Legumes in human nutrition

Health aspects – part 1

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Abstract

Legumes (soybeans, faba beans and other types of beans, peas, lentils, sweet lupins and chick peas) are rich in protein, complex carbohydrates and fiber as well as minerals. They are an important component of healthy dietary patterns emphasizing plant foods. Intake in Western populations is rather low. This review presents findings from meta-analyses and some individual studies on their impact on metabolic parameters as well as on disease risks, namely risk of metabolic syndrome and associated disorders, of cardiovascular diseases as well as cancer. There are many studies on the effect of soybeans. Non-soy legumes also decreased in intervention trials LDL cholesterol and blood pressure and improved in part glycemic control. Their intake as well as adherence to a Mediterranean diet were associated with a lower risk of coronary heart disease and cardiovascular diseases. The Mediterranean and other healthy dietary patterns were associated with a lower risk of diabetes mellitus type 2. Whether intake of non-soy legumes affects cancer risk has little been examined up to now.

Keywords: legumes, plant protein, metabolism, health

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Introduction

Legumes are the fruits or seeds of plants in the family of *fabaceae (leguminosae)*. The most common ones are soybeans, garden peas and other types of peas, faba beans and other types of beans, lentils, sweet lupins, and chick peas. In Europe, peas, faba beans, sweet lupins, and soybeans are the most economically important ones. The Food and Agriculture Organization (FAO) uses the term pulses for the dried seeds (beans, peas, lentils and chick peas). Because of their high fat content soybeans and peanuts are also called oil seed legumes [1].
Most legumes should not be consumed raw. Some contain large amounts of protease inhibitors and lectins (phytohemagglutinins). A common way to inactivate these ingredients is heating, like toasting (of soybean meal), extrusion, baking, steaming, and cooking. Sufficient heating both inactivates adverse substances and, through denaturing (unfolding of molecule structures), improves the digestibility, especially of proteins.
All nutrients (proteins, fat, carbohydrates, resistant starch and fiber, minerals and vitamins, phytochemicals) may contribute to the effect of legumes on human metabolism, isolated or in combination [2]. Particularly the effect of soybeans may be further modulated by genetics (Asians versus Caucasians) or the product type chosen (whole foods versus isolated components) (cited in [2]).

This review addresses the question of whether intake of legumes benefits human health. The major focus is on features of the metabolic syndrome (MetS), on cardiovascular diseases (CVD), and cancer, with a special interest in the role of locally grown legumes. Studies on the role of soybeans/soy products on outcomes are given for comparison. The comprehensive overview presents findings from meta-analyses of either randomized controlled intervention studies or prospective cohort studies (observational studies), once together with case-control-studies. The meta-analyses were published 2010 or later, with one excep-

tion. Furthermore, recently published individual studies on the effect of non-soy legumes are presented which were not yet included in the meta-analyses. Studies on soy isoflavones are mentioned in only a few cases.
Intervention studies examine the effect of foods or single nutrients (for example isolated proteins) on metabolic parameters. Cohort studies look for an association between the intake of foods or dietary patterns and the risk for various diseases or metabolic disorders. The checklist of consumed foods and quantities can be used to calculate intake of nutrients and their association.
Intake of legumes is low in Germany. The nutritional survey *(Ernährungsbericht)* 2016 of the German Nutrition Society estimates that the annual per capita consumption is on average 600 g [3]. Yet the interest in legumes and their role in a health promoting dietary patterns is increasing.

Ingredients

Macronutrients

Legumes are rich in proteins, complex carbohydrates and fiber (in variable proportions) as well as minerals. Starch is the main component of peas and faba beans [4, 5]. Legume carbohydrates are absorbed slowly and thus have a favorably low glycemic index [6]. Soybeans are low in utilizable carbohydrates, but are rich in fat. Lupins are rich in protein and moderately high in fat [5]. Legumes are rich in either monounsaturated or polyunsaturated fatty acids. Lupins show also a favorable ω3/ω6 fatty acid ratio [4].
The main interest concerns usually protein quality. Legume protein is rich in indispensable (essential) amino acids. Particularly noteworthy is the high content of lysine. Therefore legumes, particularly peas, faba beans, soybeans, and lentils, are well-suited to supplement cereal (e.g. wheat) proteins, which are relatively low in lysine. Even though their amino acid pattern is less ideal than that of meat or milk proteins, the combination can ensure a balanced pattern of indispensable amino acids [7]. Legume proteins may also be a source of bioactive peptides. In vitro-studies identified peptides with antioxidative, antihypertensive and anticarcinogenic properties [8].
Legumes are generally rich in fiber [1, 4, 5]. This is particularly true for lupins [4, 5]. Their fiber content is more than twice that of cereals. Therefore legumes are ideally suited to ensure, together with whole grain cereals, a sufficient dietary supply of fiber [1].

Micronutrients and phytochemicals

Among minerals and vitamins potassium and calcium (lupins and soybeans), magnesium, iron and zinc as well as vitamin B_1 and folic acid have particular importance [5]. Moreover, legumes contain a large number of phytochemicals. The major groups are polyphenols, tannins, lignans, saponins, alkaloids, lectins (e.g. phytohaemagglutinins, phasin), phytosterols, enzyme inhibitors (trypsin and chymotrypsin inhibitors, alpha-amylase inhibitors), phytic acid and oxalic acid. The polyphenols include, among others, flavonoids and phenolic acid. A subset of the flavonoids are the isoflavones (phytoestrogens like e.g. genistein and daidzein), anthocyanidins, flavonols (e.g. quercetin and kaempferol) and flavan-3-ols (e.g. catechin) (◆ Table 1).
Many of these phytochemicals show beneficial health effects. But enzyme inhibitors, lectins and some others show also antinutritive effects [9, 10]. Soybeans are rich in isoflavones (phytoestrogens) [9, 10], whereas lentils are low [9]. Because of their weak estrogenic effect, but also because of the high content of phytic acid, soy-based infant formula should only be used for specific indications [11]. The purine content of legumes ranges from moderate (peas, chick peas) to high (soybeans) [12] (◆ Table 1). But at least in a balanced vegetarian plant-based diet purines pose no appreciable risk of gout [13].
The mineral content of legumes is high, but the bioavailability is rather moderate. Phytic acid inhibits the absorption of iron and zinc and thus has an antinutritive effect. There are also iron-binding polyphenols, in particular tannins. Therefore, if applicable, phytic acid should be removed, or ascorbic acid added, in order to improve absorption. Various processing procedures may improve the activity of phytases naturally occurring in legumes, which hydrolyze phytic acid [14].
The food industry has a strong interest in plant protein preparations (as flours, concentrates, or isolates) to replace the common but scarce and expensive animal proteins. When isolating pro-

Compound		Garden beans	Peas	Chick peas	Lentils	Soy beans
Purines	mg/100 g[1]	128[a]	95[a]	109[a]	126[a]	190[a]
Phytates	g/100 g[2]	0.2–1.9	0.2–1.3	0.4–1.1	0.4–0.7	0.2–2.2[b]
Oxalates	g/100 g[2]	0.1–0.5	(0.7)	0.07	0.16	0.08–0.29[b]
Polyphenols[3]	g/100 g[2]	0–0.4	0.25	0.1–0.6	1	4.2[c]
Saponins	g/100 g[2]	n/a	0.1–0.3	0.4	0.4–0.5	0.6
Trypsin inhibitor activity	TIU/mg[2]	9.6	5.4–7.8	1–15	8.4	26–74[d]

Tab. 1: **Selected phytochemicals in legumes**
[a] Souci et al. 2016 [12]; [b] Horner et al. 2005 [80]; [c] Malencic et al. 2012 [81]; [d] Bulatova et al. 2019 [82]; others from Champ 2009 [10]
[1] dried seeds; [2] dry matter; [3] total value; n/a = no data available; TIU = trypsin inhibitor units

Authors	Subjects[a]	Foods or Dietary patterns		Studies/Comparisons n	Effect
Inflammatory parameter CRP					
Zhang et al. 2016 [16]	T2DM, MetS	soy	P	7	⇩
Salehi-Abargoue et al. 2015 [17]	H, HC, OW, others	LG excl. soy	food	8	(⇩)
Schwingshackl et al. 2018 [18]	H, HC, T2DM, OW, others	LG incl. soy	food	4/26[c]	⬄ vs. others[d, e]
Blood lipids					
Total cholesterol					
Zhang et al. 2016 [16]	T2DM, MetS	soy	P	11	⇩
Yang et al. 2011 [22]	T2DM	soy	P	7	⇩
Tokede et al. 2015 [23]	H, HC, PM, others	soy	food	12	⇩
Schwingshackl et al. 2018 [18]	H, HC, T2DM, OW, others	LG incl. soy	food	11/58[c]	⇩ vs. Rg, E, F, M[d]
Bazzano et al. 2011 [24]	H, HC	LG excl. soy	food	10	⇩
LDL cholesterol					
Zhang et al. 2016 [16]	T2DM, MetS	soy	P	11	⇩
Yang et al. 2011 [22]	T2DM	soy	P	6	⇩
Tokede et al. 2015 [23]	H, HC, PM, others	soy	food	12	⇩
Schwingshackl et al. 2018 [18]	H, HC, T2DM, OW, others	LG incl. soy	food	10/57[c]	⇩ vs. Rg, F, M[d]
Bazzano et al. 2011 [24]	H, HC	LG excl. soy	food	9	⇩
Ha et al. 2014 [25]	H, HC, T2DM, OW, others	LG excl. soy	food	26	⇩
HDL cholesterol					
Zhang et al. 2016 [16]	T2DM, MetS	soy	P	11	⬄
Yang et al. 2011 [22]	T2DM	soy	P	6	⇧
Tokede et al. 2015 [23]	H, HC, PM	soy	food	12	(⇧)
Schwingshackl et al. 2018 [18]	H, HC, T2DM, OW, others	LG incl. soy	food	10/58[c]	⇩ vs. N, Wg, Rg, F, M[d]
Bazzano et al. 2011 [24]	H, HC	LG excl. soy	food	9	⬄
Fasting triglycerides					
Zhang et al. 2016 [16]	T2DM, MetS	soy	P	12	⬄
Yang et al. 2011 [22]	T2DM	soy	P	7	⇩
Tokede et al. 2015 [23]	H, HC, PM, others	soy	food	12	⇩
Schwingshackl et al. 2018 [18]	H, HC, T2DM, OW, others	LG incl. soy	food	10/60[c]	⬄ vs. others[d]
Bazzano et al. 2011 [24]	H, HC	LG excl. soy	food	9	(⇩)
Glycemic control					
Fasting glucose					
Zhang et al. 2016 [16]	T2DM, MetS	soy	P	9	⇩
Yang et al. 2011 [22]	T2DM	soy	P	4	⬄
Liu et al. 2011 [29]	T2DM, OW, others	soy	food	9	⇩
Viguiliouk et al. 2015 [30]	T2DM	PF with LG incl. soy	food	8	⇩
Schwingshackl et al. 2018 [18]	H, HC, T2DM, OW, others	LG incl. soy	food	8/41[c]	⬄ vs. others[d, e]
Sievenpiper et al.2009 [6]	H, T2DM, HC	LG excl. soy	food	11	⇩
	H, T2DM	LG in low-GI diet	food	18	⬄
	H, T2DM	LG in high-fiber diet	food	11	⇩
Fasting insulin					
Zhang et al. 2016 [16]	T2DM, MetS	soy	P	5	⇩
Yang et al. 2011 [22]	T2DM	soy	P	3	⬄
Liu et al. 2011 [29]	T2DM, OW, others	soy	food	5	⬄
Viguiliouk et al. 2015 [30]	T2DM	PF with LG incl. soy	food	5	⇩
Sievenpiper et al. 2009 [6]	H, T2DM, HC	LG excl. soy	food	9	⇩

	H, T2DM	LG in low-GI diet	food	7	⇔
	H, T2DM	LG in high-fiber diet	food	2	⇔
HOMA-IR					
Zhang et al. 2016 [16]	T2DM, MetS	soy	P	3	⇩
Schwingshackl et al. 2018 [18]	H, HC, T2DM, OW, others	LG incl. soy	food	4/20[c]	⇩ vs. E, D[4,5]
Sievenpiper et al. 2009 [6]	H, T2DM, HC	LG excl. soy	food	9	⇔
	H, T2DM	LG in low-GI diet	food	6	⇔
	H, T2DM	LG in high-fiber diet	food	2	⇔
Glycated hemoglobin (HbA_{1c}) or glycosylated proteins[b]					
Yang et al. 2011 [22]	T2DM	soy	P	5	⇔
Viguiliouk et al. 2015 [30]	T2DM	PF with LG incl. soy	food	7	⇩
Schwingshackl et al. 2018 [18]	H, HC, T2DM, OW, others	LG incl. soy	food	3/13[c]	⇔ vs. others[d, e]
Sievenpiper et al. 2009 [6]	H, T2DM, HC	LG excl. soy	food	2	⇔
	H, T2DM	LG in low-GI diet	food	15	⇩
	H, T2DM	LG in high-fiber diet	food	7	⇩
Body weight					
Zhang et al. 2016 [16]	T2DM, MetS	soy	P	7	⇔
Akhlaghi et al. 2017 [36]	OW, others	soy	P + food	21	⇔
Kim et al. 2016 [37]	OW	LG excl. soy	food	21	⇩
Onakpoya et al. 2011 [38]	OW	kidney beans	food	3	⇔
Blood pressure (systolic/diastolic)					
Dong et al. 2011 [44]	H, HT	soy	P	27	⇩ / ⇩
Zhang et al. 2016 [16]	T2DM, MetS	soy	P	8	⇔ / ⇩
Schwingshackl et al. 2018 [18]	H, HC, T2DM, OW, others	LG incl. soy	food	4/27[c]	⇔/⇔ vs. others[d, e]
Jayalath et al. 2014 [45]	H, HT	LG excl. soy	food	8	⇩ / (⇩)
Ndanuko et al. 2016 [73]	HT, partly with T2DM, MetS	Mediterranean diet	food	3	⇩ / ⇩
		DASH	food	11	⇩ / ⇩
		Nordic Diet	food	3	⇩ / ⇩

Tab. 2: **Effect of legumes on metabolic parameters – meta-analyses of intervention studies**
The test substances or foods were compared with appropriate control substances or diets.
CRP = C-reactive protein; DASH = Dietary Approaches to Stop Hypertension; excl. = excluding; GI = glycemic index; incl. = including; LG = legumes; P = protein as supplement; PF = plant food; T2DM = type 2 diabetes mellitus; vs. = versus
Effect: ⇔ no effect; ⇩ significantly decreasing; ⇧ significantly increasing; (⇩), (⇧) only trends
[a] abbreviations of subject characteristics: H = healthy; HC = hypercholesterolemia; HT = hypertension; MetS = metabolic syndrome; others = in part also subjects with further metabolic disorders; OW = overweight/adiposity; PM = postmenopausal women
[b] In the meta-analysis of Sievenpieper et al. 2009 the parameter glycosylated proteins is given, measured as HbA_{1c} or fructosamine.
[c] Legume studies/total studies, which did measure this parameter.
[d] Legumes were compared with the food groups: nuts (N), whole grains (Wg), refined grains (Rg), fruit and vegetables, eggs (E), dairy (D), fish (F), red meat (M), and soft drinks.
[e] For these comparisons not all food groups are included.

teins from plant sources, however, other plant compounds are also extracted and remain in part in the protein fraction during the subsequent protein precipitation. Various classes of natural compounds, e.g. alkaloids, saponins, glucosinolates, products of fatty acid breakdown and polyphenols have been suspected to cause off-tastes (bitter, astringent) (cited in [15]). Recently an optimized process for the production of pea protein isolates was developed that avoids a bitter-astringent off-taste caused by lipid oxidation products [15].

Effect on metabolic parameters

Inflammation markers

Soy foods or soy protein may confer anti-inflammatory effects. In many human trials they reduced blood C-reactive protein (CRP) concentrations [2]. According to a meta-analysis soy protein supplements decreased CRP in persons with type 2 diabetes mellitus (T2DM) and with MetS.

In a subset analysis, however, the effect was only significant for trial durations > 6 months [16]. Non-soy legume intake produced a non-significant trend towards lower CRP [17] (◆ Table 2).

Schwingshackl et al. carried out a network meta-analysis on the basis of 66 intervention studies, examining in paired comparisons the effect of ten food groups (nuts, legumes, whole grains, refined grains, red meat, fish, eggs, fruit and vegetables, dairy, and soft drinks) on altogether ten outcome measures, namely CRP, blood lipids, glycemic control, and blood pressure. Legumes were a test food group in eleven studies, four of them including soy products. CRP was measured in 26 out of the 66 studies, four of them had legumes as test food. The meta-analysis found that CRP concentrations were not different between food groups [18]. In a 12-week individual weight loss intervention study, neither the lupin flour-supplemented and thus protein- and fiber-enriched diet nor the high-carbohydrate control diet reduced CRP [19].

Blood lipids

A recent meta-analysis of 46 intervention trials selected by the US Food and Drug Administration (FDA) confirmed that soy protein, mostly consumed as protein isolates, decreased LDL cholesterol relative to the respective control protein by 3–4% [20]. The significant reduction of total and LDL cholesterol was maintained from 1999 to 2013 [21].
Several meta-analyses found that soy protein [16, 22, 23] and soy products [23] decreased total and LDL cholesterol, in mixed populations of healthy subjects and others with various metabolic disorders [23] as well as in persons with T2DM [16, 22]. One meta-analysis observed a significant improvement of HDL cholesterol [22], others observed no effect [16] or merely a favorable nonsignificant trend [23]. Fasting triglycerides were sometimes decreased [22, 23], but not always [16]. In a subset analysis, however, the effect on LDL cholesterol was only significant with trial durations > 6 months, while reduction of total cholesterol was achieved earlier [16] (◆ Table 2). Isoflavones had no effect on blood lipids [23].
According to the already mentioned network meta-analysis [18] legumes (in part soy products) decreased total cholesterol as compared to refined grains, eggs, fish, and red meat. Their effect was slightly weaker than that of nuts. They decreased also LDL cholesterol as compared to refined grains, fish and red meat. Their effect came off second best after that of nuts. Yet they increased HDL cholesterol less than nuts, whole grains and refined grains, fish and red meat. The effect on fasting triglycerides did not differ from that of other food groups [18] (◆ Table 2).
According to a meta-analysis in healthy subjects and subjects with various metabolic disorders non-soy legumes (beans, lentils, peas, and chick peas) also decreased total [24] and LDL cholesterol [24, 25] (◆ Table 2). Heterogeneity between individual trials was large. The effect was more pronounced in trials with more male participants [25]. Lupin protein isolates, incorporated in foods, decreased in an individual study LDL cholesterol, yet not more than milk protein [26]. Another individual intervention study compared the effect of lupin kernel fiber and citrus fiber in moderately hypercholesterolemic subjects. The former decreased LDL cholesterol, the ratio LDL/HDL cholesterol, and fasting triglycerides significantly more [27].

Soy protein may activate LDL receptors or inhibit endogenous cholesterol synthesis [23]. Further mechanisms may contribute to the cholesterol-lowering effect [20, 22]. Soluble fiber may decrease the excretion of bile acids and thus reduce the cholesterol pool of the liver, stimulating in turn cholesterol uptake from the blood stream into the liver [24, 28]. It remains open whether proteins, fiber, or other components are primarily responsible for the hypocholesterolemic effect of legumes.

Glycemic control

A meta-analysis found that soy protein supplementation decreased fasting blood glucose and fasting insulin and improved insulin sensitivity (homeostasis model of assessment for insulin resistance index, HOMA-IR) in patients with T2DM and MetS [16]. In a subset analysis the reduction in fasting glucose was only significant for trial durations > 6 months [16]. According to other meta-analyses intake of soy protein did not decrease fasting glucose [22], but whole soy foods or soy diets did so [29]. Fasting insulin [22, 29] and glycated hemoglobin (HbA_{1c}) [22] were not changed.
A meta-analysis looked at trials in patients with T2DM, where animal foods as source of protein were replaced by plant foods. The latter decreased fasting glucose, fasting insulin and HbA_{1c} [30]. According to subset analyses the effects were more pronounced in trials exchanging ≥ 35% of the protein and for participants with longer diabetes duration. Around half of the individual trials used soy products as source of plant protein. The others used non-soy legumes, single or from mixed sources, one study used nuts [30] (◆ Table 2).
According to a network meta-analysis legumes (in part soy products) did not change fasting glucose and HbA_{1c} as compared to other food groups [18]. They decreased HOMA-IR relative to eggs and dairy [18] (◆ Table 2).
A meta-analysis of intervention trials in subjects who were either healthy or had T2DM and in part hypercholesterolemia found that intake of non-soy legumes decreased fasting glucose and fasting insulin, but not HOMA-IR and HbA_{1c}. Legumes as part of a diet with a low glycemic index decreased HbA_{1c} only. Legumes as part of a fiber-rich diet decreased both fasting glucose and HbA_{1c} [6] (◆ Table 2). Several factors modified the extent of improvement, amongst others existing diabetes, amount of legumes consumed, type of legumes and their processing, background diet, and study dura-

tion [6]. In a 12-week individual weight loss intervention study, the lupin flour-supplemented and thus protein- and fiber-enriched diet as compared to the high-carbohydrate control diet decreased fasting insulin and improved HOMA-IR [19].
It is assumed that plant proteins and their amino acids [30], slowly digestible carbohydrates and fiber [28] as well as polyphenols [28] of legumes contribute to the improved glycemic control.

Satiety

Various intervention studies suggest that the satiating effect of soy products is not different from that of animal foods [2]. Yet a meta-analysis found that meals containing non-soy legumes (beans, peas, lentils, chickpeas, and lupins), mostly tested against white bread, improved the satiety index. There was a nonsignificant trend towards a lower second meal food intake. Four out of the nine trials assessed lupins alone or together with beans [31]. This effect of legumes may be due to the high content of protein, of fiber, and low glycemic index carbohydrates, which delay digestion and absorption [9]. Certainly, also the higher filling and thus extension of the stomach contribute to a longer-lasting feeling of satiety. In an individual intervention study lupin kernel fiber improved satiety as compared to a low-fiber control diet, rated per questionnaire at the end of each 4-week intervention period. The effect of lupin kernel fiber did not differ from that of citrus fiber [27].

Gut health and microbiota

The interest in the importance of the gut and gut microorganisms (microbiota) for human health has grown considerably over recent years. Diet modifies composition and function of gut microbiome. A number of legume components are metabolized by the gut microbiome, namely proteins, complex slowly digestible carbohydrates (resistant starch) and fiber as well as polyphenols, including isoflavones. The microbiota obtains energy from the components themselves or from intermediate products, in particular from the short chain fatty acids (SCFA) acetate, propionate and butyrate [32, 33].
Particular attention goes to the slowly digestible carbohydrates and fiber. Their degradation increases the stool volume and shortens intestinal transit time. Generation of SCFA decreases the pH-value. Microbial metabolites (SCFA, secondary bile acids and others) act first in the intestinal tract itself. But SCFA may enter the blood stream and regulate endogenous lipid and glucose metabolism [9]. Thus, microbial metabolites can affect the gut and the host organism, towards protection against or promotion of various metabolic disorders and diseases. This includes inflammatory processes and immune function [32].
In an individual study with 2-week intervention periods, basic diet was supplemented with either lupin kernel fiber or citrus fiber. Both treatments increased fecal mass and the concentration of fecal SCFA. Lupin kernel fiber decreased the concentration of total fecal bile acids. For citrus fiber there was a nonsignificant trend [34].

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The literature of part 1 and part 2 of this article is available online
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Conflict of Interest
The three authors are members of the Special Committee for Human Nutrition within the Union for the Promotion of Oil and Protein Plants e. V. (UfOP).

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