Phytochemicals in Legumes: A Qualitative Reviewed Analysis

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ABSTRACT

Legumes are an excellent source of nutrients and phytochemicals. They have been recognized for their contributions to health, sustainability and the economy. Although legumes comprise several species and varieties, little is known about the differences in their phytochemical composition and the magnitude of these. Therefore, the aim of this review is to describe and compare the qualitative profile of phytochemicals contained in legumes and identified through LC-MS and GC-MS methods. Among the 478 phytochemicals reported in 52 varieties of legumes, phenolic compounds were by far the most frequently described (n = 405, 85%). Metabolomics data analysis tools were used to visualize the qualitative differences, showing beans to be the most widely analyzed legumes and those with the highest number of discriminant phytochemicals (n = 180, 38%). A Venn diagram showed that lentils, beans, soybeans and chickpeas shared only 7% of their compounds. This work highlighted the huge chemical diversity among legumes, identified the need for further research in this field, and the use of metabolomics as a promising tool to achieve it.

KEYWORDS: phytochemicals, legumes, qualitative analysis, nutrimetabolomics, polyphenols

INTRODUCTION

Legumes have been shown to promote health and reduce the risk of cardiovascular disease (CVD) as well as that of some cancers, such as colon cancer, among other pathological conditions.[1,2] They also have particular relevance for sustainability and local economies, as they reduce greenhouse gas emissions, help decrease animal-based protein consumption and are rooted in communal gastronomies.[3] In the last few decades, legumes have gained popularity worldwide as being a good source of phytochemical compounds. Phytochemicals are non-nutrient plant-based minor components that differ substantially in their biochemistry, source distribution and physiological effects. Their biological activities, such as antioxidant,[4] anti-inflammatory[5] and antimicrobial[6], have also been described, and it has been suggested that they offer significant meaningful benefits to human health.[4] The vast majority of studies conducted to describe the phytochemical composition of legumes have focused on only one type of legume[7–9] or on a small number of phytochemicals. The comparison of legumes from a phytochemical profile viewpoint is essential for distinguishing properties and potential applications of legumes as well as for enhancing the state of the art and promoting their production, consumption and use. Therefore, the aim of this review is to describe and compare the qualitative profile of bioactive compounds contained in legumes for human consumption that have been identified through LC-MS and GC-MS methods.

In this review, we described the qualitative profile of phytochemicals contained in legumes for human consumption which had been identified through LC-MS and GC-MS methods. We followed this description by conducting a comparative analysis between the different groups of legumes using statistical dichotomous techniques. Finally, a description of bioactive compounds that could discriminate between legumes was discussed.

VARIETIES AND NUTRITION OF LEGUMES

Definition and types of pulses and legumes. Legumes are the edible seeds of the *Fabaceae* or *Leguminosae* family, the third-largest group of plants (more than 20,000 species and 700 genera). They produce between 1 and 12 grains of various sizes, shapes and colors within a pod. Having been spread across the world for about 90 million years, even in regions with extreme weather, their seeds have been used for at least 10,000 years for both human and animal consumption.[10]

The Food and Agricultural Organization (FAO) considered pulses a subgroup of legumes and are defined as "Leguminosae crops harvested exclusively for their grain, including chickpeas, dry beans, peas and lentils". This definition excludes legumes harvested for oil extraction, such as soybeans and peanuts, and those used as vegetables, like green beans and green peas.[10] Specifically, the FAO recognizes the following 11 primary pulses: dry beans (kidney, pinto, navy, azuki, mung, black gram, scarlet runner, rice bean, moth and tepary beans), dry broad beans (horse, broad and field bean), dry peas (garden and field pea), chickpeas, dry cowpeas (cowpea and black-eyed pea/bean), pigeon peas (pigeon pea and cajan pea), lentils, Bambara beans (Bambara groundnut and earth pea), vetch (spring/common vetch), lupins and other "minor" pulses (hyacinth or lablab, jack or sword, winged, velvet, guar and yam beans).[11] In order to homogenize the concepts, we will use in this review the more generic term "legumes" to refer to both pulses and legumes for human consumption: soybeans, peanuts, chickpeas, lentils, beans and peas (Table S1).

Legumes are considered an essential superfood, not only thanks to their desirable nutritional profile and health properties but also to their great influence and power in two other key human aspects: the environment and society.

Nutritional composition and health effects. Recent studies have brought to light the relationship between a regular consumption of legumes and the prevention of some chronic diseases (Table 1). A daily intake of legumes is associated with a decreased risk of CVD, especially coronary heart disease (CHD).[13] In fact, legumes consumption leads to the reduction of various CVD risk factors, such as LDL cholesterol,[14,15] total cholesterol,[15] blood pressure,[13] body weight,[16,17] glycemic index (GI),[18,19] insulin resistance[20] and C-reactive protein,[21] among other metabolic syndrome risk factors.[22] This is due to several compositional traits of legumes, specifically their amount of potassium,[23] magnesium[24] and soluble fiber,[25] along with their cholesterol-free condition[1] (Table 1).

Findings also suggest an inverse association between the intake of legumes and the risk of prostate cancer.[26] One possible explanation for this could be their phytoestrogen content.[27] Additionally, maternal consumption of legumes during pregnancy may have a protective effect on acute lymphoblastic leukemia in children.[28] Furthermore, it has been suggested that consuming legumes could reduce the risk of breast cancer,[29] due mainly to their flavonol, flavone and isoflavone content,[30–33] although evidence is still limited.[34] As regards endometrial cancer, findings of a meta-analysis suggest a weak inverse association between consumption of isoflavones from soy products and legumes and endometrial cancer risk.[35] Although previous meta-analysis and systematic reviews[36] supported the notion that a high intake of legumes was also associated with a low incidence of colorectal cancer due to their high fiber content,[25] an update of the evidence of the WCRF-AICR (World Cancer Research Fund–American Institute for Cancer Research) Continuous Update Project states that legume intake is not associated with colorectal cancer risk[37] (Table 1).

Finally, having a low GI and fat content, as well as a high fiber content, increases satiety[38] and helps stabilize blood sugar and insulin levels. This makes legumes ideal for weight management.[16,17]

On the other hand, it seems that legumes consumption has no effect either on stroke risk or diabetes risk.[13] Despite this, legumes can possibly have effects on their biomarkers. In the case of stroke risk, this can be explained by the amount of potassium they contain[23] and their capacity to reduce glycemic load,[39] whereas in the case of diabetes risk, this seems to be due to the replacement of animal protein for vegetable protein effect,[19] as well as for the improvement of longer-term glycemic control markers and the reduction of metabolic syndrome risk factors.[18,22]

This beneficial role of legumes could be explained by their desirable nutritional and non-nutritional profile. Legumes have a high amount of complex carbohydrates and fiber, thereby offering an average low-energy density of 1.3 kcal/g.[1] They are also known for being poor in sodium and rich in other minerals, like potassium, zinc, calcium and iron.[1,40] Legumes are an excellent source of protein (20–30 % of their energy value), relatively low in tryptophan and sulphur-containing amino acids, such as methionine and cysteine, but rich in lysine.[1,40] Moreover, they do not contain gluten. Their predominant fatty acid is linoleic acid,[40] and vitamins A, E and B are notably abundant.[1] Legumes also contain a high variety of phytochemicals and other minor components that have significant meaningful benefits for human health: α-galactosides, phytosterols, tocopherols, saponins, alkaloids and phytic acid, as well as carotenoids and (poly)phenolic compounds.[1,41–47] Recent literature has shown that canning and household cooking significantly differ in their effects on nutritional composition and bioactive content of legumes, and even have contrary effects on different types of legumes.[48] Agronomic, storage, processing, food formulation, as well as bioaccessibility and bioavailability of the phytochemicals are also factors involved in the ultimate health outcomes of consumption of leguminous foods.

Despite the many health benefits of legumes, their cultivation and intake has been cautiously handled due to the presence of some bioactive compounds, such as phytic acid, covicine, glucosinolates, protease and amylase inhibitors, as they can act as anti-nutrients. Anti-nutritional factors may cause toxicity or interfere with the digestion and absorption of certain dietary components, causing adverse physiological effects (for example, flatulence, favism, lathyrism, small intestine damage and growth depression).[41] This is especially important since several legumes cause concern, particularly in areas characterized by poverty and malnutrition where a single type of legume can be ingested in high amounts. However, most anti-nutrients can still be reduced or removed by thermal processing (boiling, steaming, roasting, autoclaving, dry heating), storage, irradiation, soaking, de-hulling, milling, fermentation and germination. [41,49]

QUALITATIVE ANALYSIS OF PHYTOCHEMICALS IN LEGUMES

The qualitative profile of a large variety of legumes was obtained by applying the systematic search referred to in the Supporting Information. A list of different varieties of legumes and their phytochemicals was obtained after revising the literature.

Types of legumes. All the legumes reported on in this review are shown in Table S1. The biggest group of legumes were beans, where 16 varieties belonged to *Phaseolus vulgaris*: black, brown, cream, white, red, small red, cranberry, yellow, black Jamapa, red and white kidney, pinto, brown string, yellow wax, pink and common beans. Two more kinds of beans of the same genus were runner (*P. coccineus*) and butter bean (*P. lunatus*) (Table S1). Moreover, from the *Vigna* genus, nine different beans could be considered: black-eyed bean and red cowpea (*V. unguiculata*), mungo bean (*V. mungo*), rice bean (*V. umbellata*), moth bean (*V. aconitifolia*), black and green mung bean (*V. radiata*), and green and red adzuki bean (*V. angularis*). Finally, broad bean (*Vicia faba*), horse gram

(*Macrotyloma uniflorum*), hyacinth bean (*Lablab purpureus*), black and red sword bean (C*anavalia gladiata*), jack bean (*Canavalia ensiformis*), white lupin bean (*Lupinus albus*), blue lupin bean (*Lupinus angustifolius*), yellow lupin bean (*Lupinus luetus*) and morama bean (*Tylosema esculentum*) are also part of this group (Table S1). From *Lens culinaris*, commonly known as lentils, seven varieties were considered. They were beluga or black, brown, green, yellow, grey, red and tan lentils. Also, yellow and black chickpeas (*Cicer arietinum*), green, black and yellow soybeans (*Glycine max*), and peanuts (*Arachis hypogaea*) have been reported. Peas were grouped in three different species: green and yellow pea (*Pisum sativum*), snowpea (*Pisum sativum var. saccharatum*) and pigeon pea (*Cajanus cajan*).

Phytochemical foodprint of legumes. The search gave a total of 478 phytochemicals described in legumes. The biggest group was condensed tannins (n = 90), which represented 19%, followed by flavonols (n = 79), isoflavones (n = 64) and phenolic acids (n = 63), which represented 17%, 13% and 13%, respectively. The following have also been reported: 5 α-galactosides, 33 saponins, 6 phytosterols, 2 lignans, 1 coumestan, 3 tocopherols, 12 alkaloids, 6 stilbenes, 4 dihydrochalcones, 2 pterocarpans, 31 flavones, 20 flavanones, 4 flavanonols, 17 flavanols, 1 hydrolysable tannin, 21 anthocyanidins, 11 carotenoids and 3 other compounds (Table 2 and Table S3). Therefore, phenolic compounds were the major family of phytochemicals described in legumes, with 405 of them (85%). The second-biggest family was saponins, with 33 constituents (7%) (Table 2 and Table S3).

In regard to phytochemical families and legume groups, the literature showed that phytic acid, saponins, phytosterols, tocopherols, lignans, phenolic acids, isoflavones, flavonols and flavanols have been identified in all kinds of legumes, whereas carotenoids were found in lentils, chickpeas, beans and soybeans but not in peas or peanuts (Table 2 and

Table S3). Ciceritol, an α-galactoside, has been determined in all legumes except peanuts,[41,50] whilst anthocyanidins were found in lentils, beans and soybeans.[51–57] Moreover, alkaloids were only identified in beans and peas,[7,58–61] but flavanonols were found in beans and peanuts.[7,8,54,62,63] Since dihydrochalcones, pterocarpans, hydrolysable tannins and brazilin had only previously been described in beans,[7,54,64,65] to the best of our knowledge no raffinose family of oligosaccharides (RFO) in peanuts and no coumestans in peas have been determined before. Finally, soybeans had no stilbenes, flavones or squalene, and chickpeas lacked flavanones and condensed tannins.

In addition, Table 2 also shows the particular composition of each group of legumes, with beans being the group with the most compounds identified (n = 276, 58%), followed by peanuts, soybeans and lentils (n = 120, 112 and 101, respectively), while only 60 and 66 chemicals were reported in chickpeas and peas, respectively.

Qualitative cluster analysis of legumes. In this review, we decided to use visualization tools to evidence the state of the art of the phytochemicals in legumes. A heatmap analysis was constructed by using *MetaboAnalyst 3.0*[66] employing the qualitative data (Figure 1, Figure S1, Figure S2, Table S3). This heatmap shows the distribution of bioactive substances, according to each legume, that were or were not determined in them. In parallel with the heatmap, Table S4 shows the 372 discriminant compounds, marked in red in Figure 1, that were determined in the specific legumes. The group with the highest number of discriminant compounds (n = 180) was beans, representing around 38% of all compounds. Flavonols were the main phytochemicals that allowed beans to be discriminated from other legumes (e.g. quercetin 3-O-xylosyloglucoside[67] and faralatroside[54]). The next groups of legumes in terms of proportion were peanuts and soybeans, where 18% and 14% (n = 85 and n = 69), respectively, of their compounds allowed them to be discriminated from the other legumes. Peanuts stand out for condensed tannins (e.g. prorobinetidin and prodelphinidin[8]) and soybeans for isoflavones (e.g. daidzein O-di-hexoside and genistein O-hexoside[68]). There were 27 specific compounds from lentils (Table S4), with carotenoids (e.g. 9-cis-lutein and 9-cis-zeaxantin[69]) being the most prevalent, amounting to 6% of the total. Otherwise, chickpeas and peas had only a very few unique compounds, with each amounting to only 1% of all specific compounds (n = 6 and n = 5, respectively).

Therefore, given that some phytochemicals have only been determined or identified in one type of legume, such as canthoxanthine in chickpeas, glycitin and derivates in soybeans, several alkaloids such as lupanine and angustifoline in beans and morin in peas (Table S4), future analytical needs should be oriented toward validating whether these compounds are exclusive to these legumes or whether legumes have not been fully analyzed. For instance, although the literature is extensive in this field, recently other works have revealed the presence of some phytochemicals in different legumes by applying untargeted metabolomic approaches to foodprint them,[70] indicating that this is a niche area to study.

Additionally, in our qualitative review, we identified a total of 14 phytochemicals that were distributed among all groups of legumes. These compounds were α-tocopherol,[69,71–75] β+γ-tocopherol,[52,69,71–76] β-sitosterol,[71–74,77,78] campesterol,[71–74,77,78] stigmasterol,[71,73,74,77,78] biochanin A,[8,63,79–81] formononetin,[7,63,79,80] daidzein,[63,79–81] genistein,[7,68,72,79–81] genistin,[80–82] epi-catechin,[8,9,52,63,72,83–88] phytic acid, [41,61,64,89–94] secoisolariciresinol[79,95] and soyasaponin Bb,[96–98] which are basically phytosterols and isoflavones. Consequently, none of them are shown in the heatmap.

Principal component analysis of phytochemical composition of legumes. Principal component analysis (PCA) was applied to the data to highlight qualitative differences and similarities between legumes (Figure 2). Principal component 1 (PC1) was responsible for 44.2% of the variance, whereas PC2 and PC3 explained 23.7% and 17.8%, respectively. The most qualitative difference was obtained between beans and the other legumes (PC1). In addition, peanuts and soybeans also had quite a different profile from the other legumes. They are positioned in the bottom-left and top-left corner, respectively, of the PCA score plot. In fact, 65% of the compounds determined in beans were exclusively identified in them, whilst in the case of soybeans and peanuts, the proportion was 62% and 71%, respectively. On the other hand, chickpeas, lentils and peas have quite a central position in the PCA score plot (Figure 2). Only 27% of the compounds reported in lentils were specifically identified in them, while in the case of chickpeas and peas, the proportion was 10% and 8%, respectively. The PCA score plot revealed a close cluster between lentils, chickpeas and peas, where 35 compounds were shared only among them (Figure 2B), representing 32% of the chemicals found in peas, 35% of the compounds reported in chickpeas and 21% of the phytochemicals identified in lentils (Table S5). Most of them were phenolic acids, isoflavones and flavonols. Additional score plot 3D showed that lentils were separated from chickpeas and peas in the PC3 (Figure 2C).

Venn diagram analysis. A Venn diagram of the four groups has been created with the most well-known, widely considered[11] and popular legumes (lentils, beans, chickpeas and soybeans) for better interpretation and visualization of the data. The obtained diagram[99] allows us to visualize the proportion of the number of phytochemicals by group (Figure 3). Lentils, soybeans, beans and chickpeas had 26 shared compounds (7%), mainly isoflavones. Lentils and soybeans were the only ones in which soyasaponin Bd (isoflavone) was identified, while sinapic, chlorogenic and cinnamic acids (phenolic acids), luteolin 8-C-glucoside (flavone), myricetin 3-O-rhamnoside, quercetin 3-O-galactoside (flavonols) and β-carotene were identified in beans and chickpeas. Both chickpeas and lentils contained gentisic acid (phenolic acid). There was no specific compound shared between soybeans, beans and chickpeas or between soybeans, lentils and chickpeas either.

CONCLUSIONS AND FUTURE PERSPECTIVES

In the present work, a phytochemical foodprint of 478 phytochemicals from 52 varieties of legumes has been extracted from literature. This foodprint includes 405 phenolic compounds (which constitute the main group of phytochemicals), 33 saponins, 12 alkaloids, 11 carotenoids, 6 phytosterols, 5 α-galactosides, 3 tocopherols, phytic acid, brazilin and squalene. Metabolomic techniques have been used for the first time for visualizing qualitative differences between legumes. Beans are the most widely analyzed legumes globally and have the highest number of their own phytochemicals (n = 180, 38% of the total), followed by peanuts (n = 85, 18% of the total), soybeans (n = 69, 14% of the total) and lentils (n = 27, 6% of the total), with the proportion being 1% for chickpeas and peas. The qualitative PCA suggested that beans had the most differentiated profile, while lentils, chickpeas and peas revealed a central and close position with a high number of shared compounds. In addition, the Venn diagram showed that lentils, chickpeas, soybeans and beans shared only 7% of their determined compounds.

This work has allowed us to identify several niches to be developed in this field. In particular, future research directions should be aimed at establishing an exhaustive approach to uncovering the whole profile of some legumes, since our review indicates that there are meaningful differences between legumes. This is the case for peas and chickpeas, whose phytochemical profile is numerically far below the other legumes' foodprint.

It is recommended that future research should work toward increasing our knowledge about the underrepresented groups of phytochemicals, such as tocopherols and other nonpolyphenolic compounds, in order to obtain more complete phytochemical profiles of legumes. Identification of these phytochemical profiles will enable their synergistic effect on bioavailability to be studied, along with the mechanism of action and biological function, and finally enhance our understanding of the health benefits and suitability for human consumption of each type of legume. This new knowledge will also be useful for quantifying these phytochemicals and for obtaining biomarkers of compliance, as well as enabling better quality control of legume-based foods.

ABBREVIATIONS USED

CHD: coronary heart disease; CVD: cardiovascular diseases; FAO: Food and Agriculture Organization; GI: glycemic index; PCA: principal component analysis; RoM: ratio of means; RFO: raffinose family of oligosaccharides; WCRF-AICR: World Cancer Research Fund–American Institute for Cancer Research

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SUPPORTING INFORMATION DESCRIPTION

Research and visualization methodology, binomial and common name of each legume reported in the review (Table S1), legend of phytochemicals (PC) numbers with their corresponding names of phytochemicals (Table S2), families and phytochemicals described in legumes (Table S3), potential discriminant phytochemicals of each group of legumes according to the bibliographic search (Table S4), phytochemicals shared between legumes (Table S5), qualitative heatmap of the phytochemicals distributed in legumes (detailed version; Figure S1) (PDF) and original overview of the qualitative heatmap file from *MetaboAnalyst 3.0* (Figure S2).

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TABLES AND FIGURES CAPTIONS

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TABLES

Table 1. Potential health effects of legumes consumption.

Disease	Legumes consumption effect	Mechanism of action
CVD [a]	RR (95% CI) = 0.92 (0.85–0.99)[13] *Positive effect on CVD risk*	**Relation with specific nutrients and components found in legumes:** ↑ K^{+}[23] ↑ Mg^{+2}[24] ↑ fiber[25] cholesterol-free **Relation with various cardiometabolic risk factors found in non-soy legumes:** ↓ LDL cholesterol[14,15] ↓ total cholesterol[15] ↓ blood pressure[13] ↑ weight management[16,17] ↓ glycemic index[18,19] ↓ metabolic syndrome risk factors[22]
CHD [b]	RR (95% CI) = 0.90 (0.83–0.99)[13] *Positive effect on CHD risk*	**Relation with specific nutrients and components found in legumes:** ↑ K^{+}[23] **Relation with various cardiometabolic risk factors found in non-soy legumes:** ↓ glycemic index[18,19]
Prostate cancer	RR (95% CI) = 0.85 (0.75–0.96][26] *Positive effect on prostate cancer risk*	**Relation with specific nutrients and components found in legumes:** ↑ phytoestrogens[27]
Colorectal cancer	RR (95% CI) = 0.91 (0.84–0.98)[36] colorectal cancer: RR (95% CI) = 1.00 (0.95–1.06)[37] colon cancer: RR (95% CI) = 0.97 (0.83–1.15)[37] rectal cancer: RR (95% CI) = 0.99 (0.78–1.25)[37] *Controversial effects on colorectal cancer risk*	**Relation with specific nutrients and components found in legumes:** ↑ fiber[25]
Stroke	RR (95% CI) = 0.98 (0.86–1.11)[13] *No effects on stroke risk but possible effects on markers of stroke risk*	**Relation with specific nutrients and components found in legumes:** ↑ K^{+}[23] **Relation with various cardiometabolic risk factors found in non-soy legumes:** ↓ glycemic load[39]
Diabetes	RR (95% CI) = 0.93 (0.83–1.05)[13] *No effects on diabetes risk but possible effects on markers of diabetes*	Replacement animal protein for vegetable protein improves glycemic control of diabetes[19] Relation with various markers of glycemic control ($HbA_{1}c$ [c] and fructosamine)[18] **Relation with various diabetes risk factors found in non-soy legumes:** ↓ metabolic syndrome risk factors[22]
Satiety and food intake	RoM [d] (95% CI) = 1.31 (1.09–1.58) [38] *Positive effects on acute*	**Relation with specific nutrients and components found in legumes:** ↓glycemic index [38] ↓fat content [38] ↑fiber[38]

	satiety	**Relation with various risk factors found in non-soy legumes:** blood sugar and insulin levels stabilization[12]

[a]CVD: cardiovascular disease, [b]CHD: coronary heart disease, [c]HbA_1c: glycated hemoglobin; [d]RoM: ratio of means

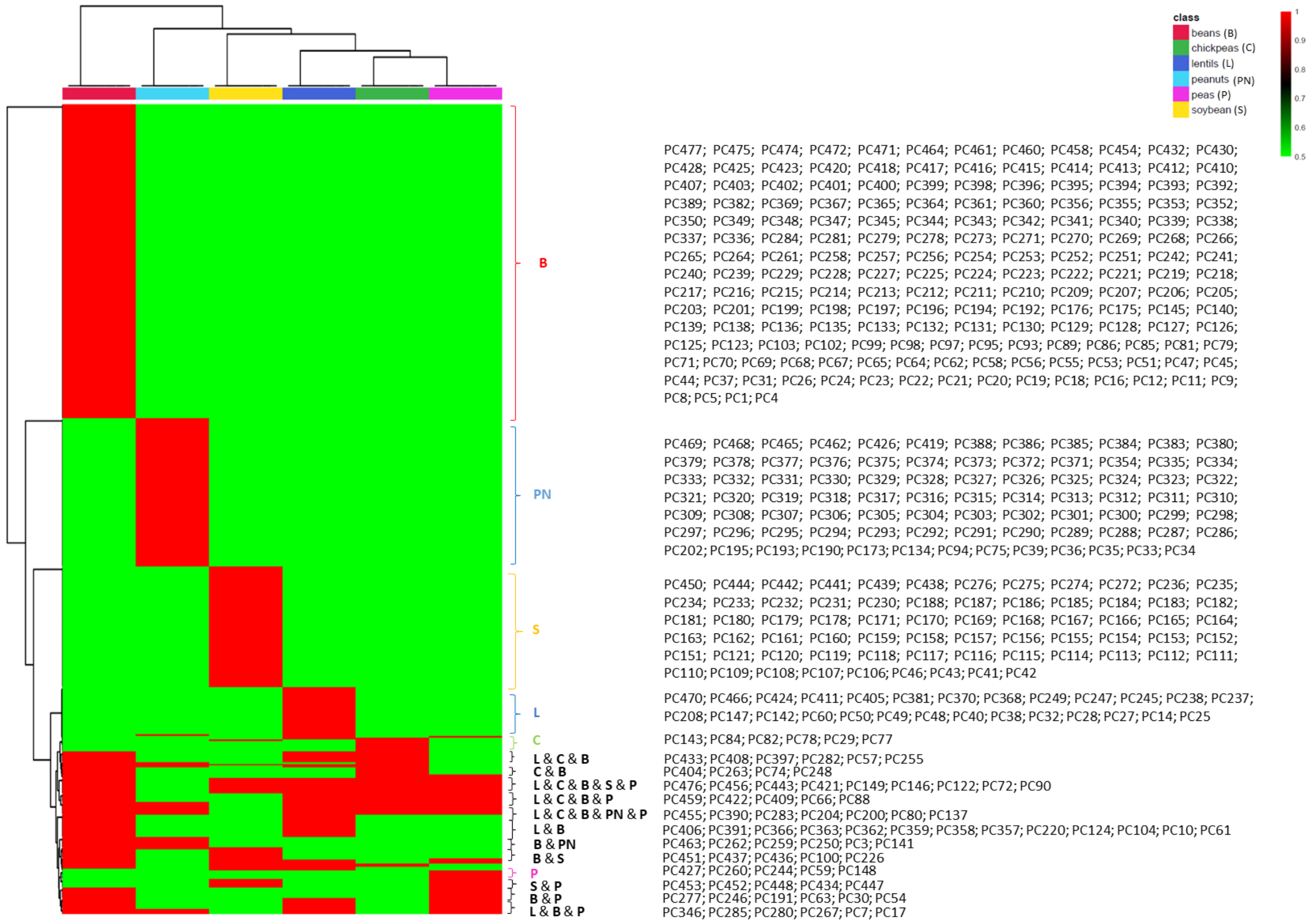
Table 2. Number of phytochemicals (and percentage) of each group of legumes in relation to their family.

Phytochemical classes		Total (%)	Lentils (%)	Beans (%)	Chickpeas (%)	Peas (%)	Soybeans (%)	Peanuts (%)	Ref
phytic acids		1 (0.2)	1 (1)	1 (0.4)	1 (2)	1 (2)	1 (1)	1 (1)	41,61,64,89–94
RFO - galactosides		5 (1)	4 (4)	5 (2)	4 (7)	4 (6)	4 (4)	0 (0.0)	41,59,64,100–105
saponins		33 (7)	4 (4)	18 (7)	2 (3)	9 (14)	71 (63)	2 (2)	96–98,106
phytosterols		6 (1)	5 (5)	5 (2)	6 (10)	5 (8)	4 (4)	3 (6)	71–74,77,78
tocopherols		3 (0.6)	3 (3)	3 (1)	3 (5)	3 (5)	3 (3)	2 (2)	52,69,71–76
carotenoids		11 (2)	8 (8)	1 (0.4)	3 (5)	0 (0.0)	1 (1)	0 (0.0)	52,69,74,90
alkaloids		12 (3)	0 (0.0)	12 (4)	0 (0.0)	1 (2)	0 (0.0)	0 (0.0)	7,58–61
Polyphenols Non-flavonoid	**stilbenoids**	6 (1)	2 (2)	2 (1)	1 (2)	1 (2)	0 (0.0)	2 (2)	7,8,63,72,107
	lignans	2 (1)	2 (2)	2 (1)	2 (3)	1 (2)	1 (0.9)	2 (2)	79,95
	coumestans	1 (0.2)	1 (1)	1 (0.4)	1 (2)	0 (0.0)	1 (0 9)	1 (0.8)	79,95
	phenolic acids	63 (13)	18 (18)	48 (17)	11 (18)	13 (20)	1 (0 9)	15 (13)	7,8,72,84,90,107–113,9,114,52–54,56,62,63,67
	hydrolysable tannins	1 (0.2)	0 (0.0)	1 (0.4)	0 (0.0)	1 (2)	0 (0.0)	0 (0.0)	64,65
Polyphenol	**isoflavones**	64 (13)	10 (10)	11 (4)	13 (22)	7 (11)	9 (8)	6 (5)	7,8,63,68,72,79–82,115–117
	dihydro-chalcones	4 (0.8)	0 (0.0)	4 (1)	0 (0.0)	0 (0 0)	0 (0.0)	0 (0.0)	7,54
	pterocarpans	2 (0.4)	0 (0.0)	2 (0.7)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	7,54

s Flavonoids	**flavones**	31 (6)	9 (9)	19 (7)	3 (5)	6 (9)	0 (0.0)	6 (5.)	7,8,53,54,56,62,63,72,85,95,107,111,113,118
	flavonols	79 (17)	13 (13)	64 (23)	8 (13)	5 (8)	8 (7)	6 (5)	7–9,52–57,62,67–69,72,84,85,95,107,110,111,113,115,118–120
	flavanones	20 (4)	1 (1)	12 (4)	0 (0.0)	3 (5)	4 (4)	3 (3)	7,8,53,54,68,110,113,118
	flavanonols	4 (0.8)	0 (0.0)	3 (1.1)	0 (0.0)	0 (0.0)	0 (0.0)	2 (2)	7,8,54,62,63
	flavanols	17 (4)	7 (7)	16 (6)	1 (2)	5 (8)	1 (0. 9)	3 (3)	7–9,52,54,63,69,72,83–88,110,113
	condensed tannins	90 (19)	10 (10)	23 (8)	0 (0.0)	0 (0.0)	1 (0.9)	65 (54)	7–9,52,61,64,85,86,88,107,112,121–124
	anthocyanidins	21 (4)	2 (2)	21 (8)	0 (0.0)	0 (0.0)	2 (2)	0 (0.0)	52–56,67,84,85
brazilin		1 (0.2)	0 (0.0)	1 (0.4)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	7,8
squalene		1 (0.2)	1 (1)	1 (0.4)	1 (1.7)	1 (1.5)	0 (0.0)	1 (0.8)	7,8
TOTAL		478 (100)	101 (100)	276 (100)	60 (100)	66 (100)	112 (100)	120 (100)	

FIGURES

Figure 1. Qualitative heatmap of the phytochemicals distributed in lentils, chickpeas, beans, peas, soybeans and peanuts. Overview (red: presence; green: absence). For a detailed version, please see Figure S1.



Note. The phytochemical name of each PC-number code is shown in Table S2. Detailed information is also stated on Table S3 and Table S4. Legume groupings with less than four common compounds are not displayed in this figure.

Figure 2. PCA score plot 2D (A), loading plot (B) and PCA score plot 3D (C).

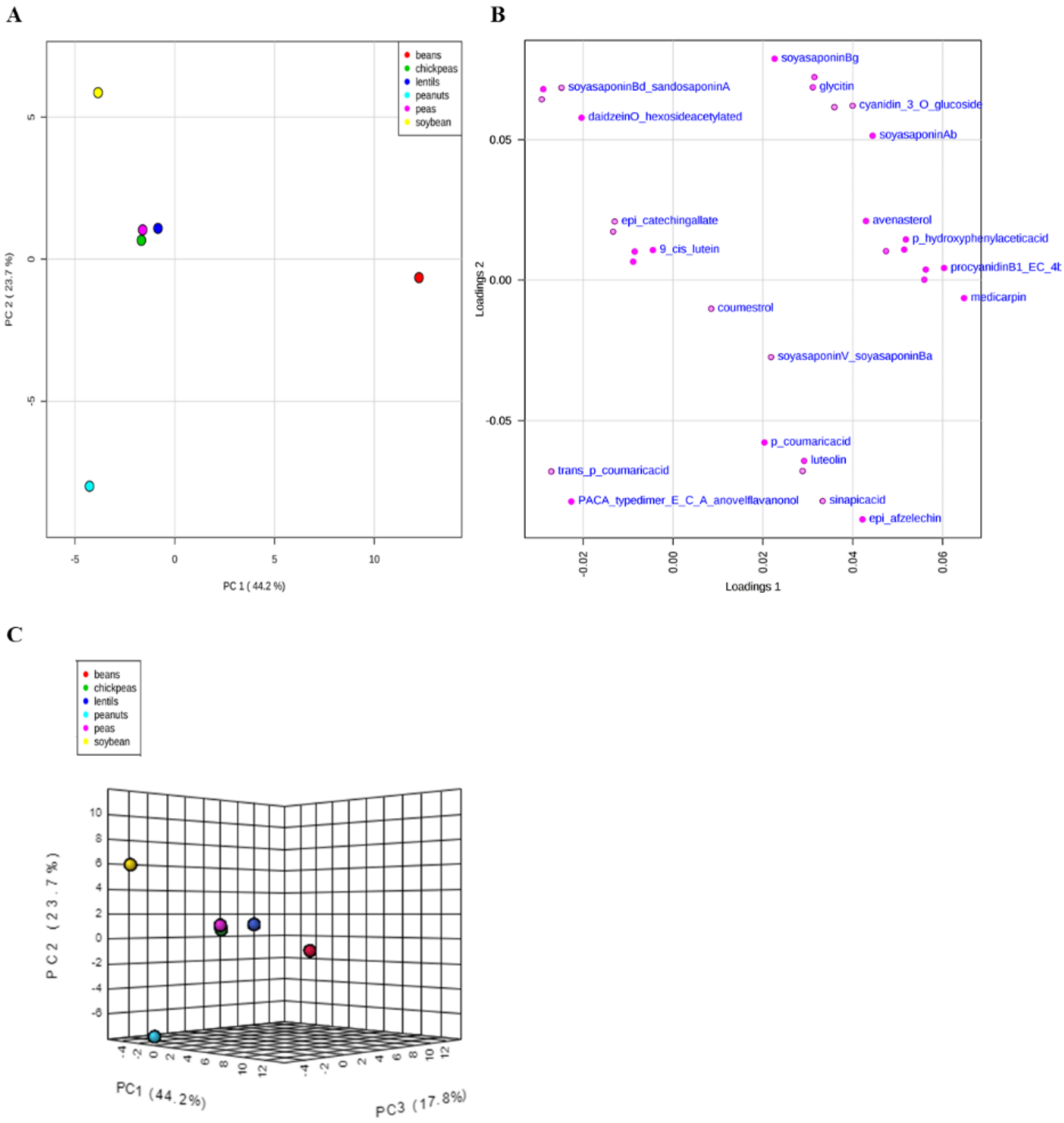
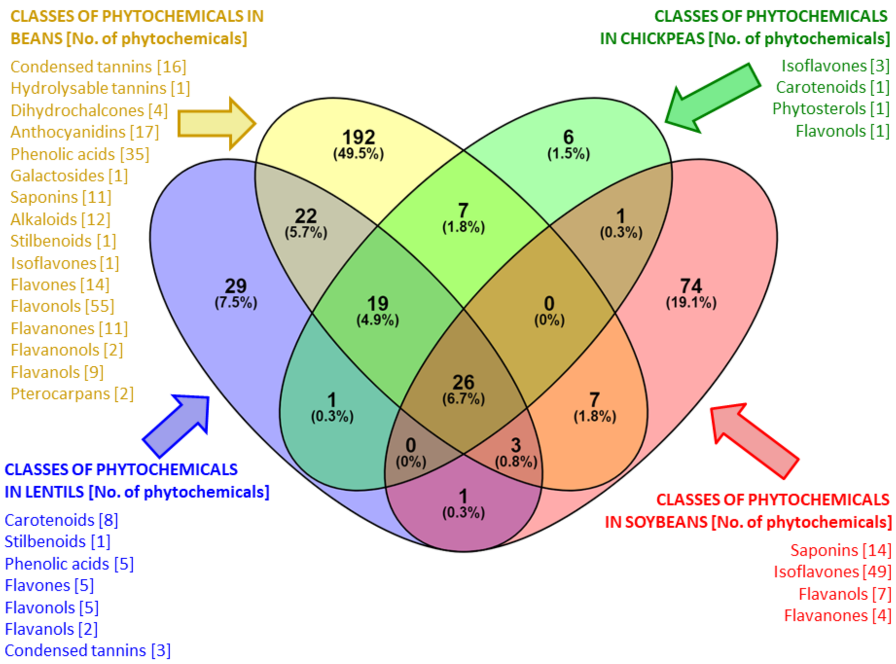


Figure 3. Venn diagram analysis of qualitative data in beans, chickpeas, lentils and soybeans.



Note. Bold numbers mean the total amount of phytochemicals on beans, chickpeas, lentils and soybeans and phytochemicals shared by each legume combination. In brackets, the percentage of phytochemicals over total number of phytochemicals.

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