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Legumes in human nutrition

Nutrient content and protein quality of pulses

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Continuation from Ernährungs Umschau issue 9/2017

Fatty acid distribution

The levels of the most important fatty acids are listed in ◆ Table 4 and 5 in g/100 g, and as a percentage of fat (ether extract or g of fatty acid methyl ester per 100 g of the sum of the fatty acid methylesters). Peas and faba beans provide almost no fats. Soybeans are a good source of linoleic acid, the most common n-6 fatty acid followed by oleic acid. However, the level of the n-3 fatty acid α-linolenic acid (ALA) is also high, which puts soybean oil in the category of fats with medium ALA content, along with oils such as rapeseed oil and walnut oil. However, unlike rapeseed oil, the ratio of linoleic acid to α-linolenic acid is not the recommended ratio for the overall diet of 5:1 [13]. In order to balance out the fats from the rest of the diet (cereals, foods of animal origin), vegetable oils should ideally have a ratio even better than 5:1. Lupine oil has such a ratio, although its absolute ALA content is rather low.
In terms of fatty acids, there are more significant differences between blue, white, and yellow lupines, so these are each shown separately in ◆ Tables 4 and 5 (according to [7]). The fat in blue lupines has higher levels of saturated fatty acids than the other two species, but the ALA level is relatively low. White lupines are richer in oleic acid, but they have less linoleic acid. Yellow lupines have particularly high levels of linoleic acid.

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Protein quality

Leguminous proteins are generally regarded as valuable sources of amino acids, and are therefore often considered nearly as valuable as animal proteins, or are used as an alternative to them. ◆ Table 6 shows all nutritional amino acids, including the indispensable ones (also known as essential amino acids).

◆ Table 7 and ◆ Figure 2 show the levels of indispensable amino acids in the various legumes expressed as a percentage of the crude protein content (N x 6.25) and compared to the reference values for a child aged 3 years or above. This allows the calculation of the Amino Acid Score (AAS), and it also allows the limiting amino acid to be determined (stated in *italic* text in ◆ Table 7).

> All nutritional amino acids are necessary, principally, because they need to be available in the right place in the right amount for protein synthesis, and therefore, they are not replaceable, but rather "essential".

> However, the dispensable amino acids, unlike the indispensable amino acids, can be synthesized through metabolic availability of the carbon skeleton and through transamination from other amino acids. Nevertheless, a sufficient quantity of the other amino acids is required for this. In order to "protect" the indispensable amino acids from this transamination, the quantity of dispensable amino acids consumed should be properly balanced in proportion to the overall amount of nutritional amino acids. As ◆ Table 6 shows, this is the case for legumes.

Pea protein roughly covers the requirements of a growing child for the sulfur-containing amino acids methionine and cysteine. In the case of faba beans and lupines, methionine and cysteine are just limiting with an AAS of 91% each. However, this is not an issue because a limiting amino acid can be compensated to a certain extent by an increased protein intake which is generally covered by the protein-rich diet that is the norm in this part of the world. Soy protein on the other hand meets all of the expectations, as is well known. Another notable amino acid is arginine which is present in particularly high levels in lupines. Compared to foods of animal origin, such as whole milk protein which contains just 4% arginine, and chicken egg and beef protein, which contain only about 7% arginine, the other leguminous proteins also contain a lot of arginine. Arginine is a donor of nitrogen oxide (NO), which causes vasodilatation and lowers blood pressure [25, 26]. Some studies investigating lupine protein suggest that the arginine contained in this protein may have some effect [27].

◆ Table 7 also shows the AAS, the true protein digestibility [28, 29], and the Protein Digestibility Corrected Amino Acid Score (PDCAAS) [14, 19]. The digestibility value for faba beans and soybeans is almost 91%, for peas it is almost 96% [28], and for lupines, it is 89.4% [29]. This means that the PDCAAS values are: 82.5 for lupines, 90.7 for soybeans, and 95.9 for peas. Since the digestibility of foods can vary depending on their composition (e.g. dietary fiber content) and on how they are processed and prepared, these differences should not be overestimated. In general, the values are very high, and very much comparable to those of animal proteins, which are only slightly higher.

PDCAAS values (not "truncated") found by Mathai et al. [20] include values for pea protein concentrate, soy protein isolate, soy meal, and wheat of 84, 102, 109, and 51 respectively, using the reference values for children aged three and above as a basis. The corresponding DIAAS values were 73, 98, 105, and 54 – a very good correlation. The somewhat lower values for the pea protein concentrate compared to the values in this paper can be explained by the lower methionine and cysteine content, which was probably caused by the processing of the product to make the concentrate.

Since humans in our part of the world do not get their protein from one protein source alone, the effects of proteins in combination with other proteins is also important. This is particularly true when plants are the main source of protein. Therefore, cereal proteins make up a large part of our diet. Proteins from wheat, corn, and rice are particularly low in lysine. Therefore, the PDCAAS value for wheat is only 58%. This is why care has always been taken to supplement wheat with protein-rich foods to ensure adequate lysine supply. The focus here was initially on lysine-rich foods of animal origin, but it was later broadened – whereupon soy protein in particular was included. Since then, other plant-derived protein sources have also been included as suitable sources. The leguminous proteins mentioned here, in particular peas, soybeans and faba beans, as well as untreated lentils and chick peas (not dealt with here), are rich in lysine. The example below illustrates this:

Fatty acids (g/100 g)	Peas[a]	Faba beans	Lupines, blue[c]	Lupines, white[c]	Lupinen, yellow[c]	Soy-beans
fat content	1.4	1.6	4.0	8.7	5.5	20
palmitic acid (16:0)	0.16	0.21	0.43	0.66	0.22	2.1
stearic acid (18:0)	0.03[b]	0.03	0.25	0.18	0.09	0.7
oleic acid (18:1)	0.33	0.33	1.26	3.86	1.16	4.4
linoleic acid (18:2)	0.62	0.64	1.27	1.59	2.52	10.0
α-linolenic acid (18:3)	0.11	0.05	0.25	0.77	0.42	1.3

Tab. 4: **Fatty acid content in the legumes (pulses) investigated in g/100 g**
[a] from Souci et al., dried peas [10]
[b] Jahreis et al. 2016 [11]
[c] Musco et al. [7]

Fatty acids (g/100 g of lipids)[a, d]	Peas[a]	Faba beans	Lupines, blue[c]	Lupines, white[c]	Lupinen, yellow[c]	Soy-beans
fat content	1.4	1.6	4.0	8.7	5.6	20
palmitic acid (16:0)	12.6	13.5	11.4	8.0	4.3	10.6
stearic acid (18:0)	2.1[c]	2.1	6.5	2.2	1.8	3.6
oleic acid (18:1)	25.0	20.8	33.3	46.5	22.3	21.8
linoleic acid (18:2)	47.7	39.7	33.5	19.2	48.6	49.8
α-linolenic acid (18:3)	8.3	2.8	6.6	9.3	8.1	6.7
ratio 18:2/18:3	5.7:1	14.2:1	5.1:1	2.1:1	6.0:1	7.5:1

Tab. 5: **Fatty acid content of the legumes (pulses) investigated in g/100 g of ether extract or per 100 g of the sum of the fatty acid methyl esters respectively**
[a] from Souci et al., dried peas [10]
[b] Jahreis et al. 2016 [11]
[c] Musco et al. [7] (in g/100 g of fatty acid methyl esters)

Amino acids (g/100 g)	Peas	Faba beans	Sweet lupines	Soybeans
lysine	1.68	1.67	1.54	2.39
methionine	0.23	0.22	0.22	0.53
cysteine	0.32	0.35	0.45	0.57
threonine	0.97	0.95	1.18	1.44
leucine	1.6	2.00	2.27	2.89
isoleucine	0.97	1.13	1.38	1.63
valine	1.04	1.22	1.28	1.82
phenylalanine + tyrosine	1.80	2.03	2.53	2.26
tryptophan	0.21	0.24	0.26	0.49
arginine	2.02	2.40	3.26	2.85
histidine	0.56	0.73	0.83	0.99
sum of indispensable amino acids	**11.40**	**12.94**	**15.20**	**17.86**
alanine	0.95	1.05	1.14	1.59
aspartic acid	2.56	2.80	3.26	3.89
glutamic acid	3.87	4.40	7.00	6.05
glycine	0.95	1.09	1.38	1.32
proline	0.94	0.99	1.37	1.65
serine	1.05	1.22	1.61	1.67
sum of dispensable amino acids	**10.32**	**11.55**	**15.76**	**16.17**

Tab. 6: **Amino acid content in the legumes (pulses) investigated in g/100 g**
AA = amino acid(s)

The recommended protein intake for a child aged between 3–10 years with a body weight of 20 kg is 18 g/day [14]. This requires 82 g of beef, 220 g of wheat bread, 78 g of peas, 67 g of faba beans, 56 g of lupines, or 47 g of soybeans (different dry substance levels are not taken into account here). The lysine requirement for the above-mentioned child of 700 mg would not be covered by the 220 g of wheat bread, which would cover only 63% of the requirement, whereas the other foods in the quantities mentioned would result in surpluses ranging from 23% (lupines) to 87% (peas) to 170% (beef). Thus, leguminous proteins are a useful complement to lysine-poor proteins, such as wheat proteins. This same principle applies to most of the other indispensable amino acids, and also to younger children who have a higher amino acid requirement. It should be emphasized that the protein intake becomes less important once a child is fully grown. Lysine requirements in particular are much lower in adults because they do not need to build as much new muscle as children.

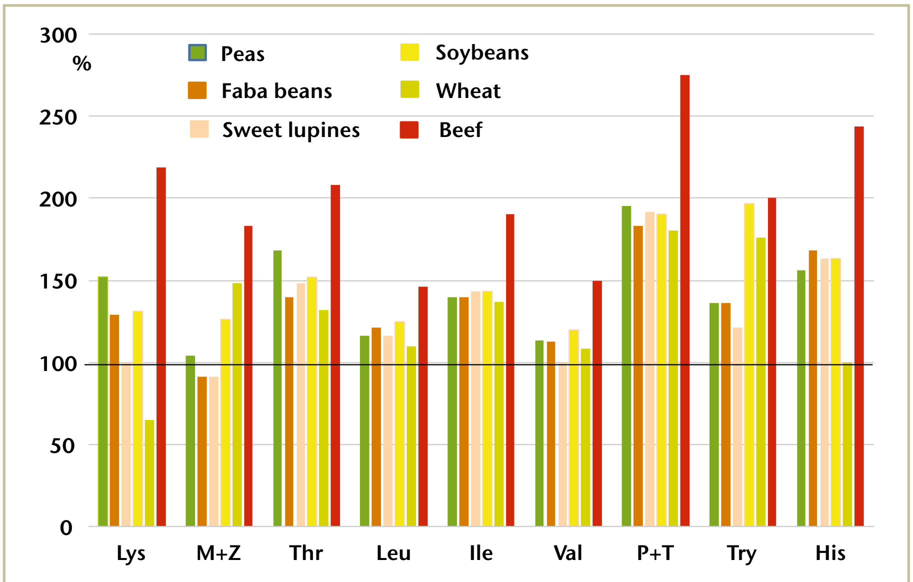

Fig. 2: **Levels of indispensable amino acids in the legumes (pulses) investigated and in wheat protein and beef protein, shown as a percentage of the ideal protein** (requirements for a child aged 3 years or above)
Lys = lysine; M + C = methionine + cysteine; Thr = threonine; Leu = leucine; Ile = isoleucine; Val = valine; P + T = phenylalanine + tyrosine; Try = tryptophan; His = histidine

For the assessment of this supplementary effect, it is advisable to use the non-"truncated" version for the AAS where appropriate – i.e. it is not possible to reduce the surpluses of individual indispensable amino acids to 100 [18]. These values for the AAS can also be found in ◆ Figure 2. In practice, many different combinations occur in nutrition, and animal-derived and plant-derived proteins make different contributions to these, as was established by Kofrany [30] many years ago.
Such calculations play an important role in the assessment of the suitability of foods for a vegan diet.

Amino acids (g/16 g N)	Ideal protein[a]	Peas	Faba beans	Sweet lupines	Soybeans
lysine	4.8	7.3	6.2	4.8	6.3
methionine	2.3 (methionine + cysteine)	1.0	*0.8*	*0.7*	1.4
cysteine	see above	1.4	*1.3*	*1.4*	1.5
threonine	2.5	4.2	3.5	3.7	3.8
leucine	6.1	7.1	7.4	7.1	7.6
isoleucine	3.0	4.2	4.2	4.3	4.3
valine	4.0	4.5	4.5	4.0	4.8
phenylalanine + tyrosine	4.1	8.0	7.5	7.9	7.8
tryptophan	0.66	0.9	0.9	0.8	1.3
arginine	–	8.8	8.9	10.2	7.5
histidine	1.6	2.5	2.7	2.6	2.6
AA score	**–**	**100**	**91**	**91**	**100**
true digestibility (%)	**–**	**95.9**	**90.8**	**89.4**	**90.7**
PDCAA score	**—**	**95.9**	**82.6**	**81.4**	**90.7**

Tab. 7: **Levels of indispensable amino acids (AA) in the legumes (pulses) investigated, given as a percentage of protein**
[a] Amino acid model of the ideal protein (based on the requirement values of children aged three and above) and the Amino Acid Score (AAS), the true protein digestibility, and the Protein Digestibility Corrected Amino Acid Score (PDCAAS)
italic values = limiting amino acids

Generally speaking, protein-rich plant-derived foodstuffs are rare, and those with high-quality protein are even rarer. This means that legumes rank highly among the native plant-derived foods, especially as protein sources for children: if carefully selected and provided in the right ratio, they can even be used as protein sources for a vegan diet for children.

Conclusion

In conclusion, we have established that legumes (pulses) are nutrient-dense, highly digestible foods that provide considerable amounts of high-quality protein. This makes them both comparable to proteins of animal origin, and a suitable replacement for them.
According to Li et al. [31] the advantages of legumes are the following:

- high protein content and high levels of amino acids that determine protein value
- particularly high soluble fiber content (baroreceptors and key satiating effect of short-chain fatty acids)
- high proportion of resistant starch after cooking
- protease and α-amylase inhibitors (slowed digestion of proteins and carbohydrates)
- long-lasting satiety due to these properties
- technological advantages (see also [5, 6])

Conflict of Interest
Prof. Erbersdobler and Prof. Barth are members of the Special Committee for Human Nutrition within the Union for the Promotion of Oil and Protein Plants e. V., and Prof. Jahreis is the Chair of this committee.

Other than those stated above, the authors declare no conflict of interest.

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References

1. *Deutsche Gesellschaft für Ernährung (Hg). 13. Ernährungsbericht. Köllen Druck und Verlag GmbH, Bonn (2016)*
2. *Sirtori CR, Triolo M, Bosisio R et al. (2012) Hypocholesteraemic effects of lupin protein and pea protein/fibre combinations in moderately hypercholesteraemic individuals. Br J Nutr 107: 1176–1183*
3. *Becerra-Tomás N, Díaz-López A, Rosique-Esteban N et al. (2017) Legume consumption is inversely associated with type 2*

diabetes incidence in adults: a prospective assessment from the PREDIMED Study. Clinical Nutrition [published online: March 23, 2017]
4. *Song M, Fung TT, Hu FB et al. (2016) Association of animal and plant protein intake with all-cause and cause-specific mortality. JAMA Intern Med 176: 1453–1463*
5. *Raikos V, Neacsu M, Russell W, Duthie G (2014) Comparative study the functional properties of lupin, green pea, fava bean, hemp and buckwheat flours as affected by pH. Food Sci Nutr 2: 802–810*
6. *Kohajdova Z, Karovicova J, Schmidt S (2011) Lupin composition and possible use in bakery – a review. Czech J Food Sci 29: 203–211*
7. *Musco N, Cutrignelli M, Calabrò S et al. (2017) Comparison of nutritional and antinutritional traits among different species (Lupinus albus L., Lupinus luteus L., Lupinus angustifolius L.) and varieties of lupin seeds. J Anim Physiol Anim Nutr [DOI: 10.1111/jpn.12643]*
8. *National Research Council (USA). Nutrient requirements of swine – ingredient composition - soybeans, lupins, field peas, faba beans. The National Academies Press, Washington, D. C. (2012)*
9. *Centraal Veevoederbureau (CVB, Niederlande). Veevoedertabel 2000. Postbus 2176 Lelystad ISBN 90-72839-13-7*
10. *Souci SW, Fachmann W, Kraut H. Die Zusammensetzung der Lebensmittel Nährwert Tabellen. Wissenschaftliche Verlagsgesellschaft mbH, Stuttgart (2016)*
11. *Jahreis G, Brese M, Leiterer M et al. (2016) Legume flours: nutritionally important sources of protein and dietary fiber. Ernahrungs Umschau 63(2): 36–42*
12. *Amtsblatt der Europäischen Union (EU). Verordnung (EU) Nr. 1169/2011 des europäischen Parlaments und des Rates (22. 11. 2011), 54, L304/18-L304/63*
13. *Deutsche Gesellschaft für Ernährung, Österreichische Gesellschaft für Ernährung, Schweizerische Gesellschaft für Ernährung (Hg). D-A-CH-Referenzwerte für die Nährstoffzufuhr. Neuer Umschau Buchverlag, Neustadt a. d. Weinstraße (2015)*
14. *Food and Agriculture Organization (FAO). Dietary protein quality evaluation in human nutrition. Expert Consultation 31 March–2 April, 2011 Auckland, New Zealand. FAO Food and Nutrition Paper 92, Rome (2013)*
15. *Milward DJ (2012) Amino acid scoring patterns for protein quality assessment. Br J Nutr 108: S31–S43*
16. *FAO/WHO Expert Consultation. Protein quality evaluation report of the joint FAO/WHO expert consultation held in Bethseda, Md., USA, in 1989. FAO Food and Nutrition Paper 51, Rome (1991)*
17. *Erbersdobler HF (1992) Ein neues System zur Proteinbewertung - Der Protein Digestibility Corrected Amino Acid Score (PDCAAS). Ernährungs Umschau 39: 243–247*
18. *Schaafsma G (2012) Advantages and limitations of the protein digestibility-corrected amino acid score (PDCAAS) as a method for evaluating protein quality in human diets. Br J Nutr 108: S333–S336*
19. *Boye F, Wijesinha-Bettoni R, Burlingame B (2012) Protein evaluation twenty years after the introduction of the protein digestibility corrected amino acid score method. Br J Nutr 108: S183–S211*
20. *John K, Mathai JK, Liu Y, Stein HH (2017) 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 117: 490–499*
21. *Saastamoinen M, Eurola M, Hietaniemi V (2013) The chemical quality of some legumes, peas, fava beans, blue and white lupins and soybeans cultivated in Finnland. J Agricultural Science and Technology 11: 92–100*
22. *Rachwał-Rosiak D, Budryn G, Żyżelewicz D, Nebesny E. Structure, technological and nutritional characteristic of oils and fats of plant origin. 2.1. Legume lipids. In: Budryn G, Zyzelewicz D (Hg). Plant lipid science, technology, nutritional value and benefits to human health. Research Signpost Trivandrum/India (2007), S. 21–42*
23. *Petterson DS. Composition and food uses of lupins. In: Gladstones JS, Atkins CA, Hamblin J (Hg). Lupins as crop plants. Biology, production, and utilization. CAB International, Wallingford/UK, New York/USA (1998), S. 353–384*
24. *Trinidad TP, Mallillin AC, Loyola AS et al. (2010) The potential health benefits of legumes as a good source of dietary fibre. Br J Nutr 103: 569–574*
25. *Jobgen WS, Fried SK, Fu WJ Meininger CJ, Wu G (2006) Regulatory role of the arginine-nitric oxide pathway in metabolism of energy substrates. J Nutr Biochem 17: 571–588*
26. *Dong JY, Qin LQ, Zhang Z et al. (2011) Effect of oral L-arginine supplementation on blood pressure: a meta-analysis of randomized, double-blind, placebo-controlled trials. Am Heart 162: 959–965*
27. *Bähr M, Fechner A, Kiehntopf M, Jahreis G (2015) Consuming a mixed diet enriched with lupin protein beneficially affects plasma lipids in hypercholesterinemic subjects: a randomized controlled trial. Clinical Nutrition 34: 7–14*
28. *Eggum B. Aminosyrekoncentration og Proteinkvalitet. Stougaards Forlag, Kopenhagen (1968)*
29. *Molvig L, Tabe LM, Eggum BO et al. (1997) Enhanced methionine levels and increased nutritive value of seeds of transgenic lupins (Lupinus angustifolius L.) expressing a sunflower seed albumin gene. Proc Natl Acad Sci U.S.A. 94: 8393–8398*
30. *Kofranyi E (1967) Die biologische Wertigkeit gemischter Proteine. Die Nahrung 11: 863–875*
31. *Li SS, Kendall CW, de Souza RJ et al. (2014) Dietary pulses, satiety, and food intake: a systematic review and meta-analysis of acute feeding trials. Obesity 22: 1773–1780*

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