorrect (18mg/kg/d) as are the SAA patterns for infants preschool and school children up to 10, (28, 26 and 24 mg/g protein).

Table 5.
Recommended amino acid scoring patterns for infants, children and older children, adolescents and adults

Age Group	His	Ile	Leu	Lys	SAA	AAA	Thr	Trp	Val
	scoring pattern mg/g protein requirement								
Infant (birth to 6 months)[1]	21	55	96	69	33	94	44	17	55
Child (6 months to 3 year)[2]	20	32	66	57	27	52	31	8.5	43
Older child, adolescent, adult[3]	16	30	61	48	23	41	25	6.6	40

[1] Infant is based on the gross amino acid content of human milk from Table 4.
[2] Child group is from the 6 month (0.5 y) values from Table 3.
[3] Older child, adolescent, adult group is from the 3-10 y values from Table 3.

1.3 PDCAAS and DIAAS

1.3.1 Differences and similarities

The PDCAAS and Digestible Indispensable Amino Acid Score (DIAAS) methods consist of the following three components:
1) Digestibility;
2) Levels of essential amino acids per gram of protein from the food source;
3) The requirements for amino acids, as determined in the reference pattern.
The scores indicate the extent to which the amino acid pattern, after digestion and absorption, corresponds with the reference pattern of amino acids.

However, there are also important differences between the DIAAS and the PDCAAS methods. As indicated in text box 1, the difference between the two methods depends very much on the methods used to establish the amino acids available in a food, meal or diet:[4]

Text box 1 Factors in the calculation of protein quality with PDCAAS and DIAAS.

Digestibility: large intestine versus small intestine	The PDCAAS method calculates protein quality on the basis of faecal digestibility at the end of the large intestine. However, there is little to no amino-acid absorption in the large intestine,[13] and intestinal flora can strongly influence the composition of the amino acid pattern in the faeces. The DIAAS method is based on measurements of the digestibility of amino acids at the end of the small intestine, which is also referred to as 'ileal digestibility'.[14] A number of uncertainties exist about digestibility data in general, such as how food preparation and the combination of foods affect digestibility.
Digestibility: whole protein versus individual amino acids	The PDCAAS is being calculated on the basis of the digestibility of the whole protein, whereas the DIAAS is based on the digestibility of the individual amino acids in the protein. The digestibility of individual amino acids can vary, also depending on their protein source. As such, it is more accurate to calculate protein quality on the basis of the digestibility of the individual amino acids in a protein source.[14-16]
Truncate to 100%: yes versus no	In both the DIAAS and PDCAAS methods, values below 100% indicate the presence of at least one limiting amino acid. In other words: the amino acid requirement in question is not met. The PDCAAS value of a food is truncated at a maximum of 100%. For a combination of foods (a meal or diet, for example), this is done after the PDCAAS has been calculated for the combination of foods. The basic principle here is that the amino acids that are not necessary (at that time) will be used as a source of energy and, as such, not to synthesise proteins. To make it possible to rank foods that score more than 100% properly, the DIAAS of foods is not truncated. However, like the PDCAAS, the DIAAS of a diet is truncated at 100%.

The two methods have been compared in various studies in recent years. Although only a limited number of foods have been studied, it would seem that the protein quality of plant-based foods or diets is (slightly) higher when using the PDCAAS method than the DIAAS method.

Several articles in which this comparison is made are listed below:[14,17,18]

- Based on a study of rats and using 14 protein sources, Rutherfurd et al. (2015)[14] concluded that (untruncated) PDCAAS values were generally higher than DIAAS values, especially for proteins with lower protein quality.
- Mathai et al (2017)[17] examined the untruncated PDCAAS values[a] in nine growing, castrated pigs and compared them with DIAAS values for eight protein sources. Their calculations were based on the amino acid reference values for children between the ages of six months and three years.[4] One limitation that the researchers identified is the fact that the protein sources were given to the pigs in unprocessed form (with impairs the generalizability to the human situation). The researchers concluded that the PDCAAS overestimates protein quality, particularly for proteins with lower protein quality, because of which the DIAAS should be used. Older age groups were disregarded (as the human target group was 3–10 years old).
- Abelilla et al. (2018)[18] studied the protein quality of oats in 10 growing, castrated pigs in the three age groups that the FAO defined in 2013.[4] Abelilla et al. found no major differences between the PDCAAS and the DIAAS, but the DIAAS values were slightly lower than the PDCAAS values, which corresponds with the findings of Rutherfurd et al.[14] and Mathai et al.[17]

1.3.2 DIAAS calculations advised by the FAO

In 2013, an FAO expert group advised that the DIAAS method be used to calculate protein quality instead of the PDCAAS method that had been used previously.
An example DIAAS calculation is shown in a copy of Table 2 from the 2013 FAO report.[4]

[a] The PDCAAS assumes the digestibility of proteins and amino acids as measured in a study on rats. However, Mathai et al. (2017) use a study on pigs to estimate digestibility. Although not stated explicitly by the researchers, the Committee believes this explains why Mathai et al. (2017) use the term ‘PDCAAS-like values’ rather than ‘PDCAAS values’.

TABLE 2.
Calculation of DIAAS value for a mixture of wheat, peas and whole milk powder

	Composition[1]						True ileal IAA Digestibility[1]					True ileal digestible IAA content in mixture[2]				
	Weight	Protein	Lys	SAA	Thr	Trp	Lys	SAA	Thr	Trp	Protein content in mixture	Lys	SAA[5]	Thr	Trp	
	(g)	(g/100g)	(mg/g protein)								(g)	(mg)				
	A	B	C	D	E	F	G	H	I	J	AxB	(AxB)xCxG	(AxB)xDxH	(AxB)xExI	(AxB) xFxJ	
Wheat	400	11	28	38	29	12	0.82	0.895	0.86	0.91	44	1 010	1488	1 097	480	
Pea	100	21	71	25	37	9	0.79	0.69	0.73	0.66	21	1 178	362	567	125	
Milk powder	35	28	78	35	44	13	0.95	0.94	0.90	0.90	10	726	322	388	115	
Totals	535										75	2 914	2 172	2052	720	
Amino acids: mg/g protein (total for each amino acid/total protein)												38.9	29.0	27.4	9.6	
Age group			**Reference pattern: mg/g protein (Refer to Table 5 in this report)**									**[3]Digestible IAA reference ratio**				**[4]DIAAS for mixture (%)**
			Lys	SAA	Thr	Trp						Lys	SAA	Thr	Trp	
Infant (birth to 6 moths)			69	33	44	17						0.56	0.88	0.62	0.56	**56 (Lys)**
Child (6 months to 3 yrs)			57	27	31	8.5						0.68	1.08	0.88	1.13	**68 (Lys)**
Older child, adolescent, adult			48	23	25	6.6						0.82	1.26	1.10	1.45	**82 (Lys)**

[1] Reference: CVB Feed Tables (2007). Chemical compositions and nutritional values of feed ingredients. Product Board Animal Feed, CVB, The Hague. True ileal indispensable amino acid (IAA) digestibility coefficients are based on the predicted human values obtained from pig data.

[2] For the sake of example, calculation is shown for four amino acids; where possible all IAA should be included in the calculation.

[3] Digestible IAA reference ratio (Digestible IAA in 1 g protein of mixed diet /mg of the same dietary indispensable amino acid in 1g of the reference protein)

[4] DIAAS for mixed diet (Lowest value of the "digestible IAA reference ratio" expressed as % for each reference pattern; for infants the mixed food has a calculated DIAAS of 56; for children 68 and for older children, adolescents and adults 82; NB: In this case as this is a mixed diet if the calculated DIAAS exceeded 100%, it would be truncated to 100%).

[5] These are the weighted average of the digestibility coefficients for methionine and cysteine.

Lys=lysine, SAA=sulphur amino acids (methionine + cysteine), Thr = threonine, Trp = tryptophan.

Despite this advice from the expert group, ileal digestibility data for individual amino acids – which are required for DIAAS calculations – were not yet available or only to a limited extent. For this reason, the report proposed using the faecal digestibility of *amino acids* or, if these data were not available (either), using the faecal digestibility of the *protein* as a whole.[4] The latter is actually similar to the (untruncated) PDCAAS. This means that the PDCAAS method is still often used in practice, or its use is still advised.[19] Although efforts are being made internationally to generate and collect ileal digestibility data for individual amino acids, access to these data at the time of this advisory process was still insufficient to calculate protein quality for the Dutch diet based on the DIAAS. This is why the Protein Transition Committee ('the Committee') used the PDCAAS method to calculate the protein quality of different combinations of products later in this background document. To this end, the Committee used the calculation from Table 2 in the 2013 FAO report, which includes the faecal digestibility of the protein as a whole instead of the ileal digestibility of individual amino acids.

Protein quality score

The possibility to define cut-off points for DIAAS values – that indicate whether a product is a source of good or high protein quality, for example – is the subject of international scientific debate. The expert report (2013) gives examples of possible cut-off points that could form the basis for food claims: 'high or excellent quality' at a value of 100 or more, 'good quality or source of quality protein' at a value between 75 and 99 and no claim at a value below 75.[4] Another expert group (FAO 2018)[19] concluded that a PDCAAS value of 90 can be regarded as adequate for follow-on formula and therapeutic foods for young children in the context of malnutrition and catch-up growth.

1.4 Methodological caveats regarding protein quality calculations

In Paragraph 1.5, the Committee compares the PDCAAS for a number of food combinations in line with various protein transition scenarios. The combinations in the protein quality calculations do not necessarily represent meal examples.

This paragraph summarises the methodological caveats regarding the sample calculations.

Reference pattern of amino acids. This reference pattern of amino acids is a main determinant of the PDCAAS value. As advised by the FAO, the Committee used the reference pattern for children (aged 3–10). The amino acid requirements of a number of population groups – the elderly, pregnant women, breastfeeding women and people who are ill, for example – are the subject of academic debate. If these requirements deviate (significantly) from the current reference pattern, this could lead to higher or lower protein quality values.

Nitrogen balance. The calculations of the Committee are based on the total nitrogen intake corresponding to the recommended amount of protein (0.83 g/kg of body weight/day). A PDCAAS value of <100% in the event of a protein intake above the recommended amount is not usually problematic for the amino acid requirement, depending on how much higher the protein intake is. A low protein quality of a food, meal or diet can almost always be compensated by a higher intake (of protein).

Timing of the protein intake. The term 'protein requirement' refers to the protein required per whole day.[1] Where limiting amino acids are concerned, protein sources can supplement each other. Scientific debate is ongoing about the period of time within which protein sources should be consumed together in order to supplement each other's limiting amino acids.[20] [21,22]

Functionality of proteins and amino acids. Protein quality expressed in a PDCAAS or DIAAS is based on digestibility and the amino acid profile in relation to the reference pattern applicable in the event of normal health. This score indicates the availability of amino acids (and nitrogen) to the body, but not the functional use of the nutrients after digestion. Proteins are involved in countless processes. Little data are available as yet about the role that nutrition plays in meeting requirements in respect of different biological functions of body protein. It follows that various amino acid profiles could be conceived for different body protein functions. Added to this, the human body is able to adapt, also to a situation with less protein.[23] Relatively little is currently known about this either.

1.5 Examples of protein-quality calculations and conversion factors for recommended amounts of protein

In 2001, the Committee that was advising on dietary reference values for protein at the time calculated conversion factors to increase the recommended amount of protein for people who consumed a vegetarian or vegan diet. These conversion factors indicate the extent to which the assumed lower protein quality can be compensated by a higher protein quantity. The recommended amounts of protein were increased for all vegetarians and vegans by dividing it by the PDCAAS for the diets in question.[7]

In light of the protein transition, the Committee is reviewing the conversion factor for vegetarians. Compared to 2001, the current calculations involve more combinations of protein sources and newer data on the digestibility of dietary proteins and their amino acid composition. Text box 2 compares the calculation method used in the 2001 advisory report with the calculation method used in the current advisory report.

Because the vegan diet is a fully plant-based diet and very different to the subject of the current request for advice, no new calculations were made for the vegan diet in this advisory process.

Text box 2 Comparison of the calculations of the PDCAAS and conversion factors (2001) and the PDCAAS (2023)

	Calculations of the PDCAAS and conversion factors (1/PDCAAS) in the 2001 advisory report	**Calculations of the PDCAAS in the current advisory report (2023)**
Ratio of animal-based to plant-based protein	The conversion factors for vegetarians were based on a ratio of 50% animal-based protein and 50% plant-based protein. However, the food consumption surveys for 2012–2016 and 2019–2021 show that the diet of the average vegetarian currently consists of approximately 40% animal-based protein and 60% plant-based protein.[24,25]	The conversion factor for vegetarians was calculated on the basis of the current ratio for a vegetarian diet according to the food consumption survey (40% animal-based:60% plant-based).
Number of protein sources	In 2001, the PDCAAS calculations were based on four protein sources: beef, milk, wheat and soy. Calculations for an omnivorous diet were based on a combination of beef, milk and wheat. Calculations for a vegetarian and vegan diet were based on milk and wheat, and wheat and soy respectively.	This time, the Committee used 14 different protein sources to create combinations of foods.
Reference pattern, data on the digestibility of proteins and their amino acid composition	The FAO/WHO 1991 reference pattern was used.[26] Older sources were used as well, for information on digestibility and amino acid composition.	The FAO adjusted the reference pattern for amino acids in its 2013 report. Amongst other things, the requirement for lysine was adjusted downwards.[4] In addition, new data were added on the amino acid composition and digestibility of foods (see Paragraph 1.6).

	Calculations of the PDCAAS and conversion factors (1/PDCAAS) in the 2001 advisory report	Calculations of the PDCAAS in the current advisory report (2023)
Calculation of the available amino acids	The amino acids available from a mix of foods were calculated by multiplying the amino acid composition of a product in the mix of foods by the weighted average of *the digestibility of the mix of foods*.[26]	The amino acids available from a mix of foods were calculated by multiplying the amino acid composition of a product by *the digestibility of the product in question* and then calculating a weighted average of the mix.[4]

The tables in this paragraph show the PDCAAS values of different combinations of protein sources. In line with the DIAAS method, the Committee did not truncate values to 100%. When interpreting the calculations, the Committee assumed that the total amount of protein consumed was equal to the recommended amount (0.83 g/kg of body weight for adults). If the protein quality expressed in a PDCAAS value is 100 or more, this means that the sample combination meets the protein and amino acid requirements.

Although the presented combinations do not necessarily simulate the protein intake per meal, the Committee has attempted to create recognisable combinations of protein sources for the Dutch diet, according to the sections of food groups within the Wheel of Five.[27,28] NB: vegetables and fruit were omitted because they provide virtually no protein.

- The **animal-based component** always consists of one of the following products from the Wheel of Five's 'fish, legumes, meat, egg, nuts and dairy'-section: red meat (NEVO code 1540), white meat (NEVO code 1392), fish (NEVO code 919), dairy (NEVO code 286) or eggs (NEVO code 84).
- A **plant-based component** is added from the Wheel of Five's 'bread, grain products and potatoes'-section: bread (NEVO code 246), pasta (NEVO code 2157), rice (NEVO code 1014) or potatoes (NEVO code 982).
- Where the Committee combined three sources, it added an **extra plant-based component** to the combinations above from the 'fish, legumes, meat, egg, nuts and dairy'-section: nuts (NEVO code 207), soy milk (NEVO code 870), vegetarian schnitzel (NEVO code 1512) or legumes (NEVO code 969). Alternatively, it added mushrooms (NEVO code 20) or an extra grain product, namely bread (NEVO code 246). The Committee sees these as products that consumers choose instead of animal-based protein sources to a greater or lesser extent.

A different ratio of animal-based and plant-based protein is shown per table. In the tables, PDCAAS values equal to or above 100% are shown in green. The light-green highlights show values between 90%–100%, while the light-orange highlights show values between 80%–90%.

Table 1 shows examples of PDCAAS values for an omnivorous (1a) and vegetarian (1b) diet with 60% animal-based protein and 40% plant-based protein. This was the ratio applicable for people with an omnivorous diet in the Food Consumption Survey 2012–2016.[24] The table shows that a PDCAAS value of <100% does not apply in any sample situation if animal-based and plant-based proteins are combined in this ratio. In line with the request for advice, Tables 2a and 2b and Tables 3a and 3b show the PDCAAS with a ratio of animal-based to plant-based protein of 40:60. The same ratio applies for the ratio of animal-based to plant-based protein for an average vegetarian diet in the Food Consumption Survey 2012–2016. Simply adjusting the ratio of animal-based to plant-based protein (to 40:60), as shown in Tables 2a and 2b, results in lower PDCAAS values. However, the PDCAAS remains above 90%, and often above 100%, when using whole wheat pasta, brown rice or wholegrain bread as a plant-based component. When potatoes are used as a plant-based component, a value of at least 85% was observed. Combinations with whole wheat pasta and potatoes show the lowest PDCAAS values in Tables 2a and 2b.
For Tables 3a and 3b, an extra plant-based source was added to these combinations (both plant-based sources each supply 30% of the average protein requirement in these examples) to see whether this improves the protein quality. In many cases, the addition of an extra plant-based protein source increases the protein quality of the combination of products. It is then often possible to achieve a PDCAAS value of above 90%–100%. However, results vary depending on the combinations chosen. For some sample combinations, the PDCAAS value ranges between 80%–90%.

It is important to note that the ratios of animal-based to plant-based proteins refer to the amount of dietary *protein,* not the amount of *food*. Plant-based foods generally contain less protein per 100 grams than animal-based foods.[28] In other words: more plant-based foods will usually need to be consumed than animal-based foods to achieve the same protein intake. The ratio of animal-based to plant-based *protein* is not the same as the corresponding ratio in grams of *foods*. Table 4 shows several examples of this. The calculations in tabel 4 were based on the recommended amount of protein in grams/day for an adult Dutch female, which is 54 grams/day.[1]

Table 1a Combinations of 40% plant-based protein (source 1) and 60% animal-based protein (source 2), based on two sources (omnivorous diet)

Source 1:	Source 2: Red meat	Source 2: White meat	Source 2: Fish
Wholegrain bread	118	126	130
Whole wheat pasta	116	125	129
Brown rice	120	122	132
Potatoes	100	101	124

Table 1b Combinations of 40% plant-based protein (source 1) and 60% animal-based protein (source 2), based on two sources (vegetarian diet)

Source 1:	Source 2: Milk	Source 2: Eggs
Wholegrain bread	126	115
Whole wheat pasta	124	113
Brown rice	124	117
Potatoes	103	122

Table 2a Combinations of 60% plant-based protein (source 1) and 40% animal-based protein (source 2), based on two sources (omnivorous diet)

Source 1:	Source 2: Red meat	Source 2: White meat	Source 2: Fish
Wholegrain bread	94	100	103
Whole wheat pasta	92	98	101
Brown rice	98	103	106
Potatoes	85	85	101

Table 2b Combinations of 40% plant-based protein (source 1) and 60% animal-based protein (source 2), based on two sources (vegetarian diet)

Source 1:	Source 2: Milk	Source 2: Eggs
Wholegrain bread	100	92
Whole wheat pasta	98	91
Brown rice	103	96
Potatoes	87	104

Table 3a Combinations of 60% plant-based protein (source 1 and source 2) and 40% animal-based protein (source 3), based on three sources (omnivorous diet)

Source 1 and source 2:	Source 3: Red meat	Source 3: White meat	Source 3: Fish
Wholegrain bread and whole wheat pasta	93	99	102
Wholegrain bread and potatoes	100	106	108
Legumes and whole wheat pasta	111	116	119
Legumes and potatoes	95	96	111
Mushrooms and whole wheat pasta	100	102	108
Mushrooms and potatoes	81	82	97
Nuts and whole wheat pasta	98	104	106
Nuts and potatoes	101	101	113
Soy milk and whole wheat pasta	120	124	129
Soy milk and potatoes	103	104	119

Table 3b Combinations of 60% plant-based protein (source 1 and source 2) and 40% animal-based protein (source 3), based on three sources (vegetarian diet)

Source 1 and source 2:	Source 3: Milk	Source 3: Eggs
Wholegrain bread and whole wheat pasta	99	92
Wholegrain bread and potatoes	106	98
Legumes and whole wheat pasta	117	109
Legumes and potatoes	97	116
Mushrooms and whole wheat pasta	105	98
Mushrooms and potatoes	83	105
Nuts and whole wheat pasta	104	96
Nuts and potatoes	103	103
Soy schnitzel and whole wheat pasta	119	112
Soy schnitzel and potatoes	115	119
Soy milk and whole wheat pasta	126	118
Soy milk and potatoes	105	125

Table 4 Examples of ratios and amounts of food for different ratios between animal and plant-based protein, based on a recommended amount of protein for adult women (54 grams/day) based on two or three protein sources

Foods	Ratio of animal-based to plant-based protein	Ratio of animal-based to plant-based product
White meat and wholegrain bread	60:40 (32.4 g and 21.6 g)	35:65 (105 g and 195 g[a])
Fish and wholegrain bread	60:40 (32.4 g and 21.6 g)	40:60 (130g and 195 g[a])
Milk and wholegrain bread	60:40 (32.4 g and 21.6 g)	83:17 (952 ml and 195 g[a])
White meat and wholegrain bread	40:60 (21.6 g and 32.4 g)	19:81 (70 g and 298 g[a])
Fish and wholegrain bread	40:60 (21.6 g and 32.4 g)	23:77 (87 g and 298 g[a])
Milk and wholegrain bread	40:60 (21.6 g and 32.4 g)	68:32 (635 ml and 298 g[a])
White meat and whole wheat pasta and legumes	40:60 (21.6 g and 2x16.2 g)	12:88 (70 g and 289 g and 203 g)

[a] One slice of wholegrain bread = 35 grams → 195 grams of wholegrain bread equates to approximately 5.5 slices of bread; 298 grams equates to approximately 8.5 slices of bread.

1.6 Amino acid composition and digestibity used in the calculations

The table below shows the protein content, the content of four essential amino acids from the reference pattern and the digestibility value for the products used in the Committee’s calculations. The four amino acids here are the same ones that were used in the calculations in the 2013 FAO report. Wageningen University & Research's Division of Human Nutrition and Health (contact person: Ms K. Borgonjen van den Berg, dietetiek@wur.nl) made the amino acid data available for the purpose of this advisory process. The Dutch Food Composition Table (*Nederlandse voedingsstoffenbestand*, NEVO) does not contain information about amino acids.

Table 5 Protein content, amino acids and digestibility

Product description	NEVO code	Digestibility (%)[29]	Protein content (g/100 g product)	Lysine (mg/100 g product)	Sulfur-containing amino acids (methionine + cysteine) (mg/100 g product)	Threonine (mg/100 g product)	Tryptophan (mg/100 g product)
Mushrooms, boiled	20	65	3.8	193.8	57	159.6	62.7
Eggs, chicken – boiled, avg.	84	97	12.3	969.47	689.77	590.99	173.35
Nuts, mixed, unsalted	207	75	21.4	875.72	709.48	701.34	342.6
Bread, wholegrain – avg. of fine and coarse	246	90	11.1	283.79	465.74	338.72	147.62
Milk, semi-skimmed	286	95	3.4	305.03	111.72	144.74	45.66
Drink, soy, plain	870	94	3.4	239.1	96.51	144.77	48.26
Pollock (Atlantic), boiled	919	90	25.0	2,460	1,090	1,180	370
Marrowfat peas, boiled	969	75	8.0	549.02	217.64	307.06	63.92
Potatoes, peeled, boiled, avg.	982	55	1.9	111.15	42.75	64.6	29.45
Rice, brown, boiled	1014	70	3.1	114.7	109.53	104.37	43.74
Chicken fillet, prepared	1392	95	30.9	2,775	988.5	1,236	321
Schnitzel, vegetarian, unprepared	1512	94	15.2	905.5	554.52	580.77	200.01
Minced beef, fried	1540	92	30.4	2,601.67	992.6	1,324.87	319.55
Whole wheat pasta, boiled	2157	70	5.6	171.7	224	177.51	78.72

References

1 Health Council of the Netherlands. *Dietary reference values for protein*. The Hague, 2021; publication no. 2021/10e.

2 Rand WM, Pellett PL, Young VR. *Meta-analysis of nitrogen balance studies for estimating protein requirements in healthy adults*. Am J Clin Nutr 2003; 77(1): 109-127.

3 World Health Organization. *Protein and amino acid requirements in human nutrition. Report of a Joint WHO/FAO/UNU Expert Consultation*. Geneva, Switzerland, 2007.

4 FAO. *Dietary protein quality evaluation in human nutrition. Report of an FAO Expert Consultation*. Rome: FAO, 2013; ISSN 0254-4725.

5 Gardner CD, Hartle JC, Garrett RD, Offringa LC, Wasserman AS. *Maximizing the intersection of human health and the health of the environment with regard to the amount and type of protein produced and consumed in the United States*. Nutr Rev 2019; 77(4): 197-215.

6 Gorissen SHM, Crombag JJR, Senden JMG, Waterval WAH, Bierau J, Verdijk LB, et al. *Protein content and amino acid composition of commercially available plant-based protein isolates*. Amino Acids 2018; 50(12): 1685-1695.

7 Gezondheidsraad. *Voedingsnormen - energie, eiwitten, vetten en verteerbare koolhydraten*. Den Haag, 2001; publicatienr. 2001/19.

8 Millward DJ. *Amino acid scoring patterns for protein quality assessment*. Br J Nutr 2012; 108 Suppl 2: S31-43.

9 Wolfe RR, Rutherfurd SM, Kim IY, Moughan PJ. *Protein quality as determined by the Digestible Indispensable Amino Acid Score: evaluation of factors underlying the calculation*. Nutr Rev 2016; 74(9): 584-599.

10 Elango R, Ball RO. *Protein and Amino Acid Requirements during Pregnancy*. Adv Nutr 2016; 7(4): 839s-844s.

11 Paoletti A, Pencharz PB, Ball RO, Kong D, Xu L, Elango R, et al. *The dietary requirement for total sulfur amino acids in adults aged ≥60 years appears to be higher in males than in females*. Am J Clin Nutr 2023; 118(3): 538-548.

12 Hodgkinson SM, Stroebinger N, Montoya CA, Moughan PJ. *Available lysine in foods as determined in adult ileostomates*. J Nutr 2023; 153(2): 505-510.

13 van der Wielen N, Moughan PJ, Mensink M. *Amino acid absorption in the large intestine of humans and porcine models*. Journal of Nutrition 2017; 147(8): 1493-1498.

14 Rutherfurd SM, Fanning AC, Miller BJ, Moughan PJ. *Protein digestibility-corrected amino acid scores and digestible indispensable amino acid scores differentially describe protein quality in growing male rats*. J Nutr 2015; 145(2): 372-379.

15 Schaafsma G. *The protein digestibility-corrected amino acid score*. J Nutr 2000; 130(7): 1865S-1867S.

16 Schaafsma G. *The Protein Digestibility-Corrected Amino Acid Score (PDCAAS)--a concept for describing protein quality in foods and food ingredients: a critical review*. J AOAC Int 2005; 88(3): 988-994.

17 Mathai JK, Liu Y, Stein HH. *Values for digestible indispensable amino acid scores (DIAAS) for some dairy and plant proteins may better describe protein quality than values calculated using the concept for protein digestibility-corrected amino acid scores (PDCAAS)*. Br J Nutr 2017; 117(4): 490-499.

18 Abelilla JJ, Liu Y, Stein HH. *Digestible indispensable amino acid score (DIAAS) and protein digestibility corrected amino acid score (PDCAAS) in oat protein concentrate measured in 20- to 30-kilogram pigs*. J Sci Food Agric 2018; 98(1): 410-414.

19 FAO. *Protein quality assessment in follow-up formula for young children and ready to use therapeutic foods*. Rome: FAO, 2018.

20 Adhikari S, Schop M, de Boer IJM, Huppertz T. *Protein quality in perspective: a review of protein quality metrics and their applications*. Nutrients 2022; 14(5): 947.

21 Young VR, Pellett PL. *Plant proteins in relation to human protein and amino acid nutrition*. Am J Clin Nutr 1994; 59(5 Suppl): 1203S-1212S.

22 Melina V, Craig W, Levin S. *Position of the Academy of Nutrition and Dietetics: Vegetarian Diets*. J Acad Nutr Diet 2016; 116(12): 1970-1980.

23 Millward DJ. *An adaptive metabolic demand model for protein and amino acid requirements*. Br J Nutr 2003; 90(2): 249-260.

24 van Rossum CTM, Buurma-Rethans E, Dinnissen CS, Beukers MH, Brants HAM, Dekkers ALM, et al. National Institute for Public Health and the Environment. *The diet of the Dutch. Results of the Dutch National Food Consumption Survey 2012-2016*. Bilthoven, 2020.

25 National Institute for Public Health and the Environment. *Memo analyses VCP 2019-2021 t.b.v. GR-advies Eiwittransitie*. Bilthoven: RIVM, 2023.

26 FAO/WHO. *Protein quality evaluation*. Rome: FAO, 1991.

27 Voedingscentrum. *Richtlijnen Schijf van Vijf 2016*. Den Haag: Voedingscentrum, Februari 2020; 6e druk.

28 *Nederlands Voedingsstoffenbestand (NEVO)*. Rijksinstituut voor Volksgezondheid en Milieu: https://www.rivm.nl/nederlands-voedingsstoffenbestand.

29 Heerschop SN, Kanellopoulos A, Biesbroek S, van 't Veer P. *Shifting towards optimized healthy and sustainable Dutch diets: impact on protein quality*. Eur J Nutr 2023; 62(5): 2115-2128.

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