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## Two Sides of the Same Coin: The Impact of Grain Legumes on Human Health: Common Bean (*Phaseolus vulgaris* L.) as a Case Study

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### Abstract

Data from Food and Agriculture Organization indicate the worrying scenario of severe food insecurity in the world and the contrasting high prevalence of obesity (13% of the world adult population) in both developing and developed countries. Sustainable agriculture systems with increased inclusion of grain legume species and the boosting of public awareness about legume importance on diet should be a priority issue to eradicate malnutrition and promote public health. However, grain legume production and consumption are in constant state of decline, especially in the European Union. Assigned as the “poor man’s meat”, “promoters of flatulence”, or incorrectly classified as “starchy foods”, grain legumes have a negative image in modern societies. In fact, legumes represent an important source of protein, fiber, vitamins (e.g. folate) and minerals (e.g. magnesium). Moreover, legumes are rich in bioactive compounds (e.g. phenolic compounds, protease and  $\alpha$ -amylase inhibitors) acting as a “double-edged sword” in human health. They may impair nutrients availability exerting at the same time beneficial biological activities in lipid profile, inflammation, glycaemia and weight. The present chapter is focused on the advantages of a legume-rich diet for health promotion at a global scale, reviewing legume nutritional and bioactive compounds, with particular emphasis on common bean.

**Keywords:** grain legumes, nutritional value, bioactive compounds, health benefits

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## 1. Introduction

Grain legumes have been neglected, regardless of their potential to ensure nutrition and food security. Nutritionally rich in protein, fiber, carbohydrates, vitamins and minerals, grain legumes are key dietary components to eradicate hunger, as well as, malnutrition [1].

The ignorance regarding grain legume nutritional composition and food preparation techniques, allied with the negative image of legumes in modern societies, contributes to decrease legumes' consumption. Besides nutrients, legumes are also a rich source of bioactive compounds which can act as a "double-edged sword", since they can impair nutrients' bioavailability (as anti-nutritional factors), acting simultaneously, as health promoting compounds in the prevention of non-communicable diseases (e.g. cardiovascular diseases, inflammatory diseases and cancer) [2]. In order to balance negative and positive effects of these bioactive compounds, crops diversity should be preserved and characterized to give valid information to breeders and molecular biologists, who can manipulate the levels of these compounds through the selection of interesting varieties.

The present chapter aims to give a general overview of the current state of the art of grain legume production, consumption and impact on world food security. It also shows the nutritional value and the bioactive composition considering some *in vitro*, *in vivo* and epidemiological studies conducted to analyze the potential health benefits associated with legumes consumption.

## 2. Legumes diversity

Legumes are dicotyledons plants, which belong to Leguminosae or Fabaceae family, with edible seeds developed in pods. By definition, it includes the fresh legumes, pulses and the seeds with high fat content (e.g. soybeans and peanuts). Pulses, also known as grain legumes, refer only to the dried seeds with virtually no fat, which excludes the fresh legumes, soybeans and peanuts. Common bean (*Phaseolus vulgaris* L.), pea (*Pisum sativum* L.), faba beans (*Vicia faba* L.), chickpea (*Cicer arietinum* L.), lentils (*Lens culinaris* L.) and grass pea (*Lathyrus sativus* L.) are examples of legumes well-adapted to several regions of the world, from semi-arid, subtropical to temperate areas.

The wild form of *P. vulgaris* is originally from Mesoamerica (which extends from northern Mexico to Colombia). Since its expansion, two independent domestication centers were formed in Mesoamerica and Andes (from southern Peru to northwestern Argentina) [3].

In Europe, particularly in Portugal [4], Spain, Italy and central-northern Europe, common bean germplasm derives mostly from the Andean domestication center (67%) and in the Eastern Europe, there is a higher predominance of the Mesoamerican type [3].

Despite the large genetic diversity in grain legume seeds held in gene banks, the genetic resources are not intensively used in breeding programs. Preservation, characterization and evaluation of the genetic variability, in what concerns agronomic performance and quality traits, is a useful approach to ensure *in situ* conservation and future breeding programs to cope with consumers' demands and environmental challenges [5].

### 3. Legumes production and consumption

Diversifying agriculture, instead of adopting an intensive specialized production system, is one of the goals to achieve a sustainable development. Grain legumes bring diversity, nutrient supply and disease control to cropping systems. In opposition to the American continent, Africa, Asia and Oceania, in the European Union, common bean production decreased drastically (−80.42%) between 1961 (817,000 tonnes) and 2013 (160,000 tonnes) [6]. During this period of time, there was a shift in land use toward an intensive cereals production [6], which contributed to the Europeans' dependence in imported grain legumes, compromising sustainability of the actual food farming system. Parallel to the decrease in common bean production data from FAOSTAT, relative to food balance, also indicate, in European Union (EU), a dramatic decrease on its consumption from 1.5 kg/capita/ year (1961) to 0.78 kg/capita/year (2013) [6].

Several factors related to crop productivity, government policies and consumers' preferences can explain the reduced investment of European farmers in grain legumes production. The promotion of breeding programs to increase genetic diversity and the development of more attractive varieties adapted to the local growing conditions and to the consumers' demands (high quality varieties) must be pursued.

#### 3.1. Food security

The Food and Agriculture Organization (FAO) of the United Nations declared 2016 as the International year of Pulses focusing on hunger and malnutrition eradication [7]. According to the second sustainable development goal of FAO, by 2030, countries should “end hunger”, adopt sustainable agriculture systems and provide food security to all population [8]. Several factors can affect food security worldwide: extreme weather events (e.g. droughts, floods and hurricanes), conflicts with violence affecting rural areas and economic recessions with increased unemployment [8]. Worrying data from FAO indicate that, in 2016, 815 million people suffer from chronic food deprivation and around 698 million people from severe food insecurity [8].

To avoid the financial pressure of malnutrition on health care systems and the economic burden of the co-morbidities related with malnutrition, governments should support sustainable agriculture practices with inclusion of legumes in cropping systems and subsidies to small farmers, especially in low- and middle-income countries dependent on agriculture [9]. Nutritional initiatives to eradicate malnutrition and protein deficiency should include public awareness about inclusion of vegetable protein in daily diet [8].

### 4. Nutritional value

Legumes are within the food items with a high nutrient value ( $330 \pm 217$  kcal/100 g) for a low cost value ( $0.26 \pm 0.22$  \$/serving) [10].

Grain legumes are distinguished as a rich source of vegetable protein, soluble and insoluble fiber, resistant starch, micronutrients (minerals and vitamins) and several bioactive compounds [11]. When complemented with the cereals' protein, grain legumes can be consumed

as a sustainable alternative to animal protein. Despite of the American Cancer Society, the Centers for Disease Control and Prevention and the US Dietary guidelines who classify beans as vegetables, many consumers continue to associate grain legumes to starchy foods, like rice, pasta and tubers [12]. The major differences between legumes and starchy food (cereals) are related with macro- and micronutrients composition.

#### 4.1. Macronutrients

The macronutrients should be provided by diet in large amounts to supply the energy and the molecular units that sustain the basal metabolism, physical activity, growth, pregnancy and lactation. The carbohydrates' contribution to total food energy is higher in cereals than in beans and there is an inverse situation for the protein contribution, with beans showing higher protein content than cereals [13].

##### 4.1.1. Protein

In legumes, proteins are stored in the parenchyma cells of cotyledons and are classified according to their solubility in different solvents as albumins, water extractable, globulins, extractable in salt solutions, prolamins, extractable in aqueous alcohol and glutelins extractable in weak acid/alkaline solutions. In common bean, globulins are the most predominant fraction of storage proteins (54–79%), followed by albumins (12–30%), glutelins (20–30%) and prolamins (2–4%). The most abundant globulin in common bean is the phaseolin (40–50% of the total globulins) [14].

The structural units of the proteins known as amino acids can be classified as essential and non-essential. The essential ones must be necessarily provided by diet. If some of the eight essential amino acids is lacking, the missing one is named as a “limiting amino acid”. In legumes, the limiting amino acids are sulfur-containing amino acids (methionine and cysteine) and in cereals lysine is the limiting one. In order to increase the protein quality of legumes and cereals, both food items must be combined in a daily diet to provide all the essential amino acids and to prevent protein malnutrition [15].

The presence of anti-nutritional factors (trypsin inhibitors, phytic acid and tannins) in grain legumes, detailed below in this chapter, and the processing method used before consumption can influence protein digestibility and protein quality [16].

##### 4.1.1.1. Legume proteins as potential allergens

As a rich protein source, legumes may cause allergenic reactions. More than 90% of the food allergies are caused by proteins of vegetable and animal origin [17]. Genetic factors and exposure to new allergenic food products, early in life, can explain the immune response of some individuals to one or more food proteins [18].

In developed countries, more than 6% of the children and around 4% of the adults have food allergies [19]. In developing countries and emerging economies (e.g. Brazil, China and India), the prevalence of food allergies is misreported and under-diagnosed [20].

The food allergy induced by legumes is an IgE immune reaction, characterized by activation of Th2-type lymphocytes [21]. In sensitized individuals, mild (cutaneous rash, diarrhea,



vomiting, abdominal pain, hypotension, arrhythmia, repetitive cough, tongue swelling, angioedema, rhinitis and asthma) to severe threatening-life symptoms can occur. The most severe reactions, rarely reported with pulses, include anaphylaxis and death [17].

Since legumes share common antigen determinants (epitopes) with other plants, the risk of an allergenic reaction, in sensitized individuals, increases if cross-reactive foods were not eliminated from diet/environment. For example, pea and common beans have cross-reactivity with pollens of *Olea europaea*, *Lolium perenne* and *Betula alba* [22]. In kidney bean, the major allergens were identified as defense proteins against biotic stress (lectin and  $\alpha$ -amylase inhibitor), storage proteins (phaseolin) and stress tolerant proteins (late embryogenesis abundant (LEA) protein). These proteins also showed cross-reactivity with other legumes such as peanut and pigeon pea [18].

To prevent the development of food allergies, the pediatric nutrition authorities recommend exclusive breastfeeding until 6 months of age. Legumes and protein-rich foods (e.g. meat, egg, milk and yoghurt) should be only introduced at the age of 6–8 months [23]. At the agriculture level, promising strategies involving the breeding of crop varieties with reduced content of allergenic proteins are being put into action. Nevertheless, the development of such crops represents a challenge for farmers, who need to deal with compromised plant feasibility [24] and does not represent the appropriate strategy for consumers with severe allergies, since immune reactivity to legumes may occur, even with minimum quantity of allergens. In these patients, the clinical approach to manage allergies should focus on the patients' awareness of a list of food items that must be avoided, and on a personalized nutritional intervention with indication of nutritive food alternatives.

#### 4.1.2. Carbohydrates

Legume carbohydrates include starch, fiber and oligosaccharides.

##### 4.1.2.1. Starch

Starch represents the main carbohydrate reserve (22–45% of total carbohydrates) in legume seeds and is used by the plant as a source of glucose and energy [25]. Chemically, it is composed by two types of polymers: the amylose and the amylopectin. Amylopectin is a highly branched polymer characterized by a linear chain of glucose moieties linked by  $\alpha$ -1,4-glycosidic bonds with several smaller glucose chains at  $\alpha$ -1,6 positions. Amylose is a long unbranched linear chain of  $\alpha$ -1,4-glucans. A comparative study of the starch structure of a legume (e.g. chickpea) and a cereal (e.g. wheat) revealed the higher content of amylose in chickpea's starch [26]. Starches with high amylose content have low glycemic index and therefore can be more adequate to type 2 *diabetes mellitus* populations [27].

##### 4.1.2.2. Dietary fiber

Dietary fiber include the total non-starch polysaccharide (NSP), divided into soluble and insoluble NSP, resistant starch and fructooligosaccharides. Soluble fiber is defined as the fermentable fiber with prebiotic action. The insoluble fiber is poorly fermented and has a bulking function in colon [28]. Compared with cooked corn, cooked beans have higher content of dietary fiber (2.4/100 g in corn against 6.3–10.4/100 g in cooked beans) [13].

Besides total dietary fiber, legumes are also a rich source of resistant starch, which is defined as a portion of starch that passes through the duodenum and jejunum without being digested [28]. In colon, resistant starch is fermented, by the local microbiota, into several products, including short-chain fatty acids (acetate, propionate and butyrate), which are responsible to maintain gut integrity, improve intestinal microflora, reinforce immune system preventing intestinal colonization by pathogens, improve blood lipid profile by reducing plasma triglycerides and LDL cholesterol, control satiety by increasing the secretion of satiety hormones and contribute to prevent several diseases from allergies and autoimmune diseases to bowel cancer [29, 30]. Legumes show higher levels of resistant starch (e.g. 4.3% in kidney beans) than cereals (e.g. 1.4% in rice) and tubers (e.g. 1.8% in potato) in a dry weight basis [31].

#### 4.1.2.3. *Fructooligosaccharides*

Grain legumes are particularly rich in oligosaccharides such as raffinose, stachyose and verbascose, which are likely to be fermented by colonic bacteria. As a consequence of bacterial fermentation, rectal gas is produced, which may be responsible for abdominal discomfort, bloating and flatulence. Since individual gas production is dependent on the individual microflora composition and consumption habits, beans are not necessarily responsible for increased flatulence [32].

Similarly to resistant starch, the colonic fermentation of oligosaccharides is also responsible for the production of short-chain fatty acids, acetate, propionate and butyrate, related to several health benefits [33]. To control the flatulence and reduce the content of oligosaccharides in legumes, many populations, especially in Asia and Africa, consume fermented legumes as an interesting nutritive food alternative [34].

#### 4.1.3. *Lipids*

Lipids represent 2–21% of the macronutrients present in legumes [35]. The content in the different fatty acids is quite variable among the different legume species. By increasing order of the monounsaturated fatty acid (oleic acid) content, common bean has the low amount (5.1–17.2%) followed by lentils (23.5–39.6%), faba beans (25.2–32.4%), peas (26.3–36%) and chickpeas (31.4–34.8%) [36]. However, common beans are particularly rich in polyunsaturated fatty acids (PUFAS), 48.4–68.7% of the lipid content, revealing an higher content of linolenic acid (9,12,15-(Z,Z,Z)-octadecatrienoic acid or C18:3, n-3) than linoleic acid (9,12-(Z,Z)-octadecadienoic acid or C18:2, n-6), ratio n6/n3 between 0.5 and 0.9, which is an indication of the common beans' protective effect against degenerative diseases, such as cardiovascular diseases and inflammatory diseases [36, 37].

### 4.2. **Micronutrients**

Contrarily to macronutrients, micronutrients are required, by human body, in small amounts performing crucial physiological roles (e.g. metabolism, hormone and enzyme synthesis, immune homeostasis and cell division). Legumes are particularly rich in B-complex vitamins, folate, vitamin E and minerals such as iron, calcium, phosphorus, magnesium, potassium, zinc, copper and selenium [38]. In low- and middle-income countries, highly dependent on legume proteins, the

malnutrition by iron deficiency is one of the major worrying public health issues [8]. Although the iron content of a vegetarian diet may be equal to the iron content of a mixed diet, in a non-vegetarian diet, with red meat, the heme iron, mostly present in the form of hemoglobin and myoglobin (10–12% of the total iron) [39] can be absorbed at a rate of 5–35% in the gut. However, in a vegetarian diet (rich in legumes, vegetables and cereals) where the main form of iron is the nonheme, the intestinal absorption decreases to 2–10% [40].

In countries where legumes are staple food products, consumption of biofortified legumes with iron and other micronutrients, such as zinc, with sources of vitamin C can be a solution for micronutrient malnutrition. The fortification of bean varieties with iron is currently a common practice in several countries, such as Rwanda, Uganda, Democratic Republic of Congo and Brazil, in order to control women and childhood iron deficiencies [41].

## 5. Bioactive compounds

Additional to the nutritional value of legumes in human health, legumes are also a rich source of several minor bioactive compounds (e.g. lectins, enzymatic inhibitors, saponins, phytates, oligosaccharides, sterols and phenolic compounds), whose presence has been linked to several nutraceutical properties [42].

### 5.1. Lectins

Lectins are proteins, globulins, accumulated in the cotyledons' vacuoles, with at least one non-catalytic domain which bind reversibly to carbohydrates or glycoproteins [43].

Many lectins present in raw or under-cooked beans are resistant to acidic and enzymatic proteolysis being absorbed into the blood stream of the animals. The affinity of some lectins (phytohemagglutinin) to the red blood cells results in red blood cells agglutination and hemolytic anemia [38]. The levels of lectins are not influenced by the soaking process and cooking until getting soft beans (60 minutes) seems to be adequate to eliminate lectins' hemagglutinating activity [44].

*In vitro* studies with the phytohemagglutinin (PHA) of *Phaseolus vulgaris* in cancer cell lines, such as SK-MEL-28, HT-144 and C32 human melanoma, showed the potential of *Phaseolus vulgaris*' lectin in inhibiting cancer cells [45]. *In vivo* studies with mice pre-treated with 0.2 g of PHA/kg, before starting oral 5-fluorouracyl (FU) revealed higher survival of intestinal epithelium functional cells than mice not pre-treated with lectin [46].

### 5.2. Phaseolin and small bioactive peptides

Phaseolin is a trimeric glycoprotein, highly resistant to *in vitro* and *in vivo* digestion, as a consequence of the compact structure given by the high percentage of  $\beta$ -strands, high glycosylation pattern and hydrophobicity. Heat treatment promotes structural changes in the tertiary and quaternary structures of the protein, increasing susceptibility to enzymatic proteolysis and digestibility [47]. Depending on the molecular weight of phaseolin subunits, phaseolin can be classified as S (Sanilac), T (Tendergreen) and I (Inca) [48].



The small peptides obtained from phaseolin hydrolysis have potential antioxidant and iron chelating activities. After hydrolysis, the phaseolin chelating activity increases highly, from 18%, before hydrolysis, to more than 81% after the hydrolytic treatment [49].

Besides the antioxidant activity, the common bean's bioactive peptides have also anti-hypertensive, through angiotensin-converting enzyme (ACE) inhibition, hypoglycemic, through  $\alpha$ -amylase,  $\alpha$ -glucosidase and dipeptidyl peptidase-IV (DPP-IV) inhibition and anti-carcinogenic properties, through cell apoptosis induction [50, 51].

### 5.3. Protease inhibitors

Serine protease inhibitors are traditionally divided into two families: the Kunitz trypsin inhibitors and the Bowman-Birk trypsin/chymotrypsin inhibitors. The Kunitz trypsin inhibitor is predominantly found in soybeans and the Bowman-Birk family is widely present in legume seeds. The Protease inhibitors of common bean (*Phaseolus vulgaris*) are included in the Bowman-Birk family [52]. Similar to the lectins, protease inhibitors protect plant from insects and predators and also protect the seed against fungi and microorganisms after harvesting, extending seeds' shelf life [53].

Protease inhibitors of raw or barely cooked legumes resist to the acidic pH of stomach and to the proteolytic enzymes (pepsin) and reach to the duodenum, interfering with digestion through irreversible inhibition of trypsin and chymotrypsin. Since, in duodenum, protease levels are reduced, protein digestibility is compromised and the absorption of amino acids decreases [54]. Despite the negative impact in serine proteases, the denaturated protease inhibitors have several health-promoting benefits in human health, mostly as anti-inflammatory and anti-carcinogenic compounds in *in vitro* and *in vivo* models [55]. Until now the molecular mechanism underlying Bowman-Birk inhibition in colorectal chemoprevention remains unknown [56].

### 5.4. $\alpha$ -Amylase inhibitors

The  $\alpha$ -amylase inhibitors are mostly found in the embryonic axes and cotyledons of the seed as a defensive strategy against predators. These inhibitors prevent starch digestion by blocking the active site of the  $\alpha$ -amylase enzyme [57]. The traditional cooking process at 100°C during 10 minutes inactivates  $\alpha$ -amylase inhibitors [57]. Several clinical studies with humans, conducted to characterize the effect of  $\alpha$ -amylase inhibitor from raw white beans in weight loss and blood glucose levels, clearly showed the potential of a concentrated extract of white bean, with 3000  $\alpha$ -amylase inhibiting units per gram (before meals with carbohydrates) in reducing body weight, body mass index (BMI), fat mass, waist/hip circumferences, systolic/diastolic blood pressure, triglycerides and post-prandial spikes in blood sugar, maintaining the lean body mass [58, 59].

### 5.5. Phytosterols

Phytosterols include plant sterols and stanols. Plant sterols are the most predominant sterols in plants, corresponding to unsaturated compounds with a double bond in the sterol ring.  $\beta$ -sitosterol, campesterol and stigmasterol are examples of sterols. Stanols represent only 10%

of the total dietary phytosterols and are distinguished from sterols based on the absence of double bonds on the sterol ring (saturated molecules) [60].

Since humans cannot synthesize phytosterols, it must be achieved through the consumption of cereals, legumes, vegetables, fruits and nuts. In legumes, the sterols content is quite variable ranging from 134 mg/100 g, in kidney beans, to 242 mg/100 g, in peas [61]. Common bean show high levels of stigmasterol, 86.2 mg/100 g and 41.4 mg/100 g, in butter and kidney beans, respectively [61]. Dietary phytosterols intake normally ranges between 78 and 500 mg/day [62]. Some negative effects have been related to phytosterols consumption up to 1 year and include nausea, diarrhea or constipation. However, *in vivo* studies with rats associate phytosterols with several beneficial biological effects including anti-inflammatory and anticarcinogenic effects [60]. Phytosterols have been extensively studied as compounds with the ability to decrease cholesterol levels in the gut [42].

#### 5.5.1. Phytates

Phytic acid is accumulated in plant seeds in the form of a salt associated with magnesium, calcium and copper, during the maturation stage. It represents 60–90% of the total phosphorus in the seed [63]. The phytate content in legumes is higher than in cereal-based food items. For instance, in cooked kidney beans it ranges from 8.3 to 13.4 mg/g dry weight (DW) while in wheat bread, the levels are considerably low (3.2–7.3 mg/g DW) [64].

Monogastric animals, including poultry and humans are unable to metabolize phytic acid as a consequence of the lack of the phytase degrading enzymes at gastrointestinal level [65].

The main anti-nutritional effects of phytates result from phytate capacity to chelate minerals such as calcium, zinc, copper and magnesium, reducing the minerals bioavailability on diet [66]. Phytates can also establish non-specific complexes with proteins which are less prone to digestion by proteolytic enzymes [67]. Processing strategies, such as soaking [68], germination [69], fermentation [64] and the addition of phytases in animal feed [70] and as food additives [71] promote dephosphorylation of phytate improving the nutritional value of legumes. Due to phytate heat-stability, cooking process does not affect phytate content [72]. Despite the anti-nutritional effects, phytates have been related to anti-oxidant effects [73], anti-carcinogenic activity [74], hypolipidemic [75] and hypoglycemic effects [76].

Regarding the impact of phytate in human health and the dose to ensure beneficial/negative effects, more studies are required and should be a priority for new research lines.

#### 5.6. Saponins

Chemically referred as triterpene and steroid glycosides, saponins are formed by one or more carbohydrate units attached to a triterpenoid or steroidal aglycone (sapogenin) [77]. Saponins are soluble in water and its content is reduced during soaking process [78]. The lowest saponin content was obtained when beans were only soaked for 6 h [78]. Saponins can be responsible for a bitter taste and astringency that compromises food intake.

Recognized as anti-nutritional compounds, saponins may reduce nutrients' bioavailability and decrease trypsin and chymotrypsin activity [79]. Despite of the anti-nutritional effects,

saponins have been explored as hypocholesterolemic [80] and hypoglycemic compounds [81]. Saponins have also been studied for their anticarcinogenic activity, considering in cell based assays with hepatocellular carcinoma cells (HepG2), fibrosarcoma cells (HT1080), cervical cancer cells (HeLa), promyelocytic leukemia cells (HL60) and breast cancer cells (MDA-MB-453) [82].

### 5.7. Phenolic compounds

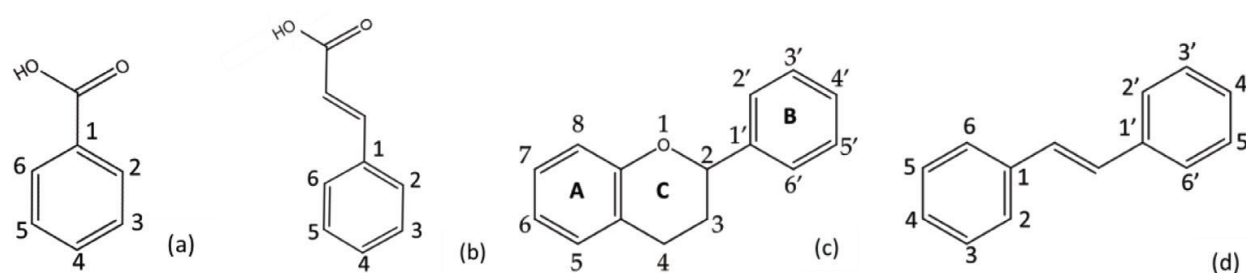
Phenolic compounds, in common bean, include a huge diversity of secondary metabolites (phenolic acids such as hydroxybenzoic and hydroxycinnamic acids, flavonoids and stilbenes) synthesized from the amino acids phenylalanine or tyrosine, in the phenylpropanoid pathway. The C6-C1 skeleton of benzoic acids is generated by shortening of the hydroxycinnamic acids, **Figure 1**. Flavonoids are characterized by a C6-C3-C6 general structure, formed by two benzene rings (A and B) linked by a three carbon chain (a heterocyclic ring with an oxygen, the C ring), **Figure 1**. Stilbenes have a general structure C6-C2-C6, **Figure 1** [83].

Based on the chemical structure, flavonoids can be classified into six different classes, the flavones, flavanones, flavonols, flavanols, anthocyanins and isoflavones [84]. In **Table 1**, the major differences in the chemical structure of compounds included into the different flavonoids' classes are summarized [84].

In dry beans such as common bean, the majority of phenolic compounds are classified as phenolic acids and flavonoids (including proanthocyanidins). The anthocyanins, isoflavones, flavanols and flavonols are mostly located in the seed coat. The cotyledons are particularly rich in phenolic acids such as the hydroxycinnamic acids (e.g. ferulic and sinapic acids), mostly in esterified and glycosylated forms [85].

The content of phenolic compounds is quite variable depending on the legumes species, cultivar, seed's coat color pattern, maturity, growing location, environmental characteristics, storage conditions and processing techniques (e.g. boiling, germination and fermentation) [86]. The dark-colored varieties have higher qualitative and quantitative diversity of phenolic compounds, especially anthocyanins and proanthocyanidins, than lighter varieties [85]. Flavonols such as quercetin and kaempferol glycoside derivatives have been described in black, pinto, dark red kidney, light red kidney and small red beans collected in the USA [87], in Mexican black, mottled gray, caffeto and pale beans [88] and in the Italian yellow and black seed coat beans [89]. Nonglycosylated isoflavones (daidzein and genistein) have been identified by LC-ESI-QTOFMS in Brazilian black varieties of common bean [90]. The phenolic acids derived from benzoic and hydroxycinnamic acids have been studied in Mexican varieties of common beans [88]. The ferulic, sinapic, vanillic and *p*-hydroxybenzoic acids were the most abundant phenolic acids in the Mexican varieties, regardless of the seed coats' color [88].

Stilbene compounds such as resveratrol glucoside was identified and quantified, by mass spectrometry, in germinated black beans [91]. The anti-nutritional impact of phenolic compounds in human health is related to its inhibitory effect in the digestion enzymes (e.g.  $\alpha$ -amylase and pancreatic lipase) [92]. In legumes, particularly rich in tannins, phenolic compounds may also interact with dietary proteins, promoting proteins' precipitation or reducing protease (e.g. pepsin, trypsin and chymotrypsin) accessibility to the hydrophobic sites on the proteins, [93] which impairs protein digestibility.



**Figure 1.** General structure of the most predominant phenolic compounds' families in common bean (a) *p*-hydroxybenzoic acids; (b) hydroxycinnamic acids; (c) flavonoids; (d) stilbenes.

Flavonoids class	Chemical structure characteristics	Examples
Flavones	<ul style="list-style-type: none"> <li>Double bond C2-C3 (unsaturated C ring)</li> <li>Ketone at C4 of the C ring</li> </ul>	Apigenin
Flavanones (Dihydroflavones)	<ul style="list-style-type: none"> <li>Saturated C ring</li> <li>Ketone at C4 of the C ring</li> </ul>	Naringenin
Flavonols	<ul style="list-style-type: none"> <li>Double bond C2-C3 (unsaturated C ring)</li> <li>Ketone at C4 of the C ring</li> <li>OH- group at C3 of the C ring</li> </ul>	Quercetin
Flavanols (Flavan-3-ols or Catechins)	<ul style="list-style-type: none"> <li>Saturated C ring</li> <li>OH- group at C3 of the C ring</li> <li>Ability to form polymers</li> </ul>	Catechin Procyanidin B1
Anthocyanins	<ul style="list-style-type: none"> <li>Flavylium cations</li> <li>Majority in glycosidic form (sugars attached at C3)</li> </ul>	Cyanidin Cyanidin-3-glucoside
Isoflavones	<ul style="list-style-type: none"> <li>Double bond C2-C3 (unsaturated C ring)</li> <li>Ketone at C4 of the C ring</li> <li>B ring attached to C ring at C3</li> </ul>	Daidzein

**Table 1.** Chemical structure of compounds included into the different flavonoids' classes.

The negative impact of phenolic compounds in nutrients' digestibility can be glimpsed as a potential property of legumes to manage body weight and prevent obesity [93]. The health benefits of phenolic compounds are dependent on phenolic compounds' absorption and metabolism, which is influenced by several factors related to phenolic compounds' structure, molecular size, solubility, concentration in food, degree of glycosylation, phenolic compounds interaction and phenolic compounds matrix binding interaction, cell wall structure, as well as, by individual factors such as enzyme activity, intestinal transit time, genetics, gender, age, microflora composition and gastrointestinal pathologies [94]. The cluster of mentioned factors indicates that the most concentrated compounds are not necessarily the most bioavailable, in fact regardless of the abundance, most of the hydroxycinnamic acids are in the esterified form which compromises hydroxycinnamic acids' intestinal absorption and bioavailability [95].

The health-promoting effects of common bean phenolic compounds include the anti-oxidant [96], anti-inflammatory [97], anti-hyperglycemic [98], anti-hyperlipidemic [99] and

anti-carcinogenic [100] activities. The molecular mechanisms responsible for such biological activities need further study. Moreover, long-term clinical studies are required to establish common beans bioactive compounds' benefits on human body.

## 6. Innovative food products

New “ready-to-eat” food products with inclusion of legumes as ingredients have been flooding the market. In the European Union, 3593 new products have been released between 2010 and 2014 [101].

In what regards common bean innovative food products, bean flour has been incorporated mostly in bakery products and snacks. In Mexico, whole wheat bread has been supplemented with 0.5% of freeze-dried black bean seed coat extract [102]. In Brazil, common bean flour has been added to rice flour and sugar in a proportion of 30:70:5%, respectively, to produce extruded breakfast flakes [103]. In Canada, a new bean snack, similar to pretzels, composed by 34% of navy bean flour has been developed. In North America, common bean flour has also been incorporated in other snacks such as potato chips and tortilla chips [104]. In Italy, biscuits have been prepared with wheat, maize and common bean flour at different proportions (26.7, 32.1, 50.0, 53.6 and 64.3% of bean flour). The biscuits prepared with a bean flour percentage of 26.7 and 32.1% were accepted with a score similar to the traditional biscuit [105].

The improved quality of the new food products that include legumes as ingredients represent a new market challenge and a concerted action between research community and food industry with divulgation of the potential health benefits should be mandatory to increase legumes consumption.

## 7. Conclusion(s)

The Fabaceae family includes a huge number of species that can bring diversity, nutrient supply and disease control to cropping systems. In Europe, beans production and consumption decreased drastically in the last decades. Nutritionally different from starchy foods, legumes have higher protein, amylose, fiber, folate and minerals contents. Therefore, the inclusion of legumes in a daily diversified diet is one of the best nutritional strategies to prevent malnutrition. Legumes are also a rich source of bioactive compounds (e.g. enzymatic inhibitors and phenolic compounds). The content of such compounds in plants is quite variable depending on the plant genotype and on the environmental and processing conditions. In fact, most of the anti-nutritional effects can be inactivated toward preparation and processing techniques (e.g. soaking, peeling, boiling, fermentation and germination). Recent research on the impact of bioactive compounds on health showed their potential to exert biological actions as anti-oxidant, anti-inflammatory, anti-hyperlipidemic, anti-hyperglycemic and anti-carcinogenic compounds.

Future research lines should focus on the characterization of legume genetic diversity, development of reliable and quick screening assays of quality-related traits to improve varieties in



legume breeding programs, update of legume consumption in each country and bioavailability studies (including assays regarding the effective doses of bioactive compounds responsible for significant biological actions in clinical studies).

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## Conflict of interest

The authors declare no conflict of interest.

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