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Legumes in human nutrition

Nutrient content and protein quality of pulses

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Abstract

Using data from the literature, we determined the nutrient content and protein quality of legumes (pulses), including peas, faba beans, sweet lupines, and soybeans. We calculated the Amino Acid Score (AAS) based on a comparison of the amino acid values with those of a standard protein that was determined based on the requirement values for children aged three years and above, and we calculated the Protein Digestibility Corrected Amino Acid Score (PDCAAS) based on the protein digestibility values.

The vitamin and mineral content of these legumes is relatively high, particularly for potassium and calcium (in the case of lupines and soybeans), magnesium, iron, and zinc, and also vitamin B1 (thiamine) and folates. Soybeans are a good source not only of linoleic acid, but also of α-linolenic acid. The remaining legumes do not play a significant role as sources of fatty acids due to their low fat content. Legumes have a very high dietary fiber content. The disaccharide and oligosaccharide levels in particular are remarkably. In the case of faba beans and lupines, the sulfur-containing amino acids (methionine and cystine) are limiting amino acids. The digestibility of the protein in all legumes is very high, ranging from 89% to 96%. This means that the PDCAAS values range from 81 (lupines) to 96 (peas). These high values are comparable to those of animal proteins. Peas and beans, and to a somewhat lesser extent lupines, are good sources of lysine, which means that they are a useful complement to cereal proteins, which are quite low in lysine. Lupine protein is also rich in arginine.

Keywords: legumes, pulses, peas, soybeans, faba beans, sweet lupines, protein quality, amino acids, minerals, vitamins, dietary fiber

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Introduction

Legumes are among the foodstuffs for which regular consumption is highly recommended. In ancient times and in the Middle Ages, they were one of the most important sources of energy (starch) and protein in the human diet. Today, they have been replaced in this role by cereals or potatoes and foods of animal origin. Consequently, the average consumption of legumes in Germany for instance is now lower than 1 kg per person per year [1]. The reasons for this lower consumption of legumes include their flatulescent (bloating) effect (especially in the case of beans), their simple and rustic image, and the perception that legumes (pulses) are frequently used as animal fodder. A further reason is the low level of cultivation, which leads to a lower supply. Last but not least, these days, the cereal products and potato products available are much more varied and diversified than legume-based products.

However, attitudes towards legumes have been improving for some time now, and they are no longer consistently viewed as old-fashioned. The reasons for this are the following:

1. The health benefits of legumes are being increasingly recognized and acknowledged (e.g. [2]). In a study by Becerra-Tomás et al. [3] in 3,349 participants with different intake levels of legumes (lentils, chick peas, beans, peas), 266 new cases of diabetes occurred within the four-year study period. In the group with the highest quartile of legume consumption (up to 35 g/day), the risk of diabetes was lower than in the group with the lowest quartile (9.5 g/day). However, it should be noted that the average consumption of legumes in Germany is less than 2 g/day.
2. There is an urgent need for more plant-derived proteins that can be used in the human diet, especially regarding the growing world population. They are also needed as an alternative to a diet that is rich in carbohydrate and fat. Legumes are relatively high in proteins,

with a protein content of 20–40% in the dry matter, whereas cereals for example only have a protein content of 10–15%.

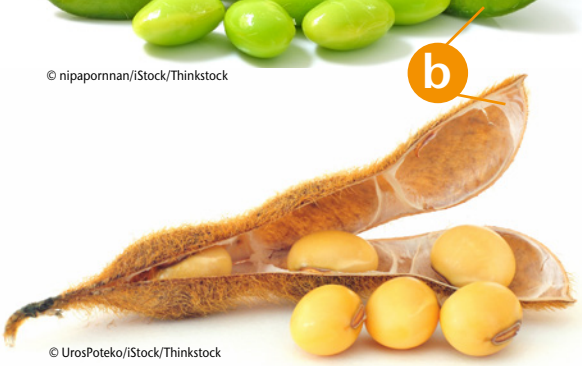
3. Protein concentrates and isolates are increasingly being used in special diets, for example in nutrition of athletes.
4. There are increasing calls to reduce consumption of foods of animal origin and replace them with plant-derived proteins, both for health reasons and for sustainability resp. environmental reasons. A prospective cohort study of 131,342 participants within the Nurses' Health Study concluded that there may be a positive correlation between a high intake of foods of animal origin and increased cardiovascular mortality. Conversely, a high intake of plant-derived proteins is associated with lower overall mortality and lower cardiovascular mortality. This relationship was particularly marked in people with at least one risk factor of lifestyle [4].
5. Protein-rich foods that can provide high-quality protein are urgently needed to supply the growing trend towards vegetarian and vegan diets.
6. Furthermore, new proteins with functional properties that are technologically useful, such as solubility or the ability to form emulsions, foams or gels, etc. are constantly being sought [5, 6]. Some protein isolates derived from various legumes meet these requirements. Legume flour and special products based on protein isolates (and sometimes also starch isolates) in particular therefore play an increasingly important role in food technology.

Consequently, it comes as no surprise that there is a growing trend towards the cultivation of legumes moving out of the "kitchen garden" and into large areas of arable land. This is why the nutrition and food industry have their focus set on animal fodder crops such as field peas, faba beans, and sweet lupines. These developments raise the question of whether these products meet human dietary requirements in terms of their nutrient content and in terms of any unfavorable substances they may contain, and whether they may even have a positive impact on human health.
This article deals primarily with the most important nutrients, and also focuses on protein quality due to the special role of protein as a nutrient.

Methodology

The most popular legume flours made of field peas *(Pisum sativum* L.*)*, faba beans *(Vicia faba)*, and sweet lupines *(Lupinus angustifolius)* were selected and compared with soybeans *(Glycine max)*. The peas that were used were dehulled peas that are very similar to garden peas.

Legumes/pulses
The word "legume" is derived from the botanical term *Leguminosae*. Legumes are the dry seeds of papilionaceae. They are the third largest family among the higher plants. In agriculture, they are known as legumes or pulses.
The most common legumes are soybeans, faba beans, peas, green beans, lentils, lupines, and chick peas. In terms of global production, soybeans are by far the most commonly cultivated, followed by faba beans and peas. Legumes have a particularly positive impact on soil fertility, not least because their roots fix nitrogen in the soil thanks to a symbiotic relationship with rhizobia, thus making the nitrogen available to other plants.



a) Faba beans *(Vicia faba)*, b) Soybeans *(Glycine max)*, c) Sweet lupines *(Lupinus angustifolius)*, d) Peas *(Pisum sativum)*

Digestibility
Digestibility is tested in experiments known as balance studies. In these studies, the relationship between N-excretion in the feces and N-intake is investigated. "True digestibility" (TD) refers to digestibility values that are corrected to allow for endogenous losses in the feces. The endogenous losses are calculated in separate tests, e.g. tests with protein-free food.

$$TD = \frac{\text{intake} - (\text{excretion} - \text{endogenous losses})}{\text{intake}}$$

This calculation does not take account of changes in individual amino acids due to the microbiome in the cecum. This phenomenon is attempted to be taken into account in calculations by ileal digestibility, of amino acids as described below.

Faba beans belong to the genus Vicia (vetches) and not to the genus *Phaseolus* like green beans. The lupines referred to here are mainly dehulled, blue-flowering sweet lupines. They are preferred in Germany over the white and yellow-flowering varieties because they are less susceptible to fungal diseases like anthracnose. The differences in the nutrient content between the species are usually no greater than the variations within a species, which depends on the variety, the cultivation conditions, the climate, etc. For some nutrients, reference is also made to white and yellow lupines. For the fatty acids, the values of the three lupine species are compared (according to [7]). For the amino acid content, the values apply to all three lupine species.
Because the German food tables provide little data for field peas, faba beans and lupines, and since these products have so far mainly been used in animal nutrition, values from feed tables have also been used [8, 9]. As a general rule, data from tables is preferred because this data is usually based on multiple analyses, making it more reliable. There was sufficient data for the energy contributing nutrients, minerals, and amino acids. However, there is little data for vitamins, fatty acids, and dietary fiber. In specific cases (especially in the case of peas), data on garden produce was used [10].

Main nutrients (per 100 g)		Peas	Faba beans	Lupines, blue	Soybeans
dry substance	g	88	88	91	92
energy	kJ kcal	1,350 322	1,250 299	1,366 327	1,376 329
protein	N x 6.25	23	27	32	38
fat	g	1.4	1.6	6.1	20
starch utilizable sugar	g g	44 2.8[a]	39 3.9	7.5 4.1	1.9 6.5
fiber	g	10[b]	18	36	22

Tab. 1: **Energy contributing (main) nutrients present in the legumes (pulses) investigated**
[a] from Souci et al., dried peas [10]
[b] Jahreis et al. 2016 [11]

The study by Jahreis et al. [11] served as the control, and some individual values from that study were used directly in this one (noted in the tables). In order to assess nutrient density, in ◆ Figure 1 the data was linked to the reference values for the supply of energy and some nutrients, vitamins and minerals provided in the EU Food Information to Consumers' Regulation (EU-FIC) [12]. With the exception of folate, these values are approximately the same as the D-A-CH reference values for a 19 to 25-year-old woman [13].

In order to calculate the protein quality, the levels of indispensable amino acids (previously known as "essential" amino acids) in the legumes were correlated with an "ideal protein" based on the requirements for a growing child of the age of 3 years or above. The data for children is considered the most reliable available to date. Furthermore, at this age, amino acid requirements are high [14, 15], and it is therefore particularly important to pay attention to them. This also applies to children on a vegan diet. The values for adults are not yet sufficiently reliable [14–16], but they are lower, which means that the biological value of the protein that applies to children is also applicable to adults. The United Nations Food and Agriculture Organization (FAO) [14] therefore recognizes only three stages of amino acid requirement: 0 to 6 months, 6 months to 3 years and 3 years and up (including adults).
Thanks to the correlation with a reference protein, it is easy to determine which amino acids are low compared to the requirements. The indispensable amino acid with the largest deficit compared to the required value ("first limiting" amino acid) determines the Amino Acid Score (AAS). Amino acid values above the requirement, i.e. an apparent amino acid index of above 100, are thus made equal to 100 (science calls these "truncated"). Example: In the case of beans and lupines, with a

value of 2.1%, the sulfur-containing amino acids methionine + cysteine only reach 91% of the "required value". The AAS is therefore 91.
However, amino acid content is not the only factor that limits protein quality. It is also limited by the digestibility of the protein and the bioavailability of the amino acids. This aspect of protein quality is most severely affected by the presence of substances that have a negative effect on protein digestibility. It is a well-known fact that legumes cannot be eaten raw. Some of them contain very large amounts of protease inhibitors, lectins (phytohemagglutinins), phytates, tannins, and other such substances. One well-known way of reducing the effect of these substances is moderate heating, such as toasting (of soy meal for example), extrusion, baking, steaming, and boiling. There is a fine line between adequate heating and overheating, and it is essential to find the happy medium in order to obtain optimum protein quality.
In order to take digestibility into account, in this evaluation the Protein Digestibility Corrected Amino Acid Score (PDCAAS) [14–19] was used. In this scoring system, the AAS is multiplied by the true digestibility quotient of the protein (as measured in animal tests on rats). It was established in previous tests that the digestibility values measured in rats are also largely applicable to humans [16, 19]. For example, if the AAS of faba beans is 91% and the true digestibility quotient is 0.95, then the PDCAAS would be 86.5. This value is approximately equivalent to the biological value of the protein. One often cited disadvantage of the PDCAAS is that it overestimates the protein quality of strongly heated foods because the bioavailability of some amino acids (lysine in particular) is impaired in such cases [14, 17]. For these reasons, it is suggested giving preference to the Digestible Indispensable Amino Acid Score (DIAAS) as a measure of protein quality over the ileal amino acid digestibility [14, 20]. The gut contents (chymus) of the ileum (usually from the pig) are removed by means of fistula and analyzed. Changes in the indigestible protein components of the food in the caecum are thus circumvented. This method is used in animal nutrition and it is also a promising method for use in human nutrition. In human nutrition, however, this method, which is more time-consuming and material-intensive than PDCAAS, has so far not become established, especially since there is still not sufficient data available on ileal amino acid digestibility [14].

Minerals		Peas	Faba beans	Lupines, blue	Soybeans
potassium	g	1.0[a]	1.2	1.1	1.8
calcium	g	0.05	0.14	0.24	0.21
magnesium	g	0.12	0.15	0.13[a]	0.22
iron	mg	5.2	6.7	5.4	8.0
copper	mg	0.66	1.1	0.6	1.2
zinc	mg	3.2	4.1	5.1	4.2
selenium	µg	1.6[a]	2.0	4.7[a]	19

Tab. 2: **The most important minerals present in the legumes (pulses) investigated**
[a] Jahreis et al. 2016 [11]

Vitamins		Peas	Faba beans	Lupines, blue	Soybeans
α-tocopherol γ-tocopherol	mg mg	0.11[b] 5.0[b]	0.08 n. d.	1.1[b] 15.3[b]	6.5[b] 23.0[b]
thiamine (vitamin B_1)	mg	0.7	0.55	0.32[b]	1.0
riboflavin (vitamin B_2)	mg	0.27[a]	0.29	0.59[b]	0.46
pyridoxine (vitamin B_6)	mg	0.12[a]	0.37	0.4	1.1
folates	µg	274	423	40	250

Tab. 3: **The most important vitamins present in the legumes (pulses) investigated**
[a] from Souci et al., dried peas [10]
[b] Jahreis et al. 2016 [11]
n. d. = not determined

Results and discussion

Preparation and use

Legumes are an established food. Some of them have been used as food for thousands of years and their preparation methods are well known. Essentially, they require sufficient heating, which not only deactivates detrimental substances, but also increases digestibility, and especially the digestibility of the protein portion, through denaturing.
Until now, dried faba beans had never been a commonly eaten foodstuff in Central Europe. They are sometimes found as an ingredient in muesli or bread, and this set to occur more often now in light of the current trend towards vegetarian and vegan diets. The use of lupines in human nutrition is also a relatively new phenomenon, especially since low-alkaloid sweet lupines have only been cultivated since the beginning of the 20th century.

Energy-supplying nutrients

In peas and faba beans, starch is the main component (◆ Table 1). Prior to the introduction of the potato, peas were an important source of starch,

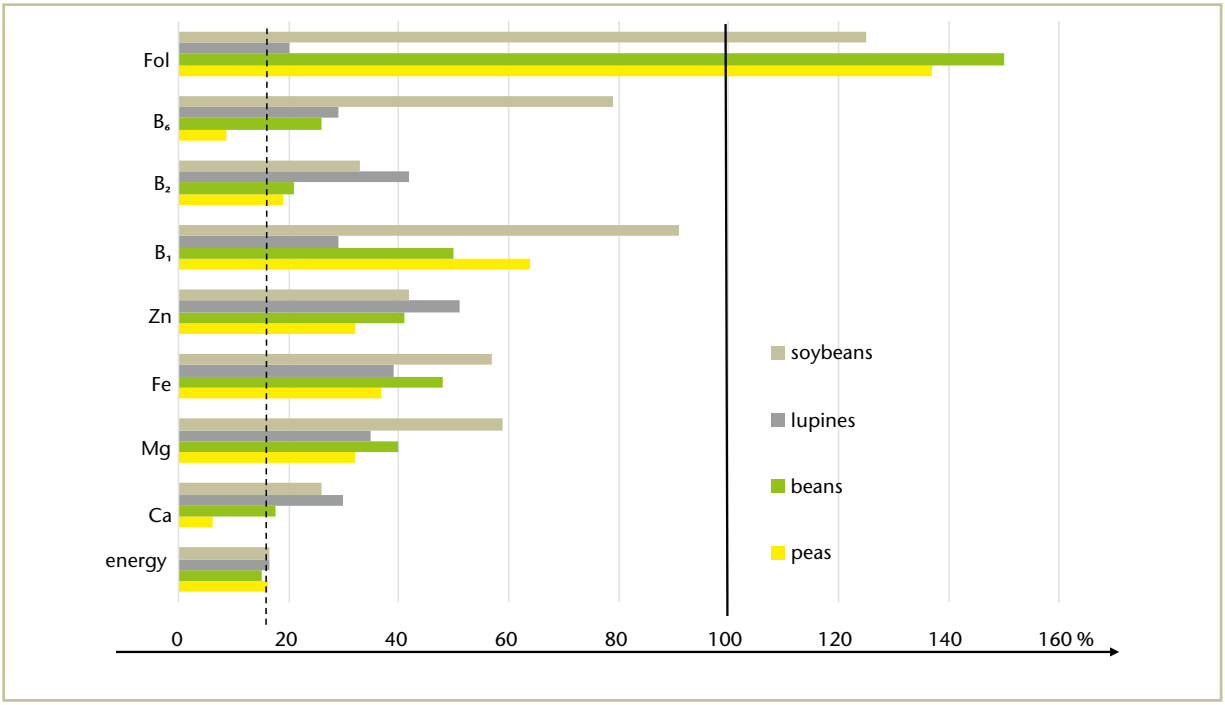


Fig. 1: **Relative levels of the most important minerals and vitamins per 100 g, with reference to the daily reference values**
Reference values for the supply of energy and some nutrients, vitamins and minerals provided in the EU Food Information for Consumers Regulation [12]
— solid line = in the case of 100% reference values
- - - dashed line = relative energy contribution of 100 g relative to the aforementioned reference value for energy
B_1 = thiamine; B_2 = riboflavin; B_6 = pyridoxine; Ca = calcium; Fe = iron; Fol = folates; Mg = magnesium; Zn = zinc

along with cereals. Soybeans are low in utilizable carbohydrates, but they have a substantial fat content. Lupines are particularly high in dietary fiber. In soybeans, and also often in lupines, protein is the largest component. It is therefore no surprise that these legumes (first soybeans, then later also lupines) are used to make protein concentrates and isolates for nutritional and technological purposes. White lupines tend to contain somewhat more protein than blue and yellow lupines, but they have less starch [21]. White lupines are the highest in fat and have a somewhat lower crude fiber content, making this lupine species particularly useful in animal nutrition.

Dietary fiber

Dietary fiber content varies greatly. It depends largely on whether the seeds are dehulled. In the non-dehulled seed, most of the fiber is insoluble fiber, including a high proportion of cellulose [22]. After dehulling of the seeds, it is predominantly soluble fiber that remains [23]. This article deals with these dehulled seeds. The lignin content is low [6]. It is worth noting the relatively high levels of trisaccharides and oligosaccharides (stachyose + raffinose 1.5–3.5%, small amounts of verbascose). Lupines and soybeans also contain ciceritol at levels of about 0.65% and 0.08% respectively [22]. These oligosaccharides cause flatulence (intestinal wind) because they are fermented in the cecum in a manner similar to that of soluble dietary fibers. These substances can be reduced through aqueous to slightly alcoholic extraction, and heat treatment partially destroys them. However, it is important to bear in mind that they can also have prebiotic effects. For further information regarding the health benefits of the dietary fiber in legumes, we refer the reader to the work of Jahreis et al. [11].

The same applies to the question of allergenicity. In the EU-FIC, soybeans and lupines are listed among the 14 allergenic foods that must be shown on packaging [12].

Minerals and vitamins

The levels of the most important vitamins and minerals are listed in ◆ Table 2 and Table 3. ◆ Figure 1 shows the relative levels for the most important minerals and vitamins, relative to the reference values for the supply of energy, some nutrients, as well as vitamins and minerals provided in EU-FIC [12]. At the same time, the energy content is shown as a percentage of the reference value. Thus, the figure gives an idea of the nutrient density of legumes. Relative nutrient content values above the relative energy value mean a high nutrient density. Values below indicate a low nutrient density for this food.

As indicated in ◆ Figure 1, the relative nutrient contents are above the relative energy contents in almost all of the cases shown, meaning that legumes can generally be considered high in vitamins and minerals. The values for magnesium and iron, thiamine (vitamin B_1), and folates are remarkably high, and in the case of lupines and soybeans, the calcium values as well. Even the trace element levels are relatively high in the case of iron, zinc and copper, but the selenium content is only of note in soybeans (there is generally little data for this) (◆ Table 2).

The bioavailability of the minerals from legumes varies and is determined by the mineral content, by mineral-mineral interactions, and by the levels of phytic acid and tannic acid. Phytic acid levels vary little between different types of cereals and legumes. Overall, they depend more on the cultivation conditions which can cause them to vary widely. With a phytic acid content of > 2%, soybeans have the highest levels, followed by faba beans and peas [11, 23]. TRINIDAD et al. [24] used the dialysability of minerals as a measure of bioavailability. The bioavailability of iron from legumes was reduced particularly drastically by a high level of tannic acid. The phytic acid and tannic acid levels in legumes did not affect the availability of zinc. Generally, the bioavailability of calcium and zinc was high, whereas the bioavailability of iron was limited.

The riboflavin levels (vitamin B_2) and pyridoxine levels (B_6) (the latter also in peas) were also high. The vitamin E content was only of note in the fat-rich soybeans. Some nutrients not listed, such as vitamins B_{12}, A, and C, were present only in small quantities or were absent.

Continuation of this article, including the references, in the next issue of ERNÄHRUNGS UMSCHAU (issue 10/2017)

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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